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Monitoring and Visualization of Tropospheric Ozone in Rural/Semi Rural Sites of Rawalpindi and Islamabad, Pakistan

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Abstract

Ozone is one of the most pervasive of the global air pollutants, with impacts on human health, food production and the environment. Present research highlights emphasized the main rural agricultural areas of Rawalpindi and Islamabad for their air quality assessment and visualization in order to evaluate and predict the risk areas to facilitate farmers and policy makers to draft critical guidelines for possible threat of ozone concentrations to the agricultural sector of country in the coming years. Model 400E ozone analyzer was used to determine the ozone concentration. Mean concentration value of O_3 recorded during the campaign is 35 ppb in Rawalpindi and Islamabad. Seasonal fluctuations in O_3 concentration levels were also observed throughout the year in different months. This can be attributed to changing climatic variables i.e. temperature, rainfall and humidity throughout the different season. Climatological parameters also showed significant association with ozone concentration. Comparison of obtained values of ozone with the WHO standards indicates that O_3 levels are still lower than standards. This indicates that we still have a time to reconsider our anthropogenic activities to control the O_3 precursors to prevent any deleterious effects on agricultural sector.

Keywords: ozone concentration, Model 400E ozone analyzer, climatic variables, semi-rural/rural areas, Rawalpindi and Islamabad, Pakistan

1. Introduction

Clean air is considered to be a basic requirement for healthy life. But, continuously increasing air pollution around the world is posing great threat to both human health and environment. O_3 is the main component of photochemical smog and third most important green house gas (Percy & Ferretti, 2004; Vingarzan, 2004). O_3 is a secondary air pollutant, produced by photochemical reaction, involving nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOC) (including CH_4). These precursors largely contributed by anthropogenic activities i.e. combustion in industries, vehicles and for domestic purposes. The O_3 precursor's breadth, the role of natural and physical process in distribution of O_3, production and destruction and complex chemical reaction makes the management of O_3 quite difficult.

O_3 is increasing at a greater pace due to the increase in anthropogenic precursor emissions (Sitch, Cox, Collins, & Huntingfor, 2007). It has been estimated that the increase in O_3 concentrations is between 0.5 and 2% per year (Vingarzan, 2004), and that by 2100 the mean monthly 24-h concentration will be above 40 ppb over most of the Earth, and above 70 ppb over some regions (Sitch, Cox, Collins, & Huntingfor, 2007). Currently, O_3 is the most important pollutant in rural areas (Ashmore, 2005) due to long-range transport from polluted sites (Vingarzan, 2004). O_3 is the most important pollutant with respect to the native vegetation and crops. It causes a visible injury and reduction in growth, series of harmful physiological and biochemical effects and altered sensitivity to biotic and abiotic stresses (Fuhrer, 2009; Calatayud et al., 2010; Pinto et al., 2010). Photochemical oxidant pollution has greatly reduced the economic yield of major agricultural crops (especially wheat and rice) which is well documented by Aunan, Berntsen and Seip (2000), Wahid et al. (2001) and Wahid (2006a, 2006b).

In contrast to developed countries like USA and European countries, little work is done on impact of air pollutants on agricultural crops in developing countries. In Pakistan number of studies has been conducted to study the impact of air pollutants on wheat, rice and soybean (major crops in Pakistan) (Wahid et al., 2001; Wahid, 2006a, 2006b). The results indicated 30-70% reduction in yield as compared to the control plants. But still not much information is available on urban, suburban and rural arable productive areas, phytotoxic pollutant concentration in Pakistan. And also there is no proper pollution control system due to technical, economical limitations and other reasons. As a result toxic pollutant concentration is continuously rising in Pakistan may lead to deleterious effects on agriculture sector in future, so it's extremely important take serious notice and actions of this alarming situation.

