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RESEARCH ARTICLE

Air pollution monitoring in the city of Kandy: possible transboundary effects

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Abstract: The city of Kandy, which is situated in a valley between two mountain ranges, is expected to have a high degree of air pollution owing to its geographic location and the ever-increasing numbers of motor vehicles entering the city. The concentrations of three criteria pollutants; nitrogen dioxide, sulphur dioxide and ozone were measured weekly, using samples collected at two locations in the city of Kandy and another location outside the city in a rural area. Passive sampling method was used to analyze these pollutants. Weekly samples were continuously collected from each station. In the laboratory, sorbent filter was analyzed for the pollutants using colorimetric and turbidimetric methods. The data revealed that the concentrations of nitrogen dioxide, sulphur dioxide and ozone during the sampling period exceeded the permitted Sri Lankan standards for ambient air quality on 14%, 41% and 28% occasions respectively. The values obtained were affected by external conditions such as rainfall, temperature and bright sunshine. A significant effect on transboundary pollution was recorded during the sampling period.

Keywords: Air pollution, Kandy, passive sampling, Sri Lanka.

INTRODUCTION

Air quality monitoring is the key component of Air Pollution Management. Air quality monitoring was carried out at two fixed stations located at Colombo Fort and the Meteorology Department premises at Bauddhaloka Mawatha. Previous studies on air pollution carried out in Sri Lanka have been reviewed.[1] The data obtained in 1996 for Colombo revealed that sulphur dioxide levels exceeded the WHO permitted standards on about 25% of the occasions while ozone level exceeded the standards on 75% of the occasions.[2] More recent data from Colombo suggest an increasing trend for the pollutants, sulphur dioxide, nitrogen dioxide and ozone.[3] Studies on the level of sulphation rate and dust fall at several city locations in Colombo have been reported[4] and this study revealed excessive levels of these pollutants at some locations. A study[5] of air quality levels at several busy intersections in Colombo identified some locations where the total suspended particulates and the non-methane hydrocarbons exceeded the safe levels of these pollutants. Fine particles appear to be the biggest air pollution problem in Sri Lanka. A study carried out[6] on the PM-10 and PM- 2.5 particles in Colombo showed that the levels exceeded the stipulated US-EPA standards on at least 95% of the occasions. A preliminary study on the air quality of Kandy carried out by us in 2001, revealed[7] that some key criteria pollutants such as sulphur dioxide, ozone and nitrogen oxides exceed the gazetted Sri Lanka ambient air quality standards on a considerable number of occasions. This prompted us to increase the scope of the monitoring programme for a longer period since there is no regular monitoring of air quality in Kandy.

Some of the developed countries and certain developing countries still use low cost passive air sampling methods for their national air quality monitoring programmes and make use of these results for air pollution management activities. These methodologies can cover a fairly wide area with a number of sampling points at a reasonable cost. The city of Kandy, which is situated in a valley between two mountain ranges, is expected to have a high degree of pollution owing to its geographic location and the ever-increasing numbers of motor vehicles entering the city. This study is aimed at monitoring air quality in the city of Kandy using the passive sampling method to analyze three criteria pollutants; NO_2, SO_2, and O_3.

METHODS AND MATERIALS

Sampling

Two sampling sites representing the Kandy Municipality area were selected, one from the Bogambara (Bo) area and the other at a distance of 1 km from this site at Kings street. In addition, a site from a rural area at Arambekade

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which is 8 km from the city of Kandy was also selected to serve as a background sampling point (Figure 1). The sampling periods were limited to 4-6 d at each station and weekly samples were continuously collected from each of the two city stations during the sampling period from February 2002 to December 2004 while data from the background station were collected till July 2003. These 24 h data were averaged over a month to give the monthly average data for a particular pollutant.

Figure 2 gives a schematic diagram of the passive sampler used to collect gaseous pollutant samples from the atmosphere through molecular diffusion.[8] During storage and transport, the sampler was kept in a small polypropylene vial sealed with a snap-on cap. Samplers were exposed at each sampling site under a shelter at a height of 1.5 m from the ground and were attached to the surface horizontally using double-sided adhesive tape with the open end facing downwards. In the laboratory, the sorbent filter was removed and analyzed for the pollutant. At the same time a set of samplers was prepared in an identical manner for each of the pollutants analysed and kept unexposed to be used as blanks. These provided the background levels of pollutants in reagents and corrections were applied to all values using the background levels so obtained.

