

Full Length Research Paper

X-ray diffractometric examination and elemental composition of solid aerosols collected from different zones of Faisalabad (Pakistan) by Matrix-Flushing Method

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For this study, 14 samples for the overall compound phase analysis, 20 samples for mass concentration and physical appearance, and 50 samples from different zones for compound phase analysis were collected from Faisalabad (Pakistan) and are found in the range of 395 to 1180 $\mu\text{g}/\text{m}^3$ with the average value of 787.5 $\mu\text{g}/\text{m}^3$ for Faisalabad respectively. Most of these values are normal as reported in the literature of other parts of the world. The major phases identified in the samples by the x-ray powder diffraction technique are Albite (Anorthite), Calcite, Clinocllore (Chlorite), Gypsum, Illite, Quartz and Talc which have also been reported by other researchers to be present in the solid aerosols of other world locations. The average weight percentages of the phases in the samples are 47.88, 22.04, 24.55, 11.02, 21.75 and 9.12 respectively for Faisalabad. Some trace metals like Cu, Mn, Zn, Fe, Ca, Ni, Cd, Mg, Cr and Co, were also detected to have no indication of location and zoning showing the heterogenous distribution of compound phases and these trace metals. The same is true with green gases. The results were compared with local and international studies and Faisalabad was found to be polluted as other cities of Pakistan and the world.

Key words: Solid aerosols, glass fiber filters, mass concentration, matrix-flushing method, x-ray diffractometry, compound phase analysis, elemental composition, misfit mapping.

INTRODUCTION

The importance of solid aerosols depends not only upon their impact on human health and environment but also on their usefulness as physico-chemical and biological members of individual pollution sources. The maintenance of environmental quality has been a continuing problem since the dawn of civilization. Man through his industrial, agricultural and domestic activities had brought about physical, chemical and biological modifications to his environment, many of which have had an injurious effect. Environmental pollution nowadays has become a matter of great concern at both the local and global level. The disastrous effects of pollution on all the living beings like human, animals and plants are quite obvious. Recently, increased attention has been focused on the problem of air pollution, being one of the greatest hazards that humanity is facing today.

Chemical characterization studies of solid aerosols using the X-ray Powder Diffraction (XRD) method have been carried out by many researchers for the last several years. Initially, identification of minerals and chemical compounds formed in the atmosphere was done by some workers and the main purpose of such studies was to assess the role of solid aerosols of those phases in the

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atmospheric microphysical processes. It is now established that hydrophobic phases may promote ice nucleation and hygroscopic phases cause droplet condensation in natural atmospheric clouds (Roberts and Hallett, 1968; Hussain et al., 1990). However, a brief review of some studies carried out for qualitative and/or quantitative analysis of solid aerosols and most relevant to the present work is subsequently presented. To start with, a XRD qualitative analysis of samples of different localities of the world is presented. Then the XRD quantitative analysis using different methods is briefly outlined.

The phases identified in solid aerosol samples of different world locations are given in Table 1. In almost all these studies (Davis and Cho, 1977; Peter et al., 1979a, b; Foster and Lott, 1980; Connor and Jaklevic, 1981; Fukasawa et al., 1983; Tani et al., 1983; Harrison and Sturges, 1984; Iwatsuki et al., 1984; Clarke and Karani, 1992; Esteve et al., 1994; Senlin et al., 2007), the minerals/phases detected in the air were found to have their origin in the soils of the areas and in some nearby industries and other pollution generating activities.

Quantitative analysis of the solid aerosols by the Matrix-flushing method has also been carried many times by researchers in the past several years after the introduction of the Chung method (Chung, 1974a, b, 1975). Some researchers did the quantitative analysis by using either the full-pattern (Rietveld) method or RIR method (Warner et al., 1972; Davis, 1978, 1980, 1981, 1984; Davis and Johnson 1982; Davis and Smith, 1988, Davis et al., 1989, 1990; Davis and Spilde 1990; Rius et al., 1987; Nakamura, 1988; Sturges et al., 1989; Bish and Post, 1993; Esteve et al., 1997). Such studies are very useful for assessing the effective role of the identified phases as ice nuclei or condensation nuclei in natural clouds. Findings (Roberts and Hallett, 1968) based on experimentation showed that only a few minerals are capable of ice nucleation in clouds. Hussain et al. (1990) calculated the lattice mismatch of various minerals identified in solid aerosols with ice and found that Kaolinite airborne particles could be the best nucleant of ice in natural clouds and Quartz airborne particles are the worst nucleant. The solid aerosols also promote condensation of droplets when they have hygroscopic content (Shahid et al., 2013). The present study was conducted in the third largest city of Punjab, Faisalabad facing the problem of air pollution severely due to urbanization, industrialization and transportation. The objectives of this study were to identify and quantify the compound phases present in solid aerosol samples randomly collected from different locations covering almost all types of pollutant expected in their environments. Compound Phase Analysis was carried out by X-ray powder diffractometry using Matrix Flushing method.

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MATERIALS AND METHODS

For the sample collection, Kimoto High Volume Air Sampler with 2000 m³ volume, 0.8 m³/min flow rate and fibre glass filter were used for compound analysis and elemental analysis. Rigaku Model DMAX/11-A diffractometer and Hitach Z-8200 spectrophotometer were employed along with standard Photocels and control environment for green house gases. WEST Gacke Method following British Standards along with EPD Mobile Lab was used. The city was divided into three zones: Zone-I (Industrial/Traffic Zone), Zone-II (Suburb Zone) and Zone-III (Residential cum Commercial Zone) as shown in Figures 1 and 2.

There are several methods used for the quantitative analysis of phases in a mixture, namely: the Internal Standard Method and the Direct Comparison Method, External Standard Method and the Full Pattern Method (Cullity, 1978). The Matrix-Flushing Method is faster to apply and its results are as accurate as the other four methods (Chung, 1974a, 1975; Battaglia 1985; Rowe et al., 1985). This latter method was applied in the present study and is described briefly here.

The quantitative analysis by any method of X-ray diffraction is based on the fact that the intensity of the diffraction pattern of a particular phase in a mixture of different phases depends on the concentration of that phase in the mixture. The relation between the intensity and concentration is not generally linear, because the diffracted intensity depends on the absorption coefficient of the mixture and this itself varies with the concentration. The expression for the intensity diffracted by a single phase powder specimen is:

$$I = \left(\frac{I_o A \lambda^3}{32n\gamma} \right) \left[\left(\frac{\mu_o}{4\pi} \right)^2 \frac{e^4}{m^2} \right] \left(\frac{1}{v^2} \right) \left[(F)^2 p \left(\frac{1 + \cos^2 2\theta}{\sin^2 \theta \cos \theta} \left(\frac{e^{-2M}}{2\mu} \right) \right) \right] \quad (1)$$

To find the relation between diffracted intensity and concentration of a phase α , in a mixture of two phases, α and β , expression 1 can be modified to another expression, known as the basic intensity equation:

$$I_\alpha = \frac{K_1 C_\alpha}{\mu_m} \quad (2)$$

In this expression, I_α is the intensity of the selected line of α phase, μ_m is the linear absorption coefficient of the mixture, C_α is the volume fraction of α in the mixture, and K_i is a constant of the unknown value.

K_i will be cancelled out if the ratio of I_α is measured to the intensity of some standard line. The concentration can then be found from this ratio.

Table 1. Phases identified in solid aerosol samples of different World locations.

