POTASSIUM AS A MARKER OF CROP RESIDUE BURNING IN TOTAL SUSPENDED PARTICULATE MATTER IN AMBIENT AIR OF PATIALA

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BY

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, **"Potassium as a Marker of Crop Residue Burning in Total Suspended Particulate Matter in Ambient Air of Patiala"**, in partial fulfillment of the requirements for the award of degree of Master of Technology in Environmental Science and Technology submitted in Department of Biotechnology and Environmental Science of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Dr. Susheel Mittal , Head of The School of Chemistry and Biochemistry, Thapar University ,Patiala.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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ABSTRACT

SPM samples of Patiala city collected for two sites for the period of Sept.2006 to Dec.2007 were analyzed for the distribution of potassium (K) metal concentration using flame photometry. Monthly average K concentration in the ambient air varied between 3.3 μgm^{-3} to 11.1 μgm^{-3} and 4.7 μgm^{-3} to 28.9 μgm^{-3} at semi urban and rural sites, respectively. Peak K concentration (28.9 μgm^{-3}) was obtained at rural area site during October 2007. The observed values of K levels were correlated with respective SPM concentration levels. Significantly higher K levels were observed at rural area site as compared to the semi urban area site especially in CRB months.

Keywords: Metal, Potassium, SPM, Crop Residue Burning (CRB)

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TERMS USED

FAO: Food and agriculture association of United Nations

IFA: International Fertilization Industry Association

Tg: Teragram

Gg: Giga gram

CRB: Crop residue burning

SPM: Suspended particulate matter

AWiFS: Advanced Wide Field sensor

dm: dry matter

yr: year

CMB: Chemical Mass Balance

RWS: Rice Wheat Cropping System

Globally, the agriculture sector has experienced phenomenal growth since the mid-twentieth century. The growth, driven by Green Revolution technology, has significantly augmented the aggregate supply of food grains, ensuring food security to the growing population. The next stage of agricultural growth however, faces a serious challenge in terms of sustainability (systems that maintain long-term economic, social and environmental viability). Agricultural intensification has had many negative environmental externalities associated with it – for instance, soil erosion, degradation of soil quality, water and air pollution. Widespread adoption of Green Revolution technologies resulted in expansion in agricultural area and subsequent inception of high-yielding varieties increased both crop as well as straw yield. In the past few decades, various advanced technological implements have been successfully introduced in agriculture particularly in the RWS (one of the widely practiced cropping systems in India and covers about 9.5 m ha). The major constraint in this system is the available short time between rice harvesting and plantation of wheat, and any delay in planting adversely affects the wheat crop. Preparation of the field also involved removal or utilization of rice straw left in the field. Increasing labour wages and labour shortage prevent timely manual harvest in major rice–wheat growing areas of India.

This led to the introduction of mechanized harvesting technologies to enhance efficiency and save time. However, mechanized harvester technologies leaves behind a large amount of loose straw in the field, whose disposal or utilization in the short time is again difficult, compelling farmers to burn the residue to get rid of it. Collection and disposal of the residue remain a practical problem and all options lack economical feasibility. The main options left are *in situ* incorporation and burning in the field. *In situ* incorporation is not feasible as the decomposition of residue takes a long time and affects the growth of wheat crop. Thus, for a farmer it is economical and easier to burn the residue in the field to enable early sowing.

1.1 AGRICULTURAL WASTE: A MAJOR COMPONENT OF BIOMASS BURNING

Recent researchers have identified biomass burning as an important source of air pollutants that has instantaneous and long term effect on the air quality. It includes the human initiated burning of vegetation for land clearing and land use changes as well as natural lighting induced fires. It has been estimated that globally an area of around 350 Mha (million hectares) was affected by vegetation fires in the year 2000 (Tansey,K., et al., 2004). Humans play an important role and are responsible for about 90% of biomass burning with only a small percentage of natural fires contributing to the total amount of vegetation burned. Biomass burning is a major source of many air-borne particles and trace gases. It is recognized as a significant global source of emissions, contributing as much as 40% of gross carbon dioxide and 38% of tropospheric ozone (Levine, J. S. *et al*., 1991). The major components of biomass burning are forests (tropical, temperate, and boreal); savannas; agricultural lands after the harvest; and wood for cooking, heating, and the production of charcoal. The immediate effect of burning is the production and release into the atmosphere of gases and particulates that result from the combustion of biomass matter.

