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SHORT COMMUNICATION

Determination of atmospheric PM_{10} concentration in Kandy in relation to traffic intensity

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Abstract: Atmospheric particulate matter (PM) concentration was measured at 25 sites in Kandy. The city is surrounded by hills and is the second most populous city in Sri Lanka, where for 3 continuous peak hours the traffic intensity is in the range of 0 to 2640 vehicles/h. A high-volume air sampler with the cyclone attachment was used to measure the concentration of particulate matter less than 10 µm in size (known as PM_{10}). The concentration of PM_{10} in the atmosphere at the average breathing level is found to have 82% variance in common with the traffic intensity. Colour indices assigned for the filtered samples, which represent the intensity of the airborne carbon particles, of the high-volume air sampler have 91% variance in common with the corresponding colour indices assigned for the filtered samples of the low-volume personal air sampler.

Keywords: Air pollution, Kandy, particulate matter, PM_{10}, Sri Lanka, traffic intensity

INTRODUCTION

Respiratory system related illness is ranked as the second leading cause of hospitalization in Sri Lanka in 2003[1]. Previous studies[2] have identified a close relationship between air pollution in colombo, the capital city of Sri Lanka, and acute childhood wheezing. One study[3] measured gaseous air pollutant levels in Kandy city using passive sampling techniques. It was found that nitrogen oxide, sulpher dioxide, and ozone concentrations exceeded the Sri Lankan standards in 38%, 53% and 40% of the 30 samples analysed, respectively.

Kandy city is located in a flat valley surrounded by hills and mountains. This results in a very low mixing height for atmospheric air in the city. The atmosphere of the city has been observed to become hazy during periods of high traffic with the haziness persisting for long hours. During these periods of high traffic there is a drastic slowing down of vehicular speeds resulting in significant increases in the emission of local air pollutants, since fuel efficiency decreases with speed, especially under stop-go driving conditions[4].

In this study, we investigated the atmospheric suspended particulate matter (SPM) pollution levels in Kandy and its surroundings. SPM, also known as aerosols, include mineral dust, acid species, black carbon (or soot) and polycyclic aromatic hydrocarbons. The primary objective of this study was to assess the SPM of size less than 10 µm, known as PM_{10}, which is respirable and hence could enter the lungs[5]. PM_{10} concentrations measured using a high-volume air sampler (HVAS), were correlated with traffic intensity. The second objective was to correlate the SPM levels measured by the HVAS to that measured by a personal air sampler (PAS), in order to assess the limitations arising from using the low-cost, easy-to-transport PAS to measure SPM levels. The cost of engaging the battery-operated and lightweight PAS to qualitatively assess the intensity of SPM is much less when compared to the HVAS and is more convenient to use.

METHODS AND MATERIALS

Air sampling was carried out at 25 sites covering the range of traffic intensities from 0 to 2640 vehicles/h. The sampling sites were grouped into 5 clusters and brief descriptions of them are given in Table 1.

A HVAS (Envirotech APM 460, India; ± 10 µg particle weight variation; ± 2% airflow rate variation) was used for atmospheric SPM sampling, which has a

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Table 1: Site descriptions

Identity	Description
Cluster 1:	sites are within the Kandy city boundary covering roadsides with high traffic intensity
1.1	Kandy bus terminus where about 100 buses are at engine-idling status during peak hours
1.2	Girls' High School, Kandy situated at a 3-way junction 200 m from Kandy bus terminus
1.3	Kandy Post Office situated at a 3-way junction adjacent to Kandy bus terminus
1.4	Kandy Police Station situated at a 4-way junction close to a school and a temple
1.5	Yatinuwara Veediya, a bus route in the city centre
1.6	D.S. Senanayake Veediya, a main street in the city centre
1.7	Sangaraja Mawatha along a main road in the city by the Kandy Lake
Cluster 2:	sites are within the Kandy city boundary covering locations away from roadsides with high traffic intensity
2.1	Girls' High School, Kandy-sampling done inside the school boundary
2.2	Pushpadana Girls' School
2.3	Trinity College, Kandy
2.4	Mahamaya Girls' School
Cluster 3:	sites are within Peradeniya (Peradeniya town is situated 6 km away from Kandy town along the Kandy-Colombo highway)
3.1	Gatambe temple along Kandy-Peradeniya highway near hospitals, a bank and a school.
3.2	Peradeniya Botanical Gardens entrance along Kandy-Peradeniya highway.
3.3	Peradeniya 3-way junction
3.4	Peradeniya Railway Crossing across Old Gampola road
3.5	Panideniya Junction along Old Gampola road 1.5 km away from Peradeniya junction
3.6	Faculty of Engineering, University of Peradeniya along Kandy-Upper Gampola road (AB037)
3.7	University of Peradeniya along Peradeniya-Doluwa-Gampola road.
Cluster 4:	sites along major national highways that feed traffic into Kandy city from other major cities.
4.1	Kadugannawa bend. High traffic. No congestion. Burn more fuel to climb up the hill while taking the bend.
4.2	Katugasthota.3-way junction. Situated along Kandy-Matale national highway. Highly congested during peak hours.
Cluster 5:	sites with very low traffic intensity away from city, that serve as control sites.
5.1	Gannoruwa Secondary School situated at very low traffic, remote areas away from busy roads. No industrial activities involved.
5.2	Idamegama Central College
5.3	Dangolla Vimalabuddhi School
5.4	Gonigoda Central College
5.5	Inside Peradeniya Botanical Gardens 300 m away from the entrance