Location	Phases Identified in SPM Samples	Reference
Japan 1, Asia	Quartz, Plagioclase (Albite & Anorthite), Calcite, Macagnite (Ammonium Sulphate), Salammoniac (Ammonium Chloride), Ammonium Nitrate Sulphate, Some Unidentified Phases	Fukasawa, 1983
Denver, USA	Biotite, Muscovite, Chlorite, Kaolinite, Montmorillonite, Quartz, Microcline, Plagioclase, Calcite, Hornblende, Anthophyllite, Magnetite, Mascagnite (Ammonium Sulphate), Gypsum, Halite, Nitratite (Sodium Nitrate), Ammonium Lead Sulphate	Davis, 1984
Sahara Desert in W. Africa	Quartz, Illite, Potassium –Feldspar, Plagioclase, Calcite, Dolomite, Gypsum, Chlorite, Kaolinite, Palygorskite, Montmorillonite	Schutz and Sebert, 1987
Japan 2, Asia	Quartz, Plagioclase, Gypsum, Bassanite, Anhydrite, Calcite, Halite	Nakamura, 1988
Nigeria, Africa	Quartz, Kaolinite, Halloysite, Illite, Muscovite, Microcline	Adedokun et al., 1989
Turkey, Europe	Calcite, Quartz, Albite Muscovite, Edenite, Diabanite, Thuringite, Dolomite, Carbon Sulphide	Arslan and Boybay, 1990
Lahore (Pakistan), Asia	Quartz, Albite, Illite, Gypsum, Talc	Hussain et al., 1990
Rabwah (Pakistan), Asia	Quartz, Calcite, Chlinchlore, Zircon, Albite, Talc, Phillipsite, Thorite, Xenotime, Carnotite	Shahid, 1997
Spain, Europe	Calcite, Quartz, Gypsum	Esteve et al., 1997
Faisalabad (Pakistan), Asia	Quartz, Illite, Talc, Gypsum, Chlorite, Albite, Calcite, Hematite, Halite, Saponite, Mullite, Wustite	Shahid, 2008

In the matrix-flushing method, a fundamental “matrix-flushing” concept is introduced. The calibration curve procedure as required particularly in the internal standard method is shunted out. The internal standard method is much more time-consuming and costly. For the method to implement, one needs to get high purity phases as identified in the mixture along with a standard material like corundum or quartz. XRD data for high intensity peaks of the synthetic mixtures prepared in known proportions of those phases and the standard material are acquired and a calibration curve is plotted from the data. On the other hand, the matrix-flushing method is

much simpler and easier to apply; the matrix effect is totally eliminated and all components crystalline or amorphous can be determined. This concept provides an exact relationship between intensity and concentration free from matrix effect. If X_i and I_i are respectively the weight fraction and intensity of a component ‘i’ in a mixture of ‘n’ components, the basic intensity can be reduced as:

$$I_i = \frac{K_i}{P_i} \cdot \frac{X_i}{\mu_i} = K_i X_i \quad (3)$$

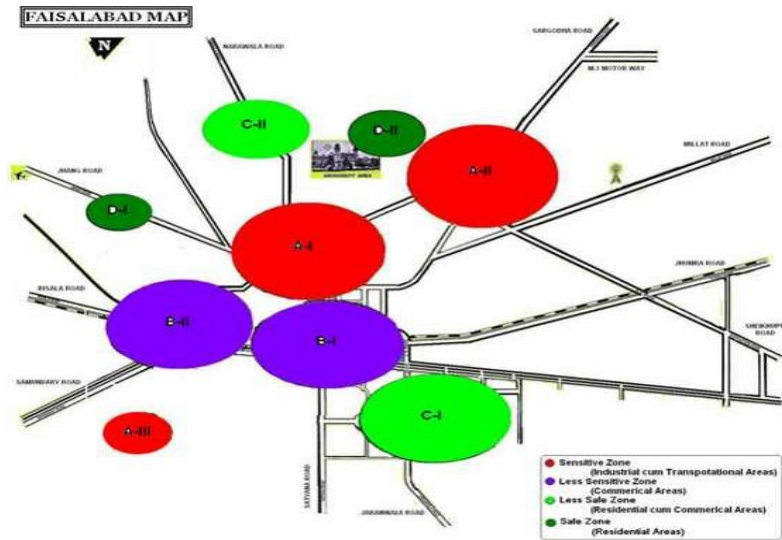


Figure 1. Zone classification of the Faisalabad City.

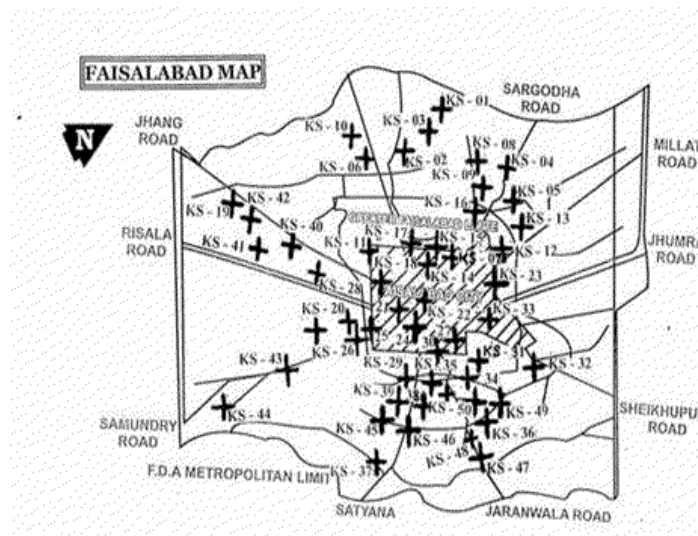


Figure 2. Site selection for Faisalabad City.

For the quantitative analysis of a mixture of 'n' components, Equation 3 becomes a matrix equation, $KX = I$, which has a unique solution if the rank of K matrix is equal to the rank of the (K,I) matrix. Thus:

$$X_i = \left[\frac{K_i}{I_i} \sum_{j=1}^n \frac{I_j}{K_j} \right]^{-1} \quad (4)$$

The equation gives the percentage composition of a
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component 'i', when all the components are crystalline. In the equation, K_i is relative intensity ratio given by:

$$K_i = \left[\frac{I_i}{I_s} \right]_{50/50} \quad (5)$$

This ratio can be calculated by mixing the component 'i' with a standard material 's' in a ratio of 50:50 by weight. The International Commission for Diffraction Data (ICDD) recommends Corundum ($\alpha\text{-Al}_2\text{O}_3$) as the standard

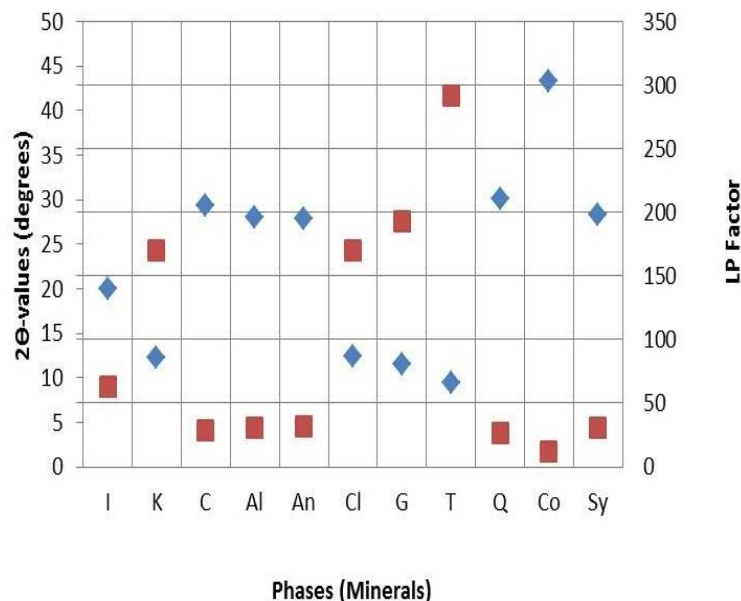


Figure 3. 2θ and LP values plotted against identified phases and corundum and sylvite.

material for reference intensities because of its purity and stability. It is convenient to choose the same Corundum as a flushing agent for the same good reasons. Equations 4 and 5 are used to quantify phases in a mixture of phases.

