Journal of Environmental Management 217 (2018) 815–824

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Source apportionment studies on particulate matter (PM_{10} and $PM_{2.5}$) in ambient air of urban Mangalore, India

Gopinath Kalaiarasan, Raj Mohan Balakrishnan*, Neethu Anitha Sethunath, Sivamoorthy Manoharan

Department of Chemical Engineering, National Institute of Technology Karnataka, Surathkal, Mangalore, 575025, India

A R T I C L E I N F O

Article history:
Received 3 November 2017
Received in revised form
4 April 2018
Accepted 7 April 2018
Available online 24 April 2018

Keywords:
Source apportionment
Particulate matter
Vehicular emissions
Chemical mass balance
Mangalore

A B S T R A C T

Particulate matter (PM_{10} and $PM_{2.5}$) samples were collected from six sites in urban Mangalore and the mass concentrations for PM_{10} and $PM_{2.5}$ were measured using gravimetric technique. The measurements were found to exceed the national ambient air quality standards (NAAQS) limits, with the highest concentration of 231.5 $\mu g/m^3$ for PM_{10} particles at Town hall and 120.3 $\mu g/m^3$ for $PM_{2.5}$ particles at KMC Attavar. The elemental analysis using inductively coupled plasma optical emission spectrophotometer (ICPOES) revealed twelve different elements (As, Ba, Cd, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Sr and Zn) for PM_{10} particles and nine different elements (Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sr and Zn) for $PM_{2.5}$ particles. Similarly, ionic composition of these samples measured by ion chromatography (IC) divulged nine different ions (F^-, Cl^-, NO_3^-, PO_4^{3-}, SO_4^{2-}, Na^+, K^+, Mg^{2+} and Ca^{2+}) for PM_{10} particles and ten different ions (F^-, Cl^-, NO_3^-, PO_4^{3-}, SO_4^{2-}, Na^+, NH_4^+, K^+, Mg^{2+} and Ca^{2+}) for $PM_{2.5}$ particles. The source apportionment study of PM_{10} and $PM_{2.5}$ for urban Mangalore in accordance with these six sample sites using chemical mass balance model (CMBv8.2) revealed nine and twelve predominant contributors for both PM_{10} and $PM_{2.5}$, respectively. The highest contributor of PM_{10} was found to be paved road dust followed by diesel and gasoline vehicle emissions. Correspondingly, $PM_{2.5}$ was found to be contributed mainly from two-wheeler vehicle emissions followed by four-wheeler and heavy vehicle emissions (diesel vehicles). The current study depicts that the PM_{10} and $PM_{2.5}$ in ambient air of Mangalore region has 70% of its contribution from vehicular emissions (both exhaust and non-exhaust).

1. Introduction

Urban air pollution is a notable concern in nations over the world. Inferring to the rapid rates of urbanization in Indian urban communities, polluted air quality is considered as a key factor in crumbling the quality of life with adverse effects on human well-being. Hence, air quality monitoring gained significant importance in recent decades since it is worsened by the emission of major pollutants including particulate matter (PM_{10} and $PM_{2.5}$), NOx, SO_2, O_3 (Begum et al., 2007) and were often found to exceed the national ambient air quality standards (NAAQS) limits (Guttikunda et al., 2014). Particulate matter (PM) emitted from both natural and anthropogenic sources are considered as a prime pollutant responsible for deteriorating the quality of ambient air. They are classified according to aerodynamic diameter as coarse ($PM_{2.5\text{-}10}$) and fine ($PM_{2.5}$) particles. Generally, vehicular traffic and its emissions were found to be the major contributor of PM including emissions from biomass burning, diesel generators and coal burning for commercial purposes. These PM emissions from vehicles were categorized as exhaust and non-exhaust emissions. Emissions from the tailpipe of the vehicles were termed as exhaust emissions and that of arising from the vehicles wear and tear (abrasions of brake, tyre, clutch and road dust re-suspension) were designated to be non-exhaust emissions. These particles are emitted in close quarters to human activities and demonstrated to have detrimental impacts on human health (Buckeridge et al., 2002; Rissler et al., 2012).

Urban air quality deterioration is considered to be a major cause of health concern in Indian cities. The various harmful pollutants and its concentration in the ambient atmosphere were found to be exceeding health-based standards. Among these pollutants, PM has been identified as one of the key public health concerns. In the recent past, vehicular population in the urban areas has taken up a

* Corresponding author.
E-mail address: rajmohanbala@gmail.com (R.M. Balakrishnan).

https://doi.org/10.1016/j.jenvman.2018.04.040
0301-4797/

hasty increase and contributes a major part in declining the quality of ambient air in urban areas. Additionally, small scale enterprises working inside urban communities were found to play a significant role in worsening the ambient air quality (Pant and Harrison, 2012). The current study area of urban Mangalore, an educational and industrial hub, with its increased urbanization and industrialization pose a threat to deteriorate the ambient air quality, especially from vehicular emissions. Thus, there is a compelling need to frame an air quality management plan to formulate effective strategies to control the ambient air pollutants, from pushing the city to a critically polluted region in the country.

