Impact Assessment of Urbanization on Air Quality in Colombo, Sri Lanka

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ABSTRACT: At present, urbanization has become the most common characteristic of many cities in developing countries. Colombo, which is the commercial capital of Sri Lanka is not an exemption. The conducted epidemiological studies reveal that both ambient and indoor air pollution is a major cause for public health deterioration and particulate matter (PM) has a strong correlation with respiratory health issues. Due to this urging need, this study aims to find the aerosol/ particulate matter dynamics in Colombo during 2001 to 2018 through AOD values retrieved from MODIS and how well this aerosol dynamic correlate with urban population growth in the city. When monthly mean AOD values were plotted against time, it showed an increasing trend during the study period. Urban population in Colombo was calculated mainly dividing the study period into two periods; 2001 to 2010 and 2011 to 2018, due to two growth rates obtained from the Colombo city development plan. At the end of the study the hypothesis of urban population growth correlates well with aerosol dynamics in Colombo is tested. It is revealed that the urban population growth from 2001 – 2018 correlates well with the increase of mean AOD values with a correlation coefficient of 0.700412. Using portable sensors, PM2.5 and PM10 data were collected as another part of this study in two random houses, two private hospitals and while travelling in between those selected locations in Colombo city. From the results, it was observed that indoor PM2.5 and PM 10 concentrations are much higher than outside garden concentrations in houses and also, the PM concentrations are beyond permissible levels in the roads in Colombo city.

1. INTRODUCTION

Many developing cities which is undergoing rapid urbanization and industrialization are facing the globally critical issue of air pollution which has captured the attention of many researchers in the world. Colombo, which is the commercial capital of Sri Lanka is not an exemption from rapid urbanization as well as air pollution. Researchers in many fields are currently trying to provide the way for sustainable development through giving high consideration to the concept of Population-Environment Systems (PES) where population size and growth are the major indicators (Han *et al*. 2018). As a result of the high rate of population growth in Colombo, the extensive growth of urbanization and industrialization of this capital city, the built-up area (including residential and commercial buildings, roads) and the number of vehicles has been rapidly increasing in the city, consequently resulting high air pollution.

Particulate matter (PM) which is an air pollutant is also referred as aerosols. AOD (Aerosol Optical Depth) retrievals were being provided since 2001 by MODIS onboard, the two Earth Observation Satellites (EOS) Terra and Aqua satellites. AOD value retrieved for a particular location can be used as a representative value for the amount of PM presented in the atmospheric column above that same location (Gupta *et al.* 2013).

Furthermore, the conducted epidemiological studies in Colombo reveal that both $PM_{2.5}$ and PM_{10} (particulate matter of 2.5 micrometers or less and particulate matter of 10 micrometers or less) has a strong correlation with respiratory health issues. This arises the need to understand the dynamics of PM over time and how it is being affected by urbanization in terms of urban growth in Colombo to provide with mitigation measures.

1.1 Objective

The objective of this study is to understand how the aerosols in Colombo city varies with time through the daily AOD values retrieved from MODIS from year 2001 to 2018. The hypothesis that urban population growth (which is the prime cause for urbanization and other anthropogenic emissions) during the study period correlates well with aerosol/ PM dynamics is also investigated comparing the timely dynamics.

2.MATERIAL and METHODS

2.1 Study Area

Colombo city, in other words Colombo Municipal Council (CMC) which is of 37.29 km^2 area, is located in the west coast of Sri Lanka between Northern Latitudes 6^0 55' to 6^0 59' and Eastern Longitudes 79^0 50' to 79^0 53' (Figure 1). Colombo is situated in the western province of Sri Lanka, being the largest city of the country. Colombo has been the capital of Sri Lanka over two hundred years until the administrative capital is shifted to Sri Jayawardenepura while still being the commercial capital and heart of Sri Lanka. In this study, CMC was used as the study area for daily AOD retrievals concentrating more on the city centre.