Table 1.1 Global estimates of annual amount of biomass burning source

Sources of burning	**Biomass burned (Tg dm/yr)**
Savannas	3690
Agricultural Waste	2020
Tropical forests	1260
Fuel wood	1430
Temperate and Boreal forests	280
Charcoal	21
World total	**8700**

Source: Andreae, M. 0. 1991.

1.2 AGRICULTURAL WASTE AND ITS GENERATION

Billions of tons of agricultural waste are generated each year in the developing and developed countries. Agricultural residue includes all leaves, straw and husks left in the field after harvest, hulls and shells removed during processing of crop at the mills, as well as animal dung. The types of crop residue (straw, stubble or chaff from a crop, or the remains of a crop that is not harvested) which play a significant role as biomass fuels are relatively few. The single largest category of crop is creals, with global production of 1800 Tg in 1985. Wheat, rice, maize, barley, and millet and sorghum account for 28, 25%, 27%, 10% and 6%, respectively, of these crops. The waste products which are main contributors to agricultural burning are wheat residue, rice straw and hulls, barley residue, maize stalks and leaves, and millet and sorghum stalks. Sugar cane provides the next sizeable residue with two major crop waste barbojo, or the leaves and stalk, and bagasse, the crop processing residue. The cotton crop also gives non negligible residue in the form of stalks and husks, both of which are used as biofuels. Four minor crops provide residue from processing that is frequently used as fuel: palm empty fruit bunch and palm fiber, palm shells, coconut residue, groundnut shells and coffee residue.

1.3 INTERNATIONAL AND NATIONAL AVAILABILITY OF AGRICULTURAL WASTE (CROP RESIDUE)

From the very beginning, the harvesting was done by hand by farm labor and most straw was removed from the farm for animal feeding. However, over the years, the maintaining of cattle on the farm for feeding becomes very expensive and in large part of country rice –wheat tract cattle have been replaced by tractors. The increasing constraints of labor and time under intensive agriculture have led to the adoption of mechanized farming in rice-wheat based cropping system. For example, under highly intensive rice–wheat cropping system in northwestern India, combine harvesting of rice and wheat fields is very popular with the farmer of Punjab, Haryana and Western

UP, which leaves a stubble of about 30 cm in height and spreads most of the straw in the field. Tentative estimates show that in Punjab 75-80 percent under rice is machine harvested and 70 to 80 million tons of rice crop residue is disposed off by burning (Badarinath, K.V.S., et al., 2006). On the global basis, Asia is the major producer of crop residue and produced 52.6 percent of the world residues production. Rice, wheat and corns are the major crops, contributing about 84 percent of the total production of crop residue in Asia. In Asia, the annual biomass is burned at a very large scale and the contribution of crop residue burning in total residue is very predominant in China (110.0 Tg) and India (84.0 Tg) (Streets, D.G., 2003).

Table:1.2 Residue Production ($\times 10^3$ tons) by Rice and Diffferent Crop Grown in Rotation with Rice in the Tropics in 1998

Crop	**Asia**	**Africa**	**South America**	**World**
Rice –straw	771,804	25968	24153	844,782
Rice –husk	154,361	5194	4831	168,956
Wheat	379,788	27,395	25,539	946,734
Barley	34,097	6753	2141	208,229
Sugarcane	53,855	8561	41,880	125,227
Cotton	6378	315	69	6801
Oats	2424	342	1604	51,604
Corn	166,205	38,729	54,626	604,013

Source: Singh, Y., 2005.

As part of inventorization of emission from open crop residue burning, it was estimated during this work that in the year 2000 about 78 and 85 million tons dry rice and wheat straw were generated in India alone, of which about 17 and 19 million tons might have ended up in field-burning, respectively (Gupta, P. K., et al. 2004). These figures may rise sharply with increase in number of combines. In 2000, the total agricultural residue production in India was 347 million tons, of which rice and wheat straw accounted for more than 200 million tons.

For every four tons of rice or wheat grain, about six tons of straw is produced (Thakur,T.C., 2003). Large amount of crop residue is produced from RWS in India from major involved States, viz. UP, MP, Punjab,Bihar, Maharashtra, Haryana, Gujarat and HP. According to this detailed state-wise study for the year 1994, the amount of residue generated from rice and wheat from the above-mentioned States is 133 Tg, which includes the highest from UP (13 and 33 Tg) followed by Punjab (10 and 20 Tg) and MP (8 and 11 Tg) respectively (Gupta, P.K, et al., 2004). According to Sarkar, A., *et al*.(1999), the RWS accounts for nearly one-fourth of the crop residue production in India. The residue generated is utilized mainly as industrial/domestic fuel, fodder for animals, packaging, bedding, wall construction, *in situ* incorporation and green manuring, thatching and left in field for open burning.

