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Ambient Air Pollution Screening Study in Dhaka and Chittagong

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Executive Summary

As a part of the Bangladesh Air Pollution Studies (BAPS) project, a screening study of air pollution was performed in Dhaka and Chittagong with assistance from local university partners. The screening study work fell under Task 1 (Emissions Inventory) of the BAPS project.

The screening study was performed in Dhaka from 16 February – 26 February 2013, and Chittagong from 20 February – 01 March 2013. The main objective of the study was to gain an overview of the background concentrations and the spatial distribution of the air pollution in the Dhaka city and Chittagong city areas. This study is also following up on a similar study performed in Dhaka in February 2011. The screening study focused on the following gaseous components in Dhaka and Chittagong: **Sulphur Dioxide (SO₂)**, **Nitrogen Dioxide (NO₂)**, and **Ozone (O₃)**. In addition, samples for persistent organic pollutants (POPs) were collected in Chittagong in connection with the study, which will be reported separately in fall 2013 under a different project.

The screening study was performed during the winter season because this is the dry period where air pollutant concentrations will be at their peak. The winter season is also the time of the year in which the brick kilns are being operated, which are suspected to be the single greatest local contribution to air quality (AQ) problems in Dhaka. Other possible sources of air pollution include re-suspension of road dust from traffic, open burning, residential cooking, and industrial sources such as cement manufacturing and metal smelting. Regional haze from India (use of high sulfur coal in industrial processes) is also a significant contribution to local particulate matter (PM) values on the regional scale.

Results from the study show that SO₂ concentrations for the sampling period averaged 60 µg/m³ in Dhaka and 40 µg/m³ in Chittagong; NO₂ concentrations were 73 µg/m³ in Dhaka and 46 µg/m³ in Chittagong; and ozone concentrations were 41 µg/m³ in Dhaka and 64 µg/m³ in Chittagong. At most sampling sites pollutant concentrations exceed WHO guidelines for all three gaseous components measured, however, at only a few sites local Bangladeshi standards are probably exceeded. The concentrations of the studied pollutants varies throughout the city area, and levels occur highest in micro-environments with sources for the particular gas.

Based on the analysis of the results, interesting discussion points arose which focus upon:

- Concentrations for SO₂ and NO₂ are higher in Dhaka in comparison to Chittagong, most likely due to that Dhaka has a much stronger source of emissions sources.
- Concentrations of SO₂ and NO₂ were higher in Dhaka during the 2011 study in comparison to this 2013 study, due to the numerous political strikes that occurred during this study period, which reduced the sources and in turn reduced the emissions.
- Spatial patterns of concentration results are fairly distinct for SO₂ in Dhaka due to the sites' location in relation to brick kiln fields and prevailing winds; spatial patterns are not evident for the other components, or for Chittagong.
- SO₂ concentration from the passive sampling were very different than the continuous monitoring station results for the sampling period, most likely due to fundamental differences in the two techniques, leading to a possible overestimation of SO₂ by the samplers and an underestimation by the station.
- Concentration results at different vertical layers show higher O₃ concentrations at higher levels over Dhaka and Chittagong indicating background values, while NO₂ shows higher concentration at lower levels closer to the sources for both cities.
- Local and regional meteorology greatly affects the gaseous and particle concentrations in both Dhaka and Chittagong due to the creation of prominent dry and winter seasons, and distinct prevailing winds during each of these seasons.
- Both in Dhaka and Chittagong we have seen from continuous data records distinct differences in the diurnal patterns for SO₂, possibly indicating the effect of emission mitigation measures implemented on heavy duty vehicles in Dhaka.

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Bangladesh Air Pollution Studies (BAPS)

Ambient Air Pollution Screening Study in Dhaka and Chittagong

1 Introduction

As a part of the Bangladesh Air Pollution Studies (BAPS) project, a screening study was performed in Bangladesh by NILU - Norwegian Institute for Air Research in cooperation with local partners. The screening study work fell under Task 1 (Emissions Inventory) of the BAPS project.

The screening study of air pollution in Dhaka was performed from 16 February – 26 February 2013, and in Chittagong from 20 February – 01 March. The main objectives of the studies were to gain an overview of the background concentrations and the spatial distribution of the gaseous air pollution in the both cities. A similar study was conducted in Dhaka in 2011, in which this study is a follow-up for that city, however, for Chittagong, such a thorough ambient air quality screening study has never before been conducted.

Passive samplers for NO₂ and SO₂ were located at 25 sites throughout the Dhaka City Corporation (DCC) city limits, whereof 12 of these sites also had passive samplers for O₃. For Chittagong, there were 24 sites for NO₂ and SO₂, whereof 11 sites also had O₃; 23 of the sites also had passive samplers for Persistent Organic Pollutants (POPs), however this samplings were conducted in conjunction with another project, and will be reported separately. Samplers were placed in an equal spatial distribution throughout the two cities within various microenvironments, taking in consideration the prevailing winds. The passive sampling campaign was performed in February during the winter season (no precipitation), and the samplers were exposed to ambient air for approximately 7-11 days.

An analysis of satellite mapping data was also performed to get a spatial and temporal picture of the general regional NO₂ concentrations.

1.1 Background

Dhaka can be considered the mega-city with the world's worst urban air quality (Gurjar et al., 2008), and most rapidly increasing NO₂ concentrations (Schneider and Van der A, 2012). A combination of numerous local emissions sources in the winter season in addition to special local and regional winter meteorological conditions gives the city exceedingly high air pollution concentrations during this time of the year. The exposure of the city's estimated 10-15 million residents to this alarmingly poor air quality demands attention including immediate research and corresponding mitigation. It is estimated that if the annual guidelines for PM concentration were met in 2004 that 1,213 premature deaths could have been avoided in Dhaka alone for that year (Aktar et al., 2005); and the World Health Organization estimates that up to 10,000 premature deaths per year in Bangladesh are attributed to air pollution (WHO, 2009).

Currently, there is a lack of comprehensive AQ data for Chittagong, as well as Dhaka to an extent. There are only three Continuous Air Monitoring Stations (CAMS), in Dhaka, and one operating in Chittagong. Moreover, these CAMS in both cities have only been fully operational since the end of 2012. Before this period, there was regular PM sampling

(Mini-vol and Gent) in two size fractions ($PM_{2.5}$ and PM_{10}), with some reporting of this data occurring in published journal articles (Begum et al., 2006, 2010a, 2010b). However, overall there has been very limited sampling of gaseous components in either city, thus resulting in a large knowledge gap of the relative concentration levels and spatial distributions.

The lack of available data and comprehensive understanding of the greater air quality problems and hot spots in Dhaka and Chittagong give rise to the need for this screening study.

1.2 Emission Sources

During the winter season, the brick kilns are the primary local source of AQ problems in Dhaka, specifically for PM and SO_2 ; kilns are also a major source in Chittagong. Figure 1 displays a map of 983 identified brick kilns in the greater Dhaka area; Chittagong has less than 120 kilns in the greater city area. A majority of these brick kilns are structurally identical (mainly Fixed Chimney Kilns), where most use “low-grade” high sulfur coal from India as their primary fuel source.

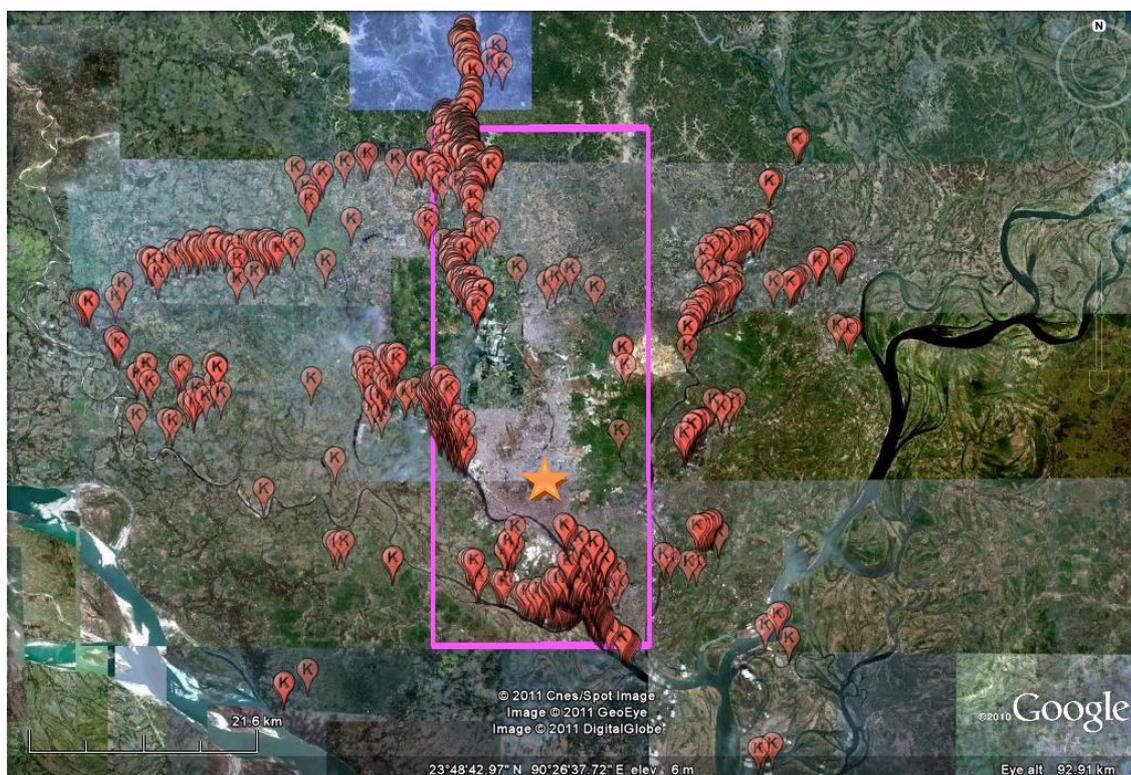


Figure 1: Map of 983 brick kilns in greater Dhaka area. The pink rectangle signifies the modelling grid area for the BAPMAN project; Dhaka city center is marked by the orange star. (Background Imagery Source: Google Earth).

In addition to brick kilns, vehicle emissions are a large source as well in both cities. However, a large percentage (up to approximately 73%) of traffic sources (excluding motorcycles) run on CNG¹ (Wadud and Kahn, 2011) so the direct contribution of vehicle traffic to PM levels is low, but during the dry winter season, re-suspension of road dust from traffic is also a considerable local-scale source of PM. While the large volume of

¹ CNG: compressed natural gas

vehicles converted to CNG reduces the PM emissions from traffic, CNG combustion can also be a considerable local source of NO_x .

Other smaller local emission sources include open-air waste burning and industrial sources, such as cement manufacturing and metal smelting, where Chittagong has much more of these industrial activities (other than brick kilns) located within the city limits in comparison to Dhaka. Most industries, including power plants, use CNG as their fuel source. Residential cooking can also be considered one of the more important smaller local area sources (Randall, 2011a).

Regional haze from the greater Bangladeshi area as well as India and the abundant use of “dirty” coal (high sulfur content, >3%) as a primary industrial fuel may be considerable regional sources of pollution transported into Dhaka.

1.3 Meteorology

In Bangladesh, the year can be divided into four distinct meteorological seasons: pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November) and winter (December–February) (Salam et al., 2003). The winter season is characterized by north and north-westerly prevailing winds with low wind speed, including minimal rainfall and low relative humidity, resulting in dry soil conditions. The wind frequency distribution (wind rose) based on wind measurements from the Darus Salem CAMS station in Dhaka is presented in Figure 2 for the specific 10 day range of the Dhaka sampling campaign. The figure also shows the average wind rose for the 2002-2008 winter seasons for comparison.

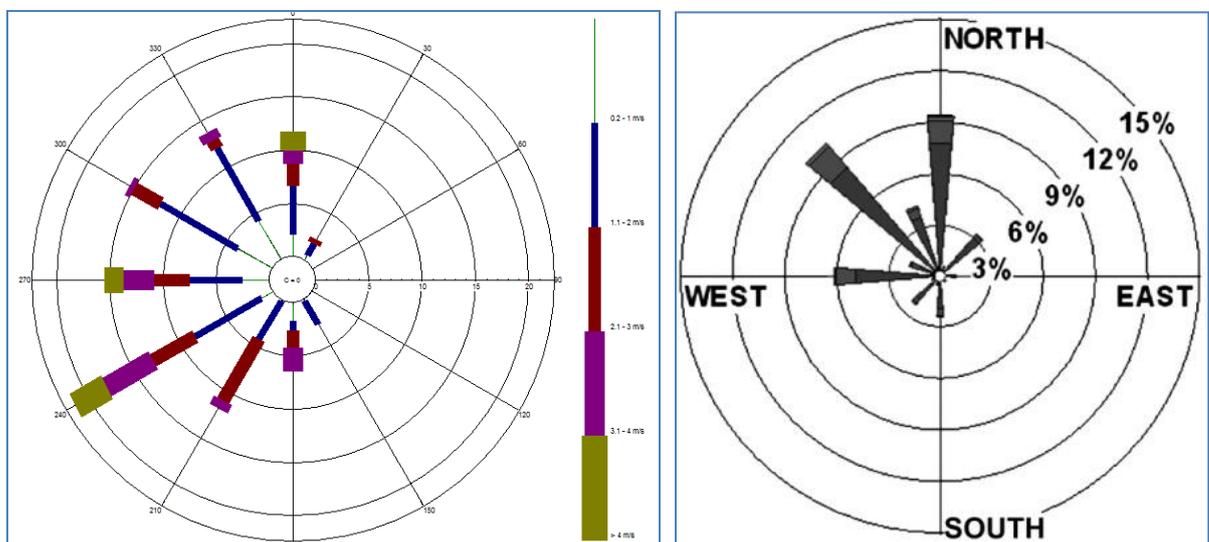


Figure 2: Left: Wind rose generated from the Darus Salem CAMS station in Dhaka during the sampling period 16 – 26 Feb 2013, using hourly meteorological data; Right: Average wind rose for Dhaka during winter seasons 2002-2008 (Source: Begum et al., 2010c).

During the February 2013 sampling period in Dhaka, the wind directions were generally from west and south west. The prevailing wind direction measured at Darus Salem was wind from west-southwest. The wind speeds normally ranged between 1 and 4 m/s.

The wind frequency distribution (wind rose) as measured at the Agrabad CAMS station in Chittagong is presented in Figure 3 for the 9-days passive sampling period. The prevailing

wind direction here was clearly from west-northwest with wind speeds between 1 and 4 m/s. The general wind pattern for Chittagong is more shifted towards the Bay of Bengal compared to the winds in Dhaka. However, the general wind flow during the measurement period confirms that winds are normally along the large scale Ganges valley axis; i.e. from westerly directions in the dry winter season.

Temperatures during the screening studies for both Dhaka and Chittagong were consistently high; 25-30°C high during the day and lower, around 15°C, during night time. There was no precipitation during the entire screening study for both cities.

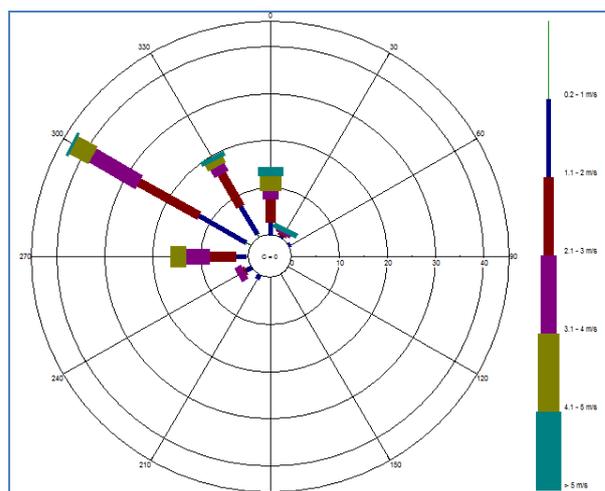


Figure 3: Wind rose generated from the Agrabad CAMS station in Chittagong during the sampling period.

2 Methods

The screening study campaign design for Dhaka and Chittagong was based on previous screening studies performed by NILU such as in Dhaka, Bangladesh (Randall et al., 2011b), Burgas, Bulgaria (Hak, 2010; Hak and Sivertsen, 2010); Dakar, Senegal (Guerreiro et al., 2005); Cairo, Egypt (Sivertsen, 2001a); and Ho Chi Min City, Vietnam (Sivertsen, 2003). Sampling design features were borrowed from these studies as well as adding new features in order to create a tailor-made study for Dhaka and Chittagong. The complete design including site selection, instrumentation, and sampling procedures is presented for the passive sampling (NO_2 , SO_2 , O_3) conducted in both cities. In addition, the method for how we examined satellite mapping of NO_2 is presented.

2.1 Passive Sampling Site Selection

It was attempted to select the passive sampling sites based on the following three main criteria:

- Measuring in different microenvironments (e.g. street canyon, road side, urban background, industrial area, regional background, etc.).
- Selection of compounds to be measured in different microenvironments depending on emission sources.
- Typically prevailing wind direction for the time of the year when sampling campaign is carried out.

Most of the selected sites followed the desired criteria, but some of the sites were also selected for security reasons. Because it was warned that there was a high probability for samplers to be stolen or damaged in public areas, a majority of samplers were located at residences of acquaintances to the project staff, ensuring a good distribution throughout the city area. Samplers not located at secure residences were located at businesses with outdoor secure areas, also ensuring an even distribution throughout the city area. Only one station resulted in missing samplers at the end of the campaign for both cities.

2.2 Passive Sampling Instrumentation

For sampling of the gases NO_2 , SO_2 , and O_3 , the passive sampling devices include an impregnated filter inside a small plastic tube (Figure 4). To avoid turbulent diffusion inside the sampler, the inlet is covered by a thin porous membrane filter. Gases are transported and collected by molecular diffusion. The samplers were bought from the Swedish Environmental Research Institute (IVL) (IVL, 2011), and the NO_2 and SO_2 filters are analyzed at the laboratories at NILU, while the O_3 samplers were analyzed by IVL in Sweden. The resulting exposure values are divided by the number of exposure days to result in the average concentration over the exposure period.

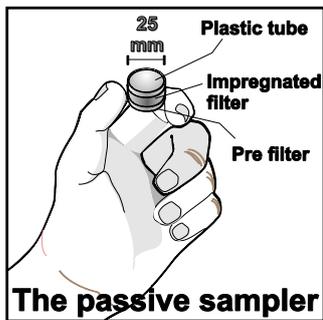


Figure 4: Illustration of passive sampler.