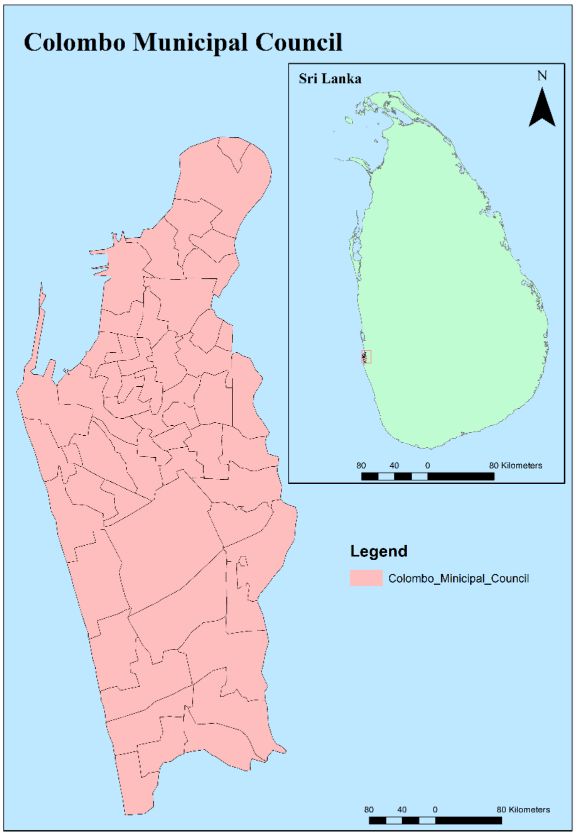

Figure 1: Colombo Municipal Council (CMC)

Using the portable senor, data was also collected in two random houses (H), two private hospitals (P) and while traveling in between those selected locations (Figure 2).

Figure 2: Location of houses (H1, H2), Private hospitals (P1, P2), Routes (R1, R2, R3)
R1: H1 to H2, R1': H2 to H1, R2: H2 to P2, R3: P2 to H1

2.2 Data and Analysis

MODIS satellite based daily AOD values for Colombo city centre was obtained (Institute of Industrial Science, The University of Tokyo, Japan and Misra *et al*. 2017). For some days AOD values were not available due to the interruption from cloud cover. Using the daily $MODIS_{AOD}$ values, monthly mean $MODIS_{AOD}$ values were calculated and plotted for the study period 2001 to 2018.

When calculating the urban population for each year from 2001 to 2018 in Colombo Municipal Council, the study period was divided into two, namely; 2001 to 2010 and 2010 to 2018 because of two different growth rates, increasing and decreasing respectively (Urban Development Authority, 1999 and 2019).

According to the population data and growth rates provided from 1881 to 2010, in City of Colombo Development Plan (Urban Development Authority, 1999), the average growth rate corresponding from 2001 to 2010 was obtained. Based on the calculated growth rate, and the population data obtained from the national census survey in 2001, population was projected until the year 2010. From 2010 to 2018 although the residential population was showing a slight decrease over the time, the non-residential population (commuting population) was increasing. Therefore, total population for each year during this period was taken as the summation of residential and non-residential population. Finally, the hypothesis of urban population growth correlates well with the dynamics of AOD values retrieved from MODIS which is a representative value for the aerosol/ PM was tested.

Using the portable sensor, readings for PM 2.5 and PM 10 data were collected in two random houses in Colombo city (inside and outside) and inside of two private hospitals. Furthermore, while travelling in between these locations by a taxi which has two open sides, data was collected for different weather conditions (sunny, rainy and night time).

3.RESULTS and DISCUSSION

When monthly mean $MODIS_{AOD}$ values were plotted against time from 2001-01 to 2018-12, an overall increasing trend of AOD values could be observed (Figure 3).