However, in case of combine harvesting almost all the residue generated is left in the field, that finally ends up in burning.Rice is grown during warm, humid season between June and October and wheat in cool, dry season between November and March.There is little time available between harvesting of rice and planting of wheat and moreover, performance of wheat crop is highly susceptible to any delay in planting.This has resulted in mechanizations of harvesting in RWS and introduction of combine harvesters. Due to the use of combine harvesters, there has been a sharp increase in the share of residue that is left in the field as it leaves major portion of the residue, including husk in the field. About 5–7 tons/ha of rice straw is left unused in the field (Gupta, R.K., et al. 2003). Collection and disposal of the residue remain a practical problem and all options lack economical feasibility.Increasing labour wages and labour shortage prevent timely manual harvest in major rice–wheat growing areas of India.Self-propelled and tractor-mounted combinations are being used (for harvesting); though these incur high capital costs, they remain economical when compared to other options available. The main options left are *in situ* incorporation and burning in the field. *In situ* incorporation is not feasible as the decomposition of residue takes a long time and affects the growth of wheat crop. Thus, for a farmer it is economical and easier to burn the residue in the field to enable early sowing. Billions of tons of agricultural waste are generated each year in the developing and developed countries. Agricultural residue includes all leaves, straw and husks left in the field after harvest, hulls and shells removed during processing of crop at the mills, as well as animal dung. The types of crop residue which play a significant role as biomass fuels are relatively few. The single largest category of crops is cereals, with global production of 1800 Tg in 1985 . Wheat, rice, maize, barley, and millet and sorghum account for 28%, 25%, 27%, 10%, and 6%, respectively, of these crops. The waste products which are the main contributors to biomass burning are wheat residue, rice straw and hulls, barley residue, maize stalks and leaves, and millet and sorghum stalks.

Table 1.3 Rice and wheat crop production and residue generation from major states in1994(Gg)

	Rice		Wheat		Total	
States-1994	Production	Residue	Production	Residue	Production	Residue
UP	10326	13284	22126	33189	32452	46473
Punjab	7688	9890	13501	20251	21189	30141
MP	6308	8115	7151	10727	13459	18842
Bihar	6251	8041	4296	6443	10547	14484
Haryana	2185	2810	7285	10928	9470	13738
Maharasthtra	2419	3112	1097	1646	3516	4758
Gujarat	916	1179	1704	2555	2620	3734
HP	110	141	553	829	663	970
All India	81435	88474	64285	96428	145720	184902

Source: Gupta, P.K., et al.,2004).

Sugar cane (0.95 gigatons) provides the next sizeable residue with two major crop wastes: barbojo, or the leaves and stalk, and bagasse, the crop processing residue. The cotton crop also gives non negligible residue in the form of stalks and husks, both of which are used as biofuels. Four minor crops provide residue from processing that is frequently used as fuel: palm empty fruit bunch and palm fiber, palm shells, coconut residue, groundnut shells, and coffee residue.

1.4 AGRICULTURAL BURNING

Agricultural burning can be defined as the burning of materials that are wholly produced from growing and harvesting crops or raising animals for the primary purpose of providing a livelihood. Agricultural burning can be divided into four categories:

1.4.1 Crop Residue Burning

Crop residue burns remove vegetative debris from farming operations. Fires used to clear fields for planting or seeding, control disease or pests, and/or improve crop propagation are examples of crop residue burns. Crop residue burning applies specifically to all crop residues, defined as any vegetative material remaining in the field after harvest, or vegetative material produced on conservation reserve program lands. Crop residue burning can only occur in fields where the crop residue was generated.

1.4.2 Ditch and Fence Line Burning

Ditch and fence line burns are initiated to remove weeds and other plants that collect along ditches, drains, and fence lines. Burning reduces the fire hazard and can improve water management efficiency.

1.4.3 Rangeland Burning

This type of open burning includes grasses, shrubs, trees, or other vegetative matter burned to improve rangeland.

1.4.4 Land Clearance and Upkeep

Brush piles, branches, stumps and other vegetative debris removed while clearing new land or while maintaining the property are included in this category.

