International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Volume 1 Issue 10 (November 2014) www.ijirae.com

A Qualitative Study of Temporal Variations in Air-Pollutant Concentrations and Associated Mortalities in Some Urban and Industrial Regions

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***Abstract** -- Increased daily mortality with elevated concentrations of air pollutants has been observed in almost every part of the world and its association with different pollutant components has been proved beyond doubt. Assuming a linear relationship between mortality rates and pollutant concentrations, data available in a variety of forms is analyzed to obtain qualitative features of temporal variations in mortality rate, daily hospital admissions, total suspended particulates and other components of particulate matter at a number of urban and industrial hotspots. Mortality rates and most other pollutant indicators exhibited periodic temporal variations during respective study periods. Observed patterns in the data could be used to predict the future conditions of atmospheric environment without performing actual measurements. This information like weather reports may be used by the inhabitants and the people from otherwise pristine regions to minimize health risks posed by the atmospheric environment.*

***Key words:** Air–pollution, mortality, temporal variations, periodic.*

1. INTRODUCTION

Millions of particles are inhaled in a single breathe and extent of damage they do to lungs is decided by concentration and composition of the pollutant. Both, particulates and gaseous type pollutants affect the respiratory system and long exposure to their concentrations may result in various respiratory problems [1]. Several epidemiological studies have suggested a strong association between concentrations of particulate matter and human mortality [2,3,4,5]. Time series analysis of epidemiological data suggests that increase in mortality is associated with high levels of particulate matter on the same day or on the previous day. U.S. EPA air quality criteria document for particulate matter showed that on an average, all cause mortality increases by 2.5 – 5% for an increment of 50 µg/m^3 in the ambient concentration of PM_{10} (particulate matter size <10 micrometer) [6].There is a remarkable consistency across various epidemiological studies and several independent meta-analyses have reported similar results [7,8,9,10]. Now, there is a strong consensus that particulate matter coarse or fine has significant associations with mortality and its affect on human health can be measured in terms of emergency room visits, daily hospital admissions and daily death.

A few studies on gaseous pollutants (ozone, NO_2, SO_2 etc) showed a strong association between pollutant concentrations and morality [11,12,13,14]. Clear evidence however exists on association of ozone with daily admissions and emergency room attendances for respiratory disease and reductions in lung function [12]. A good evidence also exists that O_3 concentrations found in London may be toxic to lungs [12,13,14]. Association between daily mortality and other pollutant indicators (ozone, BS, NO_2, SO_2 etc) suggested a stronger association with O_3 as compared to other gaseous pollutants [15]. Similar associations with O_3 have been reported for Los Angeles and New York [16,17] but several other cities in the United States exhibited no associations with ozone. Several other studies from the United States [18,19], Europe [20,21,22,23], and Australia [24] have found similar associations with ozone concentrations (same day or lagged).

These evidences if indicative of any casual relationship suggest that air pollutants have significant effect on daily mortality and extent of damage they do to human health is evident from data of daily hospital admissions, emergency visits for respiratory ailments and daily deaths. Pollutant concentration may be as high as 450µg/m^3 or more in highly polluted cities/regions and as low as a few µg/m^3 in otherwise least polluted regions. Since air pollution has strong association with mortality rates highly polluted cities/regions might show more cases of daily deaths and may need interventions to reduce the persisting high levels. Interventions are effective when their implementation results in significant reduction in pollutant concentrations and associated mortality. When the Government of Ireland intervened and banned distribution, sale and marketing of coals within the limits of Dublin city [25] average particulate concentration was reduced drastically [26]. After ban on coal sales average black smoke concentration declined from 50.20 µg /m^3 to 14.6 µg /m^3 [27]. This observation emphasizes the necessity of intervention at highly polluted city/region and awareness of atmospheric environment and associated health risks at others.

In order to implement intervention programmes at highly polluted places and awareness at others a systematic study that can be helpful in their implementation may be needed. Their implementation may need information on expected future conditions of atmospheric environment and associated health risks at the hotspots. To achieve this, air-pollution, daily mortality and their associations at several cities across different continents are studied and analyzed. This elaborate study is an extension of previous work [28] which looked at temporal behavior of pollutants and associated mortalities at some representative places.

