SPATIO-PERIODIC MONITORING AND ANALYSIS OF ATMOSPHERIC SULPHUR DIOXIDE (SO2) IN THE METROPOLITAN AREAS OF LAHORE -PAKISTAN

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ABSTRACT: For the last three decades, due to population growth and urban development, the mega cities of Pakistan like Karachi and Lahore are experiencing air pollution issues. Out of many, the sulphur dioxide (SO2) in one the most widely researched atmospheric pollutants. Therefore, present research deals with the spatial and periodic distribution of SO2and its seasonal variations and contamination at fifteen locations in the metropolitan area of Lahore. The sulphur dioxide analyzer's monitoring method has been used to find the concentration and variations which allows instantaneous and continuous analysis of gas in an unaltered state. The industries which are located within or around the metropolitan area of Lahore cause most of the Urban Air Pollution (UAP), especially the emission of sulphur dioxide (SO2).The aims of this study have been to investigate the occurrence of systematic differences in the exposure of SO2 in different Landuse of the Lahore metropolitan areas and to identify the final risk zones of the city. The spatial and temporal perspective of the Lahore combined with the Total Risk Map (TRM) of the metropolitan area highlights the extremely high to extremely low risk zones of the city. The study revealed that Lahore urban area is characterized by a number of hot-spot sites which are mainly due to the industrial emissions. It has been observed that the level of air pollution is severe especially in the Central Business District (CDB) and in and around commercial zones of Lahore. The highest sulphur dioxide values have found near industrial locations, brick kilns and main road crossings areas. Improved technology for negative SO2 emission from industries and steps to control the consumption of low quality coal in brick kilns will lead to reduce the pollution in urban air. The air quality of Lahore can be improved by regular air monitoring and evaluation networks and the integrated approach among the stakeholders both in public as well as private sectors.

Key words: Spatio-periodic, EPA, GIS, Total Risk Map, Monsoon, Metropolitan areas

INTRODUCTION

Air pollution is one of the major environmental issues in the mega cities of Pakistan. This problem has a direct impact on health and ecosystem of urban areas. The high growth rate of population in the city like Lahore and the ambitious development has led the city's urban environment towards degradation; especially the emission of air pollutants affects the environment largely. According to Henry (1996) the percentage of urban inhabitants of the LDR living in cities over 5 million has been projected to increase from 22% in 1950 to 23.5% in the year 2000, similar statistics for the MDR show a jump from 9% in 1950 to only 4% in 2000.In Lahore the increase in heavy as well as small scale industrial units have been observed due to rise of family income and high rate of growth in urbanization. This has generally causes health problems in the city life. As a result we see decline in natural resources which are needed for long-term sustainability of air quality of the city of Lahore.

The sulphur dioxide (SO2) is a composite of sulphur and oxygen and is produced when sulphur-containing fossil fuels are burned (S+ O2 _ SO2). The sulphur is mostly found in coal and oil because they are produced from the bodies of organisms that have sulphur as a component. When fossil fuels are burnt sulphur combines with oxygen to form sulphur dioxide (Enger *et al,* 2008). In addition to this, there are two major anthropogenic factors which have disturbed the natural sulphur cycle e.g., massive fossil fuel combustion which yield a massive quantity of sulphur dioxide in the atmosphere. Since it is a human induced change therefore has injected sulphur into the air which has been a matter of great concern among scientists (Asthana *et al,* 2006). The mitigation of air pollutants can only be possible by maintaining the regular monitoring network system. This leads to a reliable data collection system which is necessary to upgrade the current data base in population (age groups, sex ratio, etc.), household, internal migration, literacy, road density, traffic counts, air pollutants (Sox, NOx, Cox, etc.), solid and liquid waste, etc. Today, the more developed countries have major and dense concentrations of population which is responsible of using large quantities of fossil fuels to run the wheal of economy in the activities like manufacturing,

transportation, and domestic purposes as well. These anthropogenic activities produce and release huge quantities of pollutants in our environment (Enger *et al*, 2008).

