Seasonal Variations and Characterization of Solid Aerosols Related to Faisalabad (Pakistan) Environment

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Abstract: Black solid aerosols were monitored continuously at Faisalabad using Gaussian dispersion model and nucleation model. Data for one year 2006 was analyzed here keeping in view the meteorological and climatological conditions of Faisalabad co-relating them with concentration gradient. Winter has minimum concentration, i.e. equivalent to background level followed by summer (598.80 $\mu g/m^3$), Moon Soon (2762.00$\mu g/m^3$) and finally Post Moon Soon (8863.00$\mu g/m^3$). Temperature and pressure gradients both were negative co-relationed with black solid aerosols. These results were not in accordance with other studies, the reason may be the complexity of the Faisalabad environment on account of its geographical, geological and industrial setup confirmed by longitudinal, latitudinal effects and mix plume behavior. A positive co-relationship between biomass burning and seasonal variation i.e. low concentration of particulate matter i.e., 637.30 $\mu g/m^3$ in summer and high in winter such as 3954 $\mu g/m^3$.

Keywords: Black solid aerosols, Gaussian dispersion model, meteorological and climatological conditions, Temperature and pressure gradients, complexity of the Faisalabad environment.

1. INTRODUCTION

Atmospheric black carbon (BC) or coated aerosols particles are one of the crucial factors in the global climate change phenomena. This is mainly due to their absorptive nature, which directly accounts for the reduction in incoming shortwave solar radiation that leads to the heating of atmosphere. Whereas, at surface they give cooling effect, thus changing possibly the temperature structure in the troposphere which in turn affects the cloud micro physical properties and thereby rainfall mechanism [1]. Also, BC aerosols have been reported to be acting as cloud condensation nuclei (CCN), once they become hydrophilic [2]. In this study we described the role of BC in clouds whereby they burn off the cloud due to more heating. Apart from this, BC aerosols play an important role in tropospheric chemistry due to their porous and adsorptive nature that helps as a site for some of the chemical transformations like oxidation of SO_2 to SO_4, conversion of HNO_3 vapors to NO and NO_2 and destruction of O_3 and formation of CO [3, 4].

From human health point of view, these particles, which are generally submicron in size, pose a great threat of pulmonary diseases as they can penetrate up to lungs and also can carry some toxic elements with them. Considering the key role they play in atmospheric radioactive as well as chemical properties, studies on BC aerosols have become an important topic in recent years. Especially after the INDOEX studies, the importance of anthropogenic emissions from south Asian countries in affecting the atmosphere over north Indian Ocean has already been significantly highlighted [5, 6]. Biomass burning for agricultural and domestic purposes, from Indo plain regions has been reported to be the major source for BC emissions [7].

However, there is very few data available on BC aerosols from the Indian region though some studies [4, 8-11] reported characteristics of BC especially from the southern part of the country. But data on carbonaceous aerosols like BC particles are non-existent. In the present study, seasonal and longitudinal/latitudinal variations of BC have been discussed particularly in relation to changing meteorological conditions throughout the year. Also, the possible sources for these aerosols have been identified. Location and general meteorology of the sampling site was also noted throughout the study period.

Faisalabad, with 4 million population, is the third largest industrial city in Pakistan. Textile related Industry is spread in and around all parts of the city without the distinction of locality. This heavy industry is a major source of air pollution in the area. Also there are eight intercity high ways which lead to and out of the city. These roads are so busy that heavy traffic flows round the clock.

The district lies between East longitudes 73° and 74° and North latitudes 30° and 31.15°. It is bounded in its North by Gujranwala and Sheikhupura districts. In

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the East by Sheikhupura and Sahiwal districts and In the West by Jhang district [12].

The climate of the district is hot and dry. Its mean maximum and minimum temperatures in summer are about 39°C and 27°C and in winter about 21°C and 6°C respectively. Its summer season starts almost from the end of March and stretches up to October. May, June and July are the hottest months. The winter months are November, December and January, December and January are the coldest months. The rainy season is from July to September, July and August receives more rains than any other months of the year. Most of the winter rains are rained in the months of January, February and March. The mean minimum humidity in winter ranges from 46.9% in March to 54.5% In December while the mean maximum humidity in summer ranges from 57% in May to 79.5% in August. The mean maximum humidity in rainy season is 77.7% and the mean minimum humidity in rainy season is 59.9% (Source; Meteorological Cell Department of Crop Physiology University of Agriculture Faisalabad). Detailed knowledge of aerosol composition and meteorological conditions is helpful for identification and localization of pollutants as the characteristics of aerosol particles depend on the season. Significant differences in morphology and chemical compositions of aerosol particles collected from Faisalabad environment confirmed this state of affairs. This paper describes the change in morphology and chemical compositions of solid aerosols related to Faisalabad environment along with altitude, latitude, effect, concentration gradient, fall rate in relation with meteorological data using Gaussian dispersion model and ice nucleation model. Generally an increase in concentration of the pollutants along with dislocation will raise the interfacial energy between embryo and the nucleating particulate matter hence its nucleability and adversely disturbs the radiation balance of the environment causing abnormal global warming or abnormal global cooling which is directly co-related with the seasonal variations.

