*Aerosol and Air Quality Research*, 14: 1769–1778, 2014

ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2013.10.0327

# Air Quality Assessment in the Surroundings of KMML Industrial Area, Chavara in Kerala, South India

**Jaya Divakaran Sarasamma[1*], Beena Kochuraman Narayanan[2]**

[1] *Associate Professor, Department of Environmental Sciences, University of Kerala, Kariavattom Campus, Thiruvananthapuram, PIN-695581, Kerala, India*
[2] *Research scholar, Department of Environmental Sciences, University of Kerala, Kariavattom Campus, Thiruvananthapuram, PIN-695581, Kerala, India*

## ABSTRACT

Worldwide air pollution is responsible for large numbers of deaths and cases of respiratory disease. There are many substances in the air which may impair the health of plants and animals. Air pollutants arise from both man-made and natural processes. Point sources include major industrial facilities like chemical plants, steel mills, oil refineries, and power plants, and non-industrial stationary equipment like hazardous waste incinerators. A detailed study was conducted in the surroundings of the Chavara industrial area in Kollam district, South India, during the summer and winter seasons of the year 2011, to assess the status of air pollutants (TSPM, RPM, $SO_2$, $NO_2$ and Free $Cl_2$) and the air quality of the industrial zone and its surroundings, which are also residential areas. The results of the study show that the concentrations of gaseous pollutants, $SO_2$ and $NO_x$ were within the national ambient air quality standard limits of Central Pollution Control Board and Ministry of Environment & Forests, India. The study stations in the northern, eastern and southern directions of the industrial area recorded chlorine contamination. The presence of $PM_{10}$ and chlorine in the residential area in the vicinity of KMML industrial zone may cause different health problems in the residents, especially in children and aged people. The air quality index in the study stations was assessed, and the results showed that the residential areas surrounding the KMML industrial area have moderate air quality. Some measures are also suggested to improve the air quality in the surroundings of the KMML industrial area.

***Keywords:*** Air pollution; Air Quality; $PM_{10}$; Sulphur dioxide; Nitrogen oxides.

## INTRODUCTION

Air pollution seriously damages material sources such as building, various sculptures, and also vegetation. It may be due to particulate matter dispersed in it or gaseous pollutants completely miscible with it in all proportions. Gaseous pollutants such as $SO_2$, $NO_x$, $CO_2$ etc., dispersed in air are the major sources of air pollution. Industries in India are one of the major contributors of pollution. The air pollution causes health problems in the workers and residents in places near the industrial area, therefore it is essential to study the air quality in the surroundings of the industries. Vehicles, such as scooters, cars, buses and trucks also produce smoke by burning petrol or diesel, and such auto exhaust is also a major cause of air pollution. Air pollution contributes to lung diseases, including respiratory tract infections, asthma and lung cancer.

Managing sustainable urban development with respect to health, environment, and climate effects is the most pressing problem in mega-cities. The urban atmosphere in particular is very often affected by pollution from various anthropogenic sources and consequently the health of inhabitants is endangered (Yu *et al*., 2011). In urban areas, particulate matter come from a variety of sources such as car, trucks, buses, factories, construction sites, unpaved roads, stone crushing, and burning of wood. A common measure of particles used to quantify pollution concentrations and their effects is the $PM_{10}$ value. Janssens *et al*. (1997) found that the larger diameter component consists of urban $PM_{10}$ consisted mainly of locally deposited carbon and road dust. An epidemiological study by Schwartz *et al*. (1996) has suggested that atmospheric particulate matter in urban area has a clear correlation with number of a daily deaths and hospitalizations as a consequence of pulmonary and cardiac disease response. Particulate pollution, one of the major environmental health problems, causes approximately three million deaths per year in the world (Borrego *et al*., 2006). Long-range transportation of dust particles, which usually

* Corresponding author.
Tel.: (91) 0471-2554027
*E-mail address:* j_ds@rediffmail.com

have a median diameter considerably less than 10 mm, has been identified as an important contribution to the regional and global air pollution, the global fluxes of chemical elements and climate (Walata *et al*., 1986). A study was conducted in the Mangalore region in India covering a wide range of mountains (Bandyopadhyay, 2009). For this, the study of the application of a widely used Industrial Source Complex -Short Term Version3 (ISCST3) model to predict the ground level concentration of $SO_2$ due to a proposed thermal power plant along with other existing industries. Model calculations further showed that incorporation of $SO_2$ emission control measures, for instance, implementation of flue gas desulfurization facilities having at least 90% removal efficiency, to selected stacks would result in ambient $SO_2$ concentration well within the prescribed values under Indian condition both in simple and in complex terrains and would thus curb air pollution in the study area.

Chlorine is extremely reactive and will not remain in environmental media for long periods of time. The important equilibrium properties of chlorine in water are understood. Scientists have proposed that minute quantities of chlorine are generated naturally during the photolysis of seawater aerosols. Sunlight at tropospheric wavelengths (< 430 nm) dissociates the chlorine molecule to form two chlorine radicals. Most of the chlorine gas accumulate in the lower atmosphere because they are unreactive and do not dissolve readily in rain or snow. Natural air motions transport these accumulated gases to the stratosphere, where they are converted to more reactive gases. Some of these gases then participate in reactions that destroy ozone (FEDRIP, 2009).