2.3 Passive Sampling Procedures

Samplers were distributed to three teams for Dhaka, where each team was responsible for between 5-10 sampling sites. In Chittagong, a group of students led by professors were responsible for 19 of the 24 sites. The passive samplers were placed according to detailed instructions (Appendix A), where it was very important to document placement time/date and other important site information for later reference. It was also important to take careful notice not to place the samplers in near contact of any identifiable direct local sources (such as generators, parking lots, bus stops, etc.). A detailed field data form was used to uniformly collect the necessary data across all sampling sites (Appendix B).

2.4 Satellite Mapping

Primarily data from the Ozone Monitoring Instrument (OMI) was used for the satellite mapping. The OMI instrument is based on the experiences acquired from the previous GOME and SCIAMACHY instruments. It combines their advantages, measuring the complete spectrum in the UV/VIS wavelength range at a comparatively high spatial resolution of 13 km x 24 km, while providing daily global coverage. The OMI instrument is flying on the National Aeronautics and Space Administration's Earth Observing System Aura platform as part of the A-train constellation of satellites. In contrast to most other satellite instruments dedicated to atmospheric chemistry, which have equator crossing times around 10:00 local time, OMI has an equator crossing time of approximately 1:45

LST (local Siderial Time) in the afternoon, and therefore probes the Earth's atmosphere under different conditions. Aura/OMI was launched in 2004 and has been continuously providing data. Beginning in June 2007, OMI has suffered from several row anomalies affecting the quality of the Level 1B and Level 2 data products. Level-3 products are produced after filtering for the affected anomalies.

The OMNO2d product generated by NASA and provided through the Goddard Earth Sciences Data and Information Services Center (GES-DISC) was used. Daily data was downloaded, processed and subset for the Bangladesh region. The individual daily datasets were then mapped and time series were computed for the cities of Dhaka and Chittagong.

3 Sampling Sites

There were 25 unique sites for NO₂ and SO₂ passive sampling (of which 12 also sampled O₃) in Dhaka and 24 unique sites for NO₂ and SO₂ passive sampling (of which 11 also sampled O₃) in Chittagong.

3.1 Passive Sampling

A map of the 25 passive sampling sites for Dhaka can be seen in Figure 5; and a map of the 24 sampling sites in Chittagong can be seen in Figure 6. Passive samplers in Dhaka were placed in the field from 16-19 February and collected on 24-26 February (10 day range), for an average exposure period of 8 days. Passive samplers in Chittagong were placed from 20-22 February and all were collected on 01 March (9 day range), for an average exposure of 8 days.

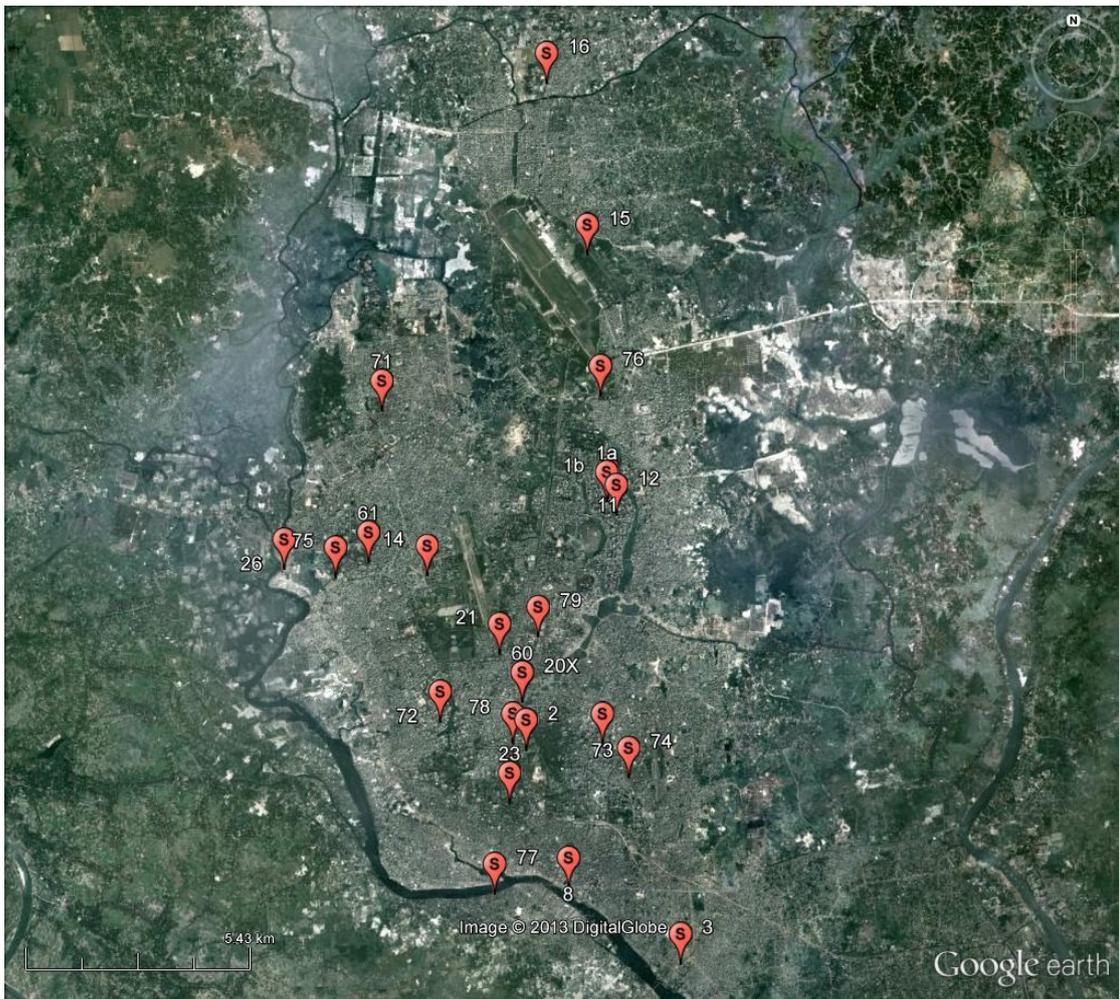


Figure 5: Location of 25 Passive Sampling Sites in Dhaka (Background Imagery Source: Google Earth).



Figure 6: Location of 24 Passive Sampling Sites for Chittagong (Background Imagery Source: Google Earth).

Site classification (micro-environment) parameters used can be seen in Table 1; these classifications are similar to internationally recognized classification schemes and were also used in the passive sampling study for Burgas, Bulgaria (Hak, 2010), and in the previous study for Dhaka (Randall et al., 2011b).

Table 1: Site classification parameters used for passive sampling sites.

Type of zone	Type of station	Characterisation of zone
Urban (U)	Traffic (T)	Residential (R)
Suburban (S)	Industrial (I)	Commercial (C)
Rural (R)	Background (B)	Industrial (I)
		Agricultural (A)
		Natural (N)
		Res. / Comm. (RC)
		Comm. / Ind. (CI)
		Ind. / Res. (IR)
		Res. / Comm. / Ind. (RCI)
		Agri. / Nat. (AN)

Basic information for all passive sampling sites, including basic classifications of each site can be seen in Table 2 for Dhaka sites and Table 3 for Chittagong sites. 13 of the 25 sites

in Dhaka were the same sites used in the previous 2011 study, these sites are indicated with an asterisk (“*”) after the site name in Table 2 below.

Table 2: Passive Sampling site placement information and classifications for Dhaka sites.

Site #	Site Name	Coordinates		Observ Initials	Location		From:		To:		SO ₂	NO ₂	Ozone
		Lat North	Long East		Hgt.(m)	Classification	date	hr.	date	hr.			
1A	Westin 150m*	23.793301	90.414790	SR	150	Background	17.02	1655	25.02	1350	X	X	X
1B	Westin 15m*	23.793301	90.414790	SR	15	Traffic	17.02	1705	**	**	X	X	
2	BSMMU*	23.739172	90.395530	SR	2	Residential	17.02	943	25.02	1450	X	X	X
3	Postogola*	23.691753	90.432360	SR	3	Traffic	17.02	1155	26.02	1115	X	X	X
8	Pink Palace*	23.708343	90.405574	SR	4	Background	17.02	1100	26.02	1205	X	X	X
11	Pearls Fair*	23.793834	90.415499	SR	3	Residential	17.02	1618	25.02	1330	X	X	
12	Norway Embassy*	23.790088	90.417212	SR	6	Residential	17.02	1350	25.02	1320	X	X	X
14	DoE garden*	23.776964	90.372102	BS/SR	2	Residential	17.02	955	25.02	1010	X	X	X
15	Balaka Building Airport*	23.847746	90.410347	BS/SR	2	Traffic	17.02	1225	25.02	1200	X	X	X
16	Tongi Bazaar*	23.884970	90.400597	BS/SR	5	Traffic	17.02	1310	25.02	1215	X	X	X
20X	Pan Pacific Sonargaon Hotel	23.749233	90.394767	BS/SR	1	Traffic	18.02	1215	26.02	950	X	X	X
21	Farmgate CAMS*	23.759123	90.392929	BS/SR	8	Traffic	17.02	1140	25.02	1130	X	X	X
23	BUET guard house*	23.727300	90.391800	SR	2	Residential	16.02	1811	25.02	1510	X	X	
26	Central Dhaka Market*	23.778156	90.338134	BS/SR	8	Industrial	17.02	1050	25.02	1040	X	X	X
60	Pan Pacific Sonargaon Hotel	23.749233	90.394767	SR	1	Residential	18.02	1225	26.02	950	X	X	
61	Darus Salem CAMS	23.779647	90.358664	BS/SR	8	Residential	17.02	1110	25.02	1100	X	X	X
71	Renata limited, Mirpur	23.813106	90.361347	EMON	7	Industrial	18.02	1300	25.02	1300	X	X	
72	Dhanmondi	23.744929	90.375316	EMON	4	Residential	19.02	1000	26.02	1000	X	X	
73	Malibagh, Shantinogor	23.740098	90.413918	EMON	4	Traffic	17.02	1300	24.02	1300	X	X	
74	Notre Dame College, Motijheel	23.732594	90.420141	EMON	14	Background	19.02	1300	26.02	1300	X	X	
75	Mohammadpur	23.776548	90.350361	EMON	18	Residential	19.02	800	26.02	810	X	X	
76	Baridhara D.O.H.S.	23.816443	90.413361	EMON	3	Background	18.02	1830	25.02	1830	X	X	
77	Najargonj, Ialbagh	23.707095	90.388298	EMON	5	Industrial	19.02	1530	26.02	1530	X	X	
78	Hatirpul, Shahabagh	23.740137	90.392590	EMON	3	Traffic	19.02	1800	26.02	1800	X	X	
79	BASF Bangladesh, Tejgaon	23.763528	90.398576	EMON	7	Industrial	18.02	1430	25.02	1430	X	X	
	*2011 Station												
	**Lost sampler												

Table 3: Passive Sampling site placement information and classifications for Chittagong sites.

Site #	Site Name	Coordinates		Observ Initials	Location		From:		To:		SO ₂	NO ₂	Ozone	POPS
		Lat North	Long East		Hgt.(m)	Class	date	hr.	date	hr.				
C1	CU Campus	22.467406	91.781309	SR/BS	8	Background	20.02	1310	1.03	1145	X	X	X	X
C2	Penninsula bottom	22.357823	91.822044	SR/BS	2	Traffic	21.02	1130	1.03	1040	X	X	X	
C3	Penninsula top	22.357823	91.822044	SR/BS	80	Background	21.02	1110	1.03	1745	X	X	X	X
C4	CAMS Khulshi	22.360670	91.800529	SR/BS	5	Background	20.02	1615	1.03	1430	X	X	X	X
C5	CAMS Agrabad	22.322858	91.802004	SR/BS	8	Residential	20.02	1725	1.03	1345	X	X	X	X
C6	Telipara, Vatiary	22.425333	91.742417	CU	5	Background	21.02	1300	1.03	757	X	X	X	X
C7	Jahanabad	22.437806	91.737611	CU	5	Residential	21.02	1340	1.03	805	X	X	X	X
C8	Kadom Rasul	22.445056	91.734944	CU	7	Residential	21.02	1430	1.03	845	X	X	X	X
C9	Baro Aulia	22.478833	91.719611	CU	5	Background	21.02	1532	1.03	934	X	X	X	X
C10	Ghatghar	22.508611	91.707444	CU	8	Background	21.02	1625	1.03	1011	X	X	X	X
C11	Mosjidida	22.520111	91.699556	CU	4	Background	21.02	1730	1.03	1045	X	X	X	X
C12	Rahattarpul	22.360722	91.851139	CU	5	Residential	21.02	2100	1.03	935	X	X		X
C13	Shah Amanat Bridge	22.332694	91.852083	CU	7	Traffic	22.02	925	1.03	1000	X	X		X
C14	Bahaddarhat	22.369861	91.843444	CU	5	Residential	22.02	1030	1.03	1040	X	X		X
C15	Mirzapul	22.365306	91.835194	CU	4	Industrial	22.02	1115	1.03	1120	X	X		X
C16	Pathanpara	22.394167	91.825389	CU	5	Residential	22.02	1210	1.03	1220	X	X		X
C17	Kunjosaya	22.380583	91.818417	CU	4	Residential	22.02	1255	1.03	1310	X	X		X
C18	C&B Colony, Gec	22.364583	91.819833	CU	4	Residential	22.02	1335	1.03	1345	X	X		X
C19	Halishahar	22.344917	91.783667	CU	8	Industrial	22.02	1630	1.03	1730	X	X		X
C20	Colonel Hat	22.367528	91.775889	CU	4	Traffic	22.02	1705	1.03	1705	X	X		X
C21	Bangshal Road	22.330750	91.837417	CU	7	Traffic	20.02	1725	1.03	1653	X	X		X
C22	Andarkilla	22.340556	91.834819	CU	5	Residential	22.02	1805	1.03	1815	X	X		X
C23	Masua Jharna Lane	22.344556	91.839083	CU	7	Residential	22.02	1850	1.03	1905	X	X		X
C24	Kalurghat	22.396389	91.876667	CU	4	Traffic	22.02	1905	1.03	1905	X	X		X

4 Limit Values

National Ambient Air Quality Standards (NAAQS) were updated for Bangladesh in 2005 through the national *S.R.O. No 220-Law*. (See Appendix D). The standards set for PM (PM₁₀ and PM_{2.5}), NO₂, SO₂, and O₃ are mostly based on the US-EPA's ambient AQ standards, where Bangladesh is the only country in South Asia which set a standard for PM_{2.5} (CAI-ASIA, 2006). These standards are not as stringent as the European Union (EU) limit values or the World Health Organization (WHO) air quality guidelines (AQG), although protection of human health is a major driving force in developing NAAQS. Adverse effects on human health (and ecosystems) occur for both short-term and long-term exposure, so different standard values are valid for different averaging periods (1 hour, 8 hours, 24 hours, 1 year, etc.).

4.1 SO₂

Sulphur dioxide (SO₂) is an air pollutant which at certain levels and exposure durations poses a human health risk. Elevated SO₂ concentrations can affect the respiratory system, and can also be harmful to ecosystems. The primary contributor of anthropogenic SO₂ is the combustion of sulphur-containing fossil-fuels (mainly coal and heavy oils used in industrial and vehicular sources). SO₂ interactions also contribute to fine particle pollution in the form of sulphates.

A summary of the SO₂ AQ standards for Bangladesh, limit values from the EU, guideline values from the WHO, and AQ standards from the US-EPA are shown in Table 4. Annual limit values for the protection of ecosystems are also given, where these values are most relevant for more remote areas.

Table 4: Various air quality standards, limit and guideline values for SO₂.

Effect	Averaging period	Bangladesh (standards) ^a	EU (limit values) ^b	WHO (guidelines) ^c	US-EPA (standards) ^d
Health	10 min	-	-	500 µg/m ³	-
Health	1 hour	-	350 µg/m ³ ⁽¹⁾	-	212 µg/m ³
Health	24 hours	365 µg/m ³	125 µg/m ³ ⁽²⁾	20 µg/m ³	365 µg/m ³
Health/Ecosystem	Annual	80 µg/m ³	20 µg/m ³	-	78 µg/m ³

^aNAAQS (CAI-Asia, 2006)

^b(EU, 2008)

^cAQG (WHO, 2005)

^dNAAQS (US-EPA, 2010)

⁽¹⁾ not to be exceeded more than 24 times a calendar year

⁽²⁾ not to be exceeded more than 3 times a calendar year

4.2 NO₂

Nitrogen Dioxide (NO₂) is a highly reactive gas within the nitrogen oxide (NO_x²) group that has human health effects to the respiratory system, as well as ecosystem effects caused by deposition of nitrogen compounds. NO_x emissions are generated mainly from anthropogenic combustion sources such as vehicles and power plants. NO emissions interact with O₃ to form NO₂, and also contribute to fine particle pollution in the form of nitrates.

A summary of the NO₂ AQ standards for Bangladesh, limit values from the EU, guideline values from the WHO, and AQ standards from the US-EPA are shown in Table 5.

² NO_x = NO + NO₂

Table 5: Various air quality standards, limit and guideline values for NO₂.

Effect	Averaging period	Bangladesh (standards) ^a	EU (limit values) ^b	WHO (guidelines) ^c	US-EPA (standards) ^d
Health	1 hour	-	200 µg/m ³ ⁽¹⁾	200 µg/m ³	200 µg/m ³
Health	Annual	100 µg/m ³ ⁽²⁾	40 µg/m ³	40 µg/m ³	100 µg/m ³

^aNAAQS (CAI-Asia, 2006)

^b(EU, 2008)

^cAQG (WHO, 2005)

^dNAAQS (US-EPA, 2010)

⁽¹⁾ not to be exceeded more than 18 times a calendar year

⁽²⁾ Limit value only available for NO_x, no specific limit value for NO₂.

4.3 O₃

Ozone (O₃) is a toxic gas and photochemical oxidant which has effects upon the ecosystem and is linked to health problems associated with the respiratory system, including rise in human inflammatory responses and decreases in lung function. In the planetary boundary layer, O₃ is formed through the action of short wavelength solar radiation on NO_x, which in the presence of VOCs produces elevated levels of ozone. In this regard, the sources of O₃ are the same as the NO₂ sources, with the addition of sunlight to produce the gas.

A summary of the O₃ standards for Bangladesh, limit values from the EU, guideline values from the WHO, and standards for the US-EPA are shown in Table 6.

Table 6: Various air quality standards, limit and guideline values for O₃.