2. METERIALS AND METHODS

2.1. Theoretical Modeling

2.1.1. Nucleation of the Ice of Particulate Matter (Nucleation Model Developed by Vonnegut (1947))

According to the model developed by Vonnegut (1947), Lattice misfit can be calculated using the following Expressions:-

$$\text{Basal misfit} = \left|\frac{a-a_0}{a_0}\right| \times 100 \quad (1)$$

$$\text{Prism misfit} = \frac{1}{2}\left\{ \left|\frac{a-a_0}{a_0}\right| \times 100 + \left|\frac{c-c_0}{c_0}\right| \times 100 \right\} \quad (2)$$

2.1.2. Gaussian Dispersion Model

This part of the study was carried out after following Gaussian dispersion model developed by Pasquil (1961).

The mathematical formulism used in this model as follows.

$$C_{x,y,0} = \frac{Q}{\pi\sigma_y \sigma_z \bar{\mu}} Exp - \left(\frac{H^2}{2\sigma_z^2} + \frac{+y^2}{2\sigma_y^2}\right) \quad (3)$$

Where,

c = ground level concentration in $\frac{\mu g}{m^3}$

Q = release rate from stack μg / Sec.

σ_y = cross wind standard deviation.(meter)

σ_z = vertical standard deviation.

$\bar{\mu}$ = mean wind speed.

H = effective stack height. (meter)

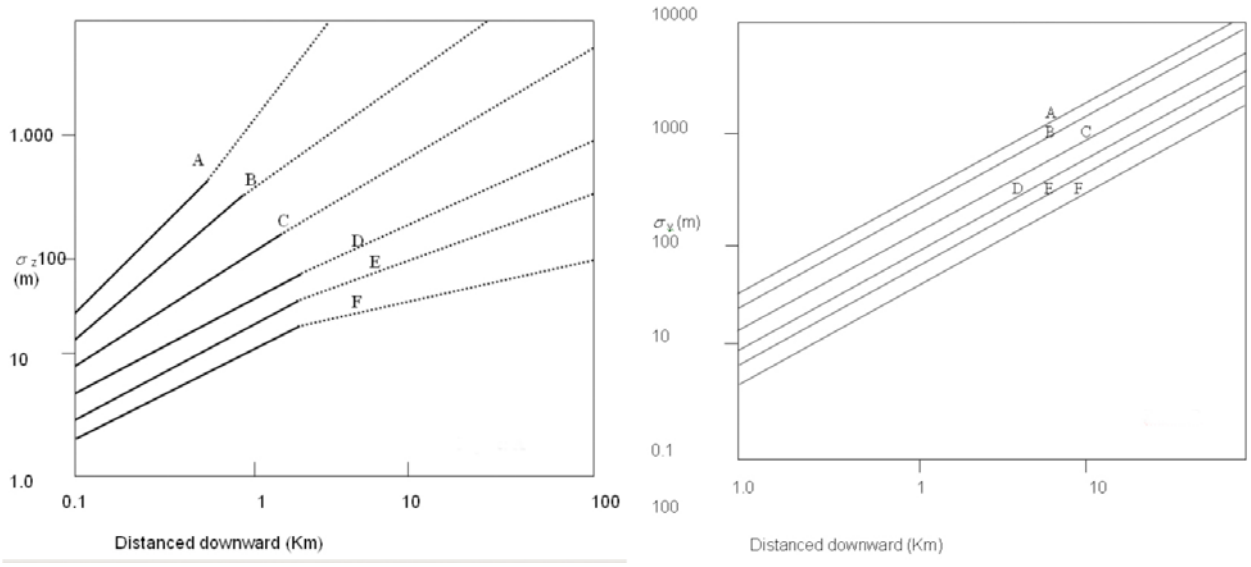
x,y = down wind and cross wind distances respectively in meters.