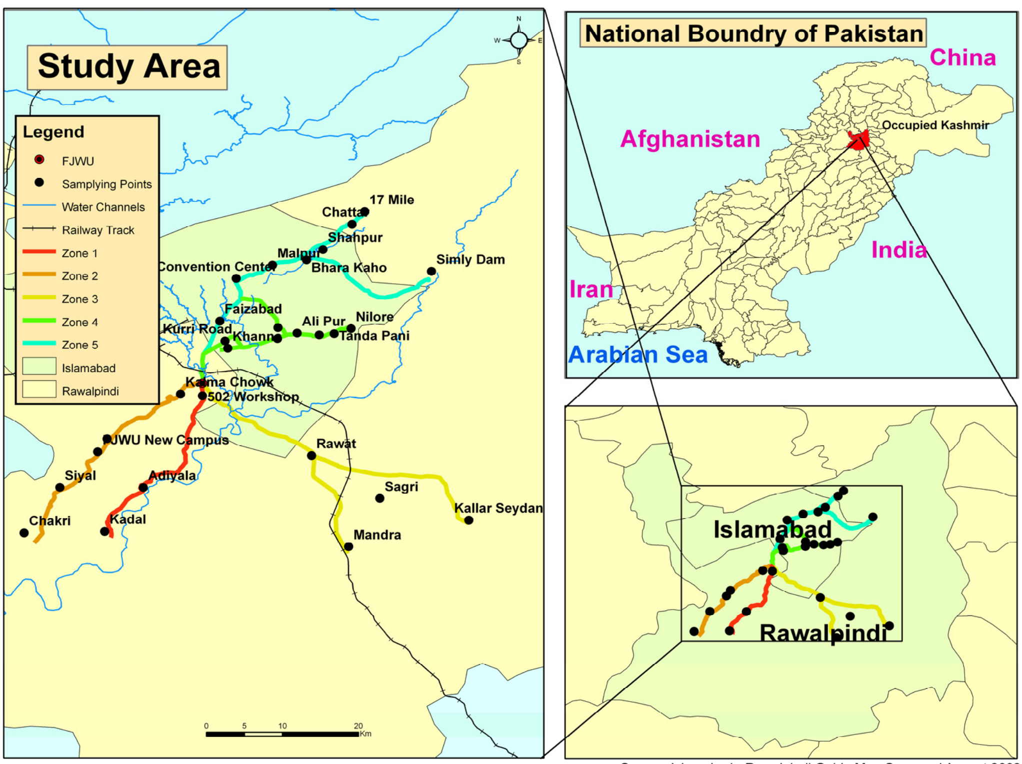
Air pollution mapping is a valuable tool for the monitoring and management of the air quality. It manages both the statistical and spatial data and enables to show the relationship between poor air quality and frequency of deficient human and environmental health (ESRI, 2007). That will help in taking steps to control emissions. Number of studies has been carried on air pollution in conjunction with GIS (Veen et al., 2010; Elbir el al., 2010; Ahmad, Bűker, Emberson, & Shabbir, 2011).

In this project ozone concentration is monitored and visualized through GIS in twin cities of Pakistan in order to evaluate and predict the risk areas to facilitate local farmers and policy makers to draft critical guidelines for possible threat of ozone concentrations to the cash crops, sustainability and food security of country in the coming years.

2. Materials and Methods

2.1 Study Area

Islamabad and Rawalpindi are commonly viewed as one unit. The two cities, which are 15 km apart, are effectively a single mega town. Islamabad is the capital of Pakistan. Both are located in the Pothwar Plateau in the northwest of country. Twin cities are located at 33°40′N 73˚10′E. total population is over 4.5 million inhabitants. Rapid growth of both Islamabad and Rawalpindi has made ever increasing demands on natural resources and caused adverse effects on the environment (Sheikh et al., 2007). A map of study area is shown in Figure 1. Agriculture after industries in Islamabad and Rawalpindi is one of the main ingredients of whole area's economy. The total rural area of Islamabad and Rawalpindi comprises of 446.20 km^2 and 259 km^2 respectively. Besides common vegetables, Rabi and Kharif crops including Rice, Wheat, Maize and Bajra are the major crops grown here. Peaches, groundnuts, apricots, plums, citrus apples, olives, pears and walnuts are the common fruits grown.



Source: Islamabad - Rawalpindi Guide Map Surveyed August 2002

Figure 1. Base Map

Based upon geographical locations of Rawalpindi / Islamabad the study area is divided into five main zones with zero point (FJWU) as a reference point. We have selected zero point as a reference position because it is an essential passing way for many routes in/out of the twin cities and have high traffic flux in the regions of under consideration. Similarly these areas are located in the form of concentric rings assuming zero point as central hub. It will also help to find spatial correlation in different agricultural fields under study. Boundaries of each zone are defined within the 40 km of reference point. 40 km distance is chosen based on previous studies in this domain. The clear demarcation of rural/semi-rural and surrounding areas are as under (within 40 km from zero point).