Air quality is defined as a measure of the condition of air relative to the requirements of one or more biotic species or to any human need or purpose (Johnson *et al*., 1997). Air quality index is one of the important tools available for analyzing and representing air quality status uniformly. The Air Quality Index (AQI) can be used as a measure to assess the relative change in the concentrations of groups of pollutants in two situations. The two situations may represent either two time periods or two regions. The relative change may also be with respect to the concentrations of pollutants and respective stipulated standards (Chelani *et al*., 2002). Air quality indices (AQI) are indices/numbers used by government agencies to characterize the quality of the ambient air at a given location and to compare it with other locations. As the AQI increases, an increasingly large percentage of the population is likely to experience increasingly severe adverse health effects. In order to compute the AQI, air pollutant concentration is required from monitoring or from a model. The function used to convert from air pollutant concentration to AQI varies by pollutant, and is different in different countries (Gupta, 2012). Interpretation of air quality data using an air quality index for the city of Kanpur, India was done by Sharma *et al*. (2003a). A study was conducted by Mandal and Bandyopadhyay (2013) analyzing the monitoring data collected by the West Bengal Pollution Control Board (WBPCB), the state environmental regulatory agency, in the Kolkata Municipal Corporation (KMC) area of India. This monitoring data covered particulate matter (PM) having diameters of less than 10 microns ($PM_{10}$), suspended PM (SPM), sulfur dioxide ($SO_2$), and nitrogen dioxide ($NO_2$). The study also examines the impacts of two environmental policies of West Bengal Pollution Control Board, India have had on Ambient Air Quality as well as the extent to which monitored levels of the four parameters are meeting the India's National Ambient Air Quality Standards (NAAQS) in the KMC area.

The industry, Kerala Minerals and Metals Ltd. (KMML) in South India is the world's first fully integrated titanium dioxide plant for the manufacture of the white pigment '$TiO_2$' through chloride process. The Indian Rare Earth Ltd. mines and separates the mineral sands into various constituents like ilmenite, rutile, leucoxene, zirconium and monazite. Rutile, ilmenite and leucoxene are titanium bearing minerals and hence the raw materials used for the manufacture of titanium dioxide pigment and titanium sponge metal. It is the only plant in India, which produces rutile grade pigment by the chloride route technology. The nearby area in the southern, eastern and northern sides of the industry is thickly populated and the western part of the industry is the Arabian Sea.

The surroundings of Chavara industrial area (Panmana and Chavara Panchayats) is subjected to air pollution problems due to different anthropogenic activities like industrial emissions from Kerala Metals and Minerals Ltd (KMML) and vehicles passing through the National Highway-47 (NH-47). Studies conducted by Beena and Jaya (2007) on the pollution stress related changes in the surrounding trees of Chavara industrial area reported changes in physio-biochemical characteristics and air pollution tolerance index of evergreen plants. Different sources of particulate pollution in the study area are vehicles, industries and domestic sources. Literature review show that there was no previous air quality studies in the Chavara industrial area in Kerala. The major objective of the present study was to find out the seasonal changes in the status of different air pollutants and to assess the air quality in the surroundings of KMML industrial area in Chavara, Kollam district, Kerala state, South India.

## MATERIALS AND METHODS

### *Study Area*

The Kerala Minerals and Metals Ltd (KMML industry) is situated in Chavara near NH-47 and has about 285 acres in area. The study area include the surroundings of KMML industrial zone and is located at Sankaramangalam in Chavara taluk, at a distance of about 32 km from the Kollam Central Railway Station and about 5 km from the Neendakara Port in the southwest direction. The Chavara taluk includes Chavara and Panmana panchayats. The important industries in this area include Kerala Minerals and Metals Ltd. (KMML) and Indian Rare Earth Ltd. The location map showing the study stations (S1, S2, S3, S4, S5 and S6) in the surroundings of KMML industrial area in Chavara taluk, Kollam district is given in Fig. 1.

### *Air Sampling*

The study was conducted at six selected stations in two

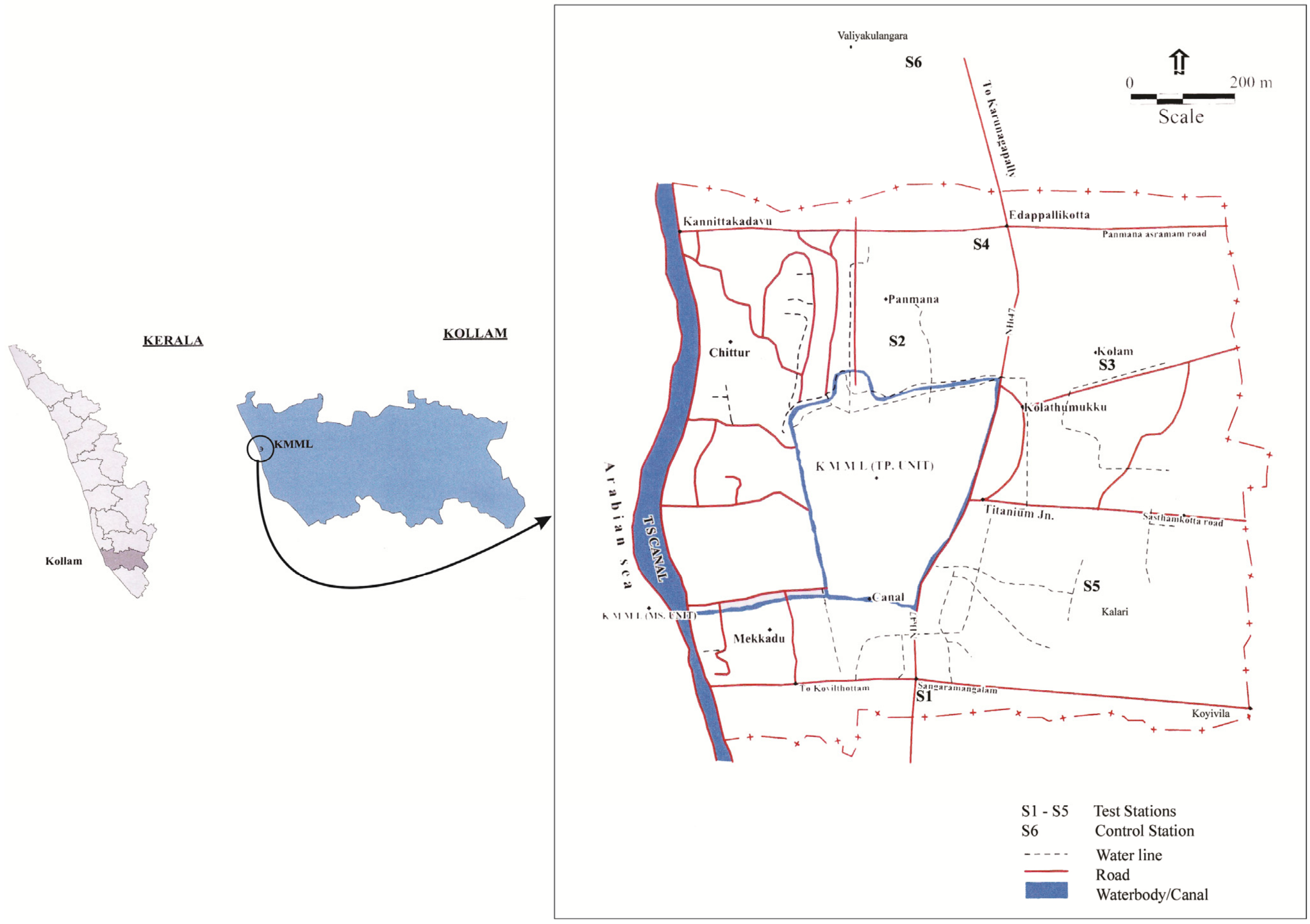


**Fig. 1.** Location map of the study area showing KMML Industry and Sampling stations.

different seasons (summer and winter) of the year 2011. Five test sampling stations (Station 1, Station 2, Station 3, Station 4, Station 5) which are in the surrounding areas were selected in different directions (radially selected in the south, east and north) around the KMML industrial zone and one control station (Station 6) in a benign environment i.e., 14 km away from the KMML industrial area in the north-west direction was also selected after a reconnaissance survey. S1 is ½ km away, in the southern side of the KMML industry, S2 is 1 km away, in the northern side, S3 is ½ km away from the industry in the eastern side, S4 is 3 km away in the northern side, and S5 is 1 km in the south eastern direction. In the western side of the industry is the Arabian Sea. Monitoring of suspended particulate matter (SPM), Respirable particulate matter (RPM), Sulphur dioxide ($SO_2$), nitrogen oxides ($NO_x$) and chlorine ($Cl_2$) were done in the ambient air during the summer (May) and winter (December) seasons of the study period. Triplicate sample collection was carried out in each study station during the study seasons and the average values for each parameter was determined.

The weather characteristics (wind speed, air temperature, relative humidity, Heat index, Dew point, Barometric pressure) of the study area in the summer and winter seasons were determined using a Portable Weather Tracker (Kestrel 4500NV, U.S.A). The weather data was collected at the mentioned stations at an interval of one hour.

The air sampling (8 hourly basis) was carried out during the summer (May) and winter (December) seasons in all the selected stations during day time using a High Volume Air sampler (Respirable Dust Sampler, Envirotech, Model APM 460 BL) with gaseous sampling attachment, at a flow rate of 1.2 $m^3$/min. The suspended particulate matter, respirable particulate matter (size < 10 µm) were sampled using the Air Sampler with Respirable Dust collection attachment using a Glass Fibre Filter (Whatman, GF/A, 20.3 × 25.5 cm). The gaseous air pollutants ($SO_2$, $NO_x$ and Free Chlorine) were absorbed in appropriate absorbing solutions in the impingers of gaseous sampling unit. The inlet tube was installed 1.5 m above the ground, which is especially relevant for human exposure.

***Methodology***

Mass concentration of particulate matter was determined by gravimetric analysis. Filters were conditioned before and after sampling. Gravimetric analysis was performed with a sensitive electronic analytical balance (Shimadzu, Japan). Reproducibility was controlled by the weighing of blank filters before and after exposure of filters for sampling. Collected samples (filters) were conditioned after sampling in a dissector during 48 h prior to gravimetrical determination. The particulate matter (RPM) collected in the pre-weighed Glass Fibre filter paper was weighed using a sensitive electronic analytical balance. From the difference in weight of the filter paper after and before sampling, the duration of sampling, and average flow rate, the concentration of respirable particulate matter in the air was calculated. The Non-respirable particulate matter (NRPM) collected in the pre-weighed cup attached to the sampler is taken out and weighed using a sensitive electronic analytical balance. The initial weight and final weight was noted. The amount of non-respirable particulate matter (NRPM) was summed up with respirable particulate matter (RPM) for calculation of TSPM (Total Suspended Particulate Matter).

The sulphur dioxide present in the ambient air was absorbed in sodium tetra chloromercurate in an impinger and estimation of sulphur dioxide (as $SO_2$) content in the air was carried out following the method described by West and Gaeke, and was given in the standard procedures in APHA (1977). The nitrogen oxides present in the ambient air was absorbed in the NaOH-arsenite absorbing medium in an impinger and the nitrogen oxides (as $NO_2$) content was determined by the modified Jacob and Hochheiser method following the standard procedures in APHA (1977). The free chlorine in the ambient air was absorbed in methyl orange solution in an impinger and the absorbance of the bleached solution and chlorine content was determined following the procedures in APHA (1977). The chlorine content in standard bleaching powder solution was also determined by titration method, and a test control was also taken, and calculations were done.

Central Pollution Control Board of India (CPCB) has developed an Air Quality Index (AQI) in collaboration with Indian Institute of Technology (IIT), Kanpur for easy calculation of air quality of a particular place/in a day/month/year for simpler way for the public and others. The index has been developed based on the dose-response relationship of various pollutants. The index is named as IND-AQI (Indian Air Quality Index). A minimum number of three pollutant parameters (RSPM, $SO_2$ and $NO_2$) are essential to calculate the IND-AQI. Any additional information on other pollutants such as $PM_{10}$, $PM_{2.5}$, CO and $O_3$ may also be included to calculate conclusive and complete value of index (Sharma *et al.*, 2001, 2003b). In the present study, IND-AQI calculations were made using the air quality rating values obtained for the pollutants, RSPM, TSPM, $SO_2$ and $NO_2$. Standard levels of chlorine in ambient air are not available. Therefore chlorine content in ambient air of study stations estimated was not included in determining the air quality of the study area.

The developed Indian Air Quality Index is classified in five categories:

**Good:** The AQI value for a community is between 0 and 100. Air quality is considered satisfactory, and air pollution poses little or no risk.

**Moderate:** The AQI for a community is between 101 and 200. Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people. For example, people who are unusually sensitive to ozone may experience respiratory symptoms.

**Poor:** When AQI values are between 201 and 300, members of sensitive groups may experience health effects. This means they are likely to be affected at lower levels than the general public. For example, people with lung disease are at greater risk from exposure to ozone, while people with either lung disease or heart disease are at greater risk from exposure to particle pollution. The general public is not likely to be affected when the AQI is in this range.

**Very Poor:** Everyone may begin to experience health effects when AQI values are between 301 and 400. Members of sensitive groups may experience more serious health effects.

**Severe**: Values between 401 and 500 trigger a health alert, meaning everyone may experience serious health effects.

Calculation for IND-AQI includes first calculation for sub-indices, which can be made by using following Eqs. (1) and (2) (Chattopadhyay *et al.*, 2010).

$$q = 100\ (V/Vs) \tag{1}$$

where, q = Quality Rating; V = observed values of the parameter and Vs = standard value recommended for the parameter (CPCB, MoEF, 1998, 2009).

If 'n' numbers of parameters are considered, the Geometric Mean of these "n" numbers of Quality Rating is found out and this is considered as Air Quality Index (AQI).

$$\text{Geometric mean, } g = \text{anti log } \{(\log a + \log b + \ldots \log x)/n\} \tag{2}$$

where a, b, c, d, x = different values of air quality rating; and n = number of values of air quality rating.

Out of all sub-AQIs, the highest value becomes the overall index and reported as IND-AQI.

## RESULTS

### *Weather Data*

The weather parameters in the study area like Wind speed, Air temperature, Relative humidity, Heat index, Dew point, Barometric pressure were recorded using the Portable Weather Tracker in the summer (May) and winter seasons (December) of 2011 and the average of the measurements recorded are given in Table 1.

The temperature of ambient air in the study area during the summer and winter seasons were noted. In summer season, the average air temperature in the study area recorded was 31.89°C, and in winter season, the air temperature was 30°C. The average relative humidity during summer was 77.09% and in winter was 76.4%. The wind direction is from west to east during the summer, and west to south-east in winter seasons studied. The average wind speed (crosswind) was 4 mph in summer season, and was 2 mph in the winter season. The average heat index recorded was 43.29°C in summer and was 37.4°C in winter 2011. Average dew point was 27.39°C in summer and 25.39°C in winter. The average barometric pressure was 29.85°C in summer and 29.85°C in winter 2011.

### *Suspended Particulate Matter in Ambient Air*

The concentrations of particulate matter (RPM and

**Table 1.** Weather data of the study area during Summer & Winter seasons.

| S. No. | Measurement | Average of Recorded values | |
|---|---|---|---|
| | | Summer | Winter |
| 1 | Wind Speed | 4 mph | 2 mph |
| 2 | Temperature | 31.89°C | 30°C |
| 3 | Relative Humidity | 77.09% | 76.4% |
| 4 | Heat Index | 43.2°C | 37.4°C |
| 5 | Dew point | 27.39°C | 25.39°C |
| 6 | Barometric Pressure | 29.85 in Hg | 29.85 in Hg |

TSPM) in the ambient air of the selected stations in the surroundings of KMML industrial area in the summer and winter seasons were shown in Figs. 2 and 3.

The RPM ($PM_{10}$) values ranged from 180 μg/m$^3$ to 208 μg/m$^3$ in summer season and 190 to 238 μg/m$^3$ in winter season. The highest concentration of RPM was recorded in Station 1 in both seasons studied and showed values up to 238 μg/m$^3$ in winter season. This station is half km away towards the southern direction of the KMML factory and is 50 m from National Highway-47. The TSPM content in ambient air of the study stations varied from 330 μg/m$^3$ to 398 μg/m$^3$ in summer season and 335 μg/m$^3$ to 425 μg/m$^3$ in winter season. The highest TSPM concentration (425 μg/m$^3$) was recorded in station 4, that 3 km away from the KMML industry and near NH-47 during both seasons studied. The particulate matter content in station 2 is low compared to other test stations and this may be due to the vegetation especially coconut trees in this station. In the present study the TSPM and RPM values obtained in the ambient air analysis of the study area were above the permissible standard limits of National Ambient Air Quality Standards for residential area and industrial areas (CPCB, MoEF, 1998, 2009). The season wise changes recorded in RSPM and TSPM content are given in Fig.6. In both seasons studied, there was a uniform change in the concentration of respirable and total particulate matter in the study stations.

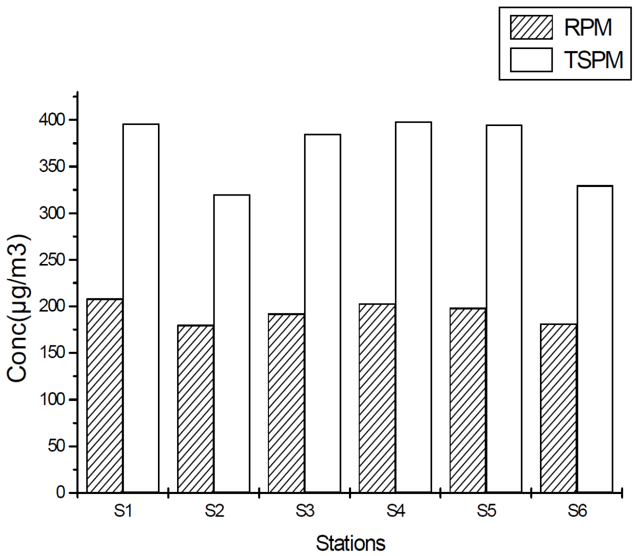


**Fig. 2.** Concentration of Particulate matter in Ambient air during Summer season.

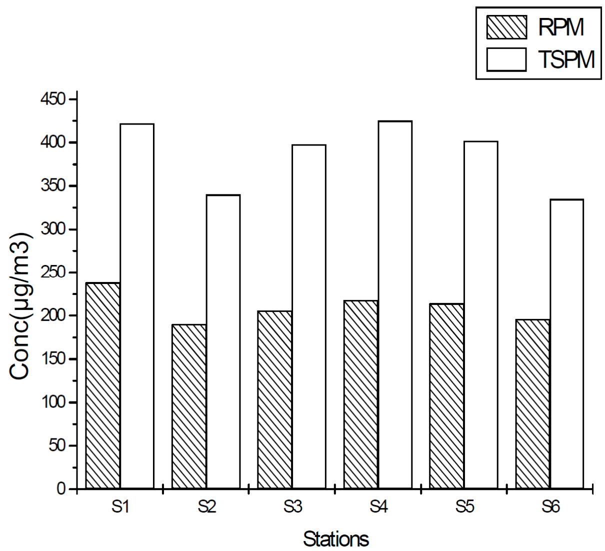


**Fig. 3.** Concentration of Particulate matter in Ambient air during Winter season.

***Concentration of Gaseous Pollutants in Ambient Air***

The concentration of gaseous air pollutants (sulphur dioxide, nitrogen oxides and free chlorine) in the ambient air of the selected study stations around the KMML industrial area in summer and winter seasons are given in Figs. 4 and 5. The $SO_2$ content in the study area ranged from 16.41 μg/m$^3$ to 95.96 μg/m$^3$ in summer season, while in winter season it varied from 21.7 μg/m$^3$ to 118.5 μg/m$^3$. The highest $SO_2$ content (118.5 μg/m$^3$) was recorded in Station 1 that is in the southern direction and half kilometer away from KMML industry, and near to NH-47. The lowest concentration (16.41 μg/m$^3$) of $SO_2$ was recorded in station 6, the control station and is 14 km away from the KMML industrial area. The concentration of $SO_2$ in all the study stations except Station 1 was within the National Ambient Air Quality Standards for residential area and industrial areas (CPCB, MoEF, 1998, 2009). The $NO_x$ content in the ambient air of study stations varied from 19.5 μg/m$^3$ to 52.2 μg/m$^3$ during summer season, and from 11.9 μg/m$^3$ to 62.8 μg/m$^3$ during winter season. The $NO_x$ content estimated in the ambient air of the study stations were within the NAAQS limits for residential area and industrial areas (CPCB, MoEF, 1998, 2009).

The concentration of free chlorine in ambient air of the study area recorded highest value (60.75 μg/m$^3$) in station 2 that is near to the factory (200 m) in the northern side.

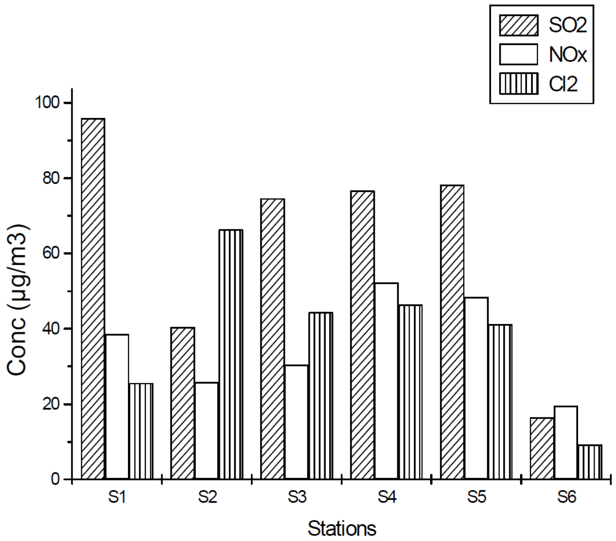


**Fig. 4.** Concentration of Gaseous Pollutants in Ambient air during Summer season.

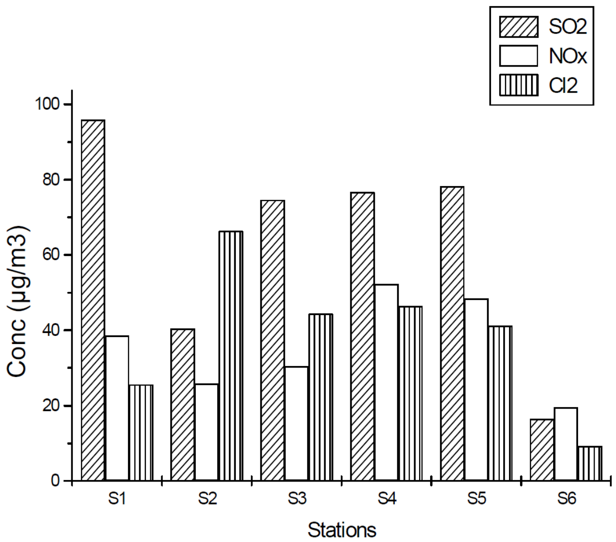


**Fig. 5.** Concentration of Gaseous Pollutants in Ambient air during Winter season.

The lowest chlorine content (9.25 $\mu g/m^3$) in ambient air was recorded in station 6 (control station) that is 14 km away from the KMML factory. Workers may be exposed to chlorine in industries where it is produced or used, particularly in the food and paper industries. In addition, persons breathing air around these industries may be exposed to chlorine (USEPA, 1992). Acute health effects result from short term exposure, usually to high concentrations of pollutants and are common following industrial exposure or accidental releases of toxic chemicals.

The season wise changes recorded in the concentration of different gaseous pollutants monitored in the study area are given in Fig. 7. The concentrations of RSPM and TSPM are higher in winter season when compared to summer season. Vehicles and construction activities contribute to re-suspended fine dust particles. In the case of $SO_2$ and $NO_2$ there is a uniform change in different stations during the summer and winter seasons. The chlorine content also shows seasonal variation with respect to the study stations and was recorded highest in station 2, in the northern direction of the KMML industry during both the seasons studied.

### *Air Quality Index*

AQI rating values for air pollutants and air quality status of the study area during the summer and winter seasons are given in Tables 2 and 3. The Indian Air Quality Index (IND-AQI) values of the study stations in summer and winter seasons were determined based on the air quality rating values for different pollutants (RPM, TSPM, $SO_2$ and $NO_2$). The IND-AQI values show that the air quality status of station 1 is moderate in both summer and winter seasons, and in Station 2 (S2), the air quality was good in summer season, and moderate in winter season. The stations, S3, S4 and S5 were with moderate air quality in both seasons studied. The degradation of air quality may cause health problems to sensitive persons especially children in this area. Also people who are unusually sensitive to ozone/ chlorine may experience respiratory symptoms. The low AQI values (< 50) obtained in station 5, the control area, show that the quality of air in this area was good in both seasons of the study period.

## DISCUSSION

The weather parameters like wind speed, air temperature, relative humidity, heat index and dew point recorded comparatively high values in summer compared to that in winter season. The barometric pressure in the study area recorded the same value (29.85 in Hg) in both seasons. Atmosphere serves as the medium through which pollutants are dispersed. While being transported, the pollutants undergo chemical reactions, which may be lethal or scavenged by chemical or physical process/method. But it all exclusively depends upon meteorological conditions (Lee *et al.*, 1994). The location, duration of release, height as well as the pollutant concentrations are also important, which effect the secondary pollutant transformation under the influence of meteorological conditions, but the atmospheric behavior is independent of their sources (Holzworth, 1974). Solar radiations influences the atmospheric chemical processes. Free radicals are formed by photo-dissociation of molecules. And these are highly reactive unstable intermediates. Although, solar radiations plays crucial role in the generation of free radical yet water vapour and temperature also influence the particular chemical pathways.

Micrometeorological parameters such as wind speed, wind direction, temperature, atmospheric pressure and relative humidity have a great effect on the movement of particulate matter as well as the concentration level at any particular area. Sedimentation, diffusion, turbulence, washout, occult depositions are the processes, which remove particulate matter from air (Beckett *et al.*, 1998).

In the present study the TSPM and RPM values obtained in the ambient air of the stations S1, S3, S4 and S5 in

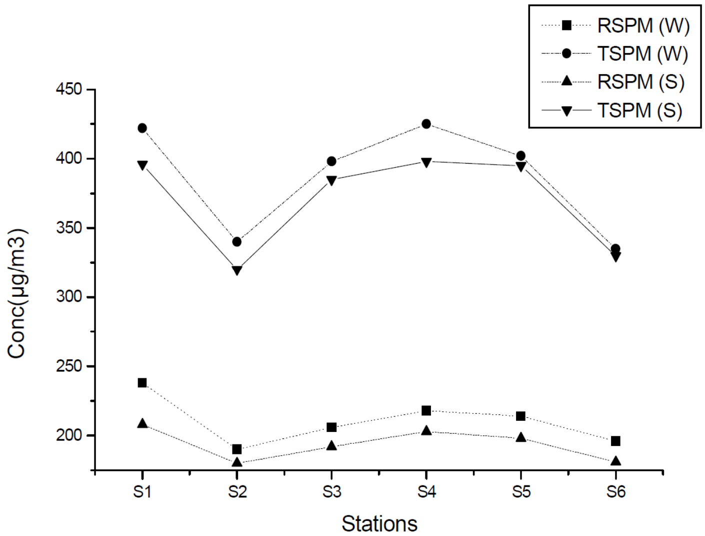


**Fig. 6.** Season wise changes in RSPM and TSPM in the study area.

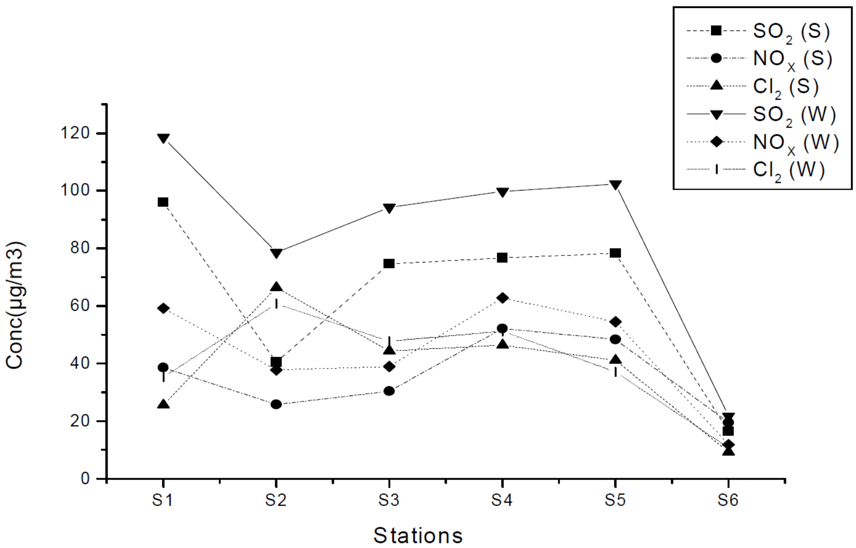


**Fig. 7.** Season wise changes in Gaseous pollutants in the study area.

**Table 2.** Air quality rating values for pollutants during Summer season.

| Stations | Air quality rating values for pollutants | | | | IND-AQI | Air Quality Status |
|---|---|---|---|---|---|---|
| | RPM | TSPM | $SO_2$ | $NO_x$ | | |
| 1 | 208 | 198 | 119.95 | 48.25 | 124.1 | Moderate |
| 2 | 180 | 160 | 50.63 | 32.25 | 82.8 | Good |
| 3 | 192 | 192.5 | 93.23 | 38.0 | 107.0 | Moderate |
| 4 | 203 | 199 | 95.83 | 65.25 | 126.0 | Moderate |
| 5 | 198 | 197.5 | 97.85 | 60.5 | 123.4 | Moderate |
| 6 | 181 | 165 | 20.51 | 24.37 | 62.3 | Good |

different seasons were above the permissible limits of National ambient air quality standards (CPCB, MoEF, 1998, 2009) for residential areas. Higher levels of RPM were observed during winter months possibly due to lower mixing heights and more calm conditions. Health survey conducted among the people in the surroundings of the KMML industrial area (Jaya, 2011) show that 10.32% of the population are with existing breathing problems related to asthma, bronchitis, or emphysema, and are liable to be adversely affected by high concentrations of particulates. Studies by Rusznak *et al.* (1994) suggests that allergic disease is becoming more common, particularly in industrialized societies. Both particle size and composition play an important in determining the health effect of particulate

**Table 3.** Air quality rating values for pollutants during Winter season.

| Stations | Air quality rating values for Pollutants | | | | IND-AQI | Air Quality Status |
|---|---|---|---|---|---|---|
| | RSPM | TSPM | $SO_2$ | $NO_x$ | | |
| 1 | 238 | 211.0 | 148.12 | 74.0 | 153.1 | Moderate |
| 2 | 190 | 170.0 | 98.25 | 47.25 | 110.4 | Moderate |
| 3 | 206 | 199.0 | 117.75 | 48.75 | 109.1 | Moderate |
| 4 | 218 | 212.5 | 124.75 | 78.5 | 146.2 | Moderate |
| 5 | 214 | 201.0 | 128.0 | 68.12 | 139.1 | Moderate |
| 6 | 196 | 167.5 | 27.12 | 18.875 | 59.4 | Good |

matter. Particles can have harmful effects on their own or they may act synergistically to enhance the toxic effects of other pollutants.

In the present study the concentration of gaseous pollutants, $SO_2$ and $NO_x$ determined in the ambient air of majority of study stations were within the NAAQS limits (CPCB, MoEF, 1998, 2009). Chronic effects on humans result from long term exposure, usually to lower, ambient levels of pollution. Studies by Banerjee and Srivastava (2010) on the impacts due to rapid industrialization and commercial activities at the Integrated Industrial Estate – Pantnagar in India from June 2007 to May 2008 and on the values of AQI reveal a gradual increasing trend with a range of 48.02–79.25, signifying the prevalence of moderate to heavy pollution levels in the area.

Chlorine is a harmful air pollutant and on inhalation can cause airway and lung irritation, and in high concentration may cause visual impairment (Wellburn, 1994). The present study shows that the study area is contaminated with chlorine which may be due to the leakage of chlorine from KMML industry, where chloride route is used for $TiO_2$ production. Titanium tetra chloride ($TiCl_4$) is produced as an intermediary product in the production of rutile grade titanium dioxide pigment. A study by Mathew (1999) and the News paper report (The Hindu, 2011) also showed previous occurrence of accidental leakage of chlorine gas/$TiCl_4$ from the chlorination plant of KMML factory which caused nausea, vomiting and unconsciousness in people residing the surroundings of this industrial area. Chlorine is not normally detected in ambient air, soil, surface water, groundwater, or drinking water. Therefore, background exposure of the general population to chlorine is not expected. Greater than 95% of the chlorine that is inhaled (over a 1–5 ppm range) reacts in the upper respiratory tract and eventually joins the chloride pool in the body. The amount of chlorine that needs to be inhaled to induce a significant increase in extracellular chloride in the body is probably a lethal amount. The principal targets of toxicity to chlorine gas are the respiratory airways and the eyes. The toxicity of chlorine appears to be dependent on the duration of exposure and exposure concentration, and the moisture content of the surface contacted by the gas, e.g., the respiratory epithelium or conjunctivae (ATSDR, 2010).

## CONCLUSIONS

The evaluation of particulate matter concentration in different sampling stations in the surroundings of KMML industry situated in Kollam district, South India show that the area was badly polluted with $PM_{10}$ i.e., the respirable particulate matter. The TSPM concentrations in the different study stations are in the order: S4 > S1 > S5> S3 > S2 > S6. The concentrations of gaseous pollutants, $SO_2$ and $NO_x$ were within the NAAQS limits of Central Pollution Control Board (CPCB) and Ministry of Environment & Forests (MoEF), India. The study stations in the northern, eastern and southern directions of the industry recorded free chlorine contamination. The free chlorine content was found highest in station II, in the northern side of the industry. Therefore the study revealed that the air pollution due to $PM_{10}$ and chlorine in the residential areas in the vicinity of KMML industry causes different health problems in the residents, especially in children and aged people.

The air quality status of the study area was assessed on the basis of the data obtained for criteria pollutants - particulate matter, sulphur dioxide and nitrogen oxides. With respect to these pollutant concentrations, the study stations S1, S3, S4, S5 were with moderate air quality in both seasons studied. The air quality in the control station (S6) was good in all the seasons studied. Considering the free chlorine contamination in the study stations S1, S2, S 3, S4, S5 detected in the present study, the quality of air in the surroundings of the KMML factory is bad. The people in the study area who are unusually sensitive to ozone/chlorine may experience respiratory symptoms. Therefore to manage the air pollution in the study area, it is recommended to install high efficiency air pollution control devices to the KMML factory. The factory authorities may also take steps to plant air pollution tolerant creepers in the surroundings of the industries to reduce air pollution problems in this area. As there is no permissible standard limits for chlorine in the ambient air in industrial/residential areas, Ministry of Environment and Forests (MoEF), Government of India should take necessary steps to promulgate Ambient Air Quality Standards for chlorine in industrial area. The present study further suggests that it is imperative to monitor the air quality in reference to chlorine as well as the health effects in selected stations of the study area at regular intervals.

## ACKNOWLEDGEMENTS

The authors gratefully acknowledge the University Grants Commission, New Delhi, India for the financial assistance rendered for this study. Also thank Head, Dept. of Environmental Sciences and the Principal, Fatima Mata National College, Kollam, India for providing necessary laboratory facilities for this study.

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*Received for review, October 31, 2013*
*Accepted, February 18, 2014*