The vertical standard deviation and cross wind standard deviation also called dispersion coefficients, are a function of atmospheric stability and the distance downward for which the calculation is being made. Graph **1** summarizes these dispersion coefficients in horizontal and vertical directions. It is possible to calculate direct ally the maximum ground level concentration from an elevated point source. The location X of the maximum ground concentration will occur approximately where

$$\sigma_z = H\sqrt{2} \quad or\ H = \frac{\sigma_z}{\sqrt{2}} \quad (4)$$

For a given stability condition, the maximum concentration can be calculated from [13, 14, 15]

$$C_{x,0,0}\ \max = \frac{0.117Q}{\sigma_y \sigma_z \bar{\mu}} \quad (\mu g/m^3) \quad (5)$$



Graph 1: Vertical distribution of solid aerosols.

2.3. SEM

SEM (Hitachi S-2380N) at 2.5KV was used for obtaining micrographs of solid aerosol samples. Photographs with different magnifications were taken using a digital Camera. Micrographs obtained were marked with different photo numbers as codes, the values of voltage applied, the Magnification and a line mark for measurement of particle size.

3. RESULTS AND DISCUSSION

Regression Equation Used

$$Y = 142.7615\text{-}0.0595X$$

with $R^2 = 0.99$ (6)

where Y = TSPM (Rate)

X = Distance from the source of TSPM

Fall rate was calculated using the relation fall rate= 21.63 wt/ A (Tons / Km^2 /month) Where wt = Total weight of the TSPM (g/cm^2) A = Surface area of the deposited dish (cm^2) Concentration is inverse square law follower.

N-W high concentration maximum load of TSPM. (Sheikhupura to Jhang) S-E Low concentration minimum load of TSPM. (Sahiwal/Okara to Sheikhupura). Which is due to Geographical and Geological setup of the selected environment. Figure **1** shows the Longitudinal, Latitudinal and Wind Direction Effect.

Black solid aerosols are of great importance in several processes in the atmosphere such as formation of clouds, irradiative transfer and transport of chemical species. The various processes often depend on the chemical compositions and size of the aerosols. The properties of aerosols can vary over a vide range of

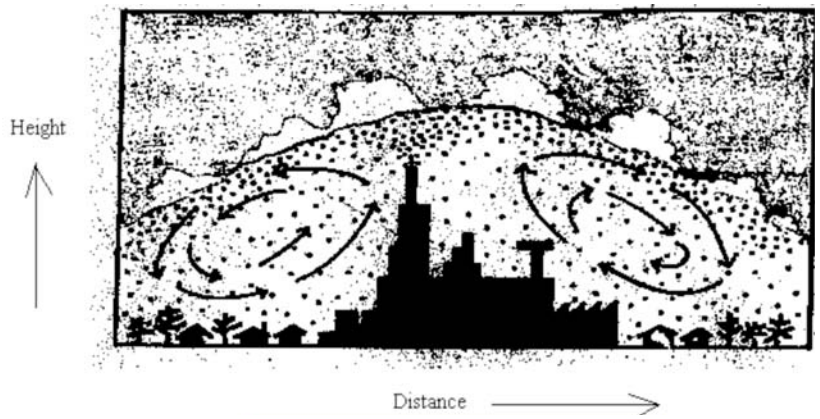


Figure 1: Wind pattern in Faisalabad environment.

different meteorological conditions. For the determination of aerosols properties complex interaction have to be taken into account. This includes processes such as condensation and evaporation, coagulation, nucleation, gravitational settling, emission and deposition, advection and diffusion. A dominant fraction of solid aerosols comes from secondary sources, where they modify their chemical composition and size during their life cycles by condensation or evaporation of gaseous precursors like ammonia, sulfuric and nitric acid, hydrogen chloride and water vapors. In this way the study of nucleation becomes very important for pollution assessments [7, 16].

In this study, the theoretical models developed by Vonnegut (1947), was used to calculate the lattice misfit parameters. The most of the identified phases in the present study have large values of both misfit parameters i.e., Basal misfit and Prism misfit for their percentages please see the Table **1**.

So they will behave as poor ice nuclei particularly illite (15.40/95.10), talc (17.5/88.0), calcite (10.9/71.7), choliridte (18.3/56.10) and albite (81.0/41.7). They remained suspended in the atmosphere for longer period of time depending upon their size; hence supplement the pollution level of the atmosphere.