Effect	Averaging period	Bangladesh (standards) ^a	EU (limit values) ^b	WHO (guidelines) ^c	US-EPA (standards) ^d
Health	1 hour	235 µg/m ³	180 µg/m ³	-	235 µg/m ³
Health	8 hours	157 µg/m ³	120 µg/m ³	100 µg/m ³	157 µg/m ³

^aNAAQS (CAI-Asia, 2006)

^b(EU, 2008), (EU, 2002)

^cAQG (WHO, 2005)

^dNAAQS (US-EPA, 2010)

5 Results

The passive sampling (SO₂, NO₂, and O₃) results are examined in detail in this section for both Dhaka and Chittagong. It should again be noted that because this data was collected during the dry winter season, the results are most likely representing the highest/maximum pollution concentrations found throughout the year, due to the special meteorological conditions during this period and the number of active emissions sources.

5.1 Dhaka

5.1.1 SO₂ Concentrations

Of the 25 SO₂ samplers placed at 23 unique sites, the concentration values ranged from 33 µg/m³ (Site 74) to 132 µg/m³ (Site 26), with an average concentration of 60 µg/m³ for all sites. SO₂ results for 24 of the 25 samplers (site 1B was lost) can be seen in Figure 7.

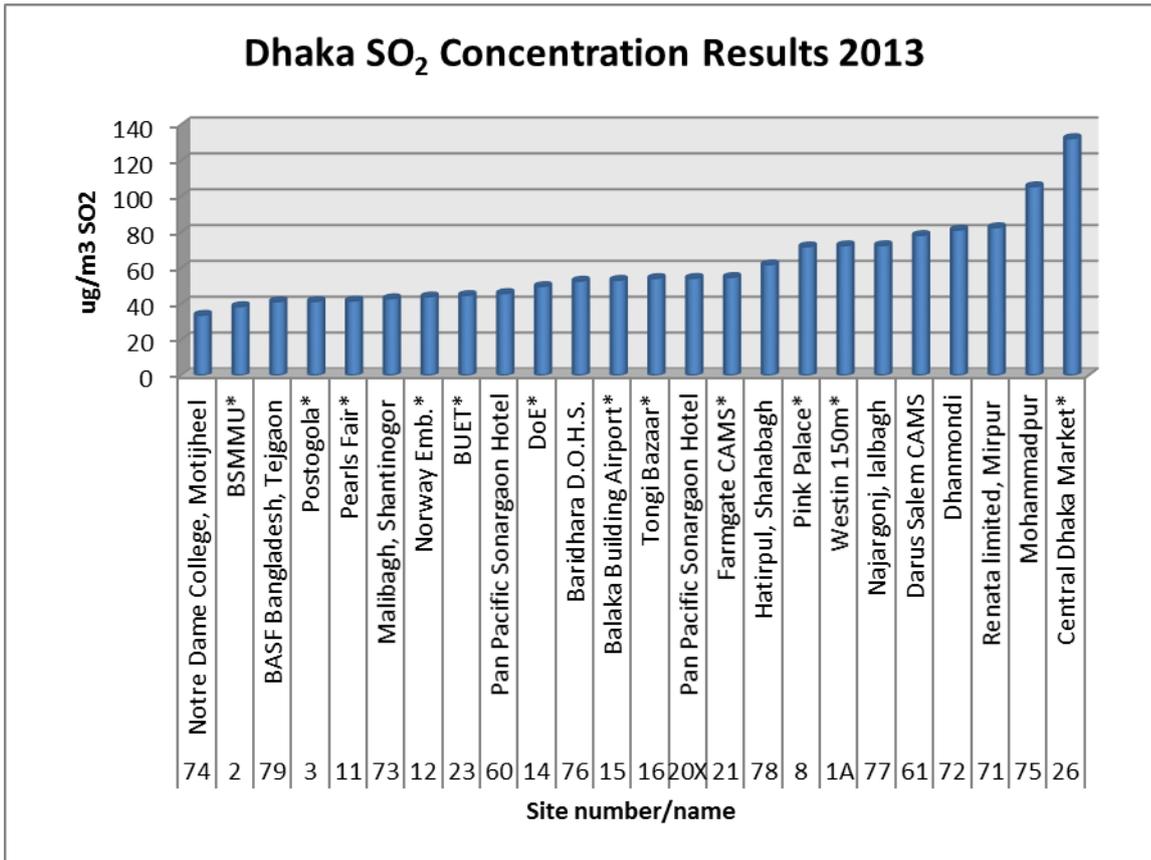


Figure 7: SO₂ concentration results, Dhaka (average concentrations over approximately 8 day period).

In relation to the Bangladeshi NAAQS for SO₂ concentrations, it is likely that none of the sites in Dhaka exceeded the standard of 365 µg/m³ SO₂ over a 24-hour period³. However, all of the sites would exceed the WHO AQG of 20 µg/m³ SO₂ over a 24-hour period, and possibly at least 1 site would exceed the EU limit value of 120 µg/m³ SO₂ over a 24-hour period.

The geographical distribution of SO₂ results (Figure 8) shows that concentrations are highest in the western and southern zones along the Buriganga River and surrounding area. Many of the smaller industrial type operations are located in these areas, as well as some of the larger brick kiln fields. Sites in these areas are also downwind of major brick kiln fields, based on the prevailing wind direction during the period. Concentrations in the city center and more eastern section of the city are approximately 50% lower compared to those along the river in the western and southern sections of the city.

³ The sampling data are averaged over a 8 day period.

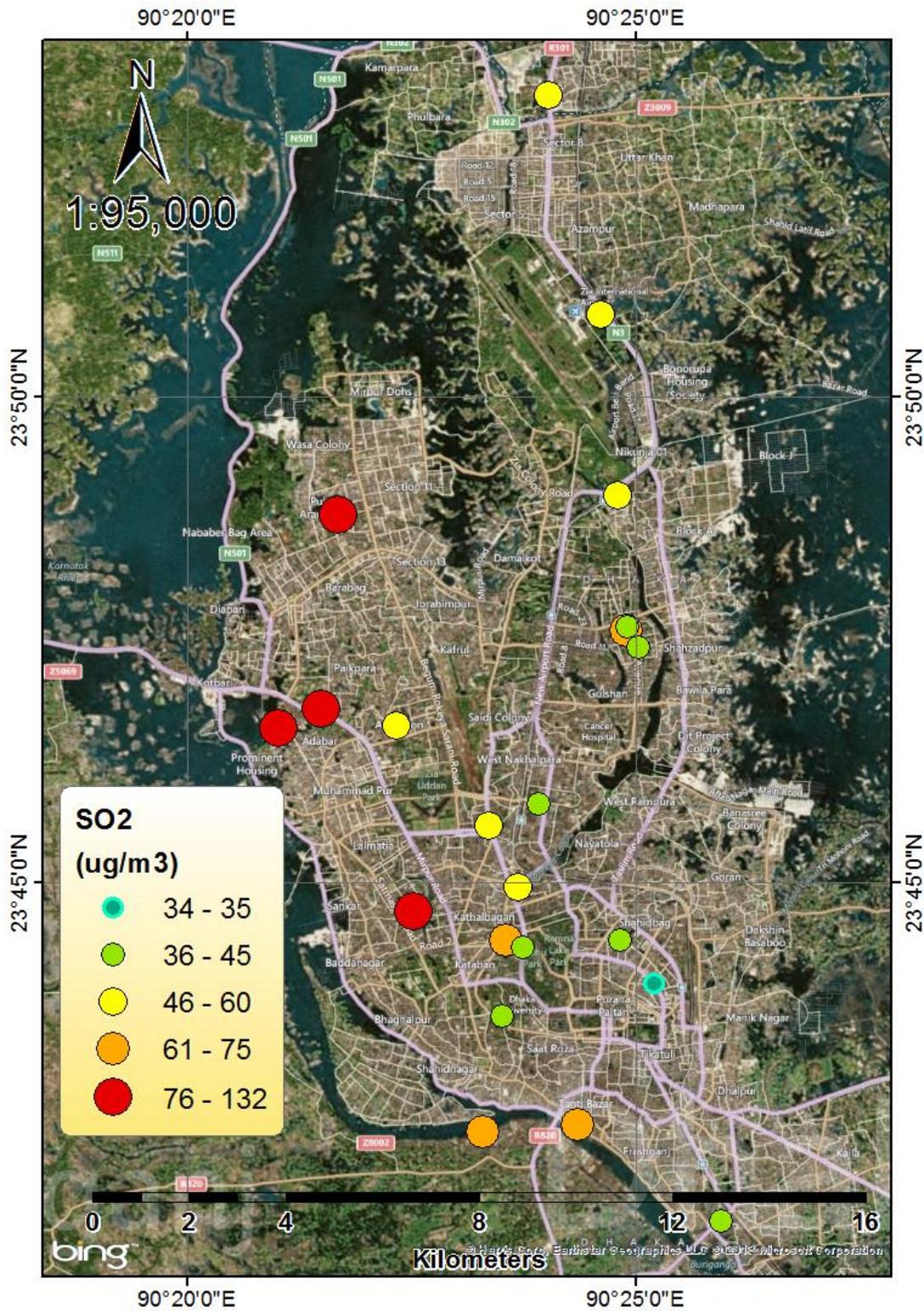


Figure 8: Geographical distribution of SO₂ concentrations measured in Dhaka over approximately 8 day sampling period.

The SO₂ results are broken down into average concentrations for each general site classification sector (Figure 9). These general station classification sectors are derived from specific site classifications found in Table 2 and explained in Table 1. As expected for SO₂, industrial sites have higher average concentrations than the other sectors.

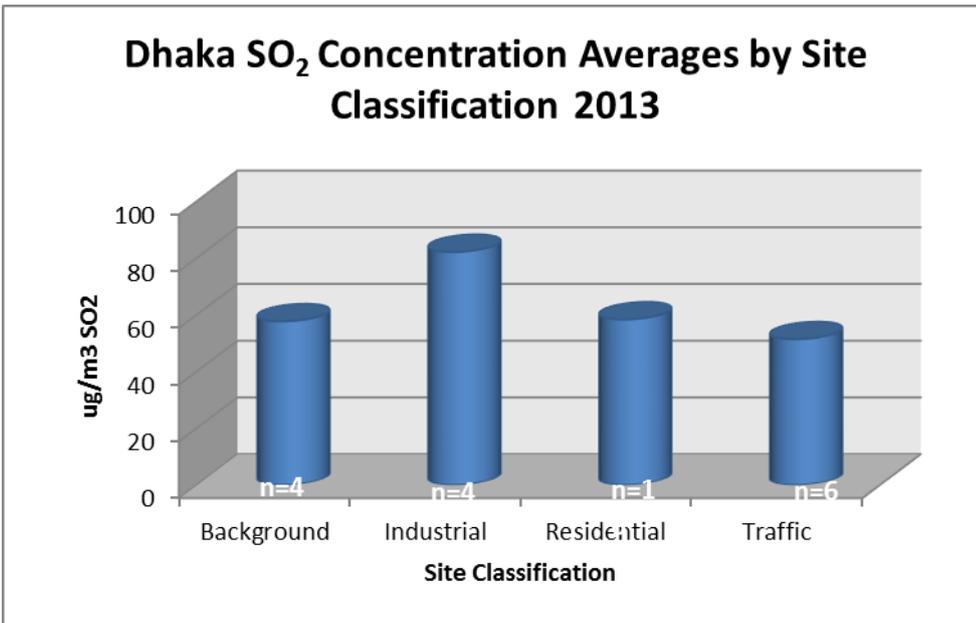


Figure 9: SO₂ concentration averages for general site classification sectors in Dhaka. The sample size, n, is also given for each category.

At 12 of those sites, samples were also collected during the 2011 passive sampling campaign for SO₂. (Randall et.al 2011 b) A comparison of the results of the two campaigns is found in Figure 10. All but one of the sites had higher concentration values in 2011 in compared to 2013, where on average the 2011 values are 35% greater. The 2011 and 2013 sampling periods were actually very similar, in that they were performed during the same time of year (February) and the meteorology during these periods was also similar (i.e. no precipitation, and same wind direction).

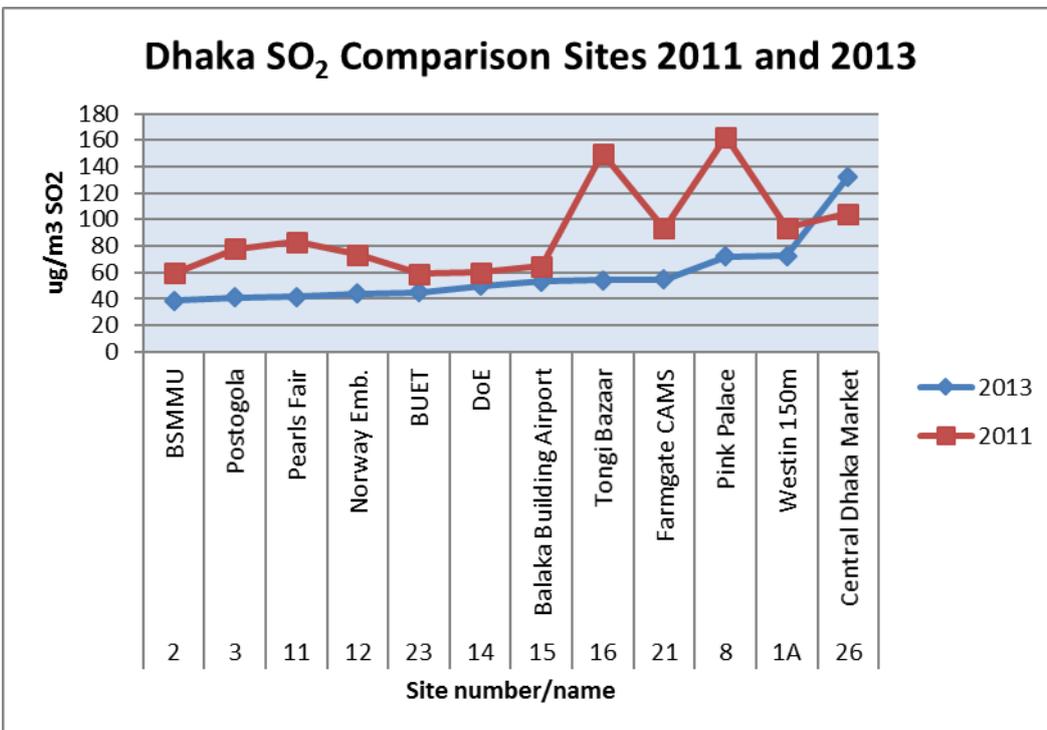


Figure 10: SO₂ concentration results comparison between 2011 and 2013 sampling periods, Dhaka.

5.1.2 NO₂ Concentrations

Of the 25 NO₂ samplers placed at 23 unique sites, the concentration values ranged from 45 µg/m³ (Site 14) to 212 µg/m³ (Site 28), with an average concentration of 73 µg/m³ for all sites. NO₂ results for 24 of the 25 sites (Site 1B was lost) can be seen in Figure 11.

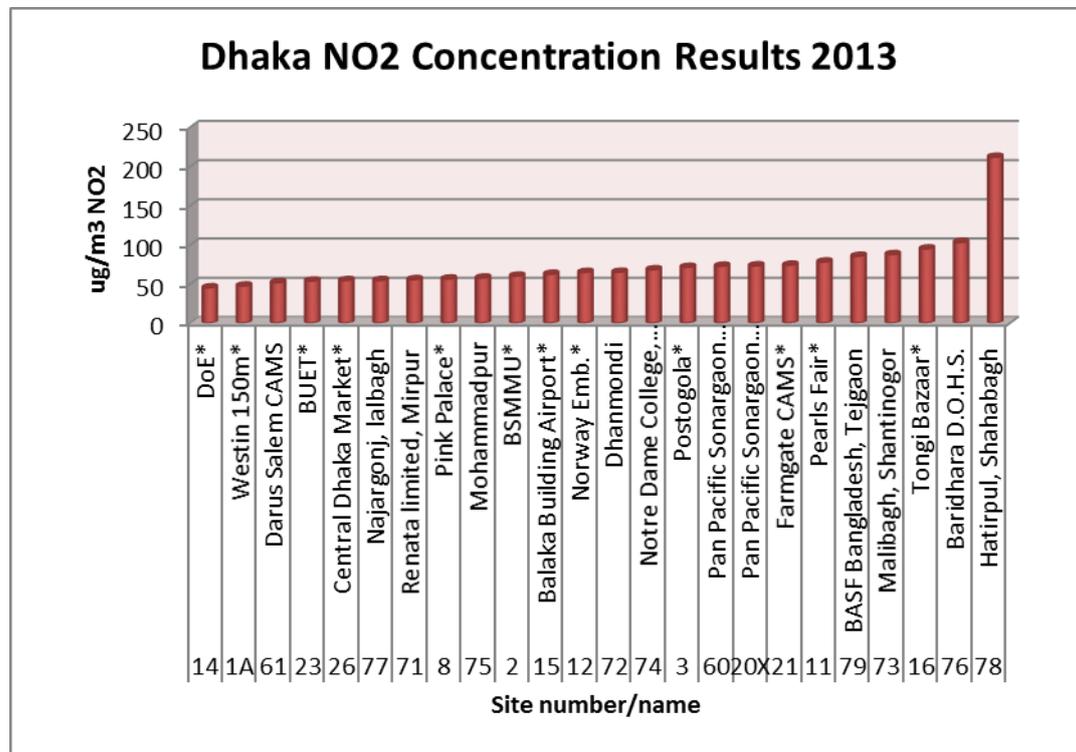


Figure 11: NO₂ concentration results, Dhaka (average concentrations over approximately 8 day period).

In relation to the Bangladeshi NAAQS for annual average NO₂ concentrations, only one of the sites (Site 78) in Dhaka could probably exceed the standard value of 100 µg/m³ NO₂ average over an annual period⁴. It is not directly useful to compare the 8 day period average concentrations with limit values given for hourly and annual average concentrations. However it is reasonable to say that a majority of the sites are likely to exceed the EU limit value and WHO guideline NO₂ value of 40 µg/m³ over an annual period. However, it has to be stated that there is probably a strong seasonal variation in concentrations, so the comparisons to annual average limit values are not straight forward, and the annual average will most likely be lower than the winter season sampling period average.

The geographical distribution of NO₂ results (Figure 12) shows that concentrations are in general highest in the city center areas and along major roads as expected, while up to 50% lower values are found in the western and southern areas. However, the spatial distribution is highly dependent on the specific micro-environments and impacts of local sources where the samplers were placed.

⁴ The annual standards and guidelines were the closest limits to be used for this comparison.