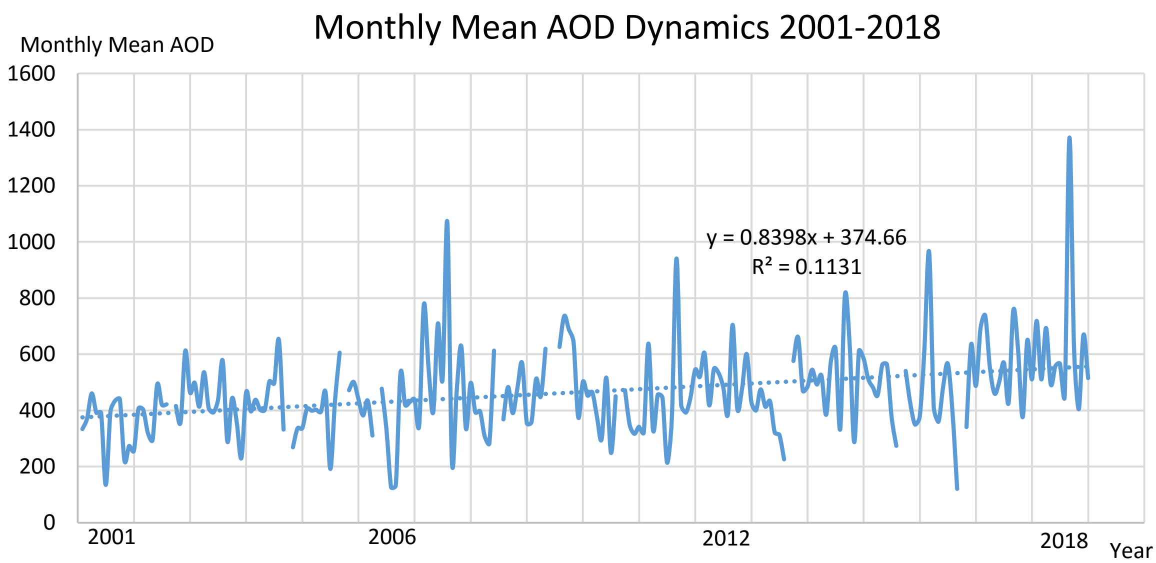

Figure 3: Time Series of Monthly Mean AOD January, 2001 to December, 2018

This can be further explained as an increment of the average aerosol/ PM concentration in Colombo during the study period.

There are two main monsoon seasons in Sir Lanka, namely, Southwest monsoon (May to September) and Northeast monsoon (November to February) within which there exist two inter monsoon periods. When Daily AOD values were being plotted for each year, lack of data availability is often encountered during the southwest monsoon from May to September in each year. This can be further confirmed from Figure 3 as the blank values in the graph are dates in which we failed to obtain AOD values due to cloud cover and often falls between the southwest monsoon period each year.

Urban population was calculated separately from 2001 to 2010 and 2011 to 2018. This is mainly because from 2001 to 2010, the residential population of Colombo was increasing and from 2011 to 2018 there has been a slight reduction of the population in Colombo Municipal Council from a rate of 0.00004 while the non-residential population, mainly commuting population to

Colombo was showing a rapid increment. The overall urban population from 2001 showed an increasing trend.

At the end of the study, we tested whether there exists a correlation between the calculated urban population in Colombo and the Yearly Mean AOD values from 2001 to 2018 and the obtained result is as shown below (Figure 4).