The data based on acidity, electrical conductivity and chemical composition of solid aero soles, related to nucleation and precipitation was calculated and analyzed which shows the wide variation in pH value that may be attributed to the relative contribution in the various solid aero soles scavenged by cloud and rain drops. Generally the cloud droplets are initially acidic due to the formation of HNO_3 in the environment. High pH value of more than 8.0 and above was noted in most of the samples collected from environment under study which may be due to alkaline species dominated over the acidic species due to higher hydrophobic nature of solid aero soles. They enter the drops through variety of scavenging process. Acidic SO_4^{-2}

Table 1A: (Special): Key to Stability Categories

Surface wind speed ($^m/_s$) at 10 m height	Day			Night	
	Strong [b]	Moderate [c]	Slight [e]	Thinly overcast or > $^1/_2$ cloud [e]	Clear to <$^1/_2$ cloud
>2(4.5 $^{mi}/_{hr}$)	A [f]	A-B	B	---	---
2-3 (4.5-6.7 $^{mi}/_{hr}$)	A-B	B	C	E	F
3-5 (6.7-11 $^{mi}/_{hr}$)	B	B-C	C	D	E
5-6 (11-13.5 $^{mi}/_{hr}$)	C	C-D	D	D	D
>6 (>13.5 $^{mi}/_{hr}$)	C	D	D	D	D

[a]Insolation, amount of sunshine.
[b]Sun > 60^o above horizontal ; sunny summer after noon; very convective.
[c]Summer day with few broken clouds.
[d]Sunny fall after noon ; summer day with broken low clouds; or summer day with sun 15^o to 35^o with clear sky.
[e]Winter day.
[f]Class a indicate greatest amount of spreading and most unstable atmospheric conditions, and class f indicates least spreading and most stable atmospheric conditions.

Table 1B: Comparison of Cell Dimensions of Ice and Minerals Identified in Suspended Particulate Matter

Identified Phase	Crystal System	a (A^o)	c (A^o)	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 2: Seasonal Variation vs Pollution Concentration

Sr. No	Season	Temp. gradient (°C)	Pressure gradient (KPa)	Concentration gradient	Remarks
1	Summer (Mar-May)	13.20	118.55	598.80	Low
2	Moon Soon (Jun-Sept)	6.50	115.06	2762.00	High
3	Post Moon Soon (Oct-Nov)	3.80	30.99	8863.30	Very High
4	Winter (Dec-Feb)	22.70	43.97	Nil (Equivalent to background)	Extremely low

Table 3: Latitude Effect on the Concentration of Particulate Matter

Serial No	Latitude (m)	Fall Rate (Tons/km^2.month)
1	3	125
2K02	6	105
2K03	9	89
2K04	12	72
2K05	15	55

Table 4: Fall Rate Versus Wind Direction (Tons/km^2.month)/Wind Direction

Distance	N-W	S-E	N-E	S-W
3 m	174	78	126	105
6m	148	64	108	102
9m	128	52	94	86
12m	106	38	72	72
15m	85	25	55	54

Table 5: Meteorological Characteristics of Selected Area of Study

Parameter	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Solar Rad(mj/m^2)	16.52	20.62	23.51	23.84	19.59	16.79	18.41	15.59	12.28	8.53
Air TEMP Max/Min c^o	28.40/ 19.90	31.60/ 15.90	41.60/ 23.10	42.60/ 25.50	37.50/ 26.20	36.10/ 25.10	36.90/ 25.40	34.30/ 16.60	30.50/ 10.70	22.70/ 5.60
WSP(m/s)	0.70	1.00	0.70	0.80	1.00	0.40	0.40	0.30	0.00	0.00
Pressure (K Pa)	73.05	95.41	191.60	197.80	133.30	82.74	116.60	102.20	71.21	43.97
RH (%)	72.29	58.33	48.60	51.60	69.06	75.37	68.50	67.13	73.30	80.80
Max R F(mm) 24 Hr	46.50	42.20	36.50	58.00	107.00	175.00	113.50	39.20	22.60	37.80
Precipitation	23	14	09	29	96	96	20	12	02	08

Ref: Meteorological Center NIAB, UAF, AARI.

Table 6: Altitude Effect on the Concentration of Particulate Matter

Code	GND (µg/m^3)	15 F (µg/m^3)	30 F (µg/m^3)
1	70.07	72.39	75.87
2K02	172.52	170.81	165.98
2K03	159.28	145.96	139.89
2K04	520.32	505.23	495.75
2K05	112.38	110.88	89.98
2K06	16.85	160.82	200.08
2K07	201.92	173.52	168.85

ions present in the drops are neutralized by minerals such as$CaCO_3$, $NaHCO_3$ or Na_2CO_3 to form $CaSO_4$ or $NaHSO_4$ and the excess carbonates which dissociate in solution, cause the rain drops to be more alkaline. Wide range values of Ec indicate the effect of geological formations and degree of anthropogenic pollution. Most of the samples had low Ec values which indicate the occurrence of frequent rains acting as washing agent and making the environment clean and friendly; Less conductance means more resistance which indicate the more rigidity, non solubility of pollutants, and stability of the Faisalabad's environments, slightly agreed with national, international studies Tables **7** and **8**.