Determination of nitrogen dioxide

The NO_2 coating solution was prepared by dissolving 0.44 g of NaOH in a small quantity of deionized water and 3.95 g of NaI was added into this mixture. Then it was diluted to 50 mL with methanol. Before analysis, the pollutant was extracted into 10 mL deionized water after sonication for 10 min in a shaker. Same procedure was carried out with the blank. The solution was then analyzed for nitrite by the colorimetric technique. The reaction to trap NO_2 (g) pollutant on the filter can be expressed as follows,

$$2NO_2(g) + 3I^- \rightarrow NO_2^- + I_3^-$$

The NO_2^- thus produced was determined by diazotizing and coupling with N- (1- napthyl)-ethylenediamine dihydrochloride to form a magenta coloured azo dye that was measured colorimetrically. A suitable calibration plot was employed for the determination of nitrite in the analyte. The Minimum Detection Limit (MDL) for NO_2 in the atmosphere is 0.002 ppm and the Linear Dynamic Range (LDR) is 0.002 – 5 ppm for this method.

Determination of sulphur dioxide

The SO_2 coating solution was prepared by dissolving 0.5 g of NaOH in a small quantity of de-ionized water and diluted to 50 mL with methanol. The reaction to trap SO_2 (g) on the filter can be expressed as follows,

$$2SO_2(g) + 4OH^- + O_2 \rightarrow 2H_2O + 2SO_4^{2-}$$

The SO_4^{2-} thus produced was analyzed employing the turbidimetric method where, sulphate ion is treated with barium chloride in an acidic medium and the resultant turbidity of the $BaSO_4$ suspension was measured using a turbidity meter (Hach Model 700S). The SO_4^{2-} concentration was determined by comparison of the

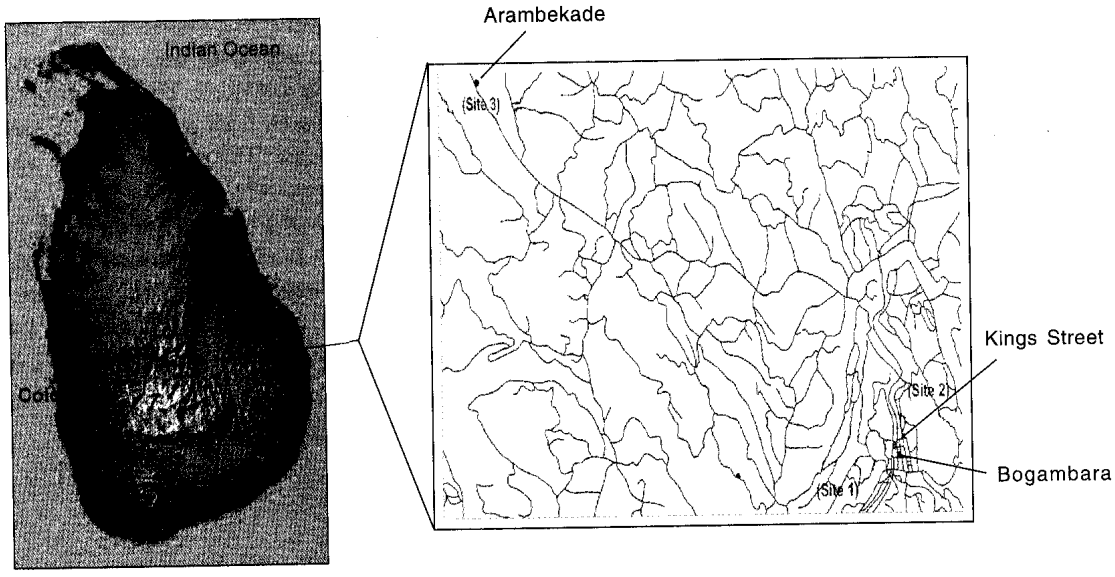

Figure 1: Map of Kandy showing location of sampling points

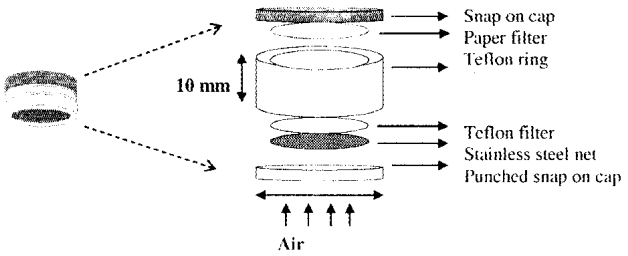

Figure 2: Schematic diagram of a passive sampler

reading with a calibration curve prepared from appropriate standards. The MDL for SO_2 in the atmosphere was 0.01 ppm and LDR was 0.01 – 0.40 ppm for this method.