In the present study, however, high purity Sylvite (KCl) was used to determine K_i values for the identified phases instead of Corundum because most of the minerals identified in the solid aerosol samples have their maximum intensity diffraction peaks lying close to the sylvite maximum intensity peak. This is important because the various factors in Equation 1, particularly the Lorentz-Polarization factor and the absorption factor, at a constant temperature, have almost similar effects on the diffracted intensities. Figure 3 gives a comparison of the maximum intensity peaks of minerals with Corundum and Sylvite shown in different colors (blue for Corundum and red for Sylvite). The figure shows clearly that 2θ value of maximum intensity peak for Sylvite is closer to those for Albite, Calcite, Chlorite (Cliochole), Gypsum, Illite, Quartz and Talc, whereas 2θ value of Corundum is larger than the 2θ values of all the mineral phases. Clearly, the effect of the various factors which depend on 2θ values would be much less on peak intensity and hence the weight percentages of phases quantified in the mixture. For quantification of mineral phases, high purity reagent grade KCl (Sylvite) (99.8% pure: SIGMA-ALDRICH, Germany) was used in the present study. Its XRD pattern was obtained with the diffractometer conditions given in

Table 2 before using it to develop K_i ratios with the minerals phases identified in aerosol samples. The observed KCl reflections resembled the NBS standard ICDD PDF card 4-587. Also the XRD pattern background was low and did not show any minor phases. The mineral phases identified in solid aerosols (namely, polycrystalline Albite of Katlang-Mardan, single crystal Calcite of Dandot, polycrystalline Chlorite of California, polycrystalline Gypsum of Khewra, Illite of Morris-Illinois, single crystal Quartz of Swat, and polycrystalline Talc of Swat) were arranged from the Institute of Geology, University of the Punjab, Lahore. XRD data of the minerals phases were identified and found to closely match with the data given in ICDD PDF Crads 9-457 (Albite), 5-586 (Calcite), 7-185 (Chlorite), 6-46 (Gypsum), 26-911 (Illite), 5-490 (Quartz) and 19-770 (Talc). Homogeneous mixture of each mineral phase was prepared with Sylvite in the 50/50 weight ratio and was run under the same diffractometer conditions for obtaining K_i values (Table 3). The K_i ratios plotted in Figure 4 were used for quantification of minerals in the samples.

RESULTS AND DISCUSSION

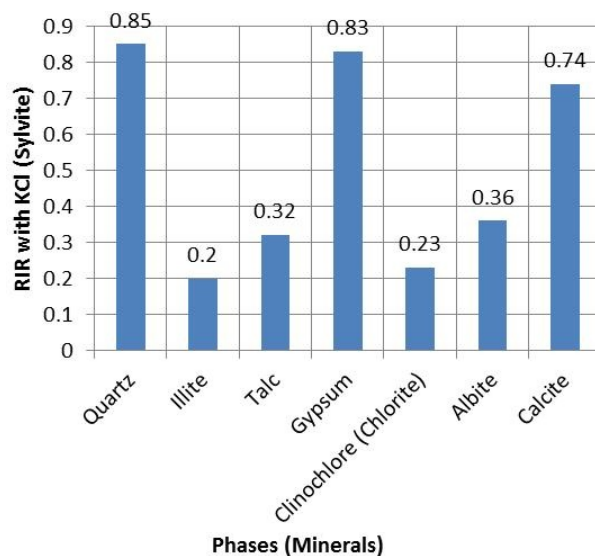
Here, qualitative and quantitative phase analysis of all aerosol samples and complete elemental analysis of samples collected from industrial/commercial sites were described.

Table 2. Diffractometer conditions for acquiring XRD data.

X-Rays	CuK α (Ni- Filtered)
Tube Voltage & Current	35 KV and 25 mA
Divergent and Antiscatter Slits	1 $^\circ$
Receiving Slit Width	0.15 mm and 0.3 mm
Goniometer Scanning Speed	0.02 $^\circ$
Step Width	0.4 s
Preset Time	1 s
Start Angle	3 $^\circ$
Stop Angle	75 $^\circ$
Detector	Scintillation Counter

Table 3. Weight percentage of identified phases in the atmosphere of Faisalabad.

Sample No	I _L	Q	C _H /C _L	C _A	A _L	Q/T
1	66.20	15.60	14.83	3.72	N.D	N.D
2	N.D	38.36	N.D	18.32	37.67	5.62
3	59.62	5.72	17.03	5.69	11.68	15.43
4	37.09	30.70	10.00	10.00	N.D	4.84
5	29.56	N.D	29.32	12.65	N.D	N.D
6	56.68	13.34	15.15	N.D	19.42	N.D
7	34.97	27.82	N.D	3.72	N.D	N.D
8	63.63	14.98	N.D	8.24	7.74	7.34
9	54.40	4.87	19.82	10.27	5.82	5.51
10	59.73	20.37	15.56	N.D	N.D	4.32
11	36.83	10.94	33.09	6.80	N.D	N.D
12	R62.00	14.58	N.D	8.92	6.54	7.94
13	R64.21	15.10	11.33	N.D	6.51	2.82
14	R37.64	19.38	13.34	11.98	17.65	N.D

**Figure 4.** RIR values of minerals against Sylvite.

Qualitative analysis

For this analysis, 50 samples were randomly collected from different zones, containing 6 city sites and 2 suburb sites along with 20 samples for mass concentration and physical appearance. Sites were selected taking into consideration residential, commercial and industrial areas of the cities.

In order to acquire XRD data for the solid aerosols, the Rigaku X-ray Powder Diffractometer (Model D-Max/II-A) was employed after its calibration using 5N purity Si powder. The lattice parameter obtained from the XRD data of Si powder was found to have an accuracy of measurement better than $\pm 0.0005\text{\AA}$. This accuracy corresponds to the accuracy of measurement in the Bragg angle better than $0.02^\circ(2\theta)$. In order to acquire XRD data, all the samples were then loaded one by one on to the diffractometer goniometer (Table 2). The diffractometer was run in the step-scan mode under the same conditions (Table 3) for obtaining data for Si and all airborne particulates. In order to minimize the background effects of the amorphous contents, if any, present in the SPM samples, a window to pass the diffracted beam to the detector was adjusted by the pulse height analyzer of the diffractometer system. So, minimizing the background of the XRD patterns in this well known procedure has shown little effect on the peak intensities.