TABLE 1 : MORTALITY AND POLLUTANT CONCENTRATIONS WITH METEOROLOGICAL PARAMETERS (TEMPERATURE AND HUMIDITY).

S. No.	City/region	Concentration of PM_{10}^{*} / $PM_{2.5}^{@}$/ $BS^{\#}$/ $TSP^{?}$ (μg/m^3) (Stat. Mean)	All cause daily mortality (Stat. Mean)	Temp. (^{0}C)	Relative Humidity % (Stat. Mean)	Data source
1	Birmingham	25.6*	29.20	< 12.4	79.4	Wordley et.al. , 1997
2	London	14.6$^{\#}$	175.5	<29.0	72.1	Anderson et.al., 1996
3	Dublin	50.2$^{\#}$ 14.6$^{\#}$($^{!}$ACSB)	9.41$^{\$}$ 8.65$^{\$}$	<14.4 <14.6	80.1 82.3	Clancy et.al., 2002
4	Sidney	20.0*	59.0	<30.0	-	Morgan et.al.,1998
5	Lugano	33.0*	-	-	-	Gehrig et.al., 2003
6	Bern	35.9*	-	-	-	Gehrig et.al., 2003
7	Zurich	24.0*	-	-	-	Gehrig et.al., 2003
8	Mexico City	27.0$^{@}$	32.0	<18.0	51.6	Borja-Aburto et. al., 1998
9	Northeast Bavaria	51.6$^{?}$	4.12	<27.1	77.0	Peters et.al., 2000
10	Coal basin (Czech Repub.)	65.9*	18.2	<28.7	73.6	Peters et.al., 2000

****PM$_{10}$*** *=Particulate matter size less than 10 micrometer;*$^{@}$***PM$_{2.5}$****= Particulate matter size less than 2.5micrometer;* $^{\#}$***BS*** *= Black smoke;* $^{!}$***ACSB = A****fter coal sale ban in Dublin;* $^{\$}$ *The data is for per1000 persons/year.*

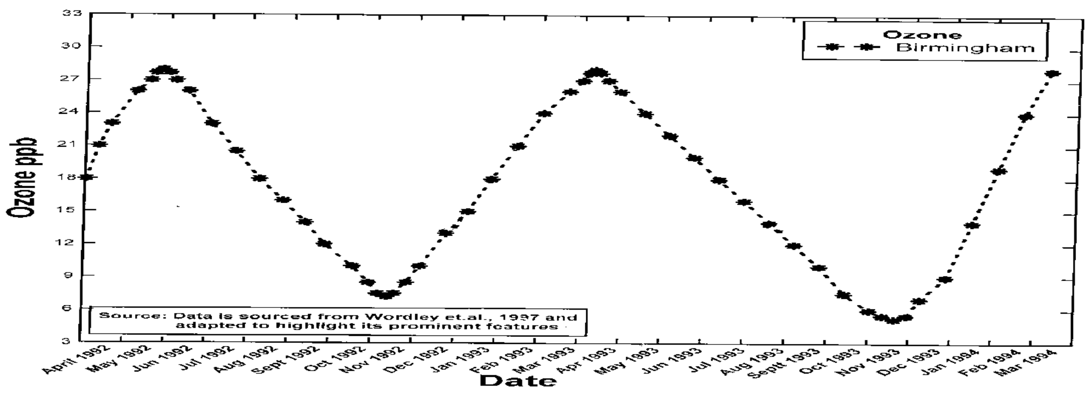

Figure 1: Plots of ozone concentration against time in Birmingham.