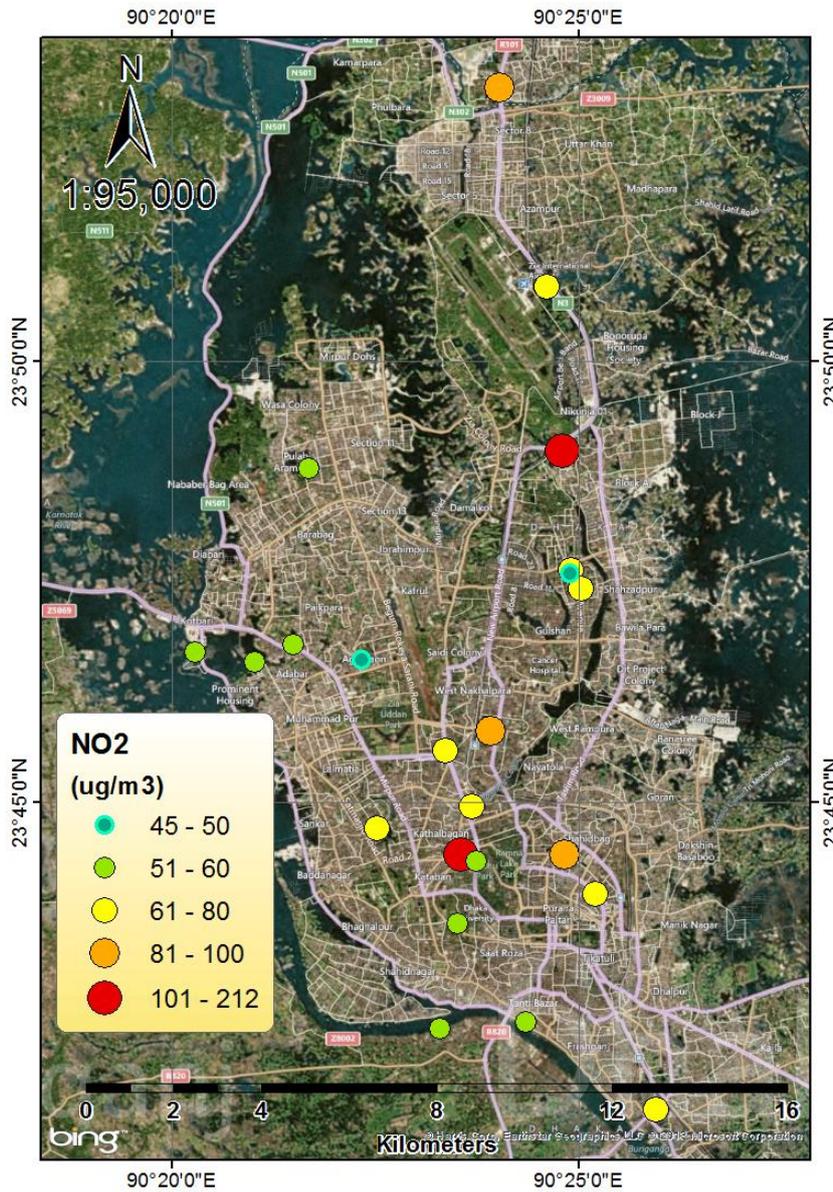


Figure 12: Geographical distribution of NO₂ concentrations measured in Dhaka over approximately 8 day sampling period.

The NO₂ results are broken down into average concentrations for each general site classification (Figure 13). These general classifications of sites are derived from specific site classifications found in Table 2 and explained in Table 1. As expected for NO₂, traffic sites have higher average concentrations than other site types. While the large percentage of vehicles running on Compressed Natural Gas (CNG) in Bangladesh significantly reduces PM emissions, CNG vehicles still emit a substantial amount of NO_x (approximately 50% less than diesel vehicles).

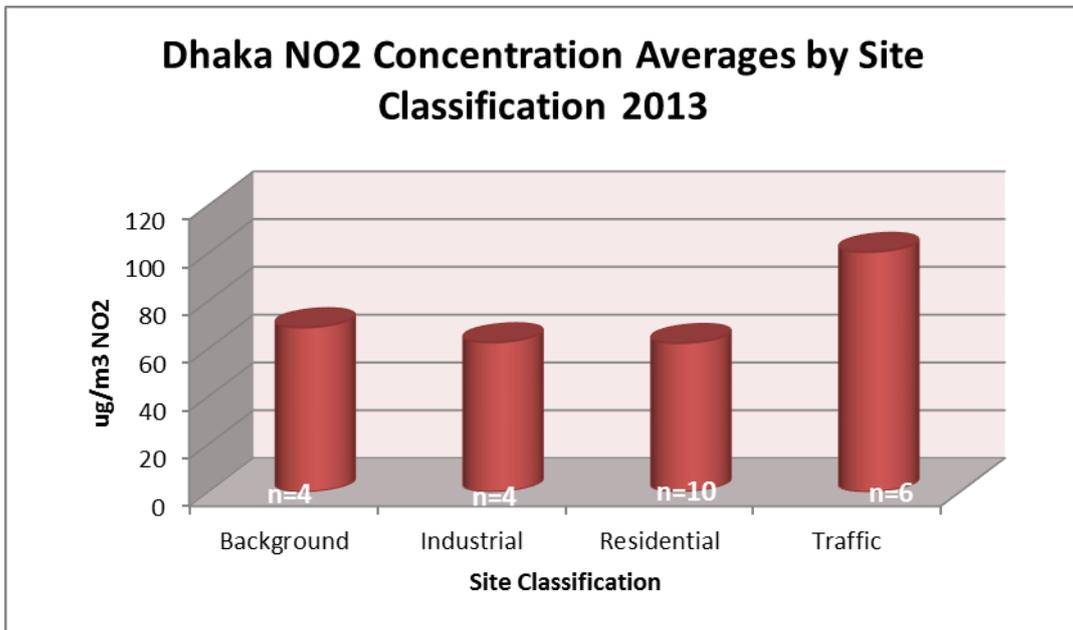


Figure 13: NO₂ concentration averages for general site classification areas in Dhaka. The sample size, n, is also given for each category.

At 11 of these sites, samples were also collected during the 2011 passive sampling campaign for NO₂ (Randall et.al 2011 b). A comparison of these results is found in Figure 14. All of the sites had higher concentration values in 2011 in comparison to 2013, where on average the 2011 values are 31% higher. As previously mentioned, the 2011 and 2013 sampling periods were actually very similar, in that they were performed during the same time of year (February) and the meteorology during these periods was also similar (i.e. no precipitation, and same wind direction). A discussion of possible reasons for the differences can be found in Section 6.

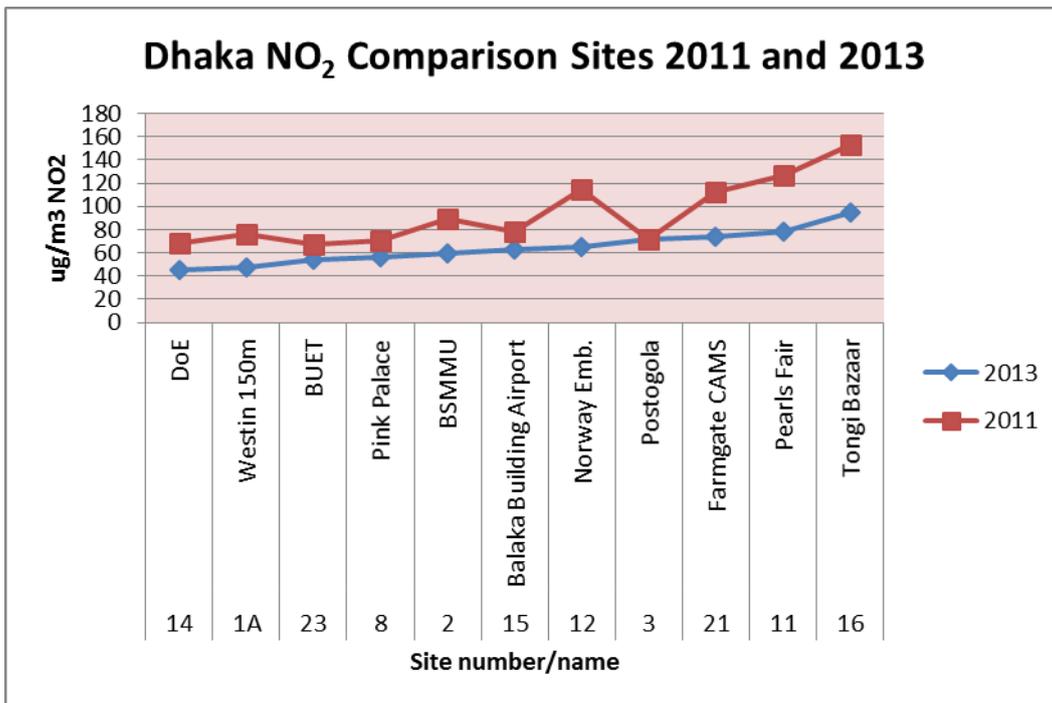


Figure 14: NO₂ concentration results comparison between 2011 and 2013 sampling periods, Dhaka.

5.1.3 O₃ Concentrations

Of the 12 O₃ samplers placed in Dhaka, the O₃ average concentration values ranged from 27 µg/m³ (Site 3) to 57 µg/m³ (Site 61), with an average concentration of 41 µg/m³ for all sites. All O₃ results can be seen in Figure 15.

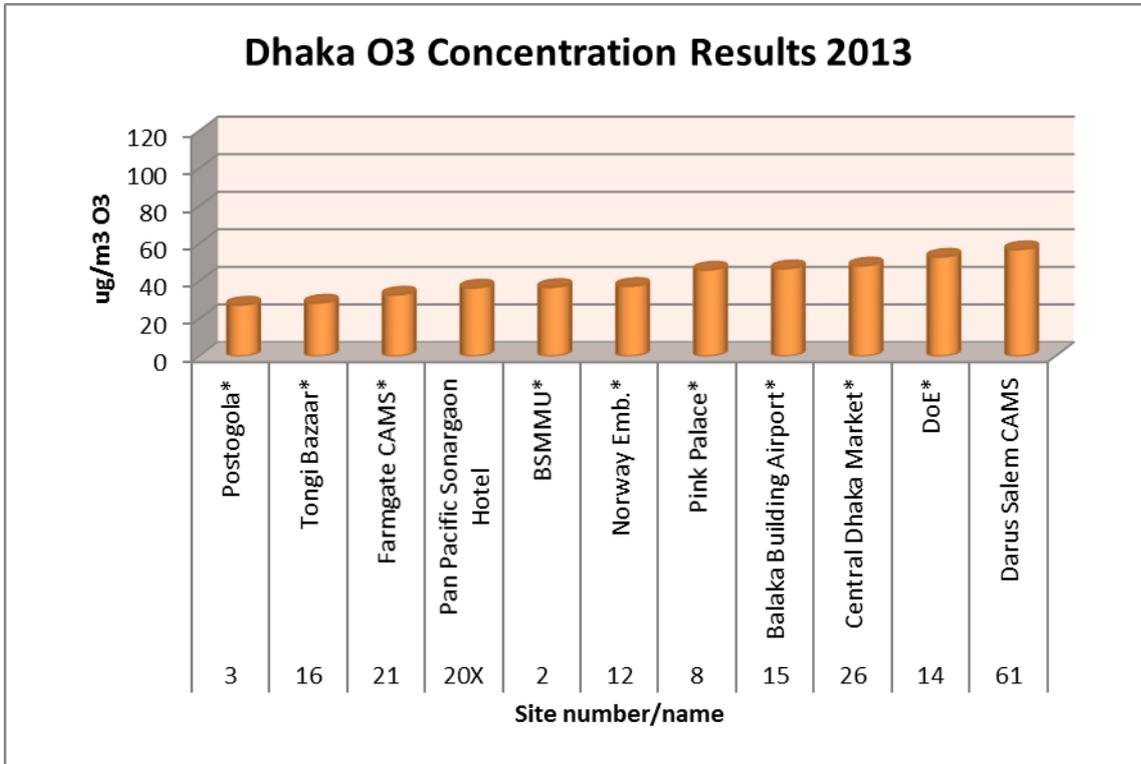


Figure 15: O₃ concentration results, all sites (average concentrations over approximately 8 day period).

In relation to the Bangladeshi NAAQS for O₃ concentrations, it cannot be definitively ascertained if the concentrations at Dhaka sites may exceed the standard and guideline values due to the strong diurnal variation of O₃ formation. The 8 day integrated average ozone concentrations cannot be used to conclude relative to (e.g. 8 hour) limit values.

The geographical distribution of O₃ results (Figure 16) shows that concentrations are sporadically distributed with no clear spatial variations, however, ozone appears to be depleted at sites where increased NO_x emissions are in close vicinity to the sampling points.

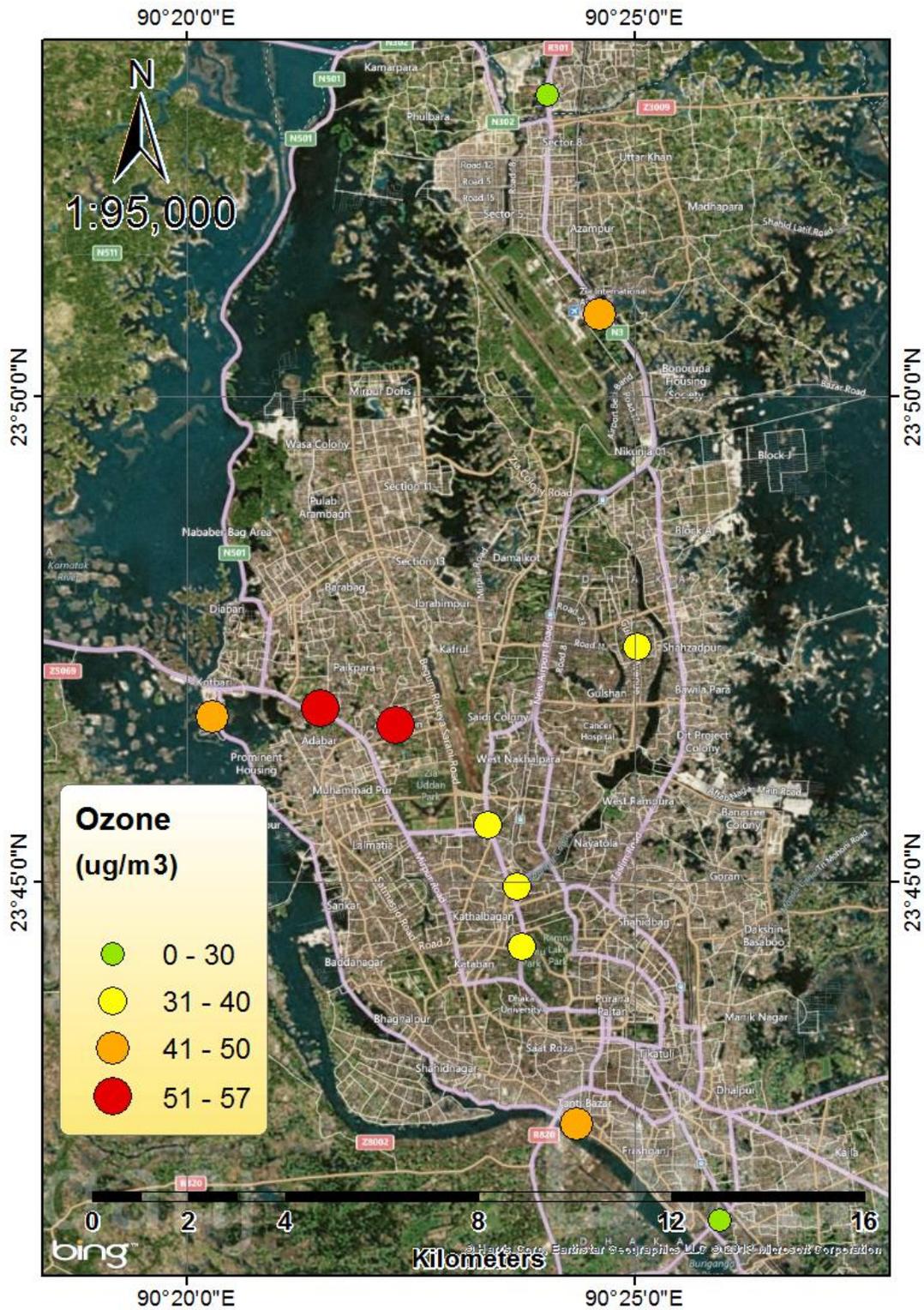


Figure 16: Geographical distribution of O₃ concentrations measured in Dhaka over approximately 8 day sampling period.

The O₃ results are broken down into average concentrations for each general site classification (Figure 17). These general station classifications are derived from specific site classifications found in Table 2 and explained in Table 1. It is difficult to make any concrete determinations from these results due to the low representative number of sites for each classification, however, it is expected that the background sites would have slightly higher average concentrations than, e.g., traffic sites.

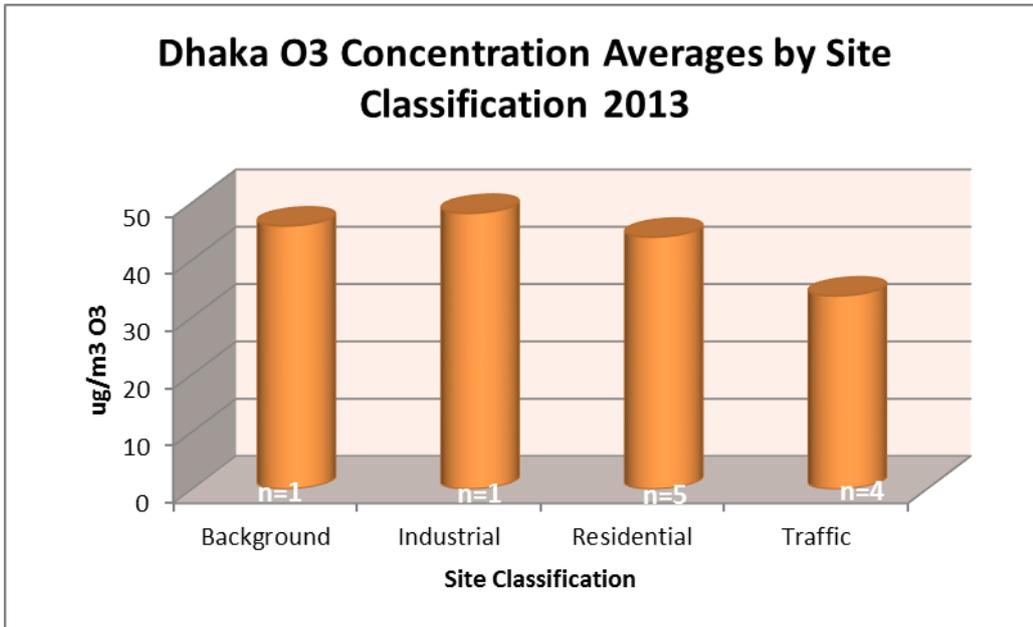


Figure 17: O₃ concentration averages for general classification of sites, Dhaka. The sample size, *n*, is also given for each category.