Qualitative phase analysis of all the samples was carried out by the well-known Hanawalt method (The Powder Diffraction File, Joint Committee on Powder Diffraction Standards, 1980). The analysis shows that the soil minerals such as Albite (Anorthite), Calcite, Chlorite (Clinocllore), Gypsum, Quartz, and Talc are contained in almost all samples. The major minerals detected in all airborne particulates with their chemical formulas and characteristic peaks are given in Table 6. The XRD data of the samples and the results of the qualitative analysis are given in Tables 7 to 10. The detected minerals are the soil minerals introduced into the air through wind erosion. A preliminary study of the Lahore aerosols and the soil samples collected from close to the sampling sites had showed that the above mentioned minerals were present in almost all the samples and have no clear indication of Faisalabad location or zoning identification showing not only the mapping of Faisalabad misfit but also the compulsory mapping of the environment (Hussain et al., 1990). The other worldwide studies reviewed in this paper also show the presence of these minerals and more soil minerals in the airborne particulates. The present results were also compared with the analyses of aerosols (SPM) reported in earlier studies. For example, the results reported for Nigerian (Adedokun et al., 1989), Denver (Davis, 1984), Japan

(Fukasawa et al., 1983; Nakamura, 1988) and Turkish (Arslan and Boybay, 1990) aerosols have showed the presence of several other compounds/phases as compared to the present results. The presence of ammonium chloride and ammonium nitrate sulphate in aerosol samples collected in Japan was due to their likely formation in the air due to photosynthesis of fuel gases such as NO_x and SO_2 and Chlorine. Here in Faisalabad, vehicular traffic has increased tremendously over the last decade but the compounds mentioned above were not indicated. It is possible that either these compounds did not grow via photosynthesis, possibly because conditions were not favorable for their formation or if they grew, their amount was below the detection limit of the diffractometer.

Quantitative phase analysis

In order to quantify the major phases, namely: Albite, Calcite, Clinocllore (Chlorite), Illite, Gypsum, Quartz, and Talc in the samples, intensities of the largest peaks of these phases and their RIR values (Figure 4) along with XRD patterns and some samples shown in Figure 5 were used in this study. Since the largest peaks of Illite and Quartz overlap at $d = 3.334\text{\AA}$, the first characteristic peak of Quartz with $d = 4.26\text{\AA}$ was used after its intensity normalized to the largest peak. It may have introduced some error in quantification of Quartz, but that effect can be ignored because the error in the quantification of phases by any quantitative analysis is not better than $\pm 10\%$. All the identified minerals except Talc and Gypsum were present in the local soil of Faisalabad which are injected into the air we breathe through wind erosion, so the soil dispersion is the dominant source for most of the compounds present in solid aerosols. The formation of Gypsum and Talc in the atmosphere through photochemical reactions is not possible at all because the conditions for growth of these compounds in the atmosphere do not exist. The presence of Talc and Gypsum as indicated in previous studies may be attributed to their sources away from Faisalabad. However, there would be local sources of Gypsum and Talc as well, because the former is used as fertilizer by the farmers and the latter is the stone crushed or ground in the mills for the production of Talcum Powder and house building materials. The identified phases are also frequently used in paper, paints, pottery, molding, dentistry, statuary, plastics and ceramics, lubricants, optical and glassware industries which confirms the involvement of industry and transportation in the environment. So, both may be injected into the atmosphere through these two industrial sources. It is to be noted that the calcite concentration in Faisalabad is in appreciable amount so the chances of acidic rain in

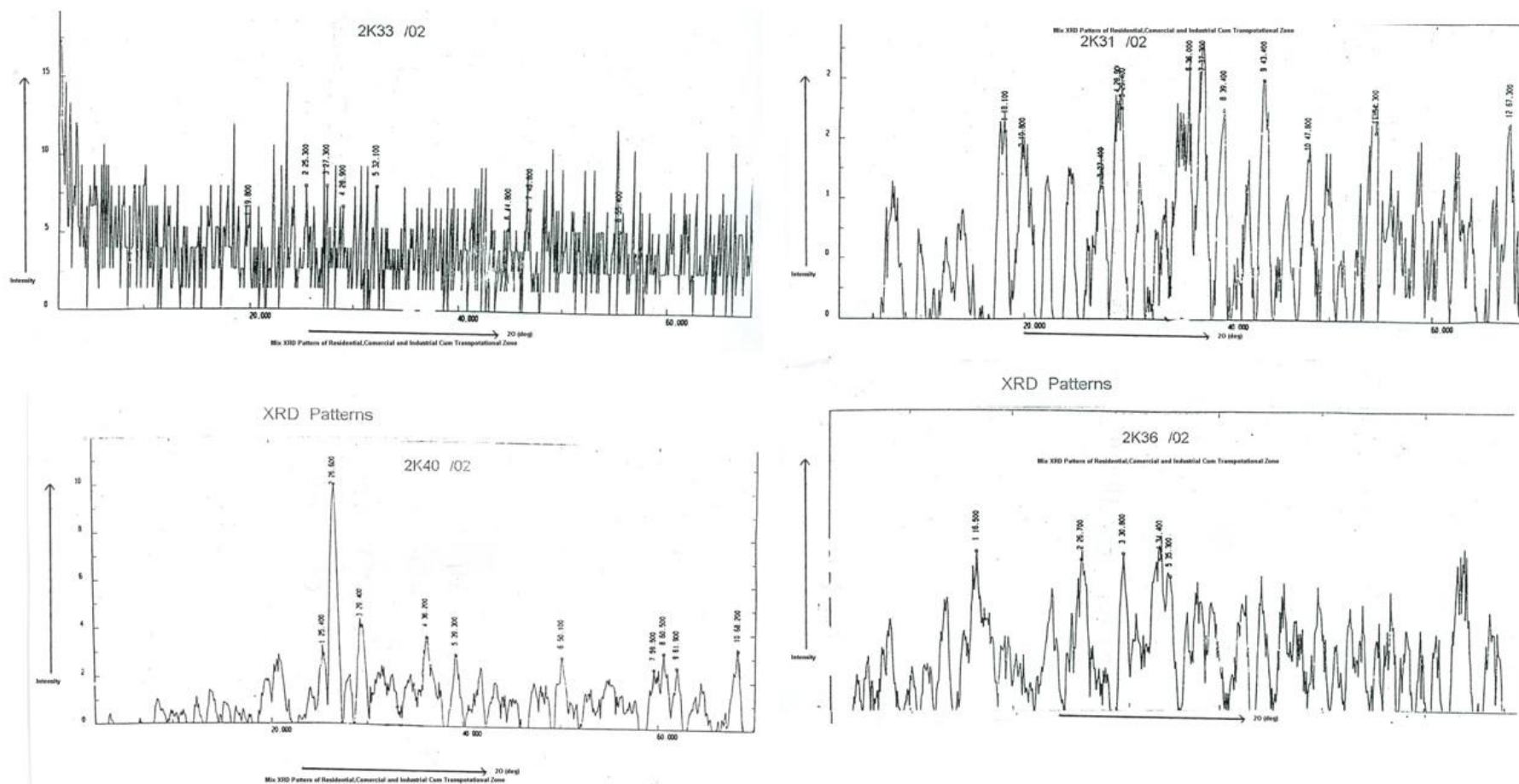


Figure 5. XRD patterns of some samples taken from Faisalabad environment.

Faisalabad due to its neutralizing capability to acidic effects of minerals and of photochemically generated compounds in the atmosphere is ruled out in the near future (Tables 4 and 5). Generally, minerals are of light color but became black/grey

and yellow due to physico-chemical changes in their components or by addition of organic compounds. Black/grey color of most of the samples is confirmed in the environment and as a result, organic compounds are also disturbing the

Physics, Chemistry and Biology of the environment. It is urged that the concerned authorities, the corporate sector and the general public must fulfill their obligation regarding air pollution issue before it is too late (Mavroidis and Chaloulakou,

Table 4. Sample locations, mass concentration and physical appearance of solid aerosols collected from Faisalabad environment.