Study Area: Lahore is the second largest city of Pakistan and is provincial capital of the Punjab. The physical structure of the Lahore metropolitan area has been characterized by different geographical conditions e.g., residential, parks, open spaces, water bodies, suburban, rural, and industrial locations as shown in Fig.1.The city of Lahore has experienced concentration of all kinds of commercial activities in and around the metropolitan area, so this leads to the contamination of air pollutants especially sulphur dioxide. In Landuse planning of the area, control urban sprawl and management in mixed Landuse are important. Lahore is the center of socio-economic and commercial activities of not only Punjab but also of the country. This city has a catchment area of hundreds of kilometers in radius, surrounded by many million cities of Punjab province as well as the country. Due to its central position, Lahore enjoys the favorable condition for the establishment of industries. The seasonal temperature (max. min), humidity, sun shine hours, wind velocity and direction have greatly impact on the trends of air pollution. Simply, if we take the example of air circulation in Lahore within the built-up areas (core of the city where buildings are high and closely spaced), the surface air flushes the air pollutants very slowly. Sometime the surface wind moves upward due to high surface temperature. This will leave calm air near the ground. In this condition the pollutants move upward with the air. Poorly air flushed areas are the places of high level of pollutants. In this way the pedestrians usually face the most polluted segments in the urban environment. In present day scenario, a continuous process of population growth , industrial activities, demand for food and energy increase the prospects of future climate change in the cities of both developing and developed countries of the world (O' Neill *et al*, 2001; Tilman *et al*, 2001).

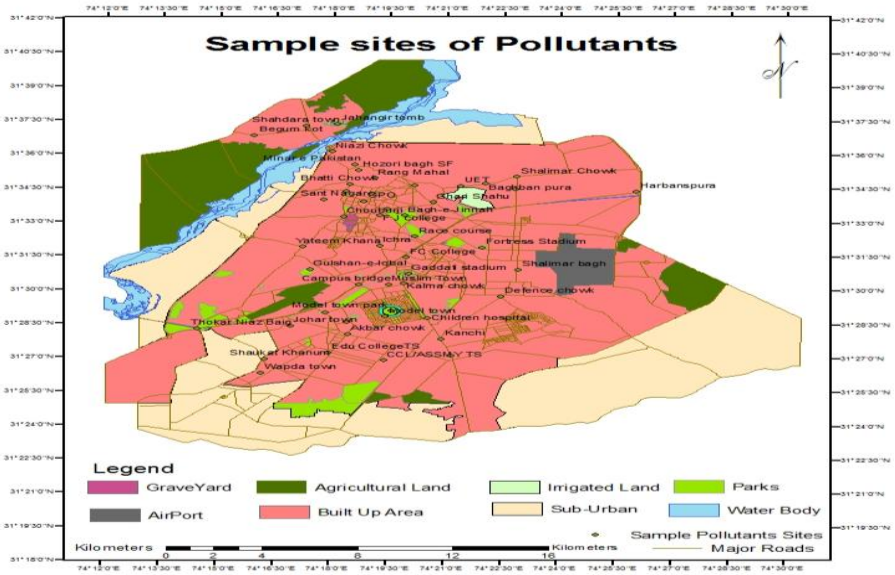

Fig.1 Sample sites and Landuse patterns of metropolitan area in Lahore

METHODS AND MATERIALS

The sulphur dioxide analyzer's monitoring method allows instantaneous and continuous analysis of gas in an unaltered state. The Horiba's innovative new fluorescence chamber has been designed to minimize scattered light. Moreover, the optical system has been designed to provide measurements with a highly stable zero point. This analyzer ranges from 0-0.05/0.1/0.2/0.5 ppm. The lowest detection limit is 0.5 ppb and its response time is <120 seconds. This sulphur dioxide analyzer is certified by U.S. EPA Reference Method EQSA-0506-159 (without converter, for ranges to 0.5 ppm). In periodic mapping of SO2sample site data, ArcGIS 9.3 is used for spatial analysis. The GIS environment is useful in networks comprised of paths traveled by variety of objects, such as traffic and transport, water, sanitation, sewage, or electricity (Price, 2006).

The Lahore urban area is characterized by hot-spots which are generally influenced by the industrial emissions. The highest Sulphur dioxide values were found near industrial locations, around brick kilns and near the main road crossings. The ambient air quality situation is strongly influenced by the meteorological conditions. The data which is obtained from different monitoring locations shows that the air pollution in Lahore urban area is not only higher than Pakistan

standards but also than the International standards. This problem can easily be identified and eradicate through creating a valid surface mapping which is used in ArcGIS software, and mapping of the Lahore metropolitan area showing spatial distribution of SO2 with respect to different environmental conditions as well as in different seasons. Spatial and temporal analyses of this air pollutant clearly show the distribution of extremely high to extremely low risk zones of the Lahore metropolitan area as shown in Fig.2 for pre monsoon, Fig.3 for monsoon and Fig.4for post monsoon. Decision making process based on the air quality factors can be collected in the form of maps and ground stations data. The spatial assessment of air pollution within Lahore metropolitan area can be used by environmental agencies and medical authorities in order to design their future strategies in planning environment.