5.1.4 O₃ and NO₂ Concentration Comparisons

Comparing O₃ results to NO₂ results (Figure 18), indicates that at sites with high traffic density (Sites 3, 20X, 21, and 16), the high NO_x emission rates (leading to NO₂ concentrations greater than 70 µg/m³) result in reduced ozone concentrations (less than 35 µg/m³). Ozone in the atmosphere oxidizes the NO to NO₂, thus reducing the ozone concentration. At sites not directly influenced by NO_x emissions from traffic (Sites 14, 61, and 26) the average ozone concentrations were higher - between 50 and 60 µg/m³.

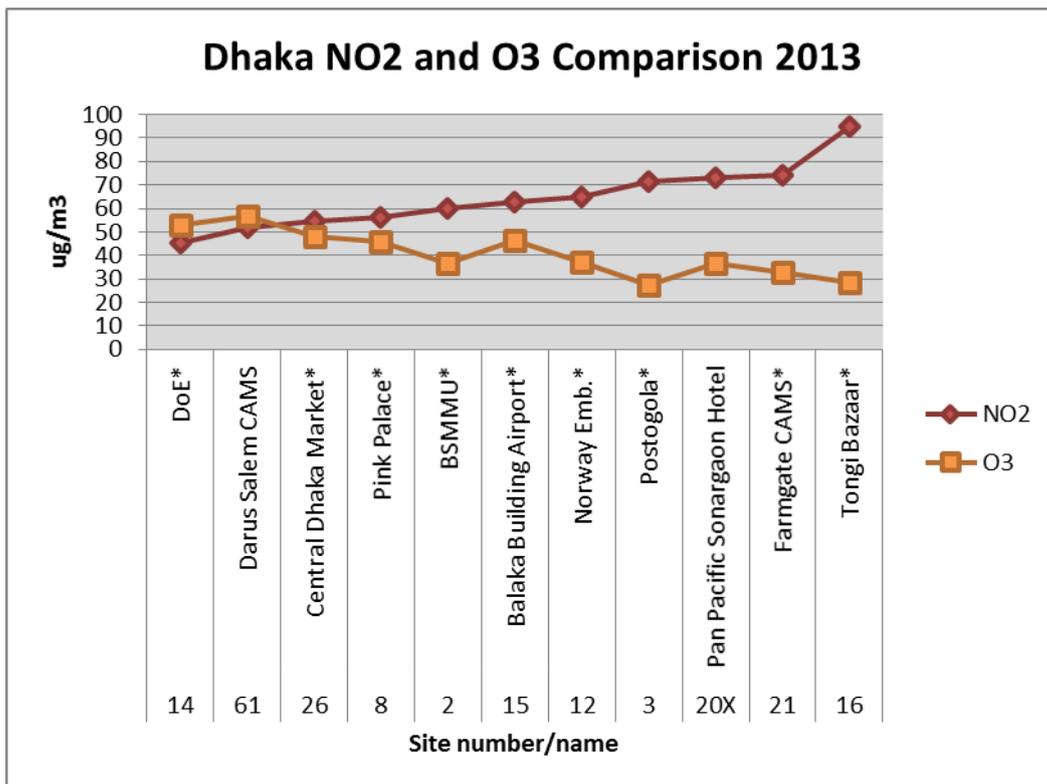


Figure 18: Comparison of O₃ and NO₂ concentrations at 11 sites in Dhaka.

5.1.5 O₃ Concentrations Comparison 2011 and 2013

At 7 of the sites sampling was also carried out during the 2011 passive sampling campaign for O₃. (Randall et.al 2011 b). A comparison of these results is found in Figure 19. In contrast to the NO₂ and SO₂ results comparisons, all of the ozone sites (except one) had higher concentration values in 2013 in comparison to 2011, where on average the 2013 values are 15% greater. As previously mentioned, the 2011 and 2013 sampling periods were actually very similar, in that they were performed during the same time of year (February) and the meteorology during these periods was also identical (i.e. no precipitation, and same wind direction). Possible reasons for the differences are discussed in Section 6.

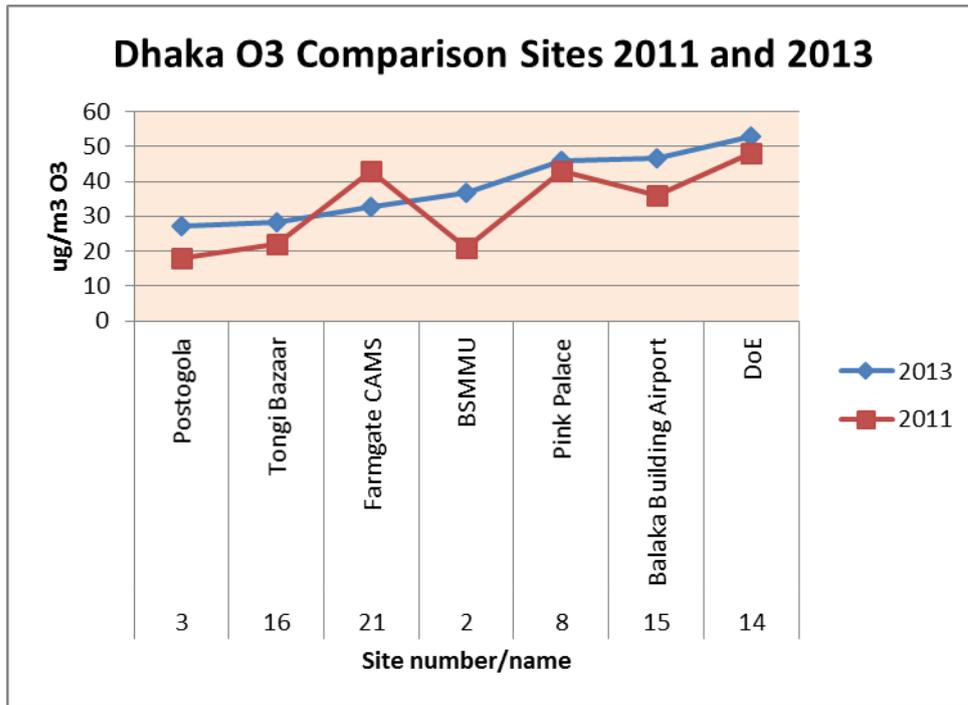


Figure 19: O₃ concentration results comparison between 2011 and 2013 sampling periods, Dhaka.

5.1.6 Comparison of NO₂, SO₂, and O₃ to Dhaka monitoring results

There was a passive sampling site at each of the two active Continuous Air Monitoring Stations (CAMS) in Dhaka. Figure 20 shows the comparison of site 61 which was placed next to the inlets of the Darus Salem CAMS and Site 21 at Farmgate CAMS in Dhaka. The values for each component are fairly different between the measured average and the sampling result. The passive samplers measured almost twice as high concentrations of SO₂ in comparison to the two CAMS. Passive sampled NO₂ was similar at one CAMS station (Darus Salem), but the other sampler (Farmgate) was measuring almost 1/3 lower concentrations than the monitors at the CAMS. For ozone, one of the CAMS (Farmgate) reported 25% higher concentrations than the passive sampler, while the other CAMS (Darus Salem) reported less than half the value of the passive sampler. Possible reasons for these major discrepancies are discussed in Section 6.

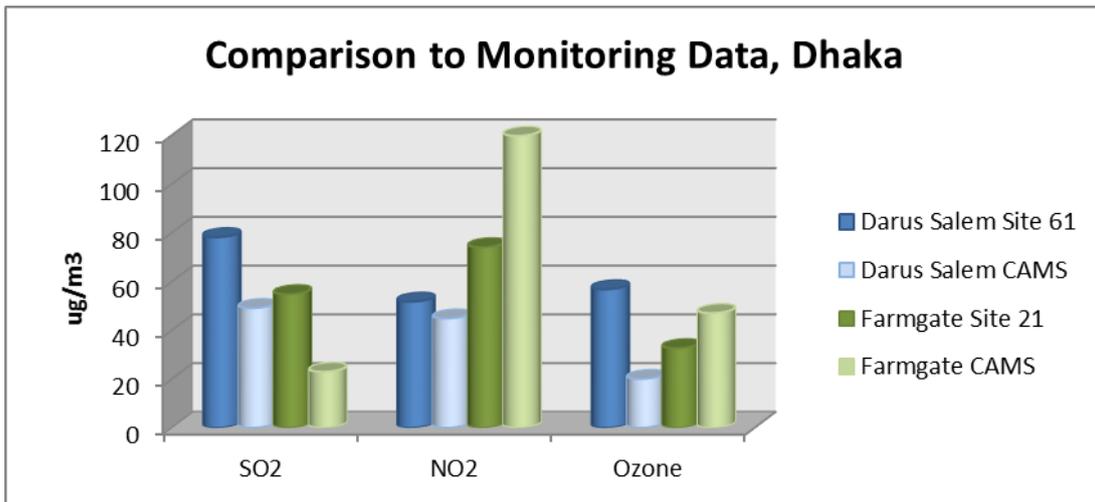


Figure 20: Comparison of Passive Sampling Results to Monitoring Data Results, Dhaka.

5.2 Chittagong

5.2.1 SO₂ Concentrations

Of the 24 SO₂ samplers placed at 24 unique sites, the concentration values ranged from 18 µg/m³ (Site C1) to 94 µg/m³ (Site C2), with an average concentration of 40 µg/m³ for all sites. All SO₂ results can be seen in Figure 21.

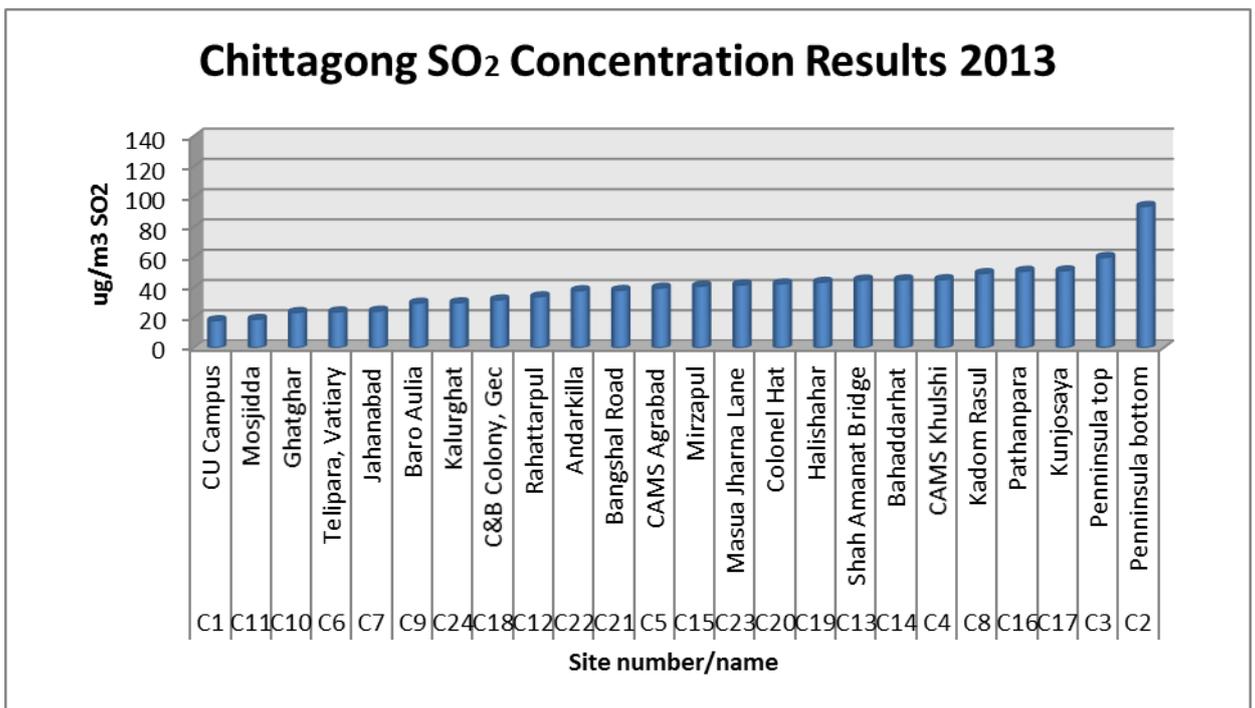


Figure 21: SO₂ concentration results, Chittagong (average concentrations over approximately 8 day period).

In relation to the Bangladeshi NAAQS for SO₂ concentrations, it is likely that at none of the sites in Chittagong the standard of 365 µg/m³ SO₂ over a 24-hour period⁵ was exceeded. However, at many of the sites, the WHO AQG of 20 µg/m³ SO₂ over a 24-hour

⁵ Since the results are averaged over a 8 day period it is difficult to draw conclusions for a daily period.

period would be exceeded, and most likely at none of the sites, would the EU limit value of 120 $\mu\text{g}/\text{m}^3$ SO_2 over a 24-hour period be exceeded.

The geographical distribution of SO_2 results in Chittagong (Figure 22) is relatively diverse, with no clear spatial patterns. Concentrations within the city center are higher than those in the north and north-west areas, due to close proximity to SO_2 sources (brick kilns, small industries, etc. in the city center area).

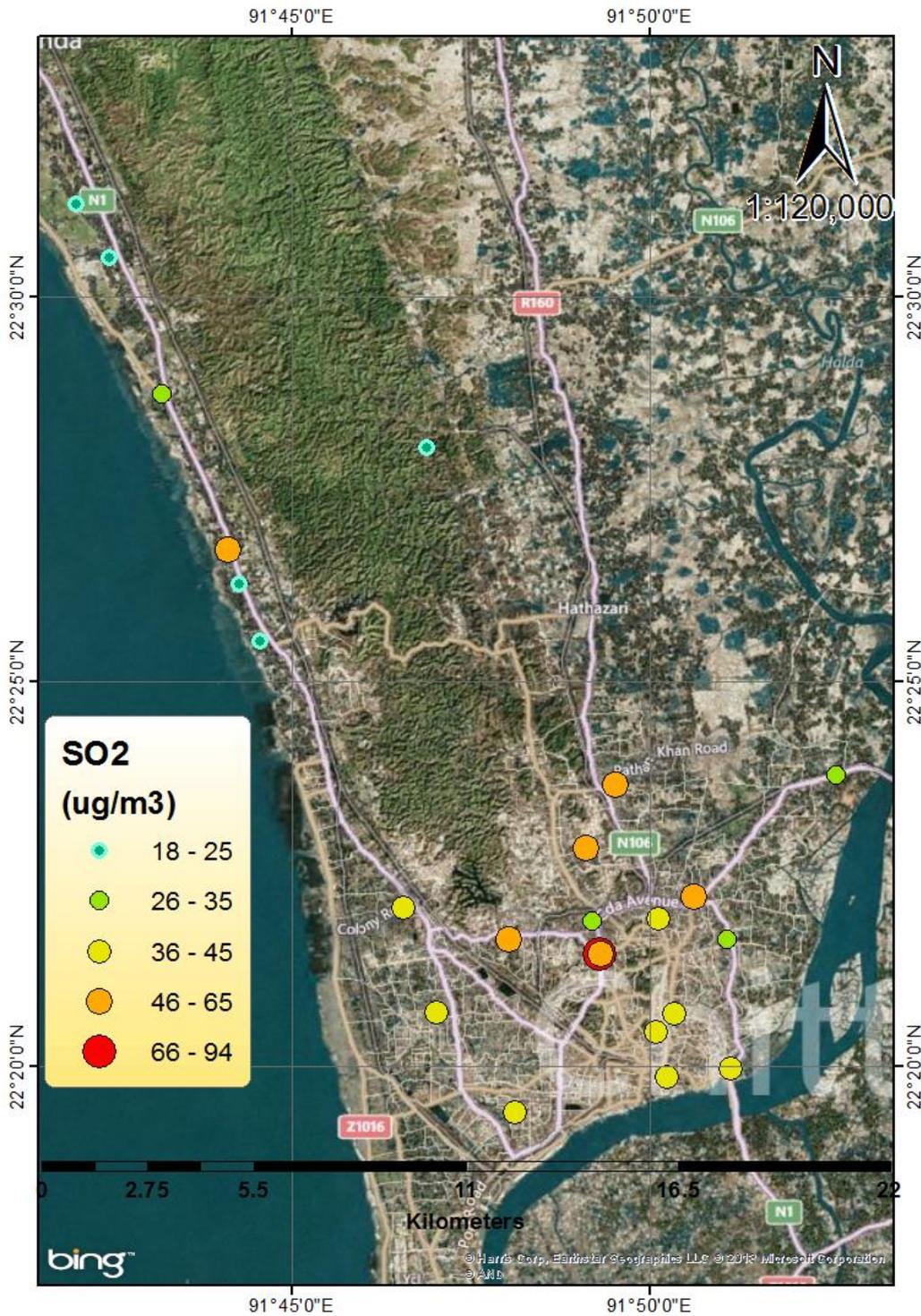


Figure 22: Geographical distribution of SO_2 concentrations measured in Chittagong over approximately 8 day sampling period.

The SO₂ results are broken down into average concentrations for each general site classification sector (Figure 23). These general station classification sectors are derived from specific site classifications found in Table 2 and explained in Table 1. Here, the traffic sites show higher SO₂ concentrations, where it is expected that the industrial sites would have the highest concentrations (as found in Dhaka).

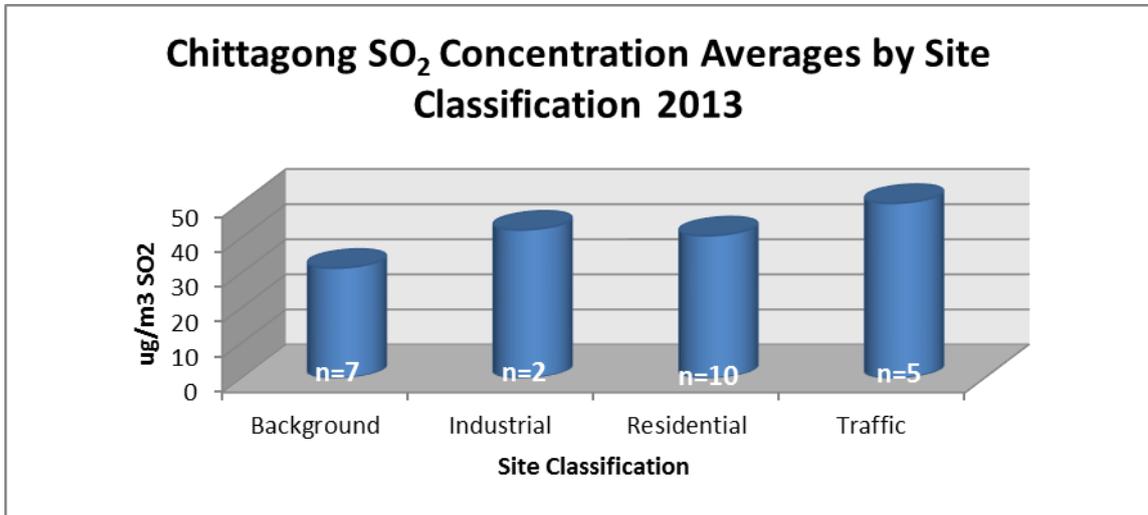


Figure 23: SO₂ concentration averages for general site classification sectors in Chittagong.