Determination of ozone

The O_3 coating solution was prepared by mixing 1 g of $NaNO_2$ and 1 g of K_2CO_3 with 2 mL glycerol and making up to 100 mL with a 70:30 water-methanol mixture. A fifty microliter aliquot of the coating solution was pipetted evenly over the paper filter and the end cap was then immediately attached to the ring. The loaded sampler was then placed in a closed polypropylene container.

Ozone is the only pollutant that was measured indirectly by analyzing for the amount of nitrate formed during the above reaction. The reaction to trap O_3 in the filter paper can be expressed as,

$$O_3 + NO_2^- \rightarrow NO_3^- + O_2.$$

The NO_3^- thus produced was then analyzed as follows. Thirty milliliters of EDTA/NH_4Cl reagent was added to the solution and mixed well. The solution was then divided into two portions. One sample was directly used to determine the amount of nitrite in the solution using the above colorimetric method. The other sample was passed through a Cd-Cu column and the amount of nitrite formed due to the reduction of nitrate was determined using the colorimetric method. The difference in the above two values was calculated as the amount of nitrite converted by ozone to nitrate in the atmosphere. The MDL for O_3 in the atmosphere was 0.002 ppm and LDR was 0.002 –5 ppm for this method.

Validation of the method

The method was validated by comparing the data obtained with this type of sampler exposed at the monitoring station at Colombo Fort with the data obtained from the automatic monitoring station at Colombo Fort. Samplers of all three pollutants were exposed for a week and the 24 h average pollutant concentrations were determined and compared with the corresponding data obtained at the automatic station. This was carried out on nine occasions for each of the three pollutants.

RESULTS AND DISCUSSION

Validation of the method

The percentage deviations of the values from the results of the automated monitoring station for the three pollutants were; -10.45% for NO_2, +1.92% for SO_2 and +5.88% for ozone for the nine measurements of each pollutant carried out periodically during the period of this study. Such deviations in method comparisons are not uncommon and have been reported by other workers.[9]

Monthly variation of NO_2

Monthly average of a pollutant was calculated using the weekly average values obtained and the variation of monthly NO_2 averages are given in figure 3. The Bogamabara site consistently recorded higher values compared to the less congested Kings street site. Background monitoring site located about 8 km away from the Kandy city at Arambekade recorded consistently lower levels of all three pollutants compared to the two city sites. Hence, monitoring at this site was carried out only till July 2003. The NO_2 value in the Kandy city limits exceeded the national standard from the month of July 2002 to February 2003. A possible explanation for this unusual trend is the burning of diesel and furnace oil reaching an all-time high during 2002 compared to previous years and the following years owing to the drought conditions which

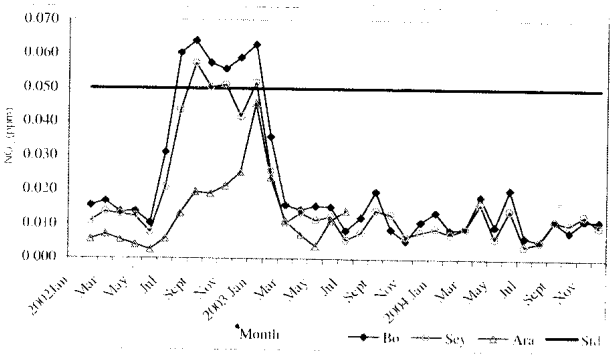

Figure 3: Monthly averages of NO_2 in Kandy (Bo-Bogambara site, Sey-King's Street site, Ara-Arambaekade site, Solid line indicates the national air quality standard)

prevailed during 2002 which reduced hydroelectricity generation. In the year 2002, 926,500 metric tons of diesel and furnace oil were burnt in thermal power plants and this dropped to 723,500 metric tons in 2003.[10] Another possibility is the Asian brown cloud which carried with itself a massive pollution cloud shifting to the skies over Sri Lanka during this period.[11] Increased levels of NO_2 and SO_2 have also been recorded from the Colombo monitoring station during this period. Average annual concentration of NO_2 in Kandy was 0.031 ppm as compared to Colombo where the corresponding value was 0.026 ppm during the year 2001. During this period there was high rainfall in some months usually in the night and the NO_2 generation during day time kept the pollutant levels high.