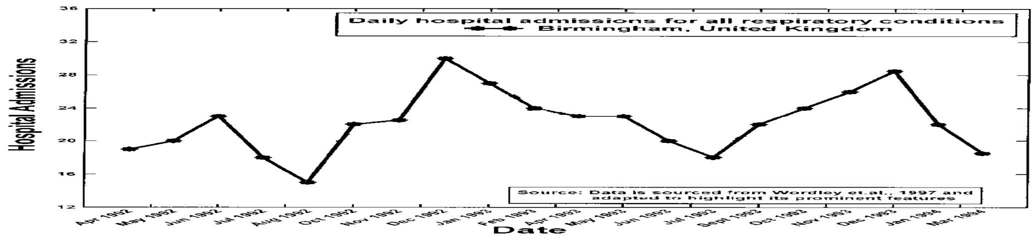

Figure 2: Plot of observed hospital admissions for all respiratory conditions over the study period in Birmingham.

2. DATA AND ANALYSIS

Birmingham, with mean concentration well within WHO levels (Table1) exhibited associations between various pollution indicators and mortality during the study period. Data of ecological time series study aimed at investigating hospital admissions and mortality during April 1992 to March 1994 on the residents of Birmingham is analyzed [29]. Measurements on PM_{10} (24h mean being 52.6 $\mu g/m^3$) showed no seasonal variations during the study period and similar trends were found for NO_2 and SO_2. However, ozone concentrations exhibited seasonal variations during the study period [**Fig.1**). Daily hospital admissions for all respiratory conditions showed temporal variations: lowest in August and the highest in December [**Fig.2**].

Atmospheric environment of Dublin city deteriorated in 1980 due to use of cheaper and more readily available solid fuel mainly bituminous coal for domestic purposes. When Irish Government banned marketing, sale and distribution of coal in the city of Dublin levels of pollution and associated mortality were reduced significantly. The effect of intervention was immediate and concentration of black smoke was reduced by 70% and associated mortality declined considerably [**27**]. The data of smoke concentrations before and after the intervention is shown in [**Fig.3**]. Data exhibited periodic temporal variations all through the study period and concentration of black smoke was reduced drastically after the ban.

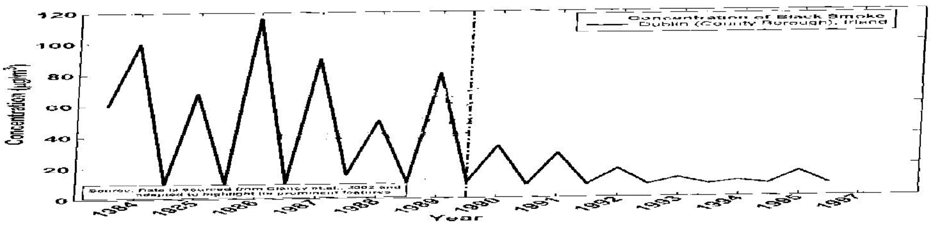

Figure 3: Seasonal black smoke concentrations during September 1984–96 in Dublin. Vertical line indicates the date when sale of coal was banned in Dublin.

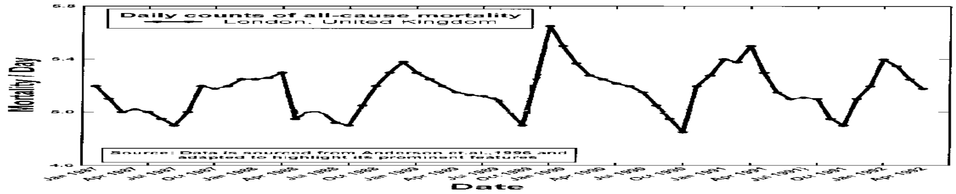

Figure 4: Plot of a time series of daily counts of log observed all-cause mortality in London.

London has been known to experience episodic events that raised pollution levels and associated mortality and morbidity substantially [30,31]. After disappearance of coal usage (a source of black smoke) in London, main sources of pollution were attributed to vehicular activities [32,33]. Other Pollutants that were potentially harmful included ozone, NO_2, SO_2, and volatile organic compounds. On most days, concentrations of the pollutants were within WHO limits, but occasional exceedences of ozone during summer and that of NO_2 in winter had been a matter of concern [34]. Data of a time series study of daily counts of all cause mortality (log observed) during April 1987 to March 1992 is shown in **Fig. 4.** Except some modulations during episodes, data showed periodic temporal variations throughout the study period.