5.2.2 NO₂ Concentrations

Of the 24 NO₂ samplers placed at 24 unique sites, the concentration values ranged from 10 µg/m³ (Site C1) to 108 µg/m³ (Site C15), with an average concentration of 46 µg/m³ for all sites. All NO₂ results can be seen in Figure 24.

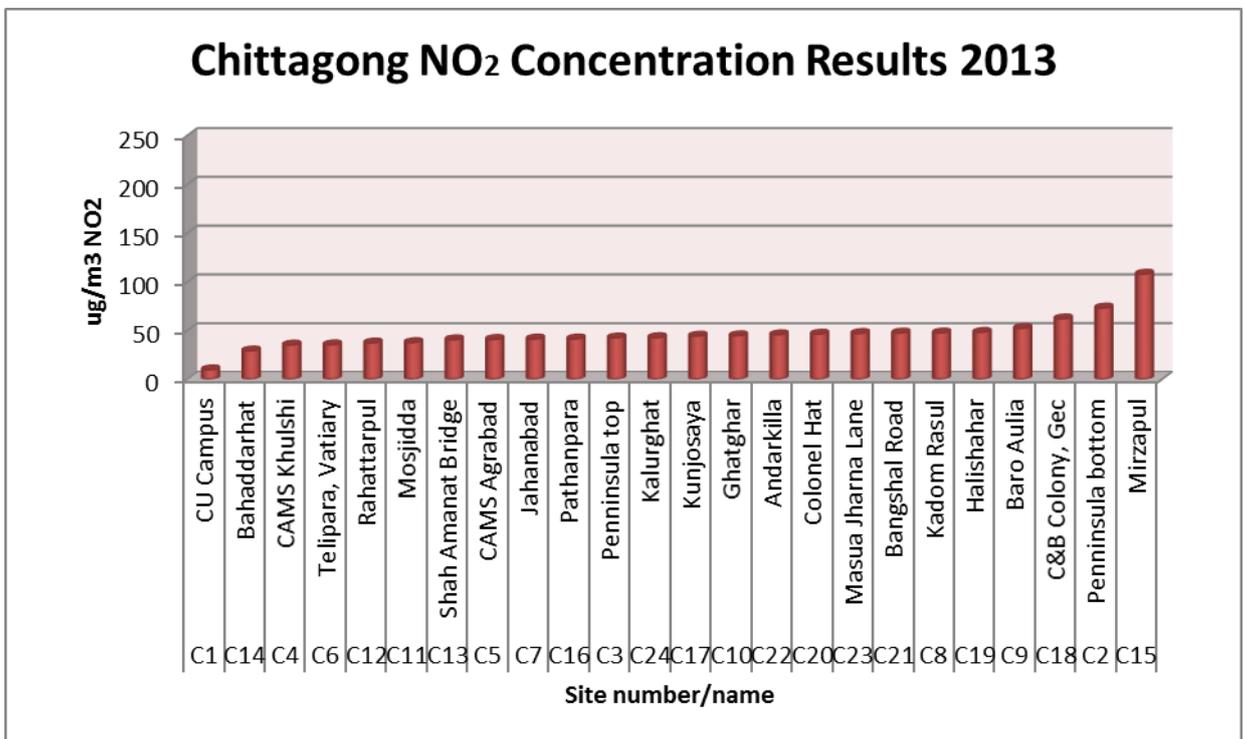


Figure 24: NO₂ concentration results, Chittagong (average concentrations over approximately 8 day period).

In relation to the Bangladeshi NAAQS for annual NO_2 concentrations, at only one of the sites (Site C15), the standard of $100 \mu\text{g}/\text{m}^3$ NO_2 average over an annual period⁶ may possibly be exceeded; and at some of the sites, the EU limit value and WHO guidelines of $40 \mu\text{g}/\text{m}^3$ NO_2 over an annual period are likely to be exceeded. However, it has to be stated that there is probably a strong seasonal variation in average concentrations due to the monsoon rains, so the comparisons to annual average standard or limit values are not straight forward.

The geographical distribution of NO_2 results in Chittagong (Figure 25) shows that the highest concentrations occur in the city center area, due to traffic sources, and within industrial areas as well.

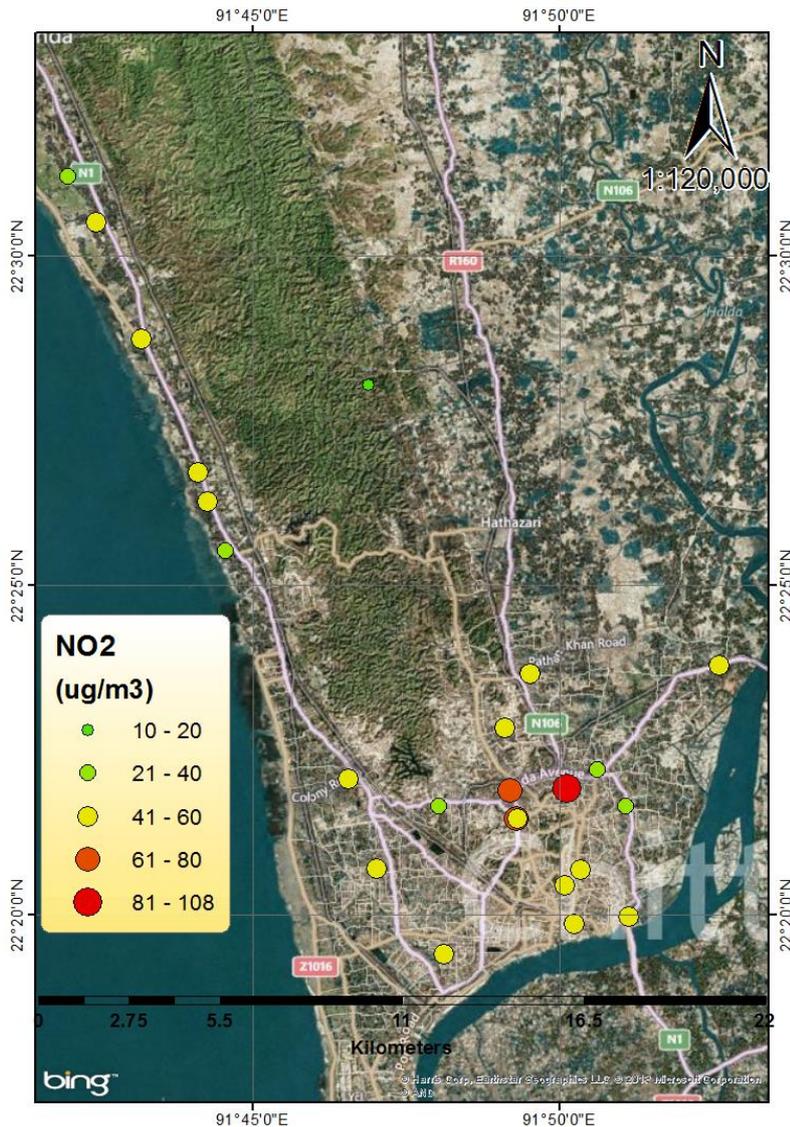


Figure 25: Geographical distribution of NO_2 measured concentrations in Chittagong over approximately 8 day sampling period.

The NO_2 results are broken down into average concentrations for each general site classification (Figure 26). These general classifications of sites are derived from specific

⁶ The annual standards and guidelines were the closest limits to be used for this comparison.

site classifications found in Table 2 and explained in Table 1. As expected for NO₂, and similar to Dhaka results, the traffic sites have higher average concentrations than other site types.

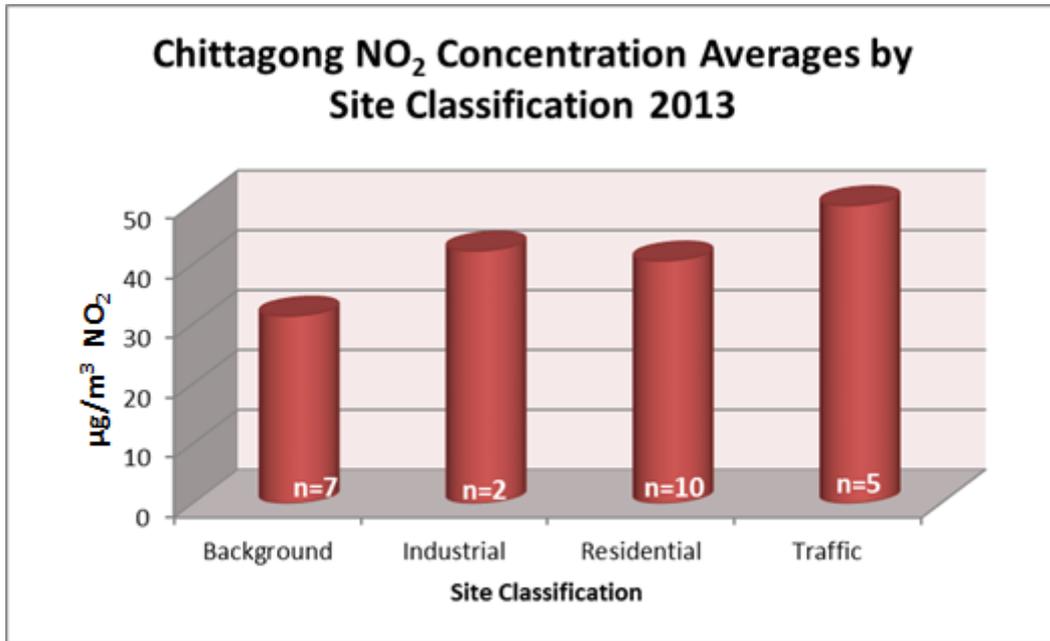


Figure 26: NO₂ concentration averages for general site classification areas in Chittagong.

5.2.3 O₃ Concentrations

Of the 11 O₃ samplers placed in Chittagong, the O₃ average concentration values ranged from 42 µg/m³ (Site C11) to 104 µg/m³ (Site C3), with an average concentration of 64 µg/m³ for all sites. All O₃ results can be seen in Figure 27.

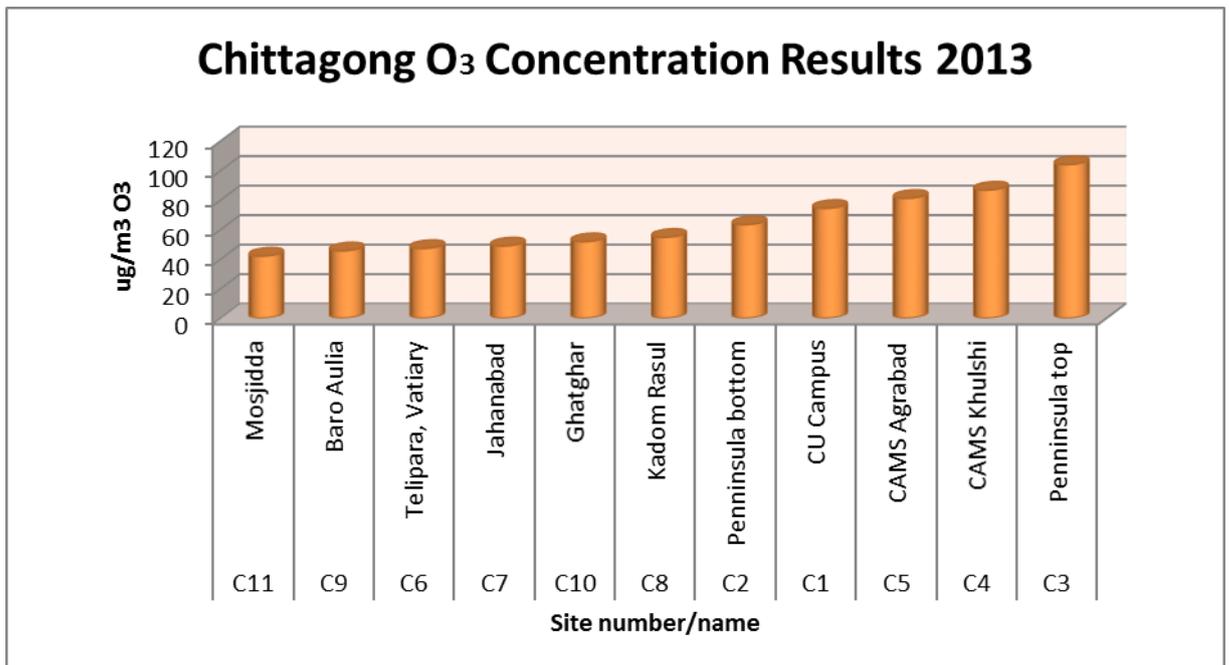


Figure 27: O₃ concentration results for Chittagong (average concentrations over approximately 8 day period).

In relation to the Bangladeshi NAAQS for O₃ concentrations, (and similarly to Dhaka O₃ concentrations) it cannot be definitively ascertained if the ozone concentrations at the sites exceeded the standard and guideline values due to the strong diurnal nature of O₃ formation, so based on this fact, the 8 day integrated average ozone concentrations cannot be used to conclude relative to limit values given for shorter averaging times.

The geographical distribution of O₃ results in Chittagong (Figure 28) shows that there seem to be slightly lower concentrations along the coast than in the city. There is also higher ozone concentration measured at the top of the Peninsula building than at the bottom (street level).

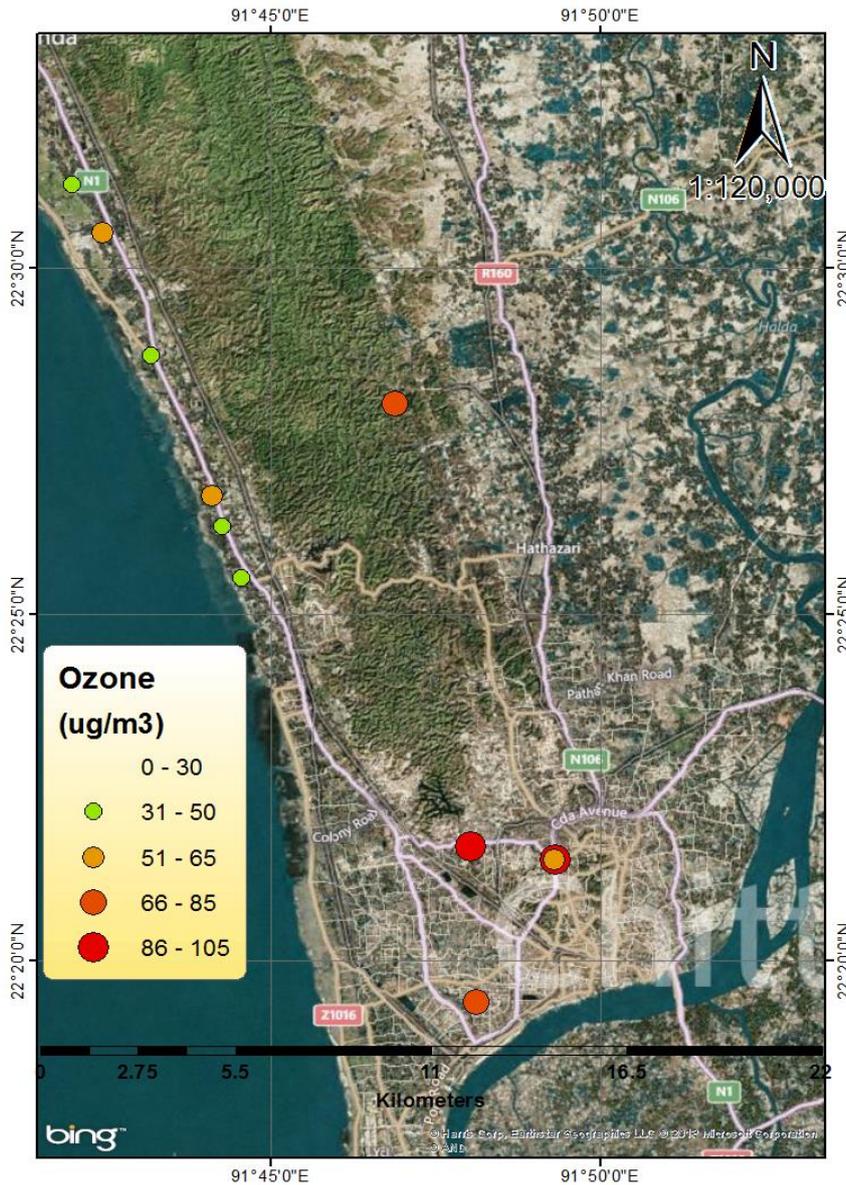


Figure 28: Geographical distribution of O₃ concentrations measured in Chittagong over approximately 8 day sampling period

5.2.4 O₃ and NO₂ Concentration Comparisons

As in Dhaka, when comparing O₃ concentrations to NO₂ concentrations in Chittagong (Figure 29), we see that the highest ozone concentrations occurred at the sites not influenced by high local emissions of NO_x (Sites C3, C5, C4, C1), where the highest ozone

concentration, exceeding $100 \mu\text{g}/\text{m}^3$, was found at the roof top of the Peninsula hotel (Site C3). We may assume that this measurement at Site C3 represents an average regional background ozone concentration available in the surrounding areas of Chittagong. At the University Campus (Site C1), far away from traffic, the (background) NO_2 concentration was only $10 \mu\text{g}/\text{m}^3$, while the average ozone concentration reached $75 \mu\text{g}/\text{m}^3$.