Monthly variation of SO_2

The variation of SO_2 concentrations during the study period is given in the figure 4 which shows that the values were high after the month of August 2002 similar to the variation of NO_2. A notable difference, however, is the repetition of such high values from July to December 2003. For the entire study period, the average monthly values exceeded the national air quality standard on 43% of the occasions. Since there are no power plants or major industries around the Kandy city, vehicular emissions are the main source for SO_2 in Kandy. According to the Kandy traffic police data, the number of vehicles entering the Kandy city was 65,000 per day in 2003 and 85,000 per day in 2004. This may account for the high concentrations of SO_2 in Kandy city along with its geographic location of being situated in a valley. There is a general decreasing trend in SO_2 emissions after March 2004. This can be attributed to the lowering of the sulphur content of diesel from 0.50 % to 0.25% by the Ceylon Petroleum corporation. This trend has also been observed from the air quality data from the Colombo automated monitoring station.[3]

Before January 2002, there was heavy traffic congestion in the city of Kandy due to the security barriers, and also due to traffic diversions. This became worse in 2001 when Sri Lanka Telecom started to lay underground telephone cables along the roads in the Kandy city which continued up to November 2001. These may be the reasons for the high degree of pollution levels recorded in 2001. The pollutant levels decreased after February 2002 when the road barriers were removed. Again after July 2002, the values became high and remained high till November 2002.

In many countries of the Asian region, ambient SO_2 levels exceed the US-EPA standard of 0.03 ppm (24 h average) and the average value of 0.032 ppm in 2001 for Kandy is very similar to values reported for other Asian cities[12]. The corresponding annual average value for Colombo is 0.018 ppm which points out to the higher degree of air pollution in Kandy compared to Colombo.

Monthly variation of O_3

Figure 5 gives the variation of ozone during the study period where the levels were found to be below the permitted standard on most occasions. The period when high values of ozone were observed coincided with the months where there were excessive sulphur dioxide levels.

Ozone in the lower atmosphere is formed according to the following photo-initiated reactions.

$$NO_2 + h\nu\ (<420\ nm) \rightarrow NO + O$$
$$O_2 + O + M \rightarrow O_3 + M$$

Here M is a third body such as a dust aerosol on which the above reactions take place. In addition, hydrocarbons originating from unburnt automobile fuels are also responsible for the formation of ozone. This explains

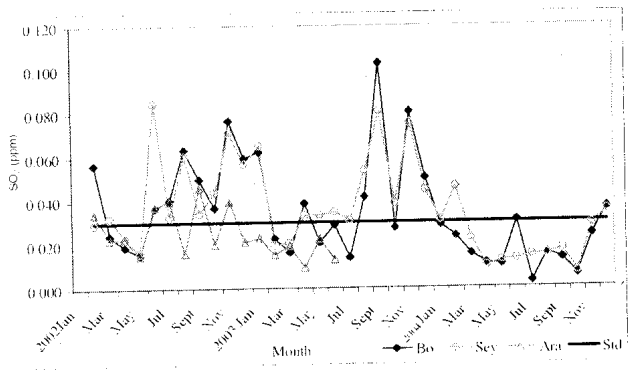

Figure 4: Monthly averages of SO_2 in Kandy (Bo-Bogambara site, Sey-King's Street site, Ara-Arambaekade site, Solid line indicates the national air quality standard)

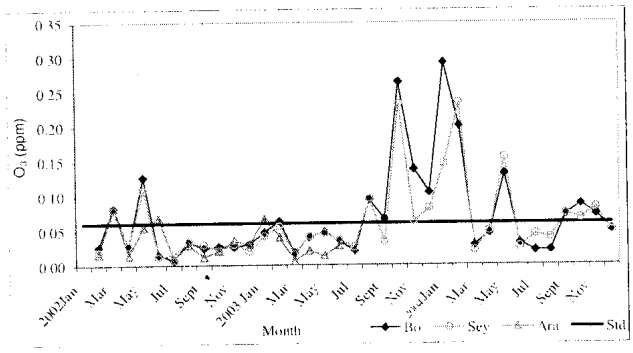

Figure 5: Monthly averages of O_3 in Kandy (Bo-Bogambara site, Sey-King's Street site, Ara-Arambaekade site, Solid line indicates the national air quality standard)

the observed approximate inverse relationship between ozone and nitrogen dioxide concentrations during the sampling period. However, there were exceptions such as during the inter-monsoonal period of April when both ozone and nitrogen dioxide concentrations were low. A similar trend was observed from the Colombo Fort monitoring station (R.N.R.Jayaratne, *personal communication).* April is typically a dry month with low rainfall and the high dust concentrations in the atmosphere could deflect the UV radiation in sunlight. This is a possible explanation for the lower levels of ozone observed during April.