Table 7: Probability of Acidic Rain

Zone	PH Value	Probability
N Zone	7-8	49.42%
H Zone	8-9	41.86%
VH Zone	9 & above	8.72%

Table 8: Probability of Acidic Rain with Respect to Color

Color	Probability
Light Color (Acidic)	20%
Dark Color (Basic)	80%

Key ---------- N = Normal H = High VH = Very High.

The longitudinal distribution patterns of solid aerosols with respect to height are given in tables 2K03-2K06 the amount of solid aerosols and ground were 70.07,172.52, 159.28, 520.32, 112.38, 16.82, 201.92 respectively, their concentration decrease to 165.98, 139.89, 495.15, 89.98, 168.85 at 30 Feet height (Inverse square law follower). In some cases like 1, 2K06, their concentration increased to 75.87, 200.08 at 30 Feet height which may be attributed to some steal rolling mills working within the vicinity of the selected area as the dark brown fumes from steel furnaces are released at about 30 Feet height and due to high inertia these fumes slowly settle down exerting their effect with the increase in height on neighboring locality. The second main cause may be due to dust blowers of pulp and paper industries installed that at approximate 30 Feet height for dust and straw separation. High concentration of solid aerosols at 30 feet indicates that these aero soles are very fine in nature and due to slight atmospheric disturbances as given in tables 2K02 and 2K05. They go up and contaminate the upper atmosphere. The reverse trends in concentration of solid aero soles was also observed which indicate some soil contribution OR anthropogenic activity at 30 feet height higher amount is also due to vehicle exhausts, exhaust from Chimneys of various chemical plants and boiler houses. In boiler houses furnace oil and natural gas is used for the production of steam, furnace oil contains heavy elements along with sulpher compounds which were removed through chimneys along with gaseous emissions and contaminate the upper atmosphere. The formation of Faisalabad urban boundary layer (UBL) at 30 ft x 15M probably related to the urban canopy may cause the shielding of solar radiation and hence decrease in luminosity and traffic accident rates becomes more significant during morning and evening (Expansion in the canopy) at noon (Contraction of the canopy) like rubber spring.

Wind direction effect, longitudinal and altitudinal effects on the concentration of solid aerosols shows that N–W direction has maximum load, hence it may be considered as potential danger region for acidic rain but due to Alkaline nature of Carbonates, bicarbonates of Ca, Na, K and Mg this may not happen. S–E direction has minimum load which favors the non

occurrence of acidic rain, so in near future the Faisalabad environment may be considered as safe environment from acidic rain point of view. This state of affairs shows that instead of direct meridional flow ,due to coriolis force produces turbulent flow. Friction of particulate matter effects the winds, reducing the effects of coriolis force which converts the turbulent flow in to highly complicated system of movement checked through froude number F, $F=V^{mean}\sqrt{gd} \geq 1$ whose value becomes super critical. The acidic rain probability may however be completely ruled out in H and VH -zones because of the high resistive capacity i.e. alkaline nature of solid aerosols to completely neutralize the acidity of the environment at present zone is in safe mode but due to change in industrial and Transportational set up it may be turned in sensitive zone and acidic rain may happen future studies on this subject will however throw more light on this aspect wide range values of Ec (0.21 to 13.30) indicates the effect of geological formations and degree of anthropogenic pollution. General increase in dissolved pollutants increase in Ec and converse. Low values of Ec means clean environments and conversely more resistivity which indicates the rigidity of the environment and non solubility of the pollutants. Electrical conductivity is more favorable through solids and stagnant fluids, less responsible in liquids and gases along with clean and fresh environment. Our experimental results show that about (73.42%) of environment has been polluted mostly through solid aerosols and stagnant pollutants dispersed by industrial and Transportational set up of Faisalabad environment. Latitude and Altitude effects indicate that concentration of solid aerosols follow inverse square law, except some samples collected from sites of special scientific interests (S^3I). This shows the heterogeneous and complex culture of Faisalabad environment. No doubt these results are slightly disagreeable with international standards, but such type of information is very vital to know the geographical and geological set up of concerned environment [17].