Sample No	Sample collection sites	Mass Conc. ($\mu\text{g}/\text{m}^3$)	Physical appearance
1	Faizabad	521	Dull Green
2	Allied Hospital	395	Light Green
3	Shaheed-i-Millat Market	534	Black Tange
4	Incom Tax Office	1180	Light Grey
5	NIAB	680	Dull Green
6	Regency Arcade	530	Light Green
7	Saint Raphael	508	Dull Green
8	Mansorabad	476	Light Green
9	Flying Coach Stand	530	Black
10	G.C Samanabad	1125	Muddy Grey
11	Kohinoor Mills	836	Dark Grey
12	Graveyard Jhang Road	480	Black
13	Over head Bridge	1052	Blackish
14	Rafhan Mills	906	Do
15	F.M.C	906	Black
16	Regency Arcade	660	Blackish Brown
17	Army Food Industries	850	Grey
18	G.C.U.F	1085	Yellow
19	Policeline	520	Light Grey
20	P.M.C	600	Light Grey

Table 5. Acidic rain probability on the basis of physical appearance.

Colour	Acidic rain probability (%)
Light colour (Acidic)	30
Dark colour(Basic)	70

Table 6. Compound phases detected in solid aerosols collected from different locations of Faisalabad and Lahore along with their chemical formulas and characteristics peaks.

Phase	Chemical Formula	Characteristic Peaks: d-values (with Relative Integrated Intensity taken on Scale of $x=10$)
Albite (A)	$\text{NaAlSi}_3\text{O}_8$	4.03 _{6.1} , 3.19 _x , 3.21 _{5.8}
Calcite (C)	CaCO_3	3.035 _x , 2.285 ₁ , 2.095 _{1.8}
Clinichlore (Chlorite) (Cl)	$(\text{Mg,Fe})_6(\text{Si,Al})_4\text{O}_{10}(\text{OH})_8$	7.16 _x , 14.3 _{6.5} , 3.58 ₆
Gypsum (G)	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	7.56 _x , 4.27 ₅ , 3.059 _{5.5}
Illite (I)	$\text{K}_{0.7}\text{Al}_{2.1}(\text{Si,Al})_4\text{O}_{10}\text{H}_2\text{O}$	10.02 ₉ , 3.34 _x , 5.02 ₅
Quartz (Q)	$\alpha\text{-SiO}_2$	3.34 _x , 4.260 _{3.5} , 1.817 _{1.7}
Talc (T)	$\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$	9.35 _x , 4.59 _{4.5} , 3.12 ₄

2010; Shahida, 2000; Shahid, 1997, 2008; Catherine and Skinner, 2007).

As far as the mass concentration of Faisalabad and Lahore is concerned, it is much higher than that of mostly

polluted Indian cities which ranges from 155 to 552 $\mu\text{g}/\text{m}^3$ and for some western cities which ranges from 160 to 169 $\mu\text{g}/\text{m}^3$ (Table 14). However, it is less than that of London Black Smoke concentration (1600 $\mu\text{g}/\text{m}^3$). Such

Table 7. Zone1 Traffic/Industrial Zone (2k05, 07, 09, 10, 15, 18, 19, 20, 22, 23, 25, 27-30, 33, 37-44, 46, 47).

Sample Code	R	IL	Q	CH/CL	AN	CA	AL	G/T	HM	HL	SP	MU	WS
2K05	BDL	BDL	74.09	BDL	BDL	5.29	BDL	11.58	BDL	9.02	BDL	BDL	BDL
2K07	BDL	BDL	72.41	BDL	5.42	15.84	BDL	6.34	BDL	BDL	BDL	BDL	BDL
2K08	BDL	BDL	26.08	BDL	BDL	13.04	BDL	26.08	BDL	BDL	17.39	BDL	BDL
2K09	BDL	BDL	76.36	BDL	BDL	23.63	BDL	17.03	12.52	16.05	BDL	BDL	BDL
2K10	BDL	BDL	41.15	BDL	BDL	BDL	BDL	29.91	12.52	BDL	BDL	BDL	BDL
2K15	BDL	BDL	29.42	BDL	BDL	BDL	BDL	70.58	BDL	BDL	BDL	BDL	BDL
2K18	BDL	BDL	18.38	BDL	BDL	BDL	16.72	BDL	BDL	39.4	13.78	16.72	BDL
2K19	BDL	66.2	15.6	14.38	BDL	3.72	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2K20	BDL	BDL	38.36	BDL	BDL	18.32	37.67	5.62	BDL	BDL	BDL	BDL	BDL
2K22	BDL	59.62	5.72	17.03	BDL	5.69	11.68	15.43	BDL	BDL	BDL	BDL	BDL
2K23	BDL	37.09	BDL	30.7	BDL	10	BDL	4.84	BDL	BDL	BDL	BDL	BDL
2K25	BDL	29.56	BDL	29.32	BDL	12.65	19.42	BDL	BDL	BDL	BDL	BDL	BDL
2K27	BDL	56.68	13.34	15.15	7.06	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2K28	BDL	34.97	27.82	BDL	BDL	3.72	7.74	BDL	BDL	BDL	BDL	BDL	BDL
2K29	BDL	63.63	14.98	BDL	BDL	8.24	5.82	7.34	BDL	BDL	BDL	BDL	BDL
2K30	BDL	BDL	9.96	14.14	BDL	7.56	23.54	10.21	BDL	BDL	BDL	BDL	BDL
2K33	BDL	8.28	BDL	35.28	BDL	BDL	22.53	8.54/25.35	BDL	BDL	BDL	BDL	BDL
2K37	BDL	38.09	BDL	33.12	BDL	BDL	21.15	7.61	BDL	BDL	BDL	BDL	BDL
2K38	BDL	33.63	BDL	29.24	BDL	BDL	18.67	8.09/10.34	BDL	BDL	BDL	BDL	BDL
2K39	BDL	54.4	4.87	19.92	BDL	10.27	BDL	5.51	BDL	BDL	BDL	BDL	BDL
2K40	BDL	59.73	20.37	15.58	BDL	BDL	BDL	4.32	31.52	BDL	BDL	BDL	BDL
2K41	BDL	36.83	10.94	33.09	BDL	6.8	12.31	BDL	BDL	BDL	BDL	BDL	BDL
2K42	BDL	6.15	14.48	BDL	BDL	13.63	34.2	BDL	19.6	BDL	BDL	BDL	BDL
2K43	BDL	48.28	11.35	6.11	BDL	5.77	28	BDL	BDL	BDL	BDL	BDL	BDL
2K44	BDL	37.03	8.71	BDL	BDL	8.47	20.57	19.60/5.60	BDL	BDL	BDL	BDL	BDL
2K46	BDL	45.82	10.77	16.33	BDL	8.09	BDL	7.22/11.73	BDL	BDL	BDL	BDL	BDL
2K47	BDL	9.87	64.02	BDL	BDL	14.17	11.93	BDL	BDL	BDL	BDL	BDL	BDL

Table 8. Zone 2 Safe Zone (2k03, 12, 21).

Sample Code	R	IL	Q	CH/CL	AN	CA	AL	G/T	HM	HL	SP	MU	WS
2K03	BDL	BDL	24.42	BDL	BDL	21.78	BDL	19.84	BDL	BDL	BDL	BDL	33.82
2K12	15.96	BDL	25.92	BDL	BDL	BDL	BDL	32.03	6.89	BDL	19.84	BDL	BDL
2K21	BDL	35.46	26.34	21.18	BDL	17	BDL	BDL	BDL	BDL	BDL	BDL	BDL

enormous loading of solid aerosols could cause serious effects on human health, climatology and meteorology of the concerned area. As most of the identified phases are nucleation misfit and hygroscopic in nature, they remain suspended for longer periods of time and may disturb ecological balance and radiation budget and may cause global cooling, global warming and abnormal seasonal variations which ultimately affect adversely the food chain

and food web (Table 11) (Brunekreef and Holgate, 2002; Shahid et al., 2012; Bonita et al., 2006).