Zone 1: 502 workshop, Adyala village, Kadal

Zone 2: Kalma Chowk, Pir Mehr Ali Shah Town, FJWU New Campus, Siyal and Chakri

Zone 3: Rawat, Kallar, Sagri and Mandra

Zone 4: Kuri, Khanna, Tarlahi, Alipur, Jhangi Syedan, Thanda Pani, Nelore and Chakshahzad

Zone 5: Convention Center, Malpur, Bara khau, Shahpur Village, Chattar, 17 Mile and Samli Dam

2.2 Ozone Determination

The Model 400E ozone analyzer (microprocessor-controlled analyzer that determines the concentration of ozone (O_3) in a sample gas drawn through the instrument) was used to measure the ozone concentrations. It requires that sample and calibration gases be supplied at ambient atmospheric pressure in order to establish a stable gas flow through the absorption tube where the gas' ability to absorb ultraviolet (UV) radiation of a certain wavelength (in this case 254 nm) is measured. Calibration of the instrument is performed in software and does not require physical adjustments to the instrument. During calibration, the microprocessor measures the current state of the UV Sensor output and various other physical parameters of the instrument and stores them in memory. This concentration value and the original information from which it was calculated are stored in one of the unit's Internal Data Acquisition System as well as reported to the user via a Front Panel \ Display or a variety of digital and analog signal outputs. The basic principle by which the Model 400E Ozone Analyzer works is called Beer's Law (also referred to as the Beer-Lambert equation). It defines the how light of a specific wavelength is absorbed by a particular gas molecule over a certain distance at a given temperature and pressure.

2.3 Spatial Modeling and Surface Interpolation through IDW

GIS is a very powerful tool for air quality management. Though there are large numbers of spatial modeling techniques regarding the applications of GIS but surface interpolation through IDW (Inverse Distance Weight age) was used in this present study to demarcate the locational distribution of O_3. This method used defined and selected set of sample points for estimating the output grid cell values. It determined the cell value using a linearly weighted combination of set of sample points and controls the importance of the known points upon the interpolated values based on their distance from the output points there by generating a surface grid. Hence surface grids or layers of O_3 were generated using spatial analyst tool bar considering sampling points as a source.

2.4 Metrological Data

Metrological parameters like temperature, relative humidity and precipitation has also been collected from Pakistan Metrological Department to study the effects of these parameters on air pollutant concentration.

3. Results and Discussion

3.1 Data Analysis

The data used for this research project were gathered from 28 different sites, divided into 5 zones in Rawalpindi and Islamabad as mentioned in the previous section. Tables 1 and 2 showed the monthly concentration levels of O_3 measured at these different locations.

Table 1. Monthly mean values of O_3 of all sites in 5 zones of semi-rural areas of Rawalpindi and Islamabad during January to September 2010