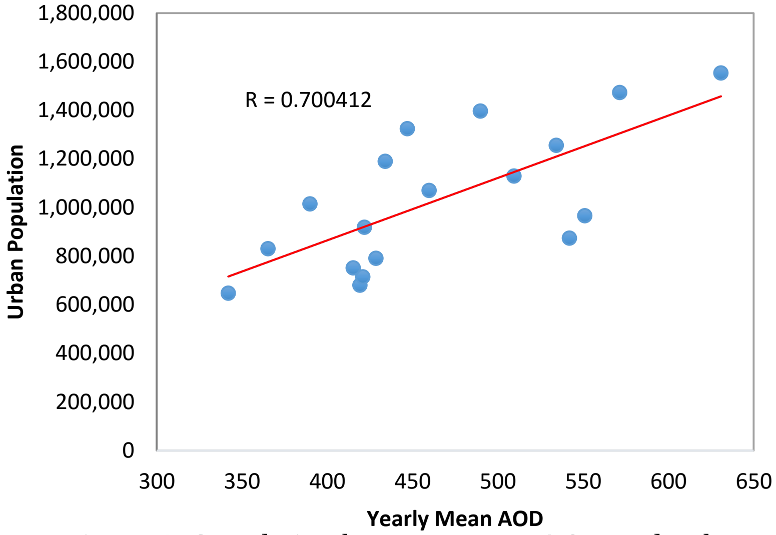

Figure 4: Correlation between Mean AOD and Urban Population

The obtained correlation coefficient was 0.700412 which highlights that the urban population growth in Colombo city correlates well with the time series of mean AOD. But this doesn't mean the cause for increase in air pollution (increase in mean AOD) is the urban population growth. However, if this study is expanded integrating with the time series of built-up area expansion, number of vehicles, industrialization, and other anthropogenic air polluting sources all which are results due to population growth, then a clearer picture on how urbanization has impacted on the decrease of air quality in Colombo can be obtained.

The collected data were plotted as concentration profiles of PM2.5 and PM10 and shown in Figure 5, 6 ,7 8 and 9). From the collected data, it was understood that the indoor PM2.5 and PM10 concentration of houses are comparatively higher than that of outside the house. At times indoor PM concentrations tend to rise above the permissible limits. Furthermore, it was observed from the collected data that both PM2.5 and PM10 are highly controlled inside the two private hospitals where observations are made. PM2.5 dynamics are minor while PM 10 shows higher timely dynamics.

From this study, it could be observed that the PM2.5 and PM10 concentration are often beyond the permissible limits on road. The highest values obtained for route 1 (R1) when travelling in a sunny day was PM2.5: 144 and PM10: 158 in a junction which was highly congested by traffic. During day time average temperature in Colombo is 32^0C while at night it drops to 27^0C. From the collected data, it could be observed that at night time, PM concentrations are much lower when compared to day time even under similar traffic congestion.

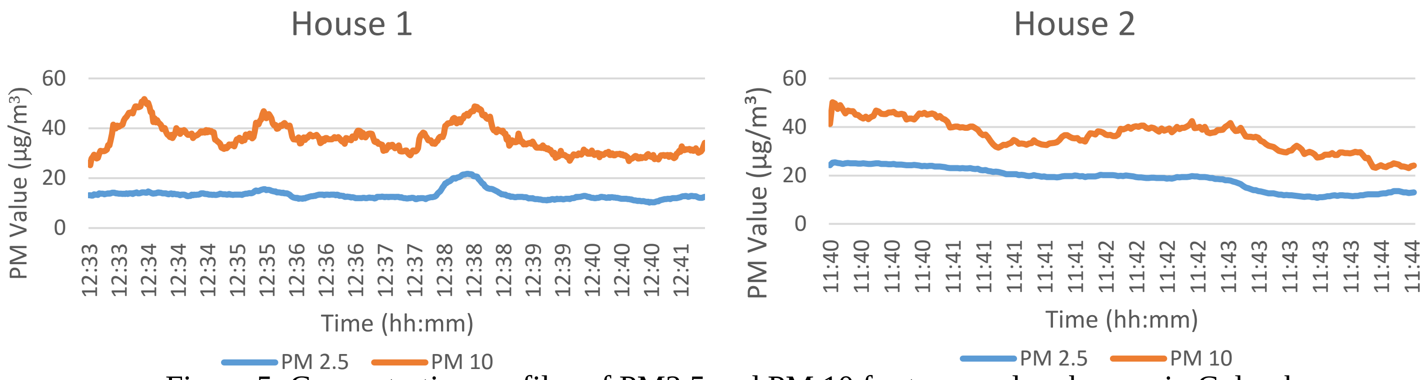

Figure 5: Concentration profiles of PM2.5 and PM 10 for two random houses in Colombo