1.5 CROP RESIDUE BURNING

Crop residue is a part of plants left in the field after the crops have been harvested and thrashed. Crop residue management is posing a serious problem in the rice (Oryza sativa)-wheat (Triticum aestivum) cropping system, which is widely practiced in the Indian Subcontinent and China, and covers about 22.56×106 ha in china, 9.66×106 ha in India, 1.56×106 ha in Pakistan and 0.5×106 ha in each of Bangladesh and Nepal (Singh R.B. and Paroda, 1994., Prasad, R., 1999). This cropping system has a long history in Asia and practiced in Asia (China) since AD 700. In the Indian subcontinent, states like Uttar Pradesh (UP; India) have practiced this cropping system since 1872, and Punjab (Pakistan and India) and Bengal (India and Bangladesh) since 1920 (Pal, S. S., et al.,2002).

Crop residue burning is commonly used to remove crop residue after harvest all over the world. In Southeast Asia, burning is the major disposal method for rice straw, which accounts for about 31% of the agricultural waste in the developing world (Singh, G., et al., 2008). Burning agricultural fields is more cost-effective for farmers than other methods for clearing agricultural fields, including but not limited to: bailing, composting, and disking crop residue. Post harvest burning helps to control pests, undesirable weeds and plant diseases, maintains future harvest yield, return nutrients and minerals to the soil and quickly removes the crop residue from the fields (Meland, B., and Boubel, R., 1966). Even though field burning is cost-effective, it releases many pollutants into the atmosphere. These pollutants include: suspended particulate matter (SPM), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO plus NO_2, or NO_X), polycyclic aromatic hydrocarbons (PAHs), formaldehyde and a variety of other products of incomplete combustion (Crutzen, P. J., and Andrea, M.O., 1990, Singh, R.P.,et al., 2008). The emissions from field burning can seriously degrade the local air quality of populated areas. Particulate matter with an aerodynamic diameter of less than 2.5 μm ($PM_{2.5}$) is a very important pollutant; the small particles can travel deep into human lungs and trigger respiratory health problems (Roberts, R., 1998).

1.6 CROP RESIDUE BURNING IN PUNJAB

Combine harvesting technologies, which have become common in the rice–wheat system (RWS) in India, leave behind large quantities of straw in the field for open burning of residues. Burning of rice stubbles is widely practiced in Punjab, India, due to a lack of suitable machinery to direct drill wheat into combine-harvested rice residues. The majority of the rice and wheat in Punjab is combine harvested, leaving anchored straw 0.3-0.6 m high, and loose straw in windrows (Gajri, P.R. et al., 2002). Management of the rice stubbles (more than 6 t/ha), is a major problem in the system. This is a rapid, cheap option which allows quick turn around between crops; hence more than 90% of the 17 Mt of rice stubble in Punjab is burnt each year (Singh, R.P., et al., 2008). Punjab, (representing 1.6% of Indian geographical area and 2.6% of its cropped area) is known as the granary of India.

Punjab has made enormous contributions to the national pool of food grains i.e. around 70% of wheat and 50% of rice. The state, on an average, accounts for 23% of wheat, 14% of cotton and 10% of rice production of the whole country (Punia, M., et al., 2008**).** Punjab has about 2,647,000 ha under paddy cultivation that yields roughly 100 million tones of rice straw and about three-fourth of crop residue amounting to 70–80 million tones of rice is disposed-off by burning (Badarinath, K.V.S., et al., 2006). At present, about 95% of the total food grain production in Punjab is from rice and wheat (Gupta, R. K., 2003). Figure 1.1 shows the estimated burned areas using Advanced Wide Field sensor (AWiFS) data obtained from knowledge-based classification approach.Figure 1.2 shows the district wise burned area distribution and the estimated total burned area is found to be around 4315.35 sq. km. Among these, Amritsar has the highest burned area (673.99 sq. km) followed by Jalandhar, Ludhiana, Firozpur and Patiala districts and Rupnagar was the least affected (41.36 sq. km).