These results were not in accordance with other studies [18-34], the reason may be the complexity of

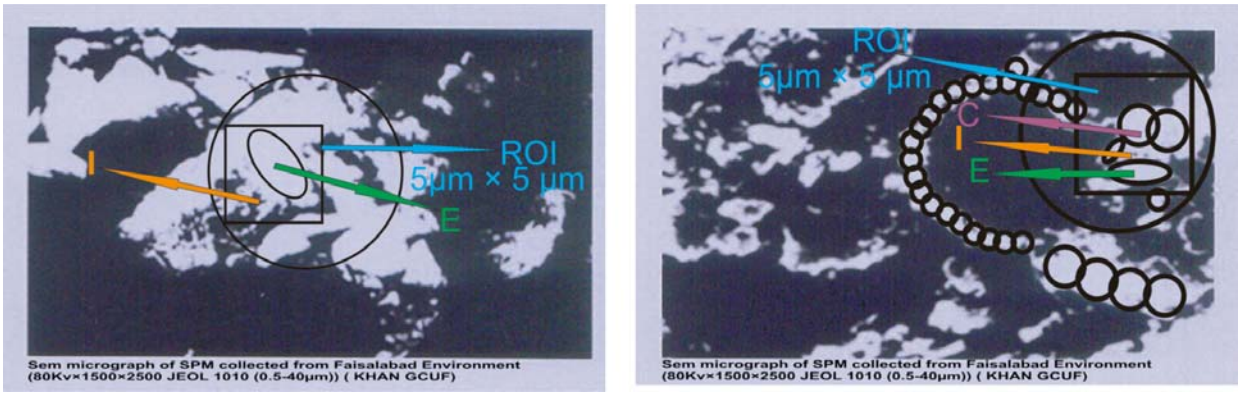


Figure 2: SEM micrographs in summer season.

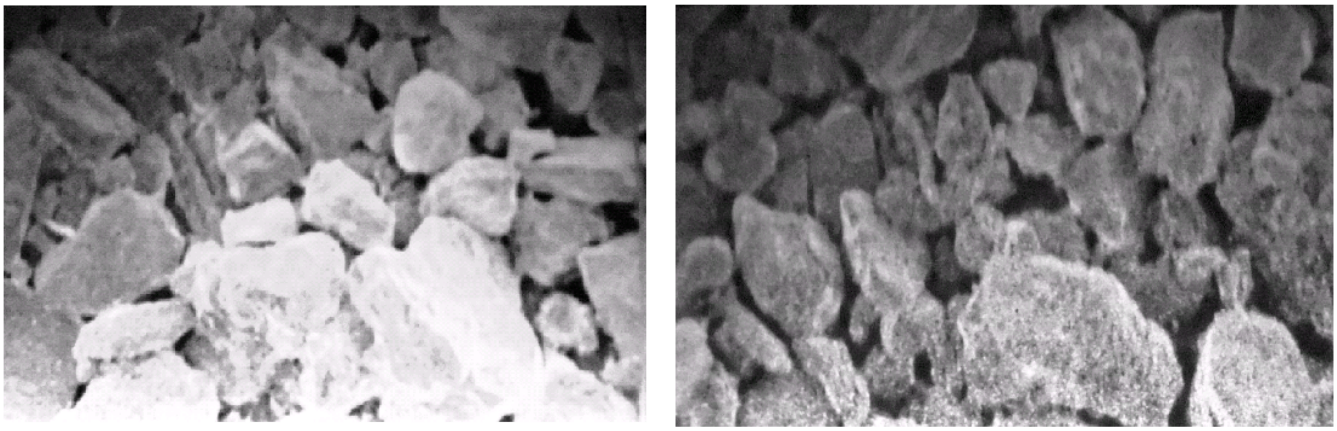


Figure 3: SEM micrographs in winter season.

the Faisalabad environment due to its geographical, geological and industrial setup confirmed by longitudinal, latitudinal effects and mix plume behavior. Luckily there is a positive co-relationship between biomass burning and seasonal variation i.e. low concentration of particulate matter 637.30µg/m^3 in summer and high in winter 3954µg/m^3 i.e., approximately the same pattern was observed in both, particle size distribution and aerosol morphology. In summer coarse particles composed about 26.70% of solid aerosols with the fine fraction making up to 33.67%, while in winter the amount of coarse particles decreased to 10.92% and amount of fine fraction increased to 43.74%. The examples of SEM micrographs showing these variations are shown in Figures **2** and **3**.

However, continuous research is needed like other developing countries to gain better scientific understanding not only for evaluation of homogeneity and heterogeneity of Faisalabad environment with respect to climatology and meteorology but also for the technological development of controlled environment inventions essential for better living conditions in order to achieve the sustainability of ecosystem and better living conditions for the human beings.