Field Surveys of Sampling Sites: The field surveys have been conducted of the Lahore metropolitan area keeping in view of the intensity of the environmental degradation. The purpose is to get accurate information and knowledge of the existing situation which is useful to manage the existing problems as well as future planning in the related areas. A planned and organized network of surveys is needed with detailed surveys (major) with longer intervals and followed by the supplement surveys (minor) at different geographical conditions. For example, the haphazard industries at different locations like Band road and Icchra can be monitored which will give the industrial air pollution behavior of the commercial areas of Lahore. There were 15 field surveys of sulphur dioxide (SO2) conducted with reference to different geographical and environmental conditions of the Lahore metropolitan areas.The mortality and morbidity in human populations, loss of land under crops, agriculture and livestock, destruction various infrastructure like homes, schools, transport, and water supply and sanitation systems can completely destabilized a region's long-term sustainable development prospects (Abramowitz, 2001; IFRC, 2001).

The samples sites of SO2in Lahore were identified and used to collect and analysis of data. This seasonal study of sulphur dioxide regarding different environmental condition along with the meteorological parameters (max.min. temperature, relative humidity, rainfall, sunshine hours, and wind velocity &direction) was collected by ground truthing of the contamination of the pollutant. The geographical locations were selected in according to the geometry of information, type of source, intensity of sources, topography, nature of land, density, meteorological conditions, etc. in the urban area with GPS surveys.

Seasonal Contamination of Sulphur Dioxide (SO2): In this study a total of forty nine sites were selected out of which, 11are residential areas, 12 are main road crossings, 8 are educational institutions, 4 are hospitals sites, 5belong to parks and 3 are suburban areas. These sample sites are representing different landuses of the city. The surveys were conducted periodically and performed during pre-monsoon, monsoon, and post-monsoon seasons. The purpose was to portray the best picture of the environmental quality of an urban area like Lahore. During pre-monsoon season as shown in Fig.2, and reported in Table.1, there are highest contaminations of the mean values of the SO2 in the urban air of Lahore because of maximum sun shine hours during the months (15^{th} April to 30^{th} June). During monsoon season (01^{st} July to 31 August) as shown in Fig.3, the map shows the lowest mean of the observed values of the air pollutants, and during post-monsoon (01^{st} September to 31^{st}October) as shown in Fig.4, the values are observed moderate to lowest because it solidifies due to low surface temperature. The variations in SO2 are changed regarding landuse patterns of Lahore.

Pre-monsoon SO2 Variations around Sample Sites: In pre-monsoon (15^{th}April to 30^{th} June) the highest to moderate concentrations of the mean of SO2 values are found during the year in the metropolitan areas of Lahore. The highest concentration is observed near main road crossings, *e.g.,* 78.13ppb in Multan Chunghi and 76.96 ppb at Akbar Chowk. We can observe extremely high cluster of SO2 around these sample sites (industrial locations and main road crossings) as shown in Fig.2 and reported in Table1. The lowest concentration in the same season was found in Suburban areas, e.g., 26.96 ppb near Begham Kot and 27.53 ppb near Harbanspura (suburban Lahore) were monitored and can be placed in extremely low to low contamination zones.

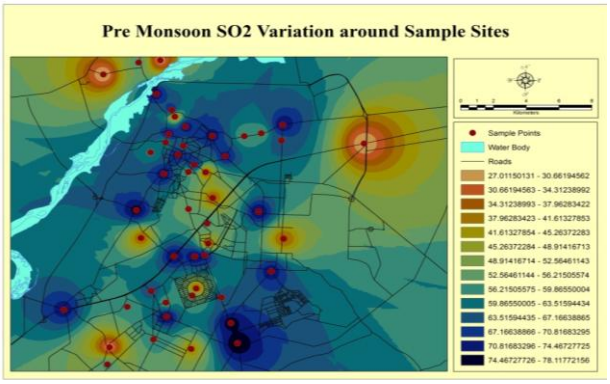

Fig. 2Pre- monsoon SO2 variations in and around the metropolitan areas of Lahore

Monsoon SO2 Variations: During monsoon season (1^{st} July to 31 August) the map shows moderate to lowest contamination of the mean values of the SO2 in the urban air of Lahore during that part of the year. During monsoon the highest concentration of SO2 is found at main road crossings, e.g., 48.96 ppb near Yateem Khana

and 48.30ppb in and around Niazi Chowk. We can observe the extremely high cluster of SO2 around these sample sites (industrial locations and main road crossings) as shown in Fig. 3 and reported in Table 1. The lowest concentrations of SO2 in the same season was found in suburban areas of Lahore, e.g., 22.50ppb in Begham Kot and 22.84 ppb near Jahangir's Tomb were monitored and can be placed in extremely low to low contamination zones.