Months	**Jan-10**	**Feb-10**	**Mar-10**	**Apr-10**	**May-10**	**Jun-10**	**Jul-10**	**Aug-10**	**Sep-10**
Sampling Sites	**Tropospheric Ozone Concentration (ppb)**								
Zone 1									
502 Workshop	26.08	27.96	40.67	41.72	42.32	41.23	29.45	27.45	33.07
Adyala Village	23.84	25.79	39.44	41.59	42.34	41.46	27.56	26.89	32.48
Kadal	28.53	29.03	41.51	42.38	43.66	42.64	29.65	28.01	34.12
Zone 2									
Kalma Chowk	27.87	29.01	41.02	43.11	42.85	41.14	29.01	27.55	34.69
Pir Mehr Ali Shah Town	26	28.22	42.64	43.81	43.74	42.57	28.89	26.92	35.31
FJWU New Campus	28.01	29.46	42.89	43.76	43.18	42.65	29.65	27.12	36.96
Siyal	27.34	28.06	41.24	42.66	41.97	41.03	27.01	26.24	34.54
Chakri	27.94	29.54	42.65	43.69	42.43	41.17	27.83	26	34.06
Zone 3									
Rawat	26.76	28.78	41.95	42.78	43.07	41.69	28.46	26.05	33.46
Kallar	26.98	28	42.76	43.56	43.36	42.38	27.76	26.32	34.23
Sagri	25.35	28.34	41.98	43.09	42.99	41.87	28.24	26.87	33.36
Mandra	27.78	28.06	42.89	43.98	43.65	41.62	27.04	25.76	34.04
Zone 4									
Kuri	26.34	27.85	42.16	42.82	42.51	41.67	27.02	26.08	33.76
Khanna	26.89	27.93	42.98	43.89	43.67	42.67	27.67	25.87	33.53
Tarlahi	27.87	29	42.76	43.01	43.24	42.65	28.67	26.54	35.03
Ali Pur	28.01	29.98	43.54	44.34	44.24	43.29	29.34	27.24	34.45
Jhangi Syedan	26.54	28.54	42.64	43.65	43.54	42.63	27.64	25.93	33.87
Thanda Pani	27	29.34	41.99	42.85	42.75	41.56	29.98	27.15	34.09
Nelore	28.18	29.35	41.35	42.12	42.36	41.15	29.05	27.63	34.09
Chakshahzad	28.03	29.35	42.55	43.32	43.45	42.65	29.07	27.65	35.8
Zone 5									
Faizabad	27.32	28.65	43.67	44.67	44.56	43.26	28.02	26.04	35.54
Convention Centre	27.34	28.51	40.82	42.63	42.15	41.14	28.01	27.55	35.39
Malpur	25.04	27.59	40.94	41.79	42.04	41.86	26.86	25.49	32.87
Bara khau	27.93	29.13	41.71	42.68	43.6	42.94	28.55	28.1	34
Shahpur Village	25.34	26.85	40.86	41.62	42.41	41.38	28.02	26.18	33.85
Chattar	26.85	27.62	41.4	42.81	42.44	41.57	27.49	26.32	34.71
17 Mile	27.11	28.64	42.09	43.16	43.1	42.07	29.05	28.82	36.06
Samli Dam	27.1	28.36	41.34	42.08	41.87	40.63	28.11	27.14	33.74

Table 2. Monthly mean values of O_3 of all sites in 5 zones of semi-rural areas of Rawalpindi and Islamabad during October 2010 to May 2011 and average O_3 conc. of all sites with standard deviation/error from January 10 to May 2011

Months	**10-Oct**	**10-Nov**	**10-Dec**	**11-Jan**	**11-Feb**	**11-Mar**	**11-Apr**	**11-May**	**Average**	**SD**
Sampling Sites	**Tropospheric Ozone Concentration (ppb)**									
Zone 1										
502 Workshop	33.05	27.65	25.01	28	29.86	41.03	42.56	42.32	34.08	7
Adyala Village	32.33	26.88	25.59	28.54	30.12	42.41	43.75	43.45	33.79	8
Kadal	33.98	28.09	26.23	28.56	29.98	43.54	44.35	44.03	35.19	7
Zone 2										
Kalma Chowk	35	28.45	26.03	27	28.26	42.31	43.11	43	34.67	7
Pir Mehr Ali Shah Town	34.94	29.14	27.87	27.85	29.86	41.96	42.99	43.06	35.05	7
FJWU New Campus	36.56	27.87	26.32	28.11	29.65	43.95	44.45	43.54	35.54	7
Siyal	35.22	26.76	25.89	27.46	28.99	42.85	43.65	43.15	34.36	7
Chakri	33.67	27.15	26.76	28	29.75	41.56	43	42.96	34.60	7
Zone 3										
Rawat	34.11	27.62	25.98	27.45	29	43.34	44.39	44.18	34.65	8
Kallar	35.06	27.68	26.76	27.23	29.24	42.62	43.56	43.49	34.76	8
Sagri	34	26.35	25.18	27.15	29.04	43.04	44.33	44.29	34.44	8
Mandra	34.23	27.51	25.03	27.69	28.19	41.56	42.56	42.87	34.38	8
Zone 4										
Kuri	34.02	27.56	26.07	27.35	28.41	41.87	42.08	42.26	34.11	7
Khanna	34.44	27	26.07	27	28.11	42.6	43.65	43.03	34.53	8
Tarlahi	35.34	26.5	25.98	26.67	28.64	43.16	43.71	43.74	34.85	8
Ali Pur	34.24	27.55	26.46	28.51	29.48	42.94	44.04	44.56	35.42	8
Jhangi Syedan	33.76	26.39	24.98	27.04	28.32	42.64	42.95	43.66	34.40	8
Thanda Pani	34.61	26.06	26.07	28.65	29.85	42.99	43.15	43.75	34.81	7
Nelore	33.65	26.65	25.18	28.16	29.55	43.03	43.56	42.72	34.58	7
Chakshahzad	35.08	27.87	25.78	28.93	29.37	42.13	43.28	43.85	35.19	7
Zone 5										
Faizabad	36.11	28.65	27.7	26.56	28.99	43.31	44.98	44.45	35.44	8
Convention Centre	36.12	28.05	27.13	27.45	29.26	43.21	44.1	43.23	34.83	7
Malpur	33.43	26.68	25.66	26.54	28.12	42.61	43.5	43.38	33.79	8
Bara khau	34.46	28.2	27.45	27.34	29.38	42.64	43.35	43.03	34.97	7
Shahpur Village	33.76	26.56	24.98	27.46	29.01	41.56	42.98	42.35	33.83	7
Chattar	35.09	28.54	26.4	26.05	28.55	42.76	43.69	42.76	34.41	7
17 Mile	36.96	27.87	26.32	27.16	29.5	43.85	44.65	43.34	35.28	7
Samli Dam	34.62	28.16	28.09	26.56	28.09	42.65	43.45	42.56	34.39	7