CONCLUSIONS

Following are the important conclusions of this study:

(i) low concentrations of the solid aerosols (637.30 µg/m^3) in summer and high concentration (3954 µg/m^3) in winter along with low concentration gradient in summer (598.80) and extremely low gradient in winter (equivalent to background level) have positive correlation ship with season and negative correlation ship with temperature and pressure gradient.

(ii) In most of the locations decrease in concentrations with increase in height (inverse square law followers) and in some cases reverse behavior (inverse square law violators) was observed which confirms the meteorological and climatological interactions with transport and industry, the main contributors of the environmental pollution.

(iii) Formation of urban boundary layer (UBL) canopy from Sheikhupura to Jhang (N-W maximum burden) to Okara to Sheikhupura (S-E low burden) confirms the contraction and expansion of solid aerosols i.e., their hydroscopic and hygroscopic nature.

(iv) Seasonal variations has direct effect on size and morphology of the aerosols 26.70% coarse and 33.67% fine fraction in summer and 10.92% coarse and 43.74% fine fraction in winter were the clear indication in this respect (see SEM micrographs).

(v) Black carbon (coated aerosols) has adverse effect on radiation budget due to their scattering and absorption property, not only disturbing the physico-chemical processes taking place in the environment but also changing the global warming and global cooling patterns.

FUTURE RECOMMENDATIONS

The present study revealed that pollutants present in the environment generated by the vehicle exhaust are being released continuously as a result of wear and tear and contaminate the road side ecosystem from where it is taken up by the leaves of different plants, vegetables and fruits, eaten by animals and human beings. In this way they are health hazardous which is confirmed through regular check up and monitoring of urban parks. So the regular check up and monitoring of urban parks should be made on emergency basis. Several key questions about the predictability of atmospheric nucleation in general about the substances, that take part in nucleation and subsequent growth and about the size and composition of the critical cluster have not so for been resolved. These questions must be addressed and their proper solutions may be found out in near future.

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REFERENCES

[1] Menon S, Hansen J, Nazaren Ko L, Leo Y. Climate effects of BC aerosols in China and India. Science 2002; 297(5590): 2250-53. http://dx.doi.org/10.1126/science.1075159

[2] Ackerman AS, Toon DB, Stevens DE, Heymsfield AJ, Ramanathan V, Welton EJ. Reduction of tropical cloudiness by soot. Science 2000; 288: 1042-47. http://dx.doi.org/10.1126/science.288.5468.1042

[3] Disselkamp RS, Carpenter MA, Cowin JP. A chamber investigation of nitric acid—soot aerosol chemistry at 298 K. J Atmosp Chem 2000; 37: 113-23. http://dx.doi.org/10.1023/A:1006304724241

[4] Latha KM, Badrinath KVS. Correlation between BC aerosols, carbon monoxide and tropospheric ozone over a tropical urban site. Atmosp Res 2004; 71: 265-74. http://dx.doi.org/10.1016/j.atmosres.2004.06.004

[5] Ramanathan V, Crutzen PJ. New directions: atmospheric brown clouds. Atmosp Environ 2003; 37: 4033-35. http://dx.doi.org/10.1016/S1352-2310(03)00536-3

[6] Lelieveld J, Crutzen PJ, Ramanathan V, Andreae MO. The Indian Ocean experiment: widespread air pollution from south & southeast Asia. Science 2001; 291: 1031-36. http://dx.doi.org/10.1126/science.1057103

[7] Venkatraman C, Habib G, Eiguren-Fernandez A, Mignel AH, Friedlander SK. Residential biofuels in South Asia: carbonaceous aerosol emissions and climate impacts. Science 2005; 307: 1454-56. http://dx.doi.org/10.1126/science.1104359

[8] Babu SS, Moorthy KK. Aerosol black carbon over a tropical station in India. Geophys Res Lett 2002; 29. http://dx.doi.org/10.1029/2002GLO15662

[9] Babu SS, Satheesh SK, Moorthy KK. Aerosol radiative forcing due to enhanced black carbon at an urban site in India. Geophys Res Lett 2002; 29: doi:10.1029/ 2002GL015826.

[10] Latha KM, Badrinath KVS, Moorthy KK. Impact of diesel vehicular emissions on ambient BC concentration at on urban locations in India. Curr Sci 2004; 86(3): 451-53.

[11] Safai PD, Rao PSP, Momin GA, *et al*. Variation in the chemistry of aerosols in two different winter seasons at Pune and Sinhagad, India. Aerosol Air Quality 2005; 5(1): 115-26.

[12] District Census Report of Faisalabad. Population census organization statistics division Govt. of Pakistan, Islamabad. Eastern Michigian University 1984; pp. 196-200.