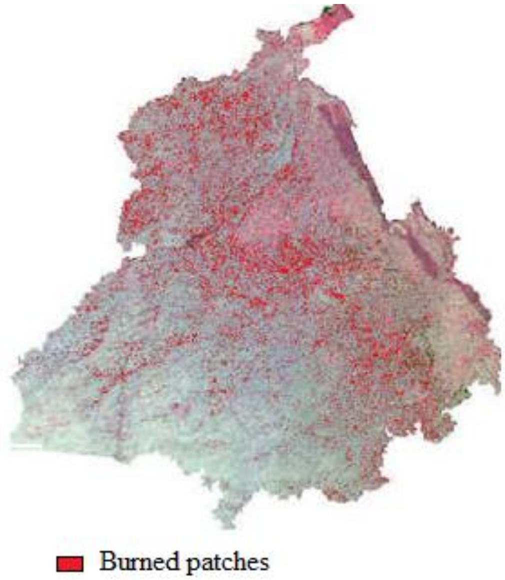

Figure1.1 Fire patches extracted from AWiFS data of 15 May 2005

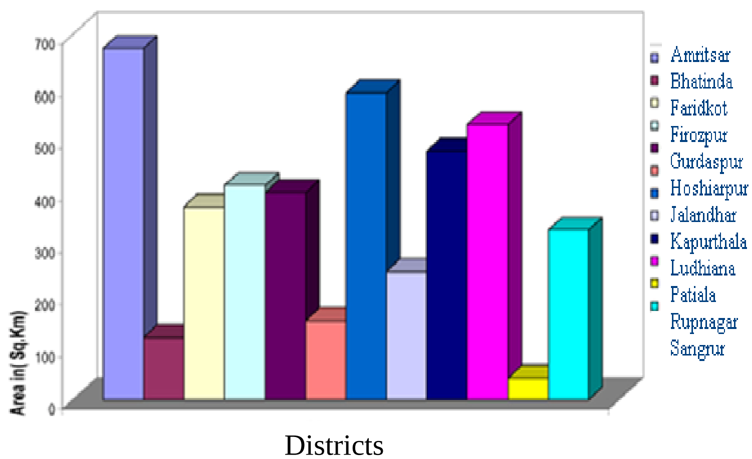

Figure1.2 District-wise burned areas over the region using AWiFS data of 15 May 2005

1.7 CONSEQUENCES OF BURNING

The burning of these residues (which is not at all a sustainable practice) leads to the following:

- Air pollution (particularly due to the release of carbon dioxide, nitrous oxide, ammonia, and particulate matter in the atmosphere), which farms environment and contributes to global climate change.
- Substantial waste of precious nutrient resources and organic matter in the soil, especially nitrogen. It is reported that 40 to 80% of the nitrogen in wheat crop residue is lost as ammonia when it is burned in the field. The ash left on the soil surface after burning crop residues causes an increase in urease activity and may cause N losses from soil and applied fertilizer.
- Deterioration of soil physical properties (crop residue, being an organic material leads to an improvement in soil structure and fertility, whereas burning residues leads to a corresponding loss in soil fertility).
- Residue burning can have a beneficial short term effect on the N supply to subsequent crops, but has negative long term effects on overall N supply and soil carbon levels.

1.8 COMPOSITION OF SMOKE FROM CROP RESIDUE BURNING

When a fire is first lit the moisture is driven off. As it gets hotter, chemical reactions occur that produce gases. Smoke is a mixture of gaseous air pollutants and particulate matter. About 90% of smoke is PM_{10}. The particulate matter produced by burning consists of particles of soot (unburned carbon), ash (unburned minerals), condensed fumes (including toxic and cancer causing aerosols) and other products of incomplete combustion. When inhaled, PM_{10} particles and any sorbed toxins can travel past the protective linings of the airways and into the deepest part of the lungs. Not all the particles are expelled when you exhale. Those retained in the lungs can cause serious harm. The gaseous pollutants include: carbon monoxide, hydrocarbons, and oxides of sulfur and nitrogen. Carbon monoxide reduces the blood's ability to supply oxygen. Those most at risk are infants, the elderly and those having heart, lung or anemic diseases. When oxides of nitrogen and sulfur mix with atmospheric moisture, the acid rain produced can damage plants and aquatic life. Ozone develops when oxides of nitrogen react with hydrocarbons in the presence of sunlight. Ozone aggravates allergies, asthma and emphysema and impairs overall lung function. When a fire is first lit the moisture is driven off. As it gets hotter, chemical reactions occur that produce gases.

Smoke contains the unburnt portion of these gases. The actual composition of smoke depends on the type of wood and vegetation being burnt, the temperature of the fire and the wind conditions. Particles from smoke tend to be very small – less than one micrometer in diameter. In comparison, a human hair is 70 micrometers in diameter. Crop residue burning also produces carbon monoxide. The concentrations of carbon monoxide are highest when the fire is smouldering. Benzene and formaldehyde are present in smoke but at much lower levels than particles and carbon monoxide.