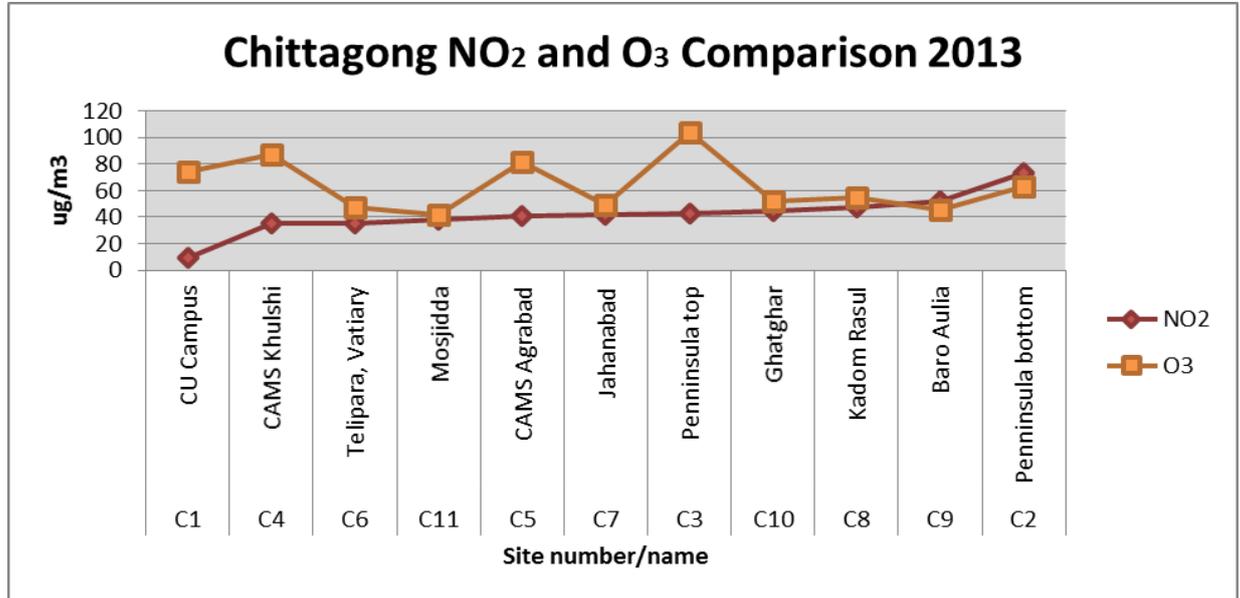


Figure 29: Comparison of O₃ and NO₂ concentrations at sampling sites in Chittagong.

5.2.5 Vertical comparison of SO₂, NO₂, and O₃ concentrations⁷

There was a sampling site at the top (on the roof) of the tallest building in Chittagong (Peninsula Hotel), as well as at the ground level entrance to the building. Results show that the ground level measurements are 56% greater for SO₂, and 72% greater for NO₂, while O₃ is 64% greater at the roof in comparison with the ground level (Figure 30). The roof-top values can give a general indication for the overall city-wide background levels for each component. These results are further analyzed and discussed in Section 6.

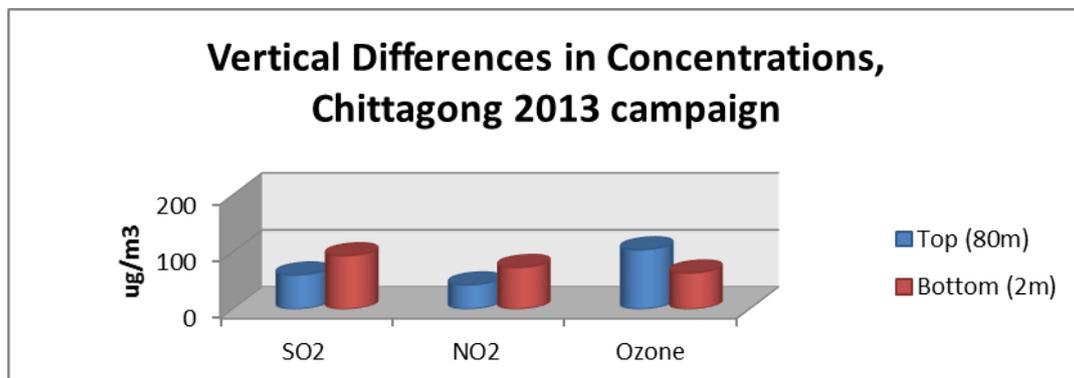


Figure 30: Comparison of vertical differences of SO₂, NO₂ and O₃ concentrations at the Peninsula Hotel, Chittagong.

⁷ A vertical comparison was attempted in Dhaka as well at the tallest building in the city (Westin Hotel), but the samplers at the ground level went missing (Site 1A) so a comparison is not possible.

5.2.6 Comparison of NO₂, SO₂, and O₃ sampling results to Chittagong monitoring data

Only the CAMS Agrabad can be used for comparison, because the other CAMS station (Khulshi) did not generate any reliable ambient air quality data while the passive samplers were exposed at that station. Figure 31 shows the comparison for site C5 where passive samplers were placed next to the inlets of the Agrabad CAMS in Chittagong. Here, a slightly better correlation was found than in Dhaka. NO₂ values at Agrabad are very similar, passive sampled SO₂ concentrations are almost 50% greater than monitored, and O₃ sampled values are about 25% greater than the CAMS monitored data.

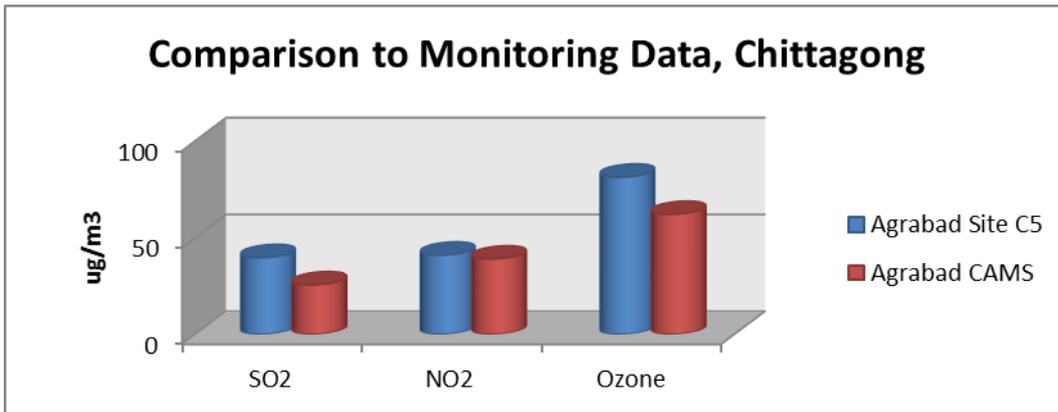


Figure 31: Comparison of Monitoring Data to Passive Sampling Data, Chittagong.

5.3 Comparison between Dhaka and Chittagong Average City Concentrations

The comparison of the average results for all samplers between the two cities for the 2013 sampling campaign shows that the SO₂ concentration average is 33% greater in Dhaka than in Chittagong⁸; the NO₂ concentration average is 37% greater in Dhaka than in Chittagong; and the Ozone concentration average is 36% greater in Chittagong than in Dhaka (Figure 32). These results are further discussed in Section 6.

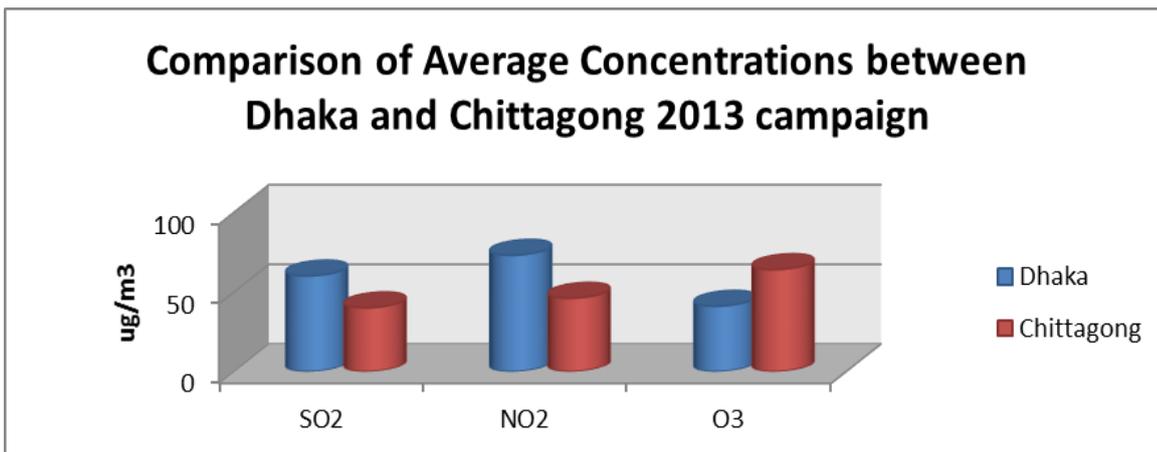


Figure 32: Comparison of average concentration results between Dhaka and Chittagong, obtained during the 8-day sampling periods in 2013

⁸ Taking into consideration that the number of sites for each category type (background, industrial, residential, traffic) is not identical between cities.

5.4 Satellite Mapping

To obtain the best possible overview of the spatial distribution of NO₂ in Bangladesh, a currently non-operational high-resolution (0.1 degree by 0.1 degree) NO₂ product produced by NASA was used. While this product was only available for the year 2009, it can provide valuable information about the more fine-scale structure of the spatial patterns of NO₂. Figure 33 shows a map of the 2009 average tropospheric NO₂ column over Bangladesh using this product.

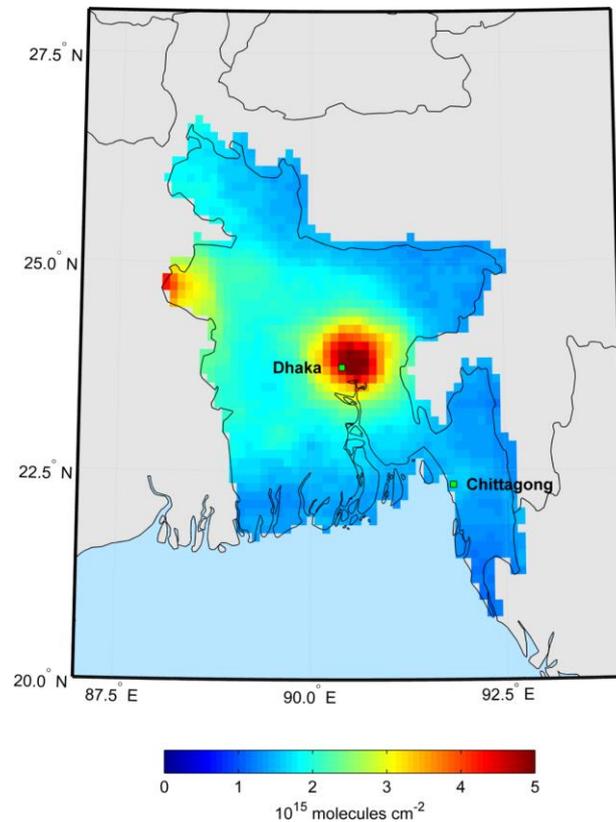


Figure 33: 2009 average tropospheric NO₂ columns over Bangladesh observed by the Ozone Monitoring Instrument (OMI). A special high-resolution (0.1 degree) OMI product was used for this purpose, which is currently only available for the year 2009.

In order to provide a more recent perspective of regional NO₂ concentration in the Bangladesh area, the maps for all the individual days during the study period (15 February 2013 to 1 March 2013) were averaged. Figure 34 shows the resulting spatial patterns of tropospheric NO₂ during the period of the screening study.

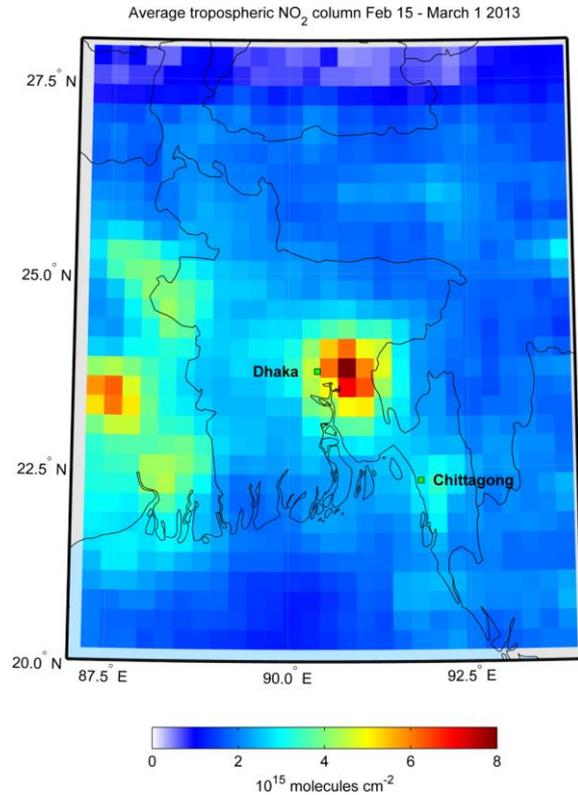


Figure 34: Average tropospheric NO₂ column over Bangladesh during the study period from 15 February 2013 to 1 March 2013. The operational 0.25 degree spatial resolution OMI product (OMNO2d) was used for this purpose.

Finally, Figure 35 shows time series of OMI-derived tropospheric NO₂ column for both Dhaka and Chittagong during the study period in February 2013. Whereas the NO₂ concentration in Chittagong appears to be fairly constant, varying approximately in the range of 2×10^{15} molec. cm⁻² to 4×10^{15} molec. cm⁻², the concentrations over Dhaka start out at significantly higher levels around 10×10^{15} molec. cm⁻² but then gradually decrease throughout the month until they reach levels of approximately 4×10^{15} molec. cm⁻² at the beginning of March.

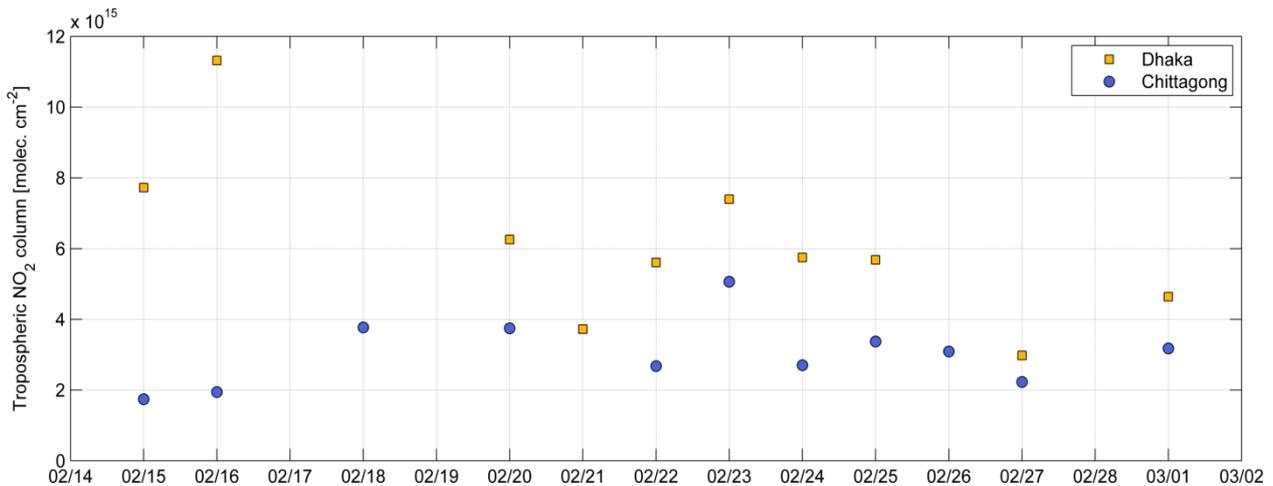


Figure 35: Average tropospheric NO₂ column over the cities of Dhaka and Chittagong during the study period from 15 February 2013 to 1 March 2013. The operational 0.25 degree spatial resolution OMI product (OMNO2d) was used for this purpose.

6 Summary and Discussion

The air quality sampling results presented can confirm that both Dhaka and Chittagong have problems meeting international standards and guidelines for the gaseous pollutants sampled at the 49 sites for both cities. The averaged concentrations over the sampling period for most sites in both cities is likely to exceed the AQGs set by WHO for the components sampled, which may impact the health of the residents of both cities (20+ million people total).

Measured SO₂ concentrations for the sampling period were somewhat high on average for Dhaka (60 µg/m³) ranging from 33 µg/m³ to 132 µg/m³; and moderately high also in Chittagong (40 µg/m³) ranging from 18 µg/m³ to 94 µg/m³. Exceedance of the WHO guideline values could be expected at most sites in both cities, with most of the higher values coming from sites in industrial areas, as expected.

NO₂ values were relatively high on average for Dhaka (73 µg/m³), ranging from 45 µg/m³ to 212 µg/m³; and moderately high average in Chittagong (46 µg/m³), ranging from 10 µg/m³ to 108 µg/m³. Most of the sites likely exceeded international standard and guideline values, more so for Dhaka than Chittagong. Most of the highest concentrations measured were at traffic sites, as expected. Analysis of satellite-derived NO₂ columns shows that Dhaka is certainly a regional hot-spot for NO₂, while Chittagong is not.

O₃ concentrations in Dhaka were on average 41 µg/m³, ranging from 27 µg/m³ to 57 µg/m³; and Chittagong 64 µg/m³, ranging from 42 µg/m³ to 104 µg/m³. However, because of the large variations in ozone concentrations from day to night and from winter to summer, we cannot specify any possible exceedances of the one-hour or eight-hour limit values for O₃ inside the large cities of Dhaka and Chittagong.

Some interesting comparisons and discussion points, which resulted from the data analysis are as follows:

- **Concentration differences between cities during 2013 sampling periods (Dhaka & Chittagong)**

SO₂ and NO₂ concentrations were 22% and 37% higher respectively in Dhaka in comparison to Chittagong, whereas O₃ was 36% higher in Chittagong. Reasons for these differences between the two cities are that Dhaka contains a much higher total number of local sources (more brick kilns, more vehicles, etc.) which results in larger emissions and higher concentrations of SO₂ and NO₂. However, Chittagong does have a greater amount of organized industry within the city limits in comparison to Dhaka, where industrial sources are outside of the city limits. Another reason is that Dhaka may be prone to a greater contribution of regional sources leading to higher local SO₂ and NO₂ concentrations in comparison to Chittagong - based on location alone and trans-boundary trajectories. Ozone concentrations are higher in Chittagong most likely due to higher emissions and thus higher concentrations of NO_x in Dhaka, which reduces the local background concentrations of ozone.

- **Concentration differences between campaigns for Dhaka (2011 & 2013)**

There were surprisingly 35% greater SO₂ concentrations on the average and 31% greater NO₂ concentrations during the 2011 sampling period compared to the 2013 sampling period in Dhaka, while O₃ concentrations were 15% greater during the 2013 period in Dhaka. It should be noted that there were relatively similar meteorological conditions during these two periods, however, this could also be a factor in understanding these differences. The most notable difference between these two periods to explain these differences between the campaigns is that during the 2013 sampling period there was an unexpected 4 days of general national political strikes (“Hartal”). During Hartal, there are dawn-to-dusk curfews on vehicular traffic, resulting in approximately 90% traffic reduction during these 12 hour periods. A future study is recommended to investigate this case further in which CAMS monitoring data can be analyzed before and after Hartals for 6 months to compare to concentrations found on actual Hartal days. It can also be concluded that the ozone levels were higher during the 2013 campaign, while NO₂ and SO₂ levels were lower due to the reduced emissions of NO_x and SO₂. The general concentration of O₃ was thus higher.