[13] Wark K, Warner C, Davis W. Air Pollution Its Origin and Control, Addison Wesley, USA 1998.

[14] Macdonald R. Theory and Objectives of Air Dispersion Modelling, Department of Mechanical Engineering, University of Waterloo, Canada 2003.

[15] Mehdizadeha F, Rifai H. Modeling point source plumes at high altitudes using a modified Gaussian model, Department of Civil and Environmental Engineering, University of Houston, USA 2003.

[16] Tripathi SN, Day S, Tare V, Satheesh SK. Aerosol black carbon radioactive forcing at an industrial city in northern India. Geophys Res Lett 2005; 32: doi:10.1029/ 2005GLO22515.

[17] Schnaiter M, Linke C, Möhler O, *et al*. Absorption amplification of black carbon internally mixed with secondary organic aerosol. J Geophys Res 2005; 110. http://dx.doi.org/10.1029/2005JD006046

[18] Zhang R, Khalizov AF, Pagels J, Zhang D, Xue H, Mcmurry PH. Variability in morphology, hygroscopicity, and optical properties of soot aerosols during atmospheric processing. PNAS 2008; 105(30): 10291-96. http://dx.doi.org/10.1073/pnas.0804860105

[19] Wawroś A, Talik E, Żelechower M, Pastuszka JS, Skrzypek D, Ujma Z. Seasonal Variation in the Chemical Composition and Morphology of Aerosol Particles in the Centre of Katowice, Poland. Polish J Environ Stud 2003; 12(5): 619-27.

[20] Stoyanova VB, Kupenova TN, Tsacheva TI, Marinov MV, Ranguelov BS, Georgieva IS. Atmospheric Dust Aerosols InSofia - Electron Microscope Characterization And Ice Nucleation Properties. J Int Res Publ 2002; 2: http://www.eJournalnet.com.

[21] Tippayawong N, Pengchai P, Lee A. Characterization of ambient aerosols in Northern Thailand and their probable sources. Int J Environ Sci Tech 2006; 3(4): 359-69.

[22] Samoli E, Schwartz J, Wojtyniak B, *et al*. Investigating regional differences in short-term effects of air pollution on daily mortality in the APHEA project: a sensitivity analysis for controlling long-term trends and seasonality. Environ Health Perspect 2001; 109: 349-53. http://dx.doi.org/10.1289/ehp.01109349

[23] Plancon. A consistent modeling of the patterns of mixed-layer phyllosilicates clays and clay minerals 2004; 52(1): 47-54.

[24] Singh AK. Study on physical and chemical characteristics of aerosols, M. Sc. Dissertation. University of Pune, India 2005.

[25] Shahid MAK, Hussain K, Mahmood A. Global warming trends at Faisalabad. Nat Forming Environ 2007; 6(1): 12-18.

[26] Shahid MAK, Sajid MR, Hussain K, Yasin HM, Tabassom. A comparative study of Environmental Air-born particulate pollution in different areas of the Punjab. Nat Forming Environ 2007; 6(1): 32-41.

[27] Shahid MAK, Hussain K, Mahmood A. Ambient Air Quality Status for Lahore City. Nat Forming Environ 2007; 6(1): 42-49.

[28] Shahid MAK, Hussain K, Mehmood A. Ambient Air Quality of selected sites at Faisalabad city. Nat Forming Environ 2007; 6(2): 25-33.

[29] Shahid MAK, Hussain K, Bhatti ZA. Comprehensive investigation of solid aero sols related to industrial areas of Faisalabad 2007; 6(2): 34-46.

[30] Shahid MAK, Hussain K. Estimation of Solid aerosol concentration collected in Faisalabad city. Nat Forming Environ 2007; 6(2): 16-24.

[31] Shahid MAK, Hussain K. Comprehensive Investagation of Solid Aerosols in Faisalabad, Pakistan Atmosphere. Int J Biol Biotech 2007; 4(4): 361-71.

[32] Shahid MAK, Hussain K, Mahmood A. Ambient Air Quality of Some Selected Sites in Faisalabad, Pakistan. Int J Biotech 2008; 5(3-4): 243-47.

[33] Shahid MAK, Hussain K, Nasim H. Comprehensive Investigation of Solid Aerosols and its Co-relationship with Soil Samples at Faisalabad, Pakistan. J Nat Sci 2009; 7(1-2): 54-66.

[34] Shahid MAK, Nasim H. Mapping and Study of the Air Pollution in Faisalabad, Pakistan. J Nat Sci 2009; 7(1-2): 95-103.

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