As mentioned earlier, the sites have been divided in to five zones. The comparison among different sites in each zone was separately taken into account. Table 1 shows that zone 1 contained three sites i.e. 502 Workshop, Adyala Village and Kadal. It was found that the highest mean O_3 concentration area in zone 1 was Kadal, which is a rural area and lowest mean O_3 concentration area in zone 1 was 502 Workshop, which is an urban area.

Table 1 shows a plot of mean concentration of O_3 in zone 2. Five sites which were selected in zone 2 including Kalma Chowk, Pir Mehr Ali Shah Town, FJWU New Campus, Siyal and Chakri. From table it can be seen that FJWU New Campus showed the highest mean O_3 concentration in zone 2.

Table 1 shows a plot of mean concentration of O_3 in zone 3 with a total of four different sites. These sites were Rawat, Kallar, Sagri and Mandra. Mean concentration of O_3 was same at all the four sites.

Table 1 shows a comparison of eight different sites in zone 4 for mean O_3 concentration. These sites include Kuri, Khanna, Tarlahi, Ali Pur, Jhangi Syedan, Thanda Pani, Nelore Ali pur and Chakshahzad had highest O_3 concentration and Chakshahzad, while other sites show similar concentration level.

Zone 5 also contains eight sites and comparison of these sites is shown in table (1). The sites were Faizabad, Convention Centre, Malpur, Bara Khau, Shahpur Village, Chattar, 17 Mile and Samli dam. It can be clearly seen from the table that Malpur and Shahpur village had lowest concentration of ozone, while 17 Mile and Faizabad had highest concentration of ozone.

3.2 Monthly Trends in O_3 Concentration Levels

The variation of ozone concentration can be considerably, on a daily, a seasonal or yearly basis. Most of these temporal variations can be explained by the weather conditions. Howe ever, variation on regional or local scale is also attributed to the influence of local pollution and to local deposition climate. Whisker box plot is used to display the seasonal trends of ozone throughout the experimental period. The box-and-whisker plot is an exploratory graphic, used to show the distribution of a dataset. A box-and-whisker plot displays the mean, quartiles, and minimum and maximum observations for a group. Figure 2 shows a plot of mean O_3 concentration of all the five zones to understand the general trends of O_3 concentration levels in different months.