high efficiency cyclone attachment that aids separation of particles less than 10 μm (denoted by PM_{10}). These particles deposit on the glass microfibre filter [6] at the outlet of the sampler. Whatman EPM2000 (20.3 × 25.4 cm and 0.6 μm) glass microfibre filters, especially designed for PM_{10} sampling with the above HVAS model (Envirotech Apm 460) were used. The samplers were placed in open areas with a minimum of obstacles such as buildings, trees and walls, and the air inlet facing the wind direction which gives maximum sample loading.

Sampling was carried out at each site for 3 continuous hours from 11.00 a.m. to 2.00 p.m. from January 2004 to June 2006 on days in which dry weather conditions prevailed. At every site the equipment was placed in such a way that the instrument's air suction opening was at a height of 1.5 m, the average breathing height of humans[7]. The sampling flow rate used was approximately 1000 L/min.

The net mass gain of the PM_{10} on the microfibre filter was determined using EPA PM_{10} sampling guidelines[8]. The mass of the ambient non-respirable suspended particulate matter (NRSPM) that are larger than 10 μm was determined by measuring the net mass gain of the cyclone cup. Weight measurements were made using a microbalance (Acculab, US/Canada, LA110) with 0.1 mg accuracy. Concentrations of PM_{10} and NRSPM were obtained by dividing their respective weights by the volume of air passed through the sampler, which was calculated using the instantaneous airflow rate data obtained from the flow meter attached to the sampler and the period of operation of the sampler.

A low-volume personal air sampler (Sensidyne Gilair–5, US/Canada, with filter holder attachment) operated at a flow rate of 3 L/min, was also used simultaneously for inter-comparison of the pollutants collected by the two types of samplers. This air sampler does not accompany a cyclone attachment to separate PM_{10} and hence it collects total SPM on the filter paper. Comparison of filter samples obtained from HVAS and PAS has been carried out using a colorimetric method[9].

Traffic flow count for the 3 h period in the two directions was monitored and recorded at each sampling site.

RESULTS AND DISCUSSION

Figure 1 shows that the PM_{10} concentrations recorded at 7 sites out of the 25 sites sampled were above 150 μg/m^3, which is the daily average ambient standard imposed by the United States Environment Protection Agency (USEPA)[11]. Of these, Sites 1.1, 1.2, 1.4 and 1.7 were within the boundaries of Kandy city and Sites 3.1, 4.1 and 4.2 were along the Kandy–Peradeniya, Kandy–Colombo and Kandy–Matale national highways [National highways comprise the Trunk (A Class) and Main (B Class) roads.] respectively.

Average traffic intensities for the 3-hour period of sampling are shown in Figure 1. The highest PM_{10} concentration of 340 μg/m^3 recorded at Site 4.2 corresponds to 2640 vehicles/h, the highest traffic intensity. This site was a 3-way junction at Katugasthota situated along the Kandy-Matale national highway (A9) that feed traffic into the city from the northern part of the country. The detailed traffic information collected in this study showed that the intensity of heavy vehicles that transport goods was high during the time of sampling and that the traffic intensity of buses and school vans was gradually increased during the period 11.00 a.m. to 2.00 p.m. The road congested most of the time because of the narrow road structure.

The second highest PM_{10} concentration of 230 μg/m^3 was recorded at Site 3.1, where the traffic intensity was as high as 1785 vehicles/h. This site was located along the Kandy-Peradeniya road in front of a popular Buddhist temple, known as the Gatambe Temple, close to the Peradeniya Police Station, Peradeniya Teaching Hospital, a bank, a school, the Botanical Garden and few other offices. Traffic from western and south-western parts of the country (such as Colombo, Nuwara Eliya, Gampola and Nawalapitiya) also passed by this site. The traffic congestion at this site was intensified by vehicles decelerating and accelerating near the Gatambe temple.