- **Spatial patterns of concentration results during the 2013 campaign (Dhaka & Chittagong)**

The clearest spatial pattern in the distribution of gaseous pollutants during the study is the location of sites with high SO₂ concentrations in Dhaka. Here, the sites in the western part of the city are close to large brick kiln fields, in addition to clearly being located downwind from these fields. This can give a good indication of the brick kiln impacts to the city. It was also assumed that the sites north-west in Chittagong would produce the same effect, based on the ship-breaking operations along the beach in this area and the prevailing winds. However, the sampling at sites in north-west Chittagong resulted in relatively low SO₂ concentrations. This might have been due to the fact that while the ship-breaking is conducted on the coast, the actual processing of the ship material is carried out further inland. In many cases, processing is undertaken inside the Chittagong city center – thus distributing the emissions a bit differently than originally anticipated. In addition, while there are no large scale general spatial patterns related to NO₂ for Dhaka and Chittagong, the sites with highest concentrations are those closest to traffic sources as expected.

- **Comparison to monitoring station SO₂ concentration results (Dhaka & Chittagong)**

Samplers were purposely located at monitoring stations in Dhaka and Chittagong in order to obtain a validation for the passive sampling results. However, there were large dissimilarities between monitoring and sampling results for all components in both cities. The possible explanation for these differences in regards to SO₂ is twofold: a) SO₂ emitted in the atmosphere is reduced due to chemical reactions in the atmosphere caused by very high concentrations of particles in the air in Dhaka (and Chittagong). The SO₂ emitted from the sources will thus be transformed into sulfate, and in addition, SO₂ may be transformed to sulfate in the monitoring station intake manifold. Thus in combination, the monitoring stations are possibly measuring significantly lower concentrations of SO₂ than is present in the atmosphere; b) The analytical methods for determining

SO₂ on the impregnated filters is based on measurements of total sulfate on the filter, which is then determining the SO₂ concentration. So the combination of these two factors may lead to the case that the monitoring stations are underestimating SO₂, while passive sampling is overestimating to an extent (analyzing SO₂ plus sulfate), resulting in the differences found in this study between these two results.

- **Vertical concentration differences (Dhaka & Chittagong)**

It is valuable to understand the vertical profile of the air pollutants, and it is optimal to have as many sites as possible with varying elevations. Concentration measurements at the rooftops of the single tallest buildings in Dhaka and Chittagong (80m+) show high ozone concentrations, thus most likely indicating the possible background level concentrations for both cities. For NO₂, Chittagong displays a strong gradient for this gas ranging from high at the bottom to lower at the top, due to the emissions from traffic at the ground level. For SO₂ in Dhaka, the sources are somewhat further outside the city center, so the concentrations are higher at the top of the tallest building in comparison to the bottom, while in Chittagong, many of the SO₂ sources are distributed throughout the city center, so here the concentrations are actually higher at the lower level.

- **Impact of meteorology on pollutant concentrations (Dhaka & Chittagong)**

Meteorological seasons greatly influence the concentrations of gaseous (and particle) pollutants in Bangladesh, also influenced by large seasonal variations in the industrial activities and thus air pollution emissions. The differences in meteorological conditions during the dry and wet seasons throughout the year play an important role on air quality in Bangladesh. Also the emissions of air pollutants vary dramatically from the dry to the wet season. During the dry season all industrial sources are in full operation resulting in the maximum emissions possible, and the road dust re-suspension plays a large role in increasing local particulate concentrations. During the wet season, on the other hand, many of the industries become inoperable due to flooding, and road dust is not an issue, thus reducing industrial emissions and re-suspension sources. Meteorology also affects air quality in Bangladesh through the creation of distinct regional prevailing winds during the different seasons. For example, on the larger scale in Dhaka, the winds transport particles from industrial sources in India during the dry season with north-west winds. North-westerly winds also transport particulate and gaseous pollutants from the industries (brick kilns) north-west of the city directly into the city center.⁹ In Chittagong, the prevailing winds play a more localized role which is dependent on the vicinity of local industrial sources – since these are generally distributed through the city center area (unlike Dhaka).

- **Differences in diurnal variation of SO₂ concentrations (Dhaka & Chittagong)**

The analysis of SO₂ monitoring results in this report presented the assumption of possible differences in diurnal variations of SO₂ concentration between Dhaka and Chittagong. An analysis of monitoring data for SO₂ diurnal variations at Darus Salem CAMS in Dhaka and Agrabad CAMS in Chittagong from 08-26 February 2013 can be seen in Appendix C. This figure clearly shows an SO₂ concentration peak at

⁹ Although Dhaka is surrounded almost 360 degrees by brick kiln fields in the suburbs, the largest active fields are in the north-west direction from the city center.

approximately 08:00 all days in Chittagong, while a more distinct concentration peak occurs around 21:00 in Dhaka.

It is presumed that the morning peak in Chittagong is due to the morning rush hour including heavy duty vehicles running on diesel, which raises the SO₂ concentrations. However, Dhaka has strict controls on heavy duty vehicles, which involve that they can only operate in the city at night time (between 2300 and 0600). The nighttime peaks in Dhaka can possibly be attributed to the heavy duty vehicles raising the SO₂ concentrations during the sampling period. Also the ground based temperature inversions after sunset can cause a general rise in the ground level concentrations.

This issue should be investigated further because it may be a good example of how the implementation of mitigation measures in Bangladeshi cities affects average pollutant concentrations and diurnal patterns. Another reason for the peak values measured just after sunset could be that open air burning of waste and local outdoor cooking activities start after sunset. It is known that close to the Darus Salem station intakes there are sources of biomass burning.

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Appendix A
Screening Study Procedures

SAMPLING INSTRUCTIONS FOR A DIFFUSIVE SAMPLER

1. Sampling equipment

The sampler is a little round plastic container with the dimensions 1.2 cm * 2.5 cm (height, diameter). It consists of a steel net placed in front (opening) of the sampler, a Teflon filter and an impregnated filter to absorb gases, in addition to the container. Together with the steel net, the Teflon filter will prevent turbulent transport to the active filter.

2. Sampling

2.1 Reception of the samplers

- The samplers must be stored in their transport boxes in a cool spot (e.g. in a refrigerator) until exposure takes place.
- If any of the different items are loose at reception, this should be noted on the drift form that follows the samplers.

2.3 Outdoor sampling

- The samplers should be located about 2 meters above the ground, ex. Under the tip of a roof, under a fence or under a shelter roof etc.
- The samplers should be attached upside down underneath the horizontal plane with a two-sided adhesive tape, with the filter side (the opening) turned down.
- It is of extreme importance to mount the samplers in such way they are not getting wet!

2.4 Ending the exposure

- After exposure, each sampler should immediately be placed in its transport box in which it was received.
- The samplers should again be stored in a cool spot until they are sent back to NILU.
- The samplers should be sent back to NILU as soon as possible after exposure.

3. Marking the diffusive samplers

- Mark the transport box, not the sampler, because of the size of the samplers.
- A little label is attached to the transport box. This label contains the name of the station, sample type (code for SO₂, NO₂ etc), the number of the sampler. The sampling start and end time has to be filled in to the form. Note the position AND the number of the samplers.

4. Filling out the drift forms

- The drift form shall always be filled in with a ball pen.
- When error in writing, cross out the error and write the correction beside.
- The drift form shall always be returned to NILU together with the samplers the drift form refers to.
- The station holder must write readably on the drift form, preferably with block letters.
- The following fields shall always be filled in:

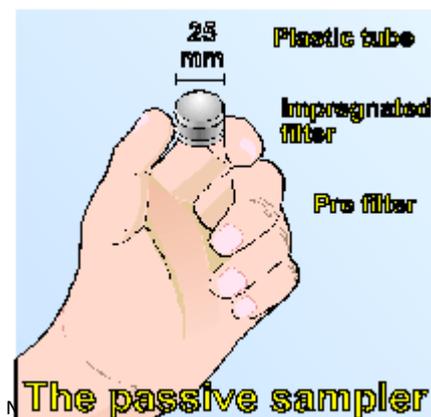
Observer:	Name of the person that has carried out the fieldwork.
Date:	Date that the sample is exposed from start and to collection day (write while in the field)
Station name:	Name of the station
Position:	When there are more than one sampler that are placed at the same spot, the samplers have to be numbered.
Sampler identification:	The number on the sampler must be noted on the drift form, (red samplers are for SO ₂ , blue samplers are for NO ₂ , white for ozone). We prefer to write the number of the sampler when starting the sampler. Remember to bring the correct box (numbered) back when you collect the sampler.
Sample type:	Diffusive samplers can be used to sample different types of gases. One must therefore note on the form, which type of sample the form refers to. The code is noted on the transport box.
Comments:	Comments may contain weather, errors, dust etc..

5. Field blanks

- The field blanks are marked with a red label(!) or with a note on the transport box, marked "FBL".
- The field blank is not to be taken out of the transport box.
- The field blank is stored in a measure stall (for outdoor measurements) or near the measure place (for indoor measurements).
The field blanks are packed with the exposed samples after ended sampling period, and the package is returned to NILU.

About the passive sampler

A simple sampler for surveillance of time integrated SO₂ and NO₂ concentration distributions has been used in this project. The sampler is inexpensive in use, simple to handle and has a good overall precision and accuracy. This method has been used in industrial areas, in urban areas and for studies of indoor/outdoor exposures



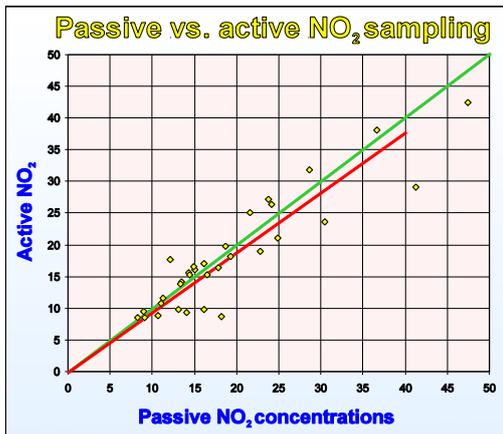
A sensitive diffusion sampler for sulphur dioxide (SO₂) and nitrogen dioxide (NO₂) in ambient air has been used in several investigations to undertake a screening of the spatial concentration distribution.

The sampler was developed by the Swedish Environmental Research Institute (IVL) and has been used in several cases by NILU. The sampler includes

an impregnated filter inside a small plastic tube. To avoid turbulent diffusion inside the sampler, the inlet is covered by a thin porous membrane filter. Gases are transported and collected by molecular diffusion. The uptake rate is only dependent upon the diffusion rate of the gas.

The collection rate is 31 l/24h for SO₂ and 36 l/24h for NO₂. Also NH₃ can be collected at a rate of 59 l/24h.

Comparison with monitors



The integrated passive sampling of SO₂ and NO₂ is well correlated with available active sampling methods.

For SO₂, the measuring ranges are approximately 0,1-80 ppb for a sampling period of one week to one month. The corresponding range for NO₂ is 0,02-40 ppb. The passive samplers are assembled and made ready for use at NILU. After exposure, the samplers are returned to NILU, where

concentrations of SO₂ are determined as sulphate by ion chromatography. NO₂ and NH₃ are determined by spectrophotometry.

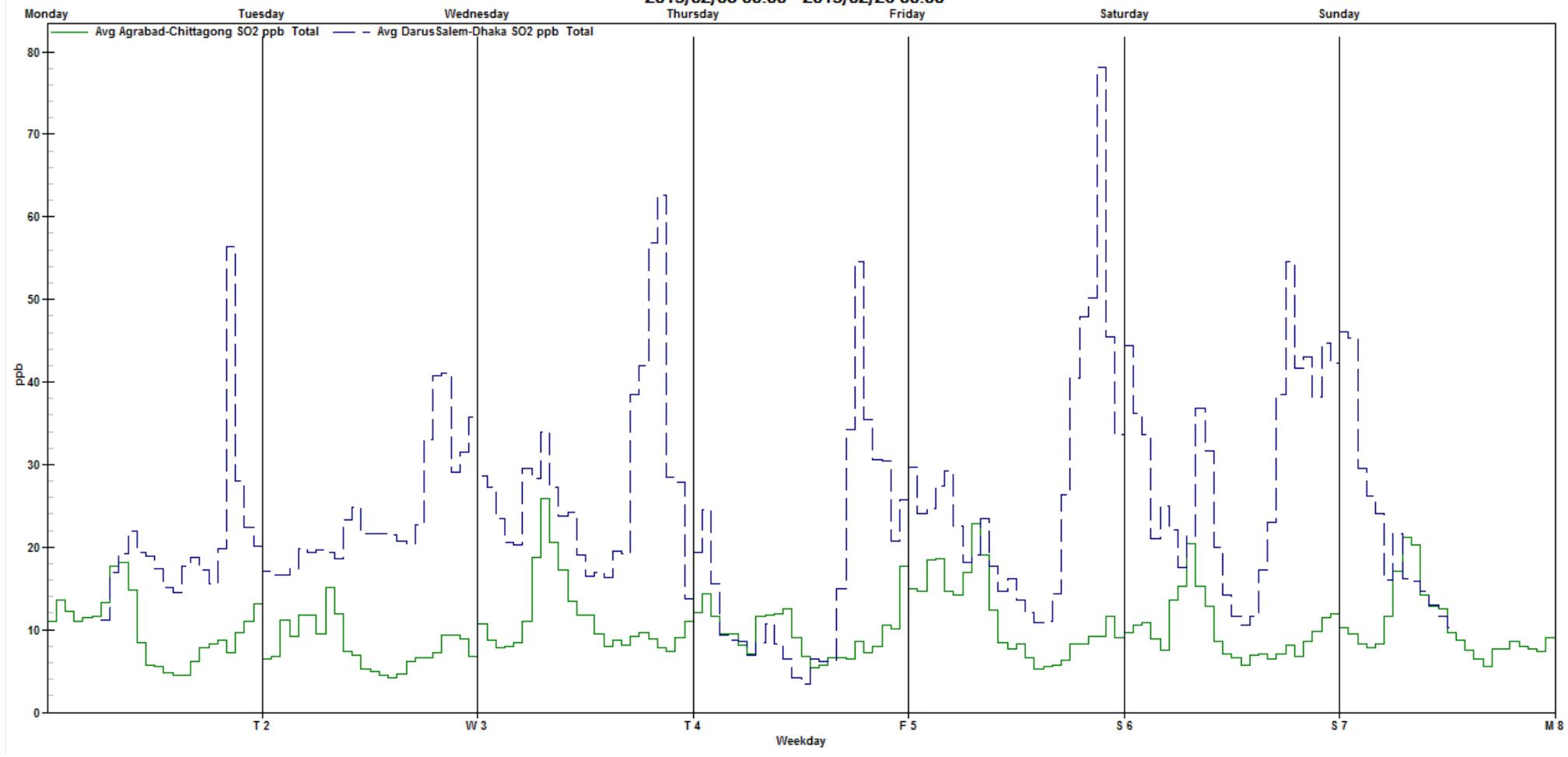
Appendix B

Passive Sampling Field Data Form

Appendix C

SO₂ Diurnal Variation at Dhaka and Chittagong

2013/02/08 00:00 - 2013/02/26 00:00



Appendix D

Limit values and air quality guideline values

Limit values and air quality guidelines

The World Health Organization air quality guideline values as well as the European Union (EU) limit values is presented in the Table below.

Pollutant	Averaging time	Limit- and Guidelines Values	
		EU 1)	WHO
Sulphur Dioxide (SO ₂)	1 hour	350 (24 x)	500 (10 min)
	24 hours	125 (3 x)	50 *
	Year	-	-
Nitrogen Dioxide (NO ₂)	1 hour	200 (18 x)	200
	Year	40	40
Ozone (O ₃)	1 hour	-	150-200
	8 hours	120 *)	120
Carbon Monoxide (CO)	1 hour	-	30 000
	8 hours	10 000	10 000
Particles <10 µm (PM10)	24 hours	50 (35 x)	(150) 50
	Year	40	(50) 20
Particles < 2,5 µm PM2,5)	24 hours	-	(75) 25
	Year	25	(25) 10
Benzene	Year	5	-
Lead (Pb)	Year	0,5	0.5-1,0

1) Ref: EU Limit values for protection of human health (2008/50/EC)

(n x) not to be exceeded more than n times

*) not to be exceeded more than 25 days per year (aver over 3 years)

WHO guideline values 2005 in () are WHO interim target values (IT2)

National Ambient Air Quality Standards (NAAQS) for Bangladesh



Pollutant	Objective	Average
CO	10 mg/m ³ (9 ppm)	8 hours(a)
	40 mg/m ³ (35 ppm)	1 hour(a)
Pb	0.5 µg/m ³	Annual
NO ₂	100 µg/m ³ (0.053 ppm)	Annual
PM ₁₀	50 µg/m ³	Annual (b)
	150 µg/m ³	24 hours (c)
PM _{2.5}	15 µg/m ³	Annual
	65 µg/m ³	24 hours
O ₃	235 µg/m ³ (0.12 ppm)	1 hour (d)
	157 µg/m ³ (0.08 ppm)	8 hours
SO ₂	80 µg/m ³ (0.03 ppm)	Annual
	365 µg/m ³ (0.14 ppm)	24 hours (a)



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<p>ABSTRACT</p> <p>As a part of the Bangladesh Air Pollution Studies (BAPS) project, a screening study of air pollution was performed in Dhaka and Chittagong with assistance from local university partners. The screening study work fell under Task 1 (Emissions Inventory) of the BAPS project.</p> <p>The screening study was performed in Dhaka from 16 February – 26 February 2013, and Chittagong from 20 February – 01 March 2013. The main objective of the study was to gain an overview of the background concentrations and the spatial distribution of the air pollution in the Dhaka city and Chittagong city areas. This study is also following up on a similar study performed in Dhaka in February 2011. The screening study focused on the following gaseous components in Dhaka and Chittagong: Sulphur Dioxide (SO₂), Nitrogen Dioxide (NO₂), and Ozone (O₃). In addition, samples for persistent organic pollutants (POPs) were collected in Chittagong in connection with the study, which will be reported separately in fall 2013 under a different project.</p>			
<p>NORWEGIAN TITLE</p> <p>Luftforurensning i Dhaka og Chittagong. En feltstudie i februar 2013.</p>			
KEYWORDS			
Air Quality	Urban Air Pollution		Environmental Monitoring
ABSTRACT (in Norwegian)			

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