Effects of transboundary pollution

In order to assess the importance of transboundary effects, weekly average values of each pollutant were categorized under the three main monsoonal periods. Percentage monsoonal variations of each pollutant type calculated for Kandy are given in table 1.

Table 1: Pollutant contributions from the different monsoonal periods

Monsoon type	SO_2(%)	NO_2(%)	O_3(%)
South-west	31	28	28
North-east	46	43	39
Inter-monsoon	23	28	33

Since the major portion of the pollution is generated in the western province one would expect a higher degree of contribution to the pollution levels of Kandy from the south-west monsoonal period where the wind direction is in a south-westerly direction. However, the opposite was found to be true where there is a greater contribution to the pollution in Kandy from north-eastern winds. Since north-eastern part of Sri Lanka does not generate appreciable local pollution, the only possible explanation to this observation is transboundary pollution. A similar trend has been observed in the air quality data obtained from 1996-2005 at the Colombo Fort monitoring station. Higher pollutant levels were regularly observed during the north-east monsoon and relatively lower pollutant levels were observed during the south-west monsoonal period where the winds come from the sea side with no pollution sources in the near vicinity. Transboundary pollution involves the long transport of air pollutants from the Indian sub-continent and also from other countries such as China where coal is extensively used for power generation. Out of the two transboundary pollutants, nitrogen dioxide and sulphur dioxide, the contribution of sulphur dioxide is particularly significant with a 46% contribution coming during the north-east monsoon. This is expected since transboundary pollution from India and China are particularly rich in sulphur dioxide owing to the high sulphur coal used in these countries for power generation. Ozone is formed as a local pollutant from the nitrogen dioxide and is only indirectly related to transboundary effects. From these results, it is evident that, transboundary pollution can be considered as making a significant contribution to air pollution in the city of Kandy.

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References

1. Ileperuma O.A. (2004). Environmental Pollution in Sri Lanka: A review. *Journal of the National Science Council of Sri Lanka* **28**(4): 301-325.
2. Samarakkody R.P.,Yalegama M.S.S.B. & Athukorale P.N. (1998). Some aspects of ambient air pollution in Colombo. In: *Proceedings of the Workshop on Acid Rain Monitoring and Air Quality Modelling,* (Ed.O.A.Ileperuma) pp.77-84. Kandy, Sri Lanka.
3. Jayawardane K.G.S. & Jayaratne R.N.R. (2004). What Colombo's Air Quality tells us. Abstracts of papers, *First National Symposium on Air Resource Management in Sri Lanka, Colombo.* p.28.
4. National Building Research Organization (1993). *Colombo Air Quality Monitoring Programme,* Phase I, Preliminary Assessment of Ambient Air Quality. National Building Research Organization (NBRO), 99/1, Jawatta Road, Colombo 5.
5. Mathes J.A.P., Gunawardana H.D. & Karunasinghe N.D. (1995). Ambient Air Quality study of the Pollution caused by vehicular exhaust emissions in the city of Colombo., *NARESA final report, Grant No. RG/89/C/09.*
6. Seneviratne M.C.S., Mahawatta P., Fernando R.K.S., Hewamanne R. & Sumithraarachchi C. (1999). A study of the air particulate pollution in Colombo using nuclear related analytical techniques. *Biological Trace Element Research* **71**: 189-194.
7. Ileperuma O. A. & Abeyratne V. D. K.(2001). Development of passive gas sampling techniques to monitor air pollution levels in cities of the Third World; A Case Study from Sri Lanka. *Analytical Sciences* (Japan) **17**: a291-a293.
8. Ferm M.A.(1991). *Sensitive Diffusional Sampler.* IVL publication B-1020, Swedish Environmental Research Institute, Goteberg, Sweden
9. Dhammapala R.S. (1996). *M.Sc. Thesis,* Potchestroom University for Christian Higher Education, South Africa.
10. Central bank of Sri Lanka. *Annual Reports.* 2002 & 2003. Central Bank of Sri Lanka, No 30, Janadhipathi Mawatha, Colombo 01.
11. UNEP and C^4 (2002). *The Asian Brown Cloud: Climate and Other Environmental Impacts.* UNEP, Nairobi.
12. Haq G., Han W.J., Kim C. & Vallack H.(2002). *Benchmarking Urban Air Management and Practice in Major and Mega Cities of Asia.* Korea Environment Institute, APMA Publication, pp.5-44.