In this study, only crystalline phases were quantized; the crystalline phases however grown in the air due to photosynthesis could not be detected by XRD because their concentration in the samples could be below the detection limit of the diffractometer as indicated in their elemental composition and green house gases detected

Table 9. Zone 3 Residential / Commercial Zone2k01, 02, 04, 06, 11, 13, 14, 16, 27, 24, 26, 31, 32, 34, 35, 36, 45, 48, 49, 50 from Zone 3.

Sample Code	R	IL	Q	CH/CL	AN	CA	AL	G/T	HM	HL	SP	MU	WS
2KO1	BDL	BDL	66.8	BDL	5.31	23.23	BDL	BDL	BDL	BDL	BDL	BDL	5.31
2KO2	BDL	BDL	29.02	BDL	BDL	BDL	BDL	28.7	BDL	11.9	BDL	30.36	BDL
2KO4	33.66	BDL	16.99	BDL	BDL	15.06	BDL	17.88	5.79	BDL	BDL	10.6	BDL
2KO6	BDL	BDL	37.8	BDL	BDL	28.61	BDL	15.97	BDL	12.13	BDL	5.47	BDL
2K11	BDL	BDL	29.17	BDL	BDL	28.38	BDL	31.39	6.88	BDL	BDL	BDL	BDL
2K13	BDL	BDL	32.03	BDL	BDL	35.92	BDL	20.9	BDL	BDL	BDL	BDL	BDL
2K14	BDL	BDL	14.57	BDL	BDL	64.52	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2K16	BDL	BDL	19.54	BDL	43.5	17.4	BDL	19.54	BDL	BDL	BDL	BDL	BDL
2K17	BDL	BDL	34.02	BDL	BDL	BDL	BDL	13.64	52.38	BDL	BDL	BDL	BDL
2K24	BDL	34.95	25.62	15.16	BDL	BDL	BDL	7.85	BDL	BDL	BDL	BDL	BDL
2K26	BDL	71.85	15.86	15.86	9.34	BDL	20.5	BDL	BDL	BDL	BDL	BDL	BDL
2K31	BDL	BDL	8.68	30.2	BDL	10.06	20.6	8.96/22.18	BDL	BDL	BDL	BDL	BDL
2K32	BDL	BDL	6.82	40.41	BDL	12.56	BDL	11.18/29.02	BDL	BDL	BDL	BDL	BDL
2K34	BDL	62	14.58	BDL	BDL	8.92	6.54	7.94	BDL	BDL	BDL	BDL	BDL
2K35	BDL	52.39	12.32	BDL	BDL	1.92	29.1	4.24	BDL	BDL	BDL	BDL	BDL
2K36	BDL	36.5	BDL	BDL	BDL	9.86	21.52	9.32/22.78	BDL	BDL	BDL	BDL	BDL
2K45	BDL	64.21	15.1	11.33	BDL	BDL	6.51	2.82	BDL	BDL	BDL	BDL	BDL
2K48	BDL	37.64	19.38	13.34	BDL	11.98	17.65	BDL	BDL	BDL	BDL	BDL	BDL
2K49	BDL	29.69	15.74	21.52	BDL	BDL	26.39	7.22	BDL	BDL	BDL	BDL	BDL
2K50	BDL	19.66	43.35	10.5	BDL	16.69	9.77	BDL	BDL	BDL	BDL	BDL	BDL

Table 10. Statistical analysis of major identified phases.

PHASES	MAX	MIN	MEAN	S.D	CV
IL	64.21	6.15	35.18	41.05	116.68
CA	64.52	1.92	33.22	44.26	133.23
G/T	70.58	4.22	37.41	46.90	125.36
Q	64.02	8.68	36.35	39.13	107.64
CH/CL	40.41	6.11	23.26	24.25	104.25
AL	34.20	6.51	20.36	19.57	99.11

Table 11. Comparison of cell dimensions of ice and minerals identified in suspended particulate matter.

Identified Phase	Crystal System	a (A°)	c (A°)	Basal Misfit%age	Prism Misfit%age
ICE	HEXAGONAL	4.490	7.338	----	----
QUARTZ	HEXAGONAL	4.913	5.450	9.2	17.8
ILLITE	MONOCLINIC	5.190	20.160	15.4	95.1
CHOLIRIDTE	MONOCLINIC	5.320	14.290	18.3	56.1
CALCITE	HEXAGONAL	4.989	17.062	10.9	71.7
GYPSUM	MONOCLINIC	5.680	6.510	16.3	18.8
TALC	MONOCLINIC	5.287	18.964	17.5	88.0
ALBITE	TRICLINIC	8.144	7.160	81.0	41.7

Table 12. Elemental analysis of solid aerosols related to Faisalabad environment.

Elements Detected	Zone 1 ($\mu\text{g}/\text{m}^3$)	Zone 2 ($\mu\text{g}/\text{m}^3$)	Zone 3 ($\mu\text{g}/\text{m}^3$)	Mixed zone ($\mu\text{g}/\text{m}^3$)	Permissible limits ($\mu\text{g}/\text{m}^3$)
Cu	ND	0.0049	0.0196	0.0049	4.9000
Mn	0.4173	0.3244	0.3133	0.2133	9.0000
Zn	0.6778	1.4278	ND	4.1528	16.0000
Fe	20.3889	16.8056	13.8611	8.0556	14.0000
Ca	3.6667	4.4722	5.1389	5.1389	7.0000
Ni	2.2778	2.4444	1.9167	1.0000	0.1200
Cd	ND	0.0997	ND	ND	0.6200
Mg	ND	ND	ND	ND	11.0000
Cr	0.0091	0.0075	0.0102	0.0090	0.3000
Co	0.0005	0.0012	0.0043	0.0021	0.0370

ND= Not detected.

Table 13. Weight percentage of green house gases.

Type of the gases	CO	HC	NOx	Sulfur contents and others
Highly polluted area	63.725	27.645	6.050	2.575
Moderately polluted area	64.665	26.825	5.910	2.600
Lightly polluted area	64.870	27.225	5.500	2.405

in the environment. When compared with India except Ni, Cr and Cd, other elements have low concentration. The high concentration of these elements is the indication that the environment of Faisalabad is highly degraded as compared with the top ten Indian polluted cities. The data were also compared with local cities keeping in view EAQS and WHO standards, and it was found that the environment of Faisalabad posed serious health hazards (Tables 12 to 16) like Lahore, Rawalpindi and Islamabad.

Critically speaking, aerosol loading in Faisalabad has increased enormously in the last few years which is a clear indication of the changing environment. The consequences of the changed environment are many including their health hazards on the climate of the region especially and on the country generally, which also have effect on agriculture and consequently on the overall economy of the country. In the several past years, the temperature of Faisalabad increased by 0.5°C . A study conducted by Hussain et al. (1994) and Shahid et al. (2007) revealed that average maximum and minimum temperature has shown decreasing trend, while number of rainy days showed an increasing trend predicting a general shift in weather and global warming trend. Due to this change, the winter has shrunk to January and February and consequently the summer months are March to almost December. The monsoon season has

also changed completely, in that there had been wide spread monsoon rains for the last decades throughout Pakistan. The country is thus facing drought conditions. Suspension of solid aerosols with high concentration in the atmosphere could remain suspended and useable to promote condensation and nucleation processes which cannot be washed out by rains thus enhancing health hazards when inhaled. Hygroscopic components of solid aerosols can cause haze, fog and smog, thus hindering not only the formation of raindrops but also increasing the accident rate in the region and hence supplementing the death rate. The biotic effects of trace metals when unduly exposed to them could become potentially life threatening hence cannot be ignored while these traces are indispensable in many ways. Good precautions and proper occupational hygiene should be taken in handling them as per recommendations.