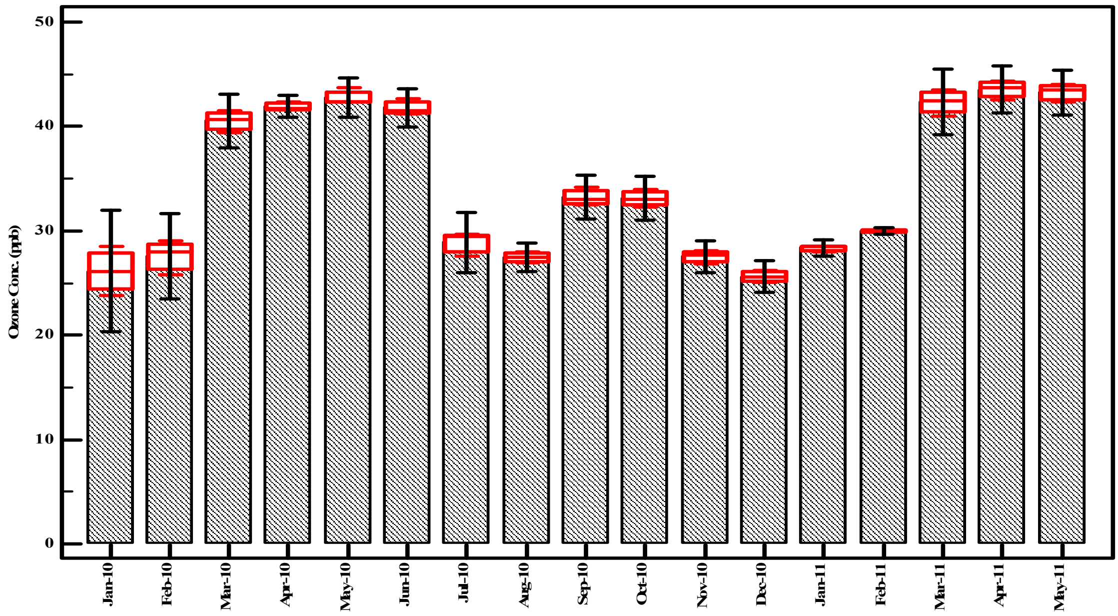


Figure 2. Monthly variations in O_3 concentrations level (January 2010 – May 2011)

It can be seen that O_3 concentration levels fluctuate throughout the year in different months. The low concentration values of O_3 were recorded in December and January (winters) and July and August (monsoon), while the high concentration values were recorded in May and June (summers) (Figure 2). As traffic emission is the predominate source of O_3 precursors, leading to more or less constant O_3 concentration levels throughout the year. Though, slightly higher levels of O_3 concentration can be attributed to the higher solar radiation intensity in summer season which enhanced the photolytic reactions tends to break down the NO_x into O_3 leading to higher O_3 levels. While in winter due to reduced solar radiations, NO_x tends to accumulate and O_3 concentration levels were lowered in the atmosphere.

Number of studies conducted on the fluctuation of O_3 concentration levels throughout the year indicates the similar results. In Spain O_3 concentration levels were measured from January to December 2007. Results show the highest concentration values of O_3 in summer and minimum values in winters (Martin et al., 2010). In a study carried out in urban Spain, the mean concentration value of O_3 was calculated from January to December 2007. During 2003-2004, SUPARCO, the Pakistan Space and Upper Atmosphere Research Commission conducted a yearlong baseline air quality study in country's major urban areas i.e. Karachi, Lahore, Quetta, Peshawar, Rawalpindi and Islamabad. Results indicated ozone highest levels in summer and spring while lower were observed in winter and monsoon. The average concentration value of O_3 in urban areas of Rawalpindi and Islamabad was calculated to be 17.46 ppb and 17.7 ppb respectively (Ghauri, Lodhi, & Mansha, 2007).

3.3 Relationship with Meteorological Variables

Attempts were made to relate monthly mean O_3 concentrations with the climatological variables such as temperature (measured in degree Celsius), relative humidity (RH in %) and rain fall (measured in mm) (supplied by Islamabad meteorological Department).