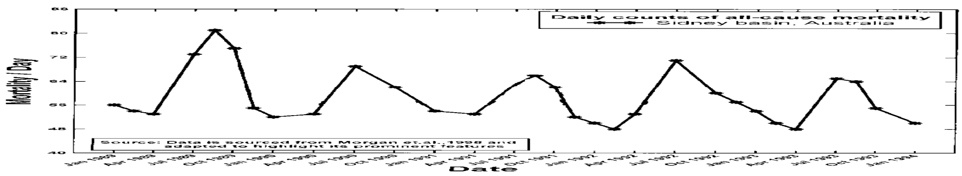

Figure 5: A time-series plot of daily counts of all-cause mortality in Sydney basin, Australia, from 1989 to 1993.

Sidney is the largest city of Australia and experiences relatively low levels of air pollution. The annual average of particulate matter (PM_{10}) in Sidney basin was 20µg/m^3 [Table1]. SO_2 levels were negligibly small owing to the low sulfer content of Australian fossil-fuels and absence of sulfer emitting industrial sources. The observed correlation between particulates and NO_2 suggested strong associations between NO_2 concentration and mortality and these associations were independent of other components of pollutants. All cause mortality associations with ozone concentrations were also evident from the data. Data of a time series study of daily counts of all cause mortality from January 1989 to November 1998 is shown in **Fig.5** [35]. All cause mortality data showed temporal variations which were periodic all through the study period.

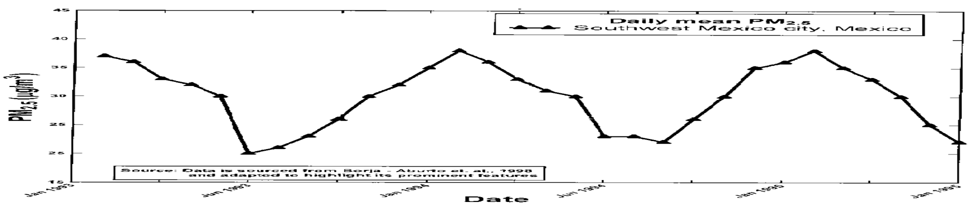

Figure 6: Time-series plot for daily mean $PM_{2.5}$ in Mexico City from 1993 to 1995.

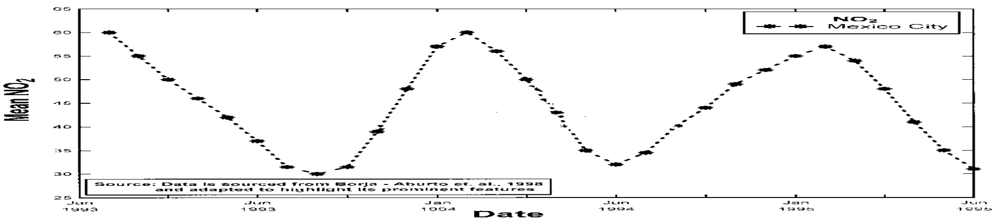

Figure 7: Nitrogen dioxide concentrations in Mexico City from 1993 to 1995.

Mexico City is one of the most populous urban area in Latin America with millions of vehicles and thousands of industrial establishments sharing the metropolitan valley of Mexico [36]. City has a mild tropical climate with temperatures varying between 0^0C to 32^0C. Relative to other urban areas in Europe and America, Mexico City has moderate to very high levels of particulates, low levels of SO_2, but very high levels of ozone. Concentrations of particulates (**Fig.6)** and NO_2 (**Fig.7)** exhibited temporal variation whereas ozone concentration remained stabilized all through the study period. Meteorological parameters like temperature (**Fig.8)** and humidity (data not shown) showed temporal variations and these variations were periodic. Mortality exhibited a very strong association with temperature a meteorological parameter. Time series plot of all cause morality for Mexico City during the study period is shown in **Fig.9**. A 10 µg/m^3 increase in concentration of fine particles was associated with a 1.3-1.7% increase in total mortality (4 days after exposure), and was independent of the presence of other air pollutants [37].