Conclusion

Major, medium and minor identified phases in solid aerosols related to Faisalabad environment using XRPD technique are as follows:

- Major phases with mean Gypsum and Talc (37.41) are each coming from remote areas. Medium phases with

Table 14. Comparisons of Faisalabad with prominent cities of India.

Sr.No	Name of the City	Solid aerosol concentration	SO ₂	Dust fall rate
01	Ahmed Abad	217 ug/m ³	31PPb	91 MT/KmS ² /Month
02	Bombay	184 ug/m ³	38 PPb	11 MT/KmS ² /Month
03	Calcutta	522 ug/m ³	90 PPb	34 MT/KmS ² /Month
04	Delhi	433 ug/m ³	31 PPb	31 MT/KmS ² /Month
05	Hydrabad	143 ug/m ³	30 PPb	31 MT/KmS ² /Month
06	Jaipur	308 ug/m ³	06 PPb	19 MT/KmS ² /Month
07	Kanpur	432 ug/m ³	13 PPb	34 MT/KmS ² /Month
08	Madras	155 ug/m ³	08 PPb	34 MT/KmS ² /Month
09	Nagpur	199 ug/m ³	12 PPb	34 MT/KmS ² /Month
10	Faisalabad	765 ug/m ³	25 PPb	125T/KmS ² /Month

Ref: NEERI (National Environmental Engineering Research Institute) India.

Table 15. Comparisons of elemental analysis (Faisalabad/ JNU India).

Trace elements	Weight percentage	Weight %age greater than standards		Remarks
	JNU India	Faisalabad	Pakistan	
Cu	3.49	2.22		Low
Zn	38.82	Nil		Low
Cd	1.74	40		High
Pb	26.22	17.77		Low
Cr	15.73	18.52		High
Ni	13.98	21.48		High

Table 16. Comparison of Solid Aerosols, SO₂, NO_x, CO data to international standards.

Solid Aerosols	Lahore	Rawalpindi	Islamabad	Faisalabad
Standards	895	709	520	4550
EAQS 200 ug/m ³	>	>	>	>
WHO 120 ug/m ³	>	>	>	>
SO ₂	44.6	30.7	28.5	2.60%
EAQS 200ppb	<	<	<	<
WHO 120ppb	<	<	<	<
NO _x	156.6	74.7	148.5	6.05%
EAQS 40-60ppb	>	>	>	<
WHO 110ppb	>	<	>	<
CO	7.36	4.04	3.30	64.87%
EAQS 20ppm	<	<	<	<
WHO 35ppm	<	<	<	<

< Means less than the standard value, >Means greater then the standard value

Ref: Comparison with comments on air quality analysis written by Y.SHIGETA (JICA Environment Expert, Pak-EPA).

mean Quartz (36.35), Illite (35.18), Calcite (33.32), Clinchlore (23.26) and Albite (20.36) come from both local and remote areas. Minor phases like R, AN, HM, HL, SP, MU and WS of metallic, semi-metallic and non-metallic nature are not detected because of large size and settling down property due to gravimetric effect. They are acting as pollutant agents forming complex compounds between air and industrial transport setup confirmed through color and odor test.

- Adverse influence of climatological factors on pollutant dispersion forms pollutant webs favoring the probability of an acidic rain, but the alkaline nature of the identified phases are not happening for the time being.

- Ten toxic metals used as trace elements like Cu, Mn, Zn, Fe, Ca, Ni, Cd, Mg, Cr and Co were also detected showing no co-relationship with location and zoning of Faisalabad Environment.

- Green house gases were also detected in the environment showing the mixed trend.

- Comparison with other western cities of the world and the most polluted Indian cities showed that the Environment of Faisalabad is not fit for healthy living, though neubration misfitness of most of the compounds make it more complex.

FUTURE RECOMMENDATIONS

The problem of environmental pollution due to solid aerosols is getting the attention of the scientists and researchers in almost all parts of the world. But in Pakistan no appreciable work has been done on this issue so far. The concerned departments and environmental scientists must take interest and put more effort for solid aerosol monitoring on a large scale.

This study is an indication that AAS technique could be used for pollutants source identification. However, complete source apportionment could be done after a detailed study covering all the seasons of the year and involving measurements of a large number of elements in the air especially emission sources related to industrial, commercial, residential, urban, sub-urban, local and remote areas, solid wastes from industries, hospital, households, municipal corporation, etc.

- It is suggested that one area should be studied at a time with at least one thousand samples (5 per site) collected in different seasons in different meteorological conditions from different selected areas for exact and long term evaluation.

- Background levels of solid aerosols including heavy metals may be assessed in other related parameters like ground water, plants, vegetables, water from rain, food stuffs and their additive pollutants in the related environment.

- Analysis of filter residues in filters may be assessed because many trace elements may remain there.

- Soil and water analysis of the concerned environment for comparison may also be carried out to elucidate the more accurate results.

- Environmental monitoring system joint venture by Pak EPA, Japan 2007 for big cities of Pakistan should be appreciated and implemented in letter throughout the country especially in Faisalabad.

- The measures taken by the Government of Punjab's Transport Department on the banning of two stroke vehicles and the induction of four stroke CNG Rickshaws and buses should be fully utilized for Faisalabad also.

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REFERENCES

- Adedokun JA, Emofurieta WO, Adedeji O.A (1989). "Physical, Mineralogical and chemical properties of harmattan dust at Ile-Ife, Nigeria". *Theoretical Appl. Climatol.*, 40:161-169.
- Arslan M, Boybay M (1990). A study on the characterization of dust fall. *Atmos. Environ.*, 24: 2667-2671.
- Bonita R, Beaglehole R, Kjellstrom W (2006) *Basic Epidemiology*. Ed. 2nd. World Health Organisation.
- Brunekreef B, Holgate ST (2002). Air Pollution and health. *Lancet*, 360: 1233-1242.
- Bish DL, Post JE (1993). Quantitative mineralogical analysis using the Rietveld full-pattern fitting method. *Am. Mineral.*, 78: 932-940.
- Battaglia S (1985). Quantitative x-ray diffraction analysis on thin samples deposited on cellulose membrane filters. *X-Ray Spectroscopy*, 14: 16-19.
- Connor BH, Jaklevic JM (1981). Characterization of ambient aerosol particulate samples from the St. Louis area by x-ray powder diffractometry". *Atmos. Environ.*, 15: 1681-1690.
- Catherine H, Skinner W (2007). *The Earth Source of the*