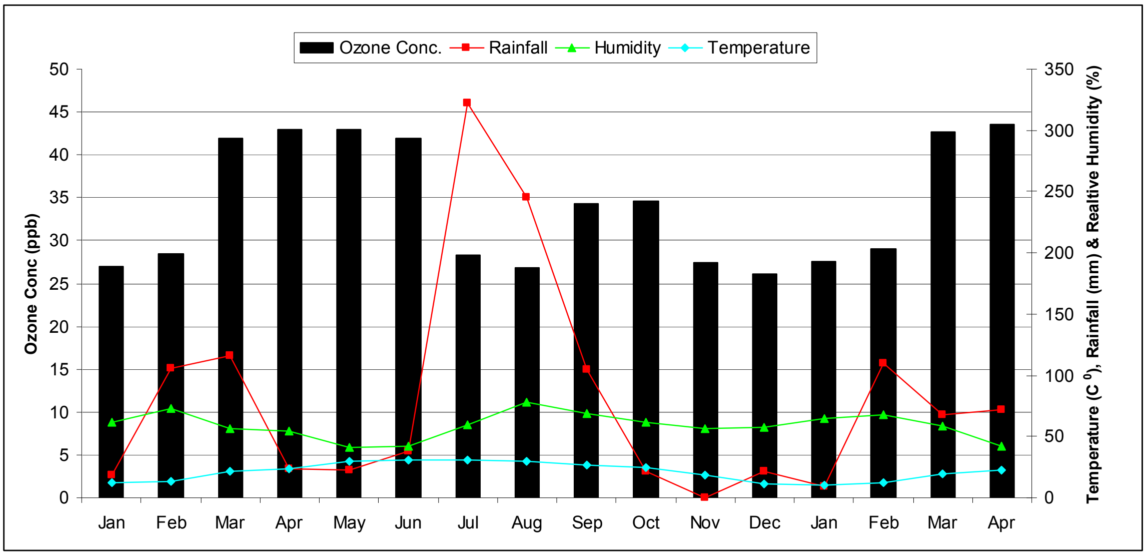


Figure 3. Relationship between O_3 concentration and climatic variables

Figure 3 depicted that the ozone concentration level is negatively related to the relative humidity (RH in %) and positively related to temperature (in ^oC). Periods with higher temperature and lower humidity usually lead to the higher level of ozone in the atmosphere and vice versa. This can again be attributed to the fact as indicated above that during summer as a result of increase solar radiation, NO_x tend to photolysed and increase the O3 concentration levels in the atmosphere. Figure 3 also showed negative correlation of ozone concentration with rainfall (in mm). Hence, in monsoon season i.e. from July to September the ozone concentration in the atmosphere decreased with increase in rate of rain fall due to dispersion and transportation of pollutants in the atmosphere leads to dilution of pollutants in the atmosphere. Similar relationship of ozone concentration levels with meteorological variables have previously been reported by Atkins and Lee (1995), Wahid et al. (1995a, 1995b) Chan, So, and Samad (2001), Ghauri, Lodhi, and Mansha (2007), Markovic et al. (2008), Shan et al. (2009) and Martin et al. (2010). Multiple regression analysis (Table 3) showed that ozone concentration is greatly influenced by the independent climatic variables i.e. temperature (^oC), rainfall (mm) and relative humidity (%). The correlation results indicated that ozone is positively related with temperature ($r = 0.4709$) and negatively associated with rainfall ($r = -0.2333$) and relative humidity ($r = -0.6999$).

Table 3. Multiple Regression Analysis Regression Equation

Independent variables	Coefficient	Std. Error	t	P
(Constant)	45.8198			
Humidity	-0.3220	0.1682	-1.914	0.0797
Rainfall	-0.01824	0.02159	-0.845	0.4147
Temperature	0.4152	0.2486	1.670	0.1207

Zero order correlation coefficients

Variable	R
Humidity	-0.6999
Rainfall	-0.2333
Temperature	0.4709

3.4 Spatial Interpolation Map

To get a better view of pollutant concentrations, the obtained values were spatially interpolated using the inverse distance weighted (IDW) method. Inverse distance weighting is the simplest interpolation method. Spatial interpolation maps for O_3 have been developed by using ArcGIS 9.2 to visualize the higher pollutant concentration areas in Rawalpindi and Islamabad (Figure 4).