Air borne particles in the atmosphere have serious environmental impacts on climate (Broecker, W.S., 2000; Prospero, J.M., et al., 2002), biogeochemical cycling in ecosystems (Nriagu, J.O., and Pacyna, J.M., 1988), outside visibility (Husar, R.B., et al., 1997) and the health of the living things (Dockery, D., et al., 1993; Schwartz J., and Dockery, DW., 1992). In the past decade, much research has focused on atmospheric aerosols, because epidemiologic studies have shown that aerosols are responsible for various pathologies of the respiratory tract (Querol, X., et al., 2000). Recent epidemiologic studies that have examined air pollutant concentrations in relation to health statistics conclude that elevated fine PM is associated with increased mortality and morbidity (Fang, G., et al., 1999, Chan, L.Y., et al., 2000, Fang, G., et al., 2000). Respiratory health effects are biologically expected to be associated with particles smaller than 10µm ($PM._{10}$) passing the nose and entering the lung alveoli (Fang, G.; et al., 1999). Epidemiologists now are focusing their studies on the fine fraction of atmospheric particles of aerodynamic diameter smaller than 2.5µm ($PM._{2.5}$), and evidence suggests that this particular fraction is responsible for the majority of health effects (Balachandran, S., et al., 2000). Particulate air pollution includes solid and liquid particles directly emitted into the air, such as soil and rock debris (terrestrial dust), volcanic dust, sea spray, wildfires, diesel soot, road and agricultural dust, and particles resulting from manufacturing processes (Fang, G., et al., 1999, Seinfeld, J.H., 1986).

One of the most basic and useful indicator for judging the degree of air pollution is the level of total suspended particulate (TSP) (Momin, G.A., et al., 1999). The national air quality standards in many countries are being reviewed currently in order to monitor aerosol quantity as well as quality to maintain healthy environment. In India recent air pollution studies in around Delhi revealed that the total suspended particulate matter exceeds the air standard prescribed by Central Pollution control Board (CPCB), New Delhi (TERI, 2001).

For effective management of air quality, great importance is attached to the identification of the sources of ambient particulates. The results of $PM_{2.5}$ source apportionment study by Seung and Young for an urban site in Seoul, Korea with a population of about 10.3 million people living in an area of 605.5 km^2 and about 2.3 million motor vehicles, using the 12-h derived source composition profiles show that the average $PM_{2.5}$ source contribution indicates, motor vehicle exhaust was the major contributor at the sampling site, contributing 26% on average of measured $PM_{2.5}$ mass (41.8 $\mu g\ m^{-3}$), followed by secondary sulfate (23%) and nitrate (16%), refuse incineration (15%), soil dust (13%), field burning (4%), oil combustion (2.7%), and marine aerosol (1.3%), (Park, S. S., et al. 2005). Large – scale agriculture field burning may substantially affect $PM_{2.5}$ concentrations under unfavorable meteorological conditions even at distances over 1000km from the burning areas (Jarkko, V., et al.2004).

In the past decade, agricultural burning has been subject to intense discussion and public debate in the semi-arid eastern Washington (Jimenez, J., 2002). The second most significant form of biomass burning in the world is the burning of leaves, grass, and trash. This smoke is particularly hazardous since it is released at ground level in populated areas. Burning a ton of leaves will produce about 117 pounds of carbon monoxide, 41 pounds of particulates (most of them smaller than 10 microns and easily absorbed in the lungs), and at least seven highly carcinogenic polycyclic aromatic hydrocarbons (Friedman, L., et al.,1977). Stubble from wheat, corn, rice and other crops is often burned away in the fields. Average airborne particulate concentrations were also more than double during September and October as compared to the rest of the year (Torigoe, K., 2000). A study in a rural Brazilian Amazon village reported average air particulates smaller than 10 micro (PM_{10}) of 191 micrograms per cubic meter of air were reported during a weeklong agricultural burning period (Reinhardt, T., et al., 2001). Smoke particles from biomass burning have direct radiative impact by scattering and absorbing shortwave radiation and indirect radiative impact by serving as cloud-condensation nuclei and changing the cloud microphysical and optical properties (Kaufman, Y. J., 1997). The emission of CH_4, CO, N_2O and NO_x has been estimated to be about 110, 2306, 2 and 84 Gg respectively, in 2000 from rice and wheat straw burning in India (Gupta, P.K., et al 2004). Studies on the impact of aerosols and gaseous pollutants in ambient air on physiological parameters of human health due to agricultural crop residue burning in and around Patiala indicated that the crop residue burning contributed towards higher levels of SPM (suspended particulate matter) all over Patiala. Respiratory parameters show significant decrease in its value after burning of crop residue, in all age groups (Mittal, S.K., et al., 