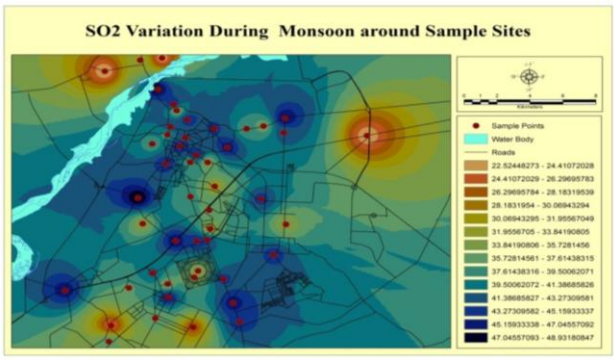

Fig.3 MonsoonSO2 variations in and around the metropolitan areas of Lahore

Post-monsoon SO2Variations: In the post-monsoon (01st September to 31st October) the map shows lowest concentration of SO2 during the year in the metropolitan areas of Lahore. The highest concentration in the season is monitored 58.34ppb which is found near Yateem Khana and 57.51 ppb near Shalimar Chowk. We can observe the extremely high cluster of SO2 around these sample sites (main road crossings) as shown in Fig.4 and reported in Table 1. The lowest concentrations were found near Jahangir Tomb, e.g., 26.85 ppb and 27.98 ppb near Begham Kot which are the suburban areas of the city were monitored and can be placed in extremely low to low contamination zones.

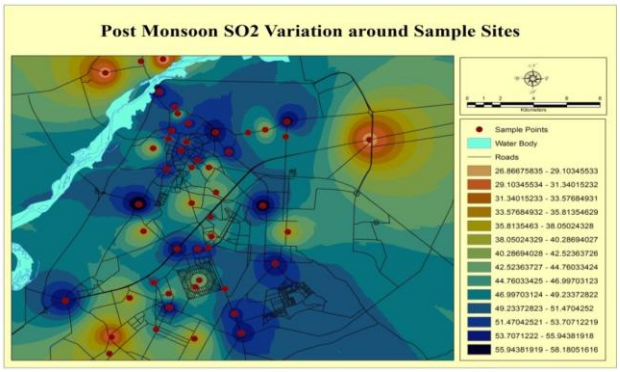

Fig. 4 Post- monsoon SO2 variation in and around the metropolitan areas of Lahore

RESULTS AND DISCUSSION

The metropolitan area of Lahore is engaged in several kinds of activities related to production and services. The economic growth of the city occupies the central position and attracts all major and minor levels stakeholders. Thus, degradation of air is directly and indirectly linked to the population living in an area and the kind of activities which they are performing (Enger *et al*, 2008).

Extremely High Risk Zone: The extremely high risk areas of SO2 in the metropolitan Lahore are main road crossings, residential areas and educational institutions. These include: NiaziChowk, Yateem Khana, Ghari Shahu, Rang Mahal, Campus Bridge, GC University, Children Hospital, Railway Station, Bhatti Chowk and Jinnah Hospital. Most of these sample sitesare comprised of mixed landuse, e.g., commercial, residential, workshops, etc. as shown in Fig.5 and reported in Table 1. The highest contamination of SO2 is found in Township which is an industrial area (CCL/ASMY) but controlled by open green spaces.

High Risk Zone: The high risk zones of SO2 contamination in the metropolitan areas of Lahore are Muslim Town, Multan Chunghi, Minar-e-Pakistan, Kanchi, Ichra, UET, Sant Nagar, Chouburji, Chearing Cross and Defance Chowk. The mean values of pollutants are found second highest in these locations as reported in Table1.

Medium Risk Zone: This zone contains traffic flow, market centers, small scale industries, like Thokar and Kalma Chowk which are also main exit and entrances of the city as shown in Fig.5.