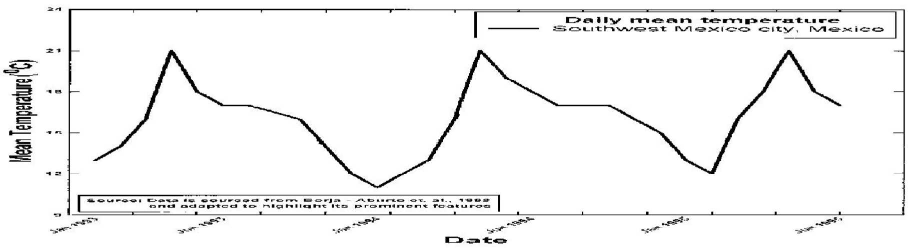

Figure 8: Daily mean temperature in Mexico City during the study period.

Industrial coal region of Czech Republic included 5 districts: Teplice, Ustin. L., Decin, Most, and Chomutov. The combined population of these districts during the study period was 630,000, in an approximately 700 square kilometer area. All cause mortality was associated with TSP concentrations but its association with SO_2 was not very significant [38]. **Fig. 10** shows the concentrations of TSP during the study period. Both TSP and SO_2 exhibited periodic temporal variation during the study period with concentrations being the lowest in August and the highest in February. A 100 µg/m^3 increment in TSP concentration was associated with 3.5% increase in mortality risk whereas the same increase in SO_2 level was associated with 1% increase in the risk.

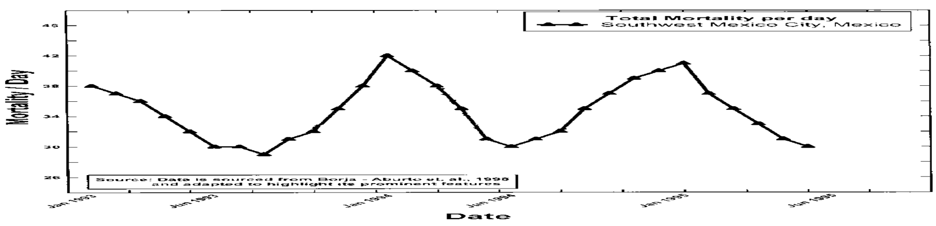

Figure 9: Time-series plot for total mortality per day in Mexico City from 1993 to 1995.

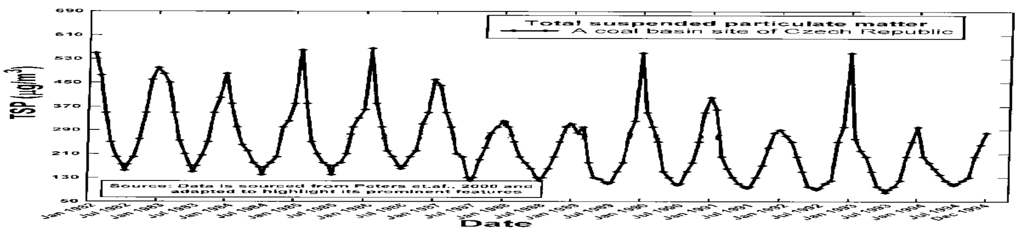

Figure 10: Daily concentrations of TSP in the coal basin study area, Czech Republic.

The Bavarian study region of Germany included 4 districts: Hof, Landkreis Hof, Wunsiedel, and Tirschenreuth. These districts had approximately 250,000 inhabitants in approximately 1,000 square kilometer area. All cause mortality during the study period did not show any association with elevated levels of TSP and SO_2 [38]. Concentrations of TSP and SO_2 during the study period are shown in **Fig 11** and **Fig.12** respectively. Both exhibited periodic temporal variations TSP variation was sharper than SO_2 however.

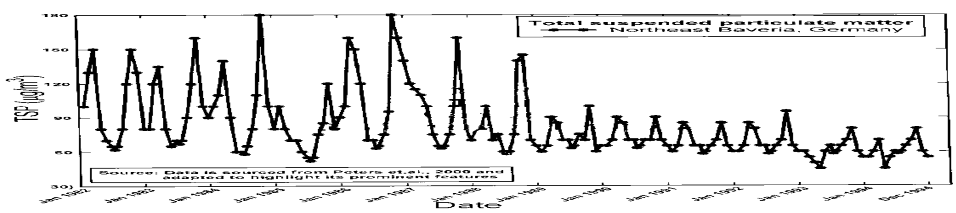

Figure 11: Daily concentrations of TSP in northeast Bavarian study area, Germany.