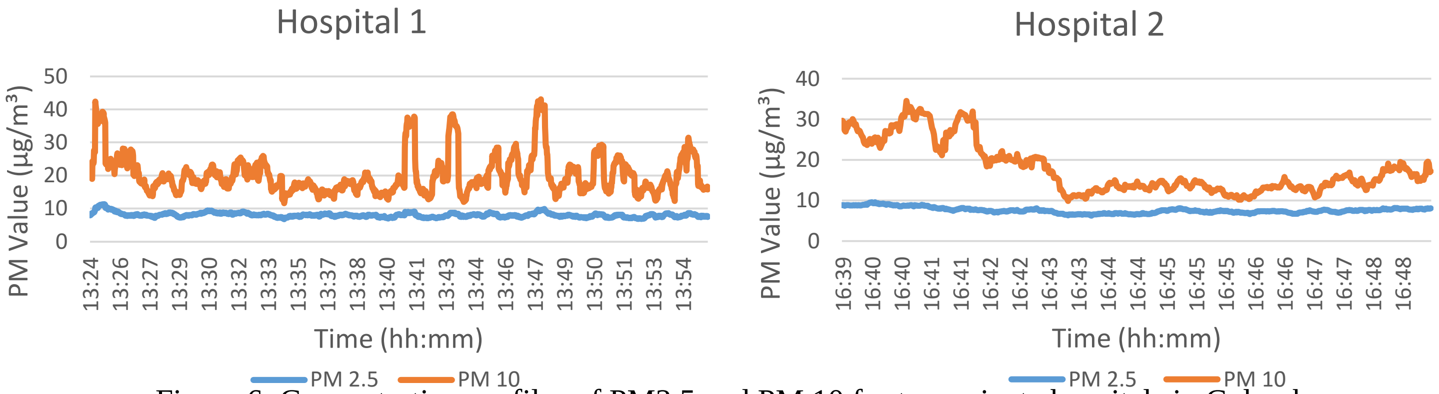

Figure 6: Concentration profiles of PM2.5 and PM 10 for two private hospitals in Colombo

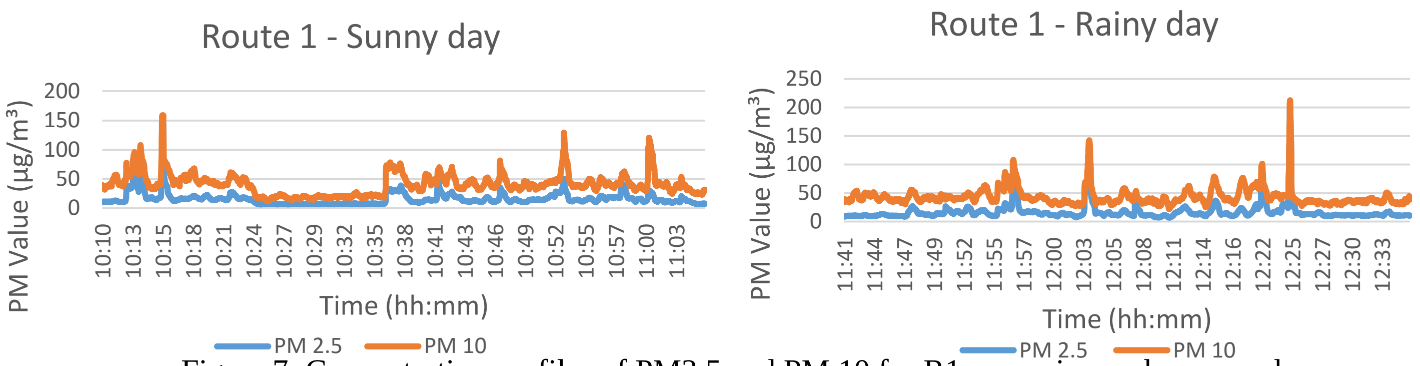

Figure 7: Concentration profiles of PM2.5 and PM 10 for R1 on a rainy and a sunny day