Low Risk Zone: It covers areas which are closer to open spaces like parks, and Fortress Stadium, etc.

Extremely Low Risk Zone: The extremely low risk zones are mostly closed to or around the suburban places, gardens and water bodies like Shauket Khanum, Beghum Kot, Jahangir Tomb, Harbanspura, Bagh-e-Jinnah, Model Town Park and Race Course Park as shown in Fig.5 and reported in Table 1. The contaminations of SO2 are found lowest (Mean values).

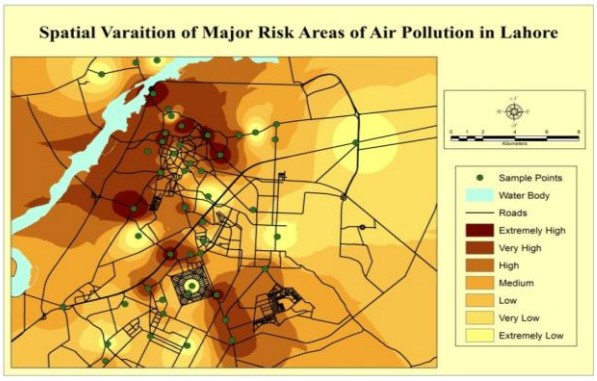

Fig.5. Total Risk Map of major risk zones of air pollution in Lahore Metropolitan area

Table.1. Mean values of the Sulphur dioxide in and around the metropolitan areas of Lahore

(MEAN Values of SO2)			
	Pre-Monsoon	**Monsoon**	**Post-Monsoon**
Sampling Sites	**Mean**	**Mean**	**Mean**
Main Road Crossing			
Chouburji Chowk	74.00	45.56	54.64
GPO Chowk	74.23	46.24	55.05
Chearing cross	73.91	46.12	56.66
Niazi Chowk	74.04	48.30	56.17
Ghari Shahu	73.16	46.72	55.18
Bhatti Chowk	75.44	44.03	55.69
Shalimar Chowk	74.96	47.74	57.51
Railway station	73.51	43.87	56.91
Multan chunghi	78.13	44.49	55.25
Rang Mahal	75.12	45.03	55.11
Defense Chowk	73.31	44.32	56.08
Kalma Chowk	74.09	44.34	54.95
Akbar Chowk	76.96	46.80	57.20
Thokar	72.68	46.23	56.22
Yateem Khana	76.19	48.96	58.34
Muslim Town	76.54	45.82	55.31
Campus bridge	75.88	47.52	57.11
Kanchi	76.64	46.72	54.61
Fortress stadium	74.97	44.15	57.46
Yadgar	73.61	46.08	56.42
Education Institutions			
FC College	57.05	37.34	47.49
GC U/Nasir bagh	57.59	37.77	50.16
UET	55.56	37.37	48.71
GC Edu college TS	57.48	36.05	45.70
FJ college	54.28	36.73	45.34
Hospitals			
Shalimar hospital	66.57	42.24	47.61
Children hospital	65.84	44.03	51.26
Jinnah hospital	66.98	42.01	50.18
Mayo hospital	63.98	41.66	50.30
Industrial			
CCL/ASSMY township	42.39	26.54	37.21
Residential			
Shahdara town	55.12	32.96	41.41
Faisal town	56.52	35.02	42.36
Model town	57.18	35.23	41.75
Ichra	54.05	37.71	38.68
Johar town	56.95	37.42	38.59
Wapda town	57.56	37.67	39.49
Sant nagar	58.87	37.25	38.67
Bagh ban pura	55.75	35.80	40.43
Parks			
Ghazhafi stadium	36.13	31.60	39.62
Bab-e-Jinnah	35.49	33.99	38.57
Shahi fort/Hozori bagh	37.17	33.47	41.08
Shalimar bagh	36.67	33.76	38.52
Gulshan-e-Iqbal	37.38	33.97	38.82
Model Town park	35.19	33.22	42.77

Race Course	35.73	32.13	42.29
		Suburban	
Begum kot	26.96	22.50	27.98
Harbanspura	27.53	23.13	28.27
Shauket Khanum	28.01	23.95	28.20

The impact of air pollutants especially SO2 varies according to location as it is highlighted in Fig.5 and they largely affect the life of the related environment in urban areas. It also depends on the type of pollution as well as air pollutants with its seasonal concentration. The impact has its own nature, its complexity and intensity of the problem that can be dangerous to human health, plant life, crops and the most important one is the related environment or ecosystem. Oxides of Sulphur, primarily Sulphur dioxide is the second most important pollutant of the atmosphere in magnitude and severity (next only to oxides of carbon) of effects on a biological system Most of the atmospheric Sulphur dioxide comes from burning of organic matter, fossil fuels and from industrial units processing sulphur bearing ores. It is evident from many studies that Sulphur dioxide is capable of causing numerous harmful effects on both plants and animals of a region (Asthana *et al,* 2006).