A source apportionment study on the ambient air pollutants is a key factor for framing an effective air quality management. Numerous researchers found that a receptor modeling technique is found to be an appropriate and efficient tool in apportioning the sources of air borne particulate matter in any urban atmosphere. More than a few receptor models, such as principal component analysis (PCA), enrichment factors (EFs), chemical mass balance (CMB), positive matrix factorization (PMF) and empirical orthogonal functions (EOF), multiple linear regression, neural networks, edge detection, cluster analysis, fourier transform time series and a number of other multivariate data analysis methods were used by various researchers (Amato et al., 2009; Begum et al., 2007; Chow et al., 1993; Gelencsér et al., 2007; Gugamsetty, 2012; Landis et al., 2017; Lee and Hieu, 2011; Pant and Harrison, 2013; Vega et al., 2000; Viana et al., 2008; Villalobos et al., 2015; Watson et al., 2002; Yatkin and Bayram, 2008) to estimate the source contributions at any sampling site. In the midst of these above mentioned receptor models, chemical mass balance (Coulter, 2004) was used in this study, since it estimates the source contribution by determining the best-fit combination of chemical profiles of emission sources and chemical composition of ambient particulate matter (Watson, 1994). On line with that, the receptor modeling studies for PM in Indian cities (see Table 1) have revealed the anthropogenic sources of heavy metals in PM and these were primarily from vehicular activity, irrespective of the size range (Gummeneni et al., 2011; Gupta et al., 2007; Karar et al., 2006; Kothai et al., 2008; Negi et al., 2002; Pandey et al., 1998; Parthasarathy et al., 2016; Rastogi and Sarin, 2009; Roy et al., 2014; Srivastava et al., 2009). Additionally, the six city study proposed by the central pollution control board of India (CPCB) (CPCB, 2011) has brought in few insights about the major sources contributing to the ambient air quality which are mainly from vehicular emissions (about 60%). In this context, with the increased urbanization and vehicular population of Mangalore, the present study has been carried out to estimate PM concentration in ambient air of urban Mangalore, and to determine the elemental and ionic composition of PM, to investigate and trial the source apportionment method using CMBv8.2 that quantifies the emission contributions.

2. Materials and methods

2.1. Site description

Mangalore is located at 12.87°N 74.88°E in Dakshina Kannada district and the fourth largest city in the state of Karnataka, India. It has an average elevation of 22 m (72 ft) above mean sea level surrounded by the Arabian Sea to the west and Western Ghats to the east. Mangalore city, as a municipal entity spans an area of 200 km^2 with a population of 619,664, while its metropolitan area has a population of 445,180 (Census of India, 2011). Mangalore falls under a tropical monsoon region that has hot and humid climate between March and May and monsoon from June to October. The post monsoon season from November to February has relatively moderate temperatures ranging from 17 °C to 34 °C influenced by active coastal winds. Mangalore receives about 95% of its total annual rainfall between June and October, with an annual precipitation of 3479 mm (137 in) and a humidity of 75%.

2.2. Sampling procedure

2.2.1. Sampling sites

The sampling sites were selected as per the guidelines proposed by the CPCB. Six sampling sites (Fig. 1) were selected according to their characteristics Lady hill (LH) (residential/traffic site), City centre (CC) (traffic site), KMC Attavar (KMCA) (residential site), KMC Jyothi (KMCJ) (traffic/commercial site), Town hall (TH) (traffic site/commercial site) and Baikampady industrial estate (KSPCB) (industrial site) which were representative of urban Mangalore.

2.3. PM sampling

The PM_{10} and $PM_{2.5}$ sampling for Mangalore was done at all the six sampling sites for a period of 24 h ($8 \times 8 \times 8$) using high volume respirable suspended particulate matter (RSPM) samplers (APM460 BL, Envirotech, India) on glass fibre filters (Whatman GF/A 20.3×25.4 cm) for PM_{10} particles. Whereas, $PM_{2.5}$ samples were collected on polytetrafluoroethylene (PTFE) filter paper of 47 mm diameter using a fine dust sampler at a flow rate of 16.67 LPM ($PM_{2.5}$ fine dust sampler, model no. IPM-FDS-2.5μ/10μ, Instrumex, India). A stringent quality assurance/quality control (QA/QC) program was employed throughout the sampling. The filter papers were desiccated before and after sampling for 24 h at a temperature of 27 ± 3 °C and at a relative humidity (RH) of $55 \pm 2\%$ to remove the moisture present in them. The PM_{10} and $PM_{2.5}$ field samples and their trip blanks were collected periodically throughout the sampling period.

2.4. Analysis of PM

2.4.1. Gravimetric analysis

The exposed filters were analysed using gravimetric technique (IO-3.1, 1999) using a weighing balance (Oahu pioneer with accuracy 0.0001 g, Scales galore, USA) for PM_{10} particles and using a micro balance (MYA 5.4Y.F, Radwag balances and scales, USA) for $PM_{2.5}$ particles with a precision of ± 5 μg with automatic (internal) calibration.

2.4.2. Chemical composition analysis

2.4.2.1. Elemental analysis. PM_{10} samples collected on glass fibre filters were digested (IO-3.1, 1999) in a microwave digester (MARS 5, CEM Corporation, NC, USA). The sample was made up to 50 mL using deionized distilled water (TWF water purification system (Type I, III) of resistivity 18 MΩ-cm, Siemens labostar, Germany). Similarly, the exposed filters containing $PM_{2.5}$ particles were cut equally into 2 halves. A part of the exposed filter was used for ions analysis. Whereas, the other half was cut into tiny fragments and digested (IO-3.1, 1999) on a hot plate and made up to 15 mL using distilled deionized water. The obtained samples (both PM_{10} and $PM_{2.5}$) after digestion were stored in vials and refrigerated at 4 °C until further analysis. These samples were later subjected to estimate the elemental composition (IO-3.4, 1999) using ICPOES (5100, Agilent, USA).

2.4.2.2. Ions analysis. The filter papers containing both PM_{10} & $PM_{2.5}$ samples were extracted and subjected to ion analysis as per the standards (SOPMLD064). The filter papers were divided into tiny fragments and moistened with isopropanol slightly before extraction, since the filters are hydrophobic. Further 25 mL of