Air pollution in Switzerland is low as compared to other European cities [Table1].PM_{10} and $PM_{2.5}$ concentrations at three different urban sites are shown in **Fig.13** and **Fig.14** respectively [39]. Despite higher vehicular activities in Bern it experienced low levels of $PM_{2.5}$ than Lugano an otherwise low traffic urban area in Switzerland. Strong influence of the Milan plume on the atmospheric environment of southern Switzerland seemed the most likely reason for this effect [40, 41]. Both, PM_{10} and $PM_{2.5}$ exhibited periodic temporal variations during the study period with concentrations being lowest in July and highest in February.

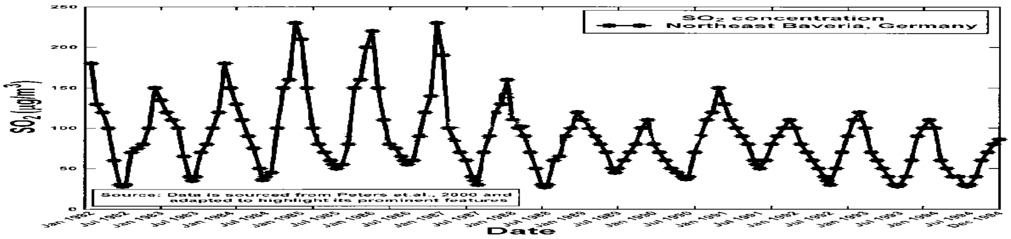

Figure 12: Daily concentrations of $S0_2$ in northeast Bavarian study area, Germany.

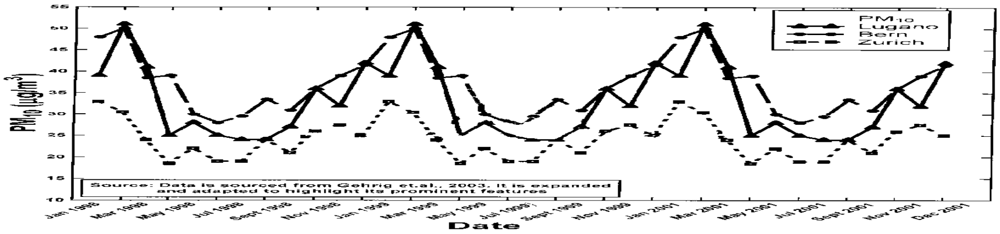

Figure 13: Seasonal variations of monthly mean concentrations of PM_{10} during the study period in Switzerland,

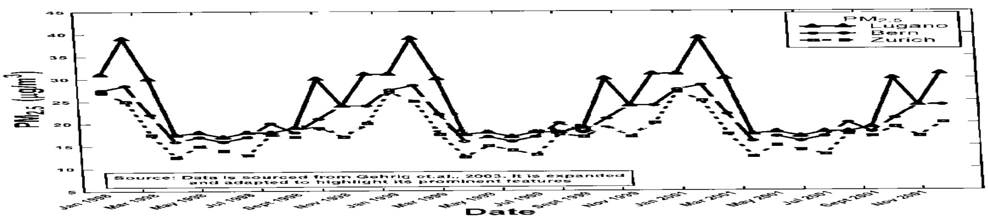

Figure 14: Seasonal variations of monthly mean concentrations of $PM_{2.5}$ during the study period in Switzerland,