The focus is the accurate assessment of the problem where we can manage the problem caused by the pollution. The after effect may be in the form of climate change, degradation of ecosystem and rise in temperature which may be measured economically. Air pollution may have direct or indirect impact on the life of the city dwellers. The direct effect can be in the form of SO2 impact on human life in the urban areas or damage the vegetation in the urban region. Indirect impact may be due to acid rain which can damage the ecosystem of the region. Therefore, the impact of SO2has not only direct but also an indirect impact on the life of the human being. It is believed that Sulphur dioxide and ions of sulphate are perhaps second only to smoking which generally causes air pollution related health damages in many parts of the world (Cunningham *et al,* 2008).

In conclusion, Sulphur dioxide is noticed maximum during pre-monsoon, moderate in post monsoon, low in monsoon and moderate to lowest during winter season because it solidifies due to low surface air temperature. The variations in air pollutants depend on change in landuse/cover patterns of Lahore. There are many ways to control our resources by energy efficiency and energy conservation. This is the only way by which we can reduce air pollution. Similarly solar thermal energy system isfundamentally more efficient and effective than other solar technologies in the market because they only concentrate upon the insolation. With improved engineering, manufacturing, and construction methods, solar energy may become cost-effective and competitive with other traditional fuels (Raven et al, 2010).The CNG powered vehicles (all types of modes); hybrid cars, rapid transit system in traffic flow, etc. produce much lower emissions than their predecessors. More important are the high tech industries which are introduced to reduce emission and to control all the forms of air pollution and consequently save the environment. In this way, we can limit the emission before it generates. However, this high technology establishment is expensive, but it has long term impacts on the environment. The alternatives are cheaper and can change the industrial process to reduce emissions but there are short term planning to reduce pollution and save the environment.

There are many methods for the removal of sulphur oxides from gases emitted from chimneys and are less expensive than to switch to a low sulphur fuel such as natural gas or even a non-fossil fuel energy source such as wind mill, solar energy, etc. Since this sort of change could damage to living system and is likely to trigger a rise in disease and death among the populations which adopt them (Martens and Martens, 1998). Sulphur contents can be removed from the fuels before they are burned, as in coal gasification. Low sulphur contents in coal, high brick kilns and smokestacks fitted with electrostatic precipitators, fabric filters, scrubbers or other technologies reduce the emission and remove particulate matter. The particulate matter is reduced or in other words controlled by careful techniques in land excavating activities, like sprinkling water on dry soil and during road construction when soil is being moved. Similarly, it is the need of the hour that we shall look towards other resources which are beyond the finite resource of fossil fuels and use the nuclear power generation for a sustainable development based on emission-free and renewable energy sources(Dincer, 2000; Elliott, 2000).The followings are the major contributions of the study,

- The mean values ofSO2in and around the metropolitan areas of Lahore with respect to different Landuse range from place to place and from season to season.
- Temporal and spatial modeling techniques of air pollutants especially SO2give the Total Risk evaluation of the city. The correlation model is helpful for the effective control of air pollution especially SO2 and management of industrial emission as well as the industrial zoning.
- The study has evaluated the foundation for future industrial planning and urban developmental projects.

- The Total Risk Mapping (TRM) has developed a spatial relationship among air quality evaluation and established a relationship with the adjoining landuse.
- Industrial Concentration Mapping has highlighted the recommendations to urban planners to guide them as to where the future production and services related activities should establish. Moreover, it recommends them to manage the existing environment for the benefit of the residents of Lahore.
- The study has calculated the periodic and seasonal air sampling of the metropolitan areas of Lahore.
- It has been finally highlighted that the industrial growth pattern must be in accordance with the Landuse pattern of Lahore. The level and intensity of air pollution especially SO2 monitored regularly on periodic bases (short and long terms), so a network of field surveys for the monitoring of air pollutants, industrial flow pattern with respect to seasonal variations be organized. This will give the planners a true picture of the intensity of growth of industries in different locations and the emission of SO2 at different seasons of the year.

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