The third highest PM_{10} concentration of 220 μg/m^3 was recorded at Site 4.1, and the traffic intensity at this site was 1260 vehicles/h. This site was located by the Kadugannawa bend along the Kandy-Colombo national highway (A1). Vehicles travelling towards Kandy have to climb up a sloping road while making a 300^o angle turn at this bend. This caused the vehicles to burn more fuel at this site even though there was no traffic congestion. A number of vehicles let out black smoke upon acceleration.

Figure 1 shows that the PM_{10} concentrations, in general, were high along the national highways of the urban and near-urban environments of Kandy city (Cluster 1) and Peradeniya (Cluster 3).

Sites 2.1, 2.2 and 2.3 of Cluster 2 were all located within the Kandy city limits and had PM_{10} concentrations in the range of 25 to 40 μg/m^3. It was probably because the sampler was placed within the school premises away from the roads with high traffic. The measurements at these three sites which are away from high traffic roads may be taken as background PM_{10} concentrations. Site 2.4 of Cluster 2 however, gave a comparatively high PM_{10} concentration. It was perhaps due to the increased emissions stemming from the traffic that slowed down to take the sharp bend on the road adjacent to the school.

Sites 5.1, 5.2 and 5.3 of Cluster 5, located within school premises away from the city had PM_{10} concentrations as low as 10 to 20 μg/m^3, and the traffic intensities near these sites were less than 1 vehicle per minute. The comparatively high value of PM_{10} level at Site 5.4 in comparison to the other 4 sites of cluster 5 could be explained as being due to the dust from the gravel road adjacent to the school and the uncovered playground within the school.

The lowest PM_{10} concentration of approximately 4 μg/m^3 was recorded at Site 5.5, which was located within the Peradeniya Botanical Garden premises about 300 m away from the Kandy-Peradeniya road. It is of interest to note that PM_{10} concentrations were as high as 110 μg/m^3 and 230 μg/m^3 when the measurements were made along the Kandy-Peradeniya road at the entrance to the Peradeniya Botanical Gardens (Site 3.2) and near the

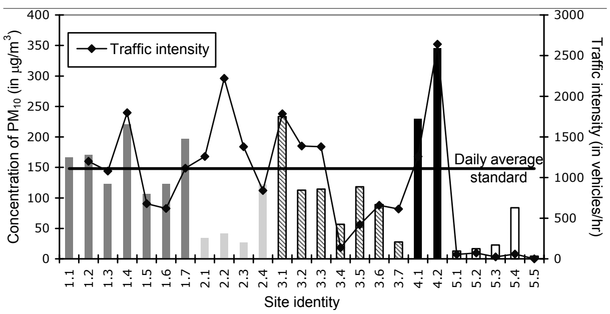

Figure 1: Concentration of PM_{10} and traffic intensity at the 25 sites studied, with sites of different clusters being identified with different shades.

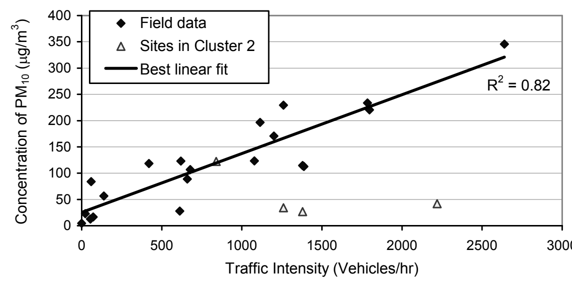

Figure 2: Correlating the PM_{10} concentration to traffic intensity with 20 data, excluding Site 1.1 and Sites 2.1, 2.2, 2.3 and 2.4.

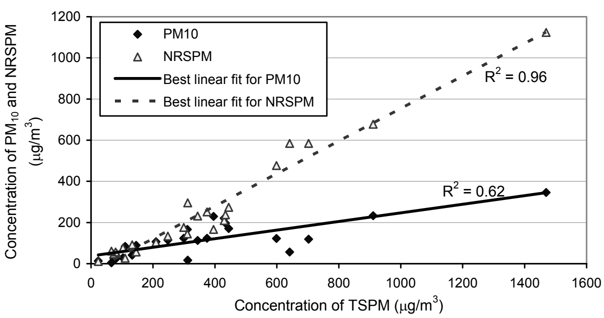

Figure 3: Correlating the concentrations of PM larger than 10 μm (NRSPM) and smaller than 10 μm (i.e. PM_{10}) to the concentration of TSPM, respectively.