- Health Hazards: An Introduction to Medical Geology. *Annu. Rev. Earth Planet.Sci.*, 35: 177-213.
- Chung FH (1974a). "Quantitative Interpretation of x-ray diffraction patterns of mixtures I. Matrix-flushing method for quantitative multicomponent analysis. *J. Appl. Crystallogr.*, 7: 519-525.
- Chung FH (1974b). Quantitative Interpretation of X-ray diffraction patterns of mixtures II. Adiabatic principle of X-ray diffraction analysis of mixtures. *J. Appl. Crystallogr.*, 7: 526-531.
- Chung FH (1975). Quantitative Interpretation of X-ray diffraction patterns of mixtures III. Simultaneous determination of a set of reference intensities. *J. Appl. Crystallogr.*, 8: 17-19.
- Cullity BD (1978). *Elements of X-ray Diffraction*, Addison-Wesley, London.
- Clarke G, Karani GN (1992). Characterizations of the carbonate content of atmospheric aerosols". *J. Atmos. Chem.*, 14:119-128.
- Davis BL (1978). Additional suggestions for x-ray quantitative analysis of high volume filter samples. *Atmos. Environ.*, 12: 2403-2406.
- Davis BL (1980). Standardless X-Ray diffraction quantitative analysis. *Atmos. Environ.*, 14: 17-220.
- Davis BL (1981). A study of the errors in x-ray quantitative analysis procedures for aerosols collected on filter media". *Atmos. Environ.*, 15: 291- 296.
- Davis BL, Johnson LR (1982). On the use of various filter substrates for quantitative particulate analysis of x-ray diffraction. *Atmos. Environ.*, 16: 273-282.
- Davis BL (1984). X-ray diffraction analysis and source apportionment of Denver aerosol. *Atmos. Environ.*, 18: 2197-2208.
- Davis BL, Smith DK (1988). Tables of experimental reference intensity ratios. *Powder Diffraction*, 3: 205-208.
- Davis BL, (1989).Semi-quantitative X-ray diffraction analysis of size fractionated atmospheric particles. *Atmos. Environ.*, 23: 2329-2332.
- Davis BL, Smith DK, Holomany MA (1989). Tables of experimental reference intensity ratios table no. 2". *Powder Diffraction*, 4: 201-205.
- Davis BL, Spilde MN (1990). Quantitative x-ray powder diffraction analysis applied to transmission diffraction. *J. Appl. Crystallogr.*, 23: 315-320.
- Davis BL, Kath R, Spilde M (1990). The reference intensity ratio: Its measurement and significance. *Powder Diffraction*, 5:76-78.
- Davis BL, Cho NK (1977). Theory and application of X-ray diffraction compound analysis to Hi-Volume filter samples. *Atmos. Environ.*, 1: 73-85.
- Esteve V, Justo A, Amigo JM (1994). X-ray diffraction analysis of airborne particulates collected by a cascade impactor sampler phases distribution versus particle size". *Mater. Sci. Forum*, 166-169: 705-710.
- Esteve V, Rius J, Ochando LE, Amigo JM (1997). Quantitative x-ray diffraction phase analysis of coarse airborne particulate collected by cascade impactor sampling. *Atmos. Environ.*, 31: 3963-3967.
- Foster RL, Lott PF (1980). X-ray diffractometry examination of air filters for compounds emitted by leads melting operations. *Environ. Sci. Technol.*, 14: 1240-1244.
- Fukasawa T, Iwatsuki M, Tillekeratne SP (1983). X-ray diffraction analysis of airborne particulates collected by an Andersen sampler: Compound distribution vs. particle size". *Environ. Sci. Technol.*, 17: 596-602.
- Fukasawa T, Iwasuki M, Tillekeratne SP (1983). X-ray diffraction analysis of airborne particulates collected by an Andersen sampler. Compound distribution vs. particle size. *Environ. Sci. Technol.*, 17: 596-602.
- Harrison RM, Sturges WT (1984). Physico-chemical speciation and transformation reactions of particulate atmospheric Nitrogen and Sulphur compounds. *Atmos. Environ.*, 18: 1829-1833.
- Hussain K, Riffat R, Shaukat A, Siddiqui MA (1990). A Study of Suspended Particulate Matter in Lahore(Pakistan). *Adv. Atmos. Sci.*, 7: 178-185.
- Iwatsuki M, Tillekeratne SP, Fukasawa T(1984). X-ray analysis of airborne particulates collected by an Andersen sampler, Compound and elemental distributions vs particle size of laboratory particulates. *Environ. Sci. Technol.*, 18: 818-822.
- Nakamura T (1988). Quantitative Determination by x-ray diffractometry of calcium sulfate and calcium carbonate in airborne dusts", *Powder Diffraction*, 3: 86-90.
- Mavroidis I, Chaloulakou A (2010). Characteristics and expected health implications of annual PM₁₀ concentrations in Athens, Greece. *Int. J. Environ. Poll.*, 41: 124-139.
- Peter D, Biggins E, Roy Harrison M (1979a). Atmospheric chemistry of automotive lead", *Environ. Sci. Technol.*, 13: 558-565.
- Peter D, Biggins E, Roy HM (1979b). Characterization and classification atmospheric sulfates. *J. Air Pollut. Control Assoc.*, 29: 838-840.
- Rowe DR, Nouth MA, Al-Dhowalla KH (1985). Indoor-Outdoor relationship of suspended Particulate matter in Riyadh, Saudi Arabia. *JAPCA*, 35: 24-26.
- Rius J, Plana F, Palanques A (1987). A standardless X-ray diffraction method or the quantitative analysis of multiphase mixtures. *J. Appl. Crystallogr.*, 20: 457-460.
- Roberts P, Hallett J (1968). A laboratory study of the ice nucleating properties of some mineral particulates, *Quart J. Roy Meteorol. Soc.*, 94: 25-34.
- Shahid MAK (2008). A comprehensive investigation of solid aerosols using RPD and AAS Techniques. Ph. D., Thesis, Department of Physics, Punjab University,

- Lahore, Pakistan.
- Shahid MAK (1997). Radioactive pollution and its Health Hazards, A study by SSNTDs and XRPD Analysis M. Phil. Thesis, Centre for Solid State Physics, Punjab University, Lahore, Pakistan.
- Shahid MAK, Hussain K, Mahmood A (2007). Global warming trends at Faisalabad by Attiq-Khan-Shahid, Dr. Khadum Hussain and Arif Mahmood. *Nat. Forming Environ.*, 6(1): 12-18.
- Shahid MAK, Hussain K, Awan MS (2012). Physico-Chemical Analysis of Solid Aerosols Generated from Different Industries of Faisalabad. *J. Basic Appl. Sci.*, 8(2): 498-507.
- Shahid MAK, Awan MS, Hussain K, Sabir R (2013). Acidic rain probability and solid aerosol concentration in the atmosphere of Faisalabad (Pakistan). *Peak J. Phys. Environ. Sci. Res.*, 1(2): 12-22.
- Shahid MAK, Hussain K (2013). Quantification and Characterization of Solid Aerosols collected from various Zones of Faisalabad city and their associated Health Hazards. *Int. J. Environ. Sci. Technol. Environ. Res.*, 1(1): 17-32.
- Sturges WT, Harrison RM, Barrie LA (1989). Semi-quantitative x-ray diffraction analysis of size fractionated atmospheric particles". *Atmos. Environ.*, 23: 1083-1098.
- Shahida P (2000). Characterization of the compounds present in the atmosphere of Rawalpindi using x-ray diffraction technique, M.Sc. Thesis, Department of Physics, University of Agriculture, Faisalabad.
- Senlin L, Qixia L, Zheng J, Minghong W, Zhen L, Longyi S, Fushun W (2007). Mineralogy of inhalable particulate matter (pm10) in the atmosphere of Beijing, China". *Water, Air Soil Pollut.*, 186: 129-137.
- The Powder Diffraction File, Joint Committee on Powder Diffraction Standards, 1980.
- Tani B, Siegel S, Johnson S.A, Kumar R (1983). X-ray diffraction investigation of atmospheric aerosols in the 0.3-1.0 μm aerodynamic size range. *Atmos. Environ.*, 17: 2277- 2283.
- Warner PO, Saad L, Jackson JO (1972). Identification and quantitative analysis of particulate air contaminants by x-ray diffraction spectrometry. *J. Pollut. Control Assoc.*, 22: 887-890.