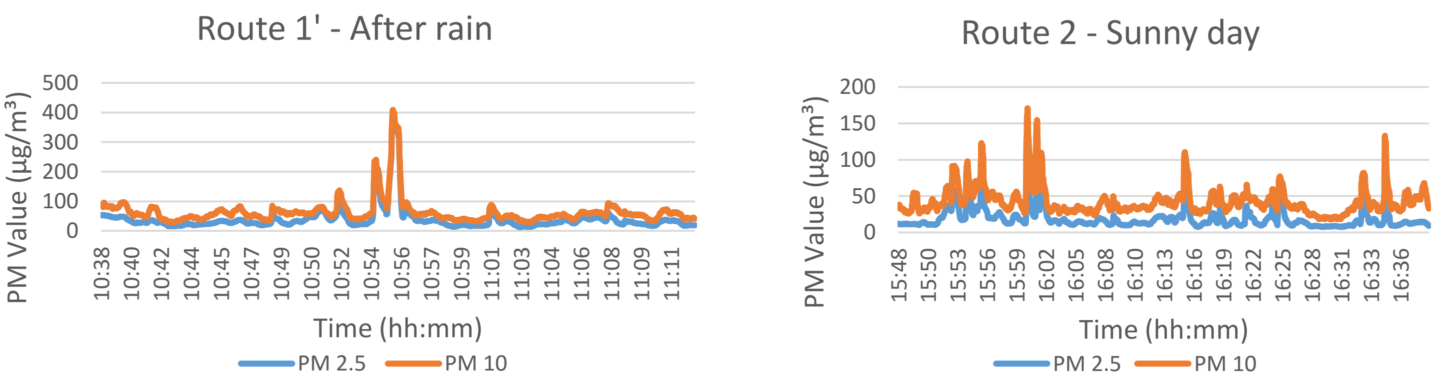

Figure 8: Concentration profiles of PM2.5 and PM 10 for R1' after heavy rain and R2 on a sunny day

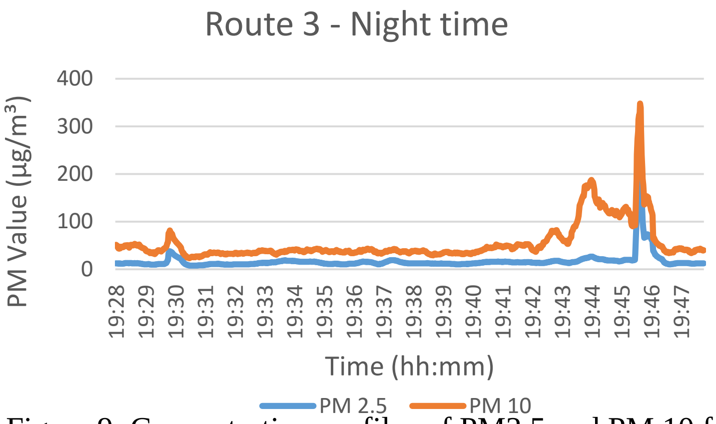

Figure 9: Concentration profiles of PM2.5 and PM 10 for R3

4.CONCLUSION

Several conclusions can be obtained from this study. Mainly in the cities of developing countries, the urban population shows a rapid increment as people migrate from rural areas to urban in search of social as well as economic opportunities. Furthermore, since most of the land available for residential purposes are highly utilized by 2010 in Colombo, it is noted that commuting population to the city is increasing greatly since then with a considerable population growth being recorded in cities adjacent to Colombo. Mean aerosol concentration shows an increasing trend during the study period highlighting air pollution in Colombo is increasing from 2001 to 2018. In this study, we mainly considered the monthly mean AOD value dynamics with urban population growth, therefore, this study can be further developed integrating how expansion of built-up area, vehicle population, industrialization affects air pollution in Colombo.

Usually the indoor PM 2.5 and PM 10 concentrations are higher than outdoor concentrations of home gardens. This might be due to poor ventilations inside houses as nowadays most of the people go out for work, and windows are closed in houses for longer time periods. From this study, it can be concluded that PM2.5 and PM10 concentrations are more often beyond the permissible levels on roads in Colombo city and very much higher in junctions which are under traffic congestions. It was also observed from this study that, night time PM2.5 and PM10 concentrations are much lower when compared to day time showing that temperature is a crucial factor for PM concentrations.

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