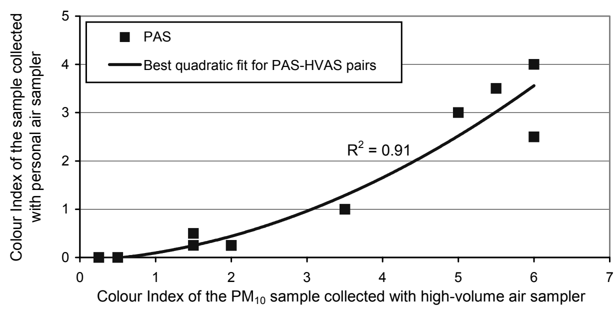

Figure 4: Correlating the colour indices of the SPM samples collected using the personal air samplers, PAS1 and PAS2, with the colour index of the PM_{10} sample collected using the HVAS at 11 sites.

Gatambe temple (Site 3.1), which is 100 m away from the Botanical Garden entrance, respectively. This is a good example of the impact of greenery on air quality.

Figure 2 shows the plot of PM_{10} against the traffic intensity with 24 data points. Excluded is Site 1.1 owing to the inability to make a meaningful traffic count at the centre of the bus terminus. When the correlation coefficient was estimated excluding the data points of Cluster 2 where air sampling was carried out within the school premises away from the roads along which the traffic intensities were recorded, the correlation coefficient (R statistic) was about 90% implying that, about 82% (= R^2) variance is common between the PM_{10} concentration and traffic intensity. The other factors that could have influenced the PM_{10} concentrations measured in this study are dust from uncovered land, unpaved roads and construction sites and emissions from burning fire wood. Kandy is almost free from power plant emissions and other industrial emissions.

The measurements taken inside Peradeniya Botanical Gardens (Site 5.5) with no traffic emissions as well as all other factors that can affect PM_{10} gives the background reference concentration of PM_{10} in Kandy, which is almost close to the equipment detection limits.

Figure 3 shows that the total amount of suspended particulate matter (TSPM) has 62% variance in common with PM_{10} and 96% variance in common with NRSPM. This indicates that TSPM, which is an addition of PM_{10} and NRSPM, is mainly a measure of NRSPM.

Figure 4 reveals that the colour indices (in grey scale) of the filtered samples from the PAS are quadratically related to those of the HVAS with the R^2 statistic as high as 91%. The colour indices assess the intensity of the grey patch on the filter paper caused only by soot (suspended carbon particles)[11]. Soot particles in the atmosphere normally take the size range of less than 10 μm[12]. The fact that HVAS collects PM_{10} on its filter paper while PAS collects total SPM on its filter paper allows comparison between the colour indices of the two filter papers as evidence for suspended carbon particles emitted mainly by traffic where there is no appreciable amount of smoke emissions.

The aforementioned results show that the handy, small and light-weight, 10 W rechargeable battery-operated PAS, which can be transported easily to the sampling sites, could indeed be used to obtain approximate information regarding the level of suspended carbon particulate mater pollutants present in the atmosphere. At locations where the PAS indicates objectionable levels of PM pollution, the HVAS, which has to be transported in an automobile and requires 500 W power supplied from the grid, could be used to obtain accurate information on the levels of PM pollution.

CONCLUSION

At seven of the twenty five sites sampled, the PM_{10} concentrations measured with a HVAS during the period 11.00 a.m. to 2.00 p.m. were above the daily average ambient standard imposed by the US EPA. The PM_{10} concentrations indicate that the respirable particulate matter pollution is significant along roads with high traffic intensity. The variance in common between the PM_{10} concentration and traffic intensity is 82%. The PM_{10} measurement obtained inside the Peradeniya Botanical Gardens where there are no traffic emissions and other factors that can affect PM_{10} gave the background reference concentration of PM_{10} in Kandy as 4 μg/m^3.

The R^2 statistic is as high as 91% between the colour indices of the filtered samples of HVAS and the PAS. The colour indices assess the intensity of the grey patch on the filter paper caused only by soot (suspended carbon particles). This result indicates that the handy, PAS with a low operational cost could be used to initially obtain approximate information on the level of airborne carbon particulate mater pollutants present in the atmosphere.

Combining the use of a HVAS with a PAS could reduce the cost of assessing the PM pollution levels and thereby enable the extension of the PM pollution study to other major cities in Sri Lanka.

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