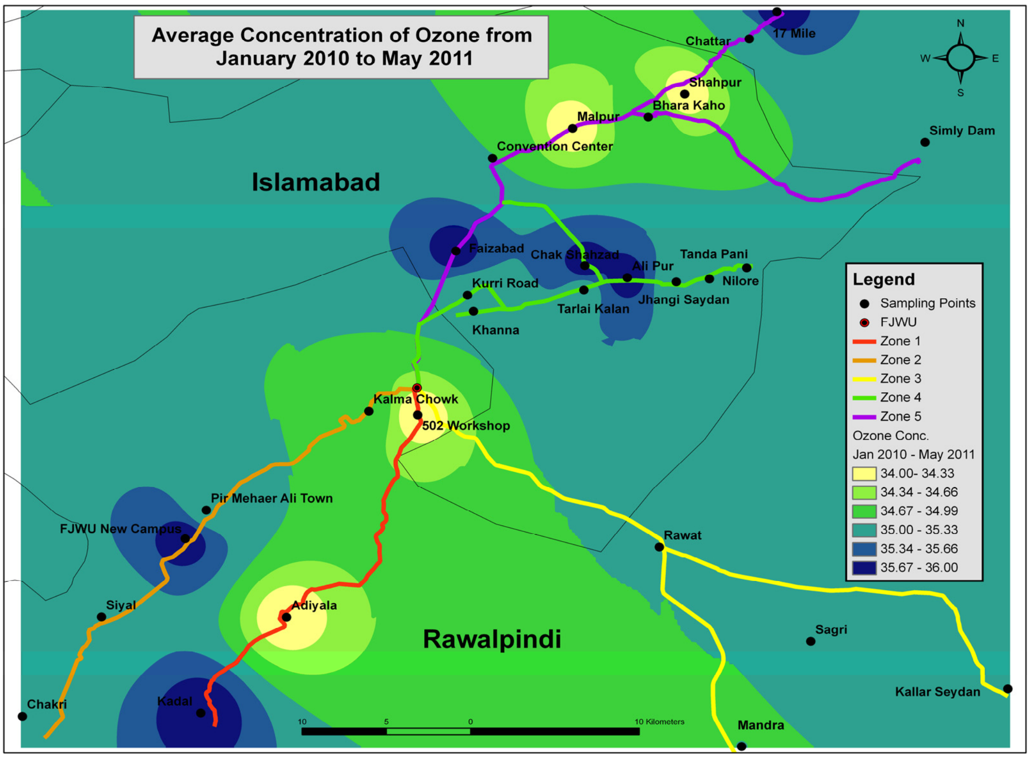


Figure 4. Spatial Interpolation of Ozone in study area (January 2010 – May 2011)

Interpolation map clearly depicts the areas of higher and lower concentration level of O_3 in Rawalpindi and Islamabad. Darker color depicts the higher concentration areas while the lighter color indicates the lower concentrations. Elevated levels of O_3 can be attributed to the intense traffic flow and congestion. Traffic growth rate is extremely high in twin cities. Traffic congestion is continuously increasing with this growing vehicle population leading to the highest emission rates per vehicle. Rawalpindi show high concentration levels of both the pollutants than Islamabad. This because the road network of twin cities is quite different. Islamabad is planned city with wide and extensive road network laid on the grid structure, while the road network of Rawalpindi is narrow and congested; represent a spider net like structure as shown in Figure 5 (Ministry of Communication of Pakistan and Scandia consult, 1995). Resulting in case of Islamabad pollutants get easily dispersed and diluted, while in case of Rawalpindi pollutants get more contained in the atmosphere.

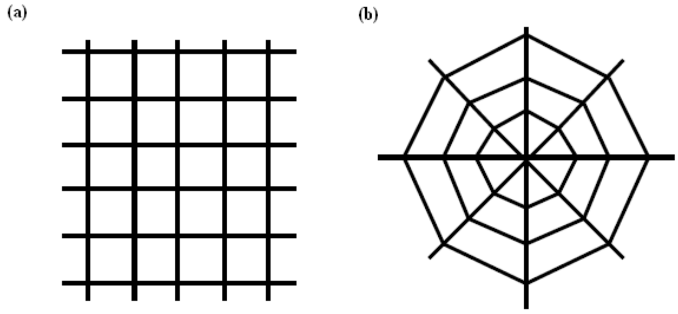


Figure 5. (a) Grid Structure (Islamabad) and (b) Spider net Structure (Rawalpindi) (Source: Ministry of Communication of Pakistan and Scandia consult, 1995)

Comparison of ozone concentration levels mentioned in Table 1-5 with the World Health Organization (WHO) standards i.e. 75 ppb shows that values of O_3 obtained are under the WHO standards. But still due to increase in O_3 precursors the O_3 levels are continuously increasing. So Pakistan being an agriculture country need to take appropriate steps before it reaches the alarming levels and become a serious hazard for human health, agriculture sector and environment.

4. Conclusion

The present research study highlights the importance of air quality management. It is concluded that O_3 concentration has been increasing day by day. O_3 was more in Rawalpindi as compared to Islamabad. Spatial interpolation showed variations graphically in O_3 concentration at different sampling sites of twin cities in different months. Correlation analysis showed significant association of O_3 concentration with climatic variables. Through present research work hot spots of O_3 in twin city have been identified and this work will be helpful in future for calculation of O_3 in atmosphere and for drawing spatial interpolation of O_3. Moreover study highlights the areas of high concentration to control it before it increase above alarming levels.

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