3. DISCUSSION

Particulates & associated mortality: While it is accepted that major episodic events such as London smog episode 1952 have more hazardous health effects it is more difficult to believe that low levels of pollution prevailing at several other places pose smaller health risks. Low concentration of particulates and significant associated mortality may require more information on chemistry of the particulates and their toxic effect on lungs. Nonetheless, plausible mechanism that might explain the toxic effects of low concentration inhaled particles on lungs have been postulated [42]. Mortality associations with particulate matter were similar to the ones observed in several other cities across the globe and lower pollutant concentrations did not weaken these associations. 5.5% increase in mortality with 50 $\mu g/m^3$ increment in black smoke (London), 2.5% increase in all respiratory admissions with 10 $\mu g/m^3$ increase in PM_{10} (Birmingham), 8% decrease in deaths with 35.6% reduction in black smoke concentrations (Dublin County Borough), 1.4% increase in total mortality with 10$\mu g/m^3$ increment in $PM_{2.5}$ level (Mexico city) and a 2.68% increases in all-cause mortality with 10th to 90th percentile change in Sidney basin are considerably important results. Although various studies differ in geographical location, thus they differ in their background concentrations, source of particulates, meteorological parameters, and in their approach to confounding factors, they all support the contention that associated mortality increases 2.5-5% with 50µg/m^3 increase in particulate matter and that the lower particulate concentration (within World Health Organization limits) poses no smaller health risk.

Gaseous pollutants & Mortality: Other important components of air pollution that have considerable associations with daily mortality are ozone, nitrogen dioxide, and sulpher dioxide. Although their associations are weaker than particulates they seem to pose significant health risks.

Ozone, an important component of gaseous pollutants, exhibited considerable association with daily mortality and these associations were broadly consistent in several cities across the globe. Mexico City showed higher levels of O_3 all through the year and it did not show temporal/seasonal variation during the study period. In contrast ozone concentration in Birmingham exhibited temporal variations and these variations were periodic all through the study period **(Fig.1)**.

Nitrogen dioxide exposures are known to cause acute pulmonary toxic responses and could increase susceptibility to respiratory infections [43]. Studies have suggested that nitrogen dioxide exposure could potentiate the bronchoconstrictor response to common aeroallergens [44,45]. Daily respiratory mortality among children in Brazil has been associated with oxides of nitrogen [46]. An episodic event of high nitrogen dioxide pollution in London (December 1991) was associated with increased mortality and morbidity [34]. On the basis of these evidences, it would be difficult to dismiss a possible association between nitrogen dioxide and mortality. However, studies that have looked at SO_2 and its associations with mortality are not insignificant but they are less consistent than those of the particulates.

Temporal variation & periodic nature: While geographically different regions exhibited varying conditions of atmospheric environment their associations with mortalities remained the same. Assuming that temporal variations in mortality and other pollutant indicators may reveal some characteristics features, long term data of each city/region is put together to identify regularity in patterns to study the possible variability in health risks posed by the atmospheric environment. Except some modulation during episodic events, data of various cities exhibited similar periodic variation in mortality and other pollutant indicators. Observed patterns are important as they may be used to predict future conditions of atmospheric environments of the hotspots. Since atmospheric environment of most urban or industrial regions poses serious threat to human health, it is suggested that this information like weather report could be useful to the inhabitants in general and to the people/visitors from otherwise pristine regions in particular to minimize health risks. Places/regions where high levels of pollutants are sustained for long, their atmospheric environment my affect the quality of ambient air of the neighboring regions, considerably. To study this effect temporal behavior of pollutants at the hotspots may be needed. These temporal - patterns could provide important input to the study and may be helpful in devising measures to control/minimize the rising pollution levels and associated morbidity and mortality.

Though study of temporal patterns is limited to cities or regions where systematic data for a considerable period of time is available, it may be extended to other cities/regions either by combining the scattered data available in literature or by performing measurement afresh to identify the nature of long term or short term patterns. The observed patterns are important as they enable us predict future conditions of atmospheric environment without performing actual measurements thus saving time and energy.

4. CONCLUSIVE REMARKS

Air pollution and mortality data of several cities/regions exhibited periodic temporal variations (patterns). Observed patterns are important as they could be used to predict the future conditions of atmospheric environment without performing actual measurements. This information like weather report may be used by the inhabitants and the people/visitors from otherwise pristine regions to minimize associated health risks. Since many urban and industrial hotspots have become a major source of air pollution this information may also be used to study the affect of elevated levels on the ambient environment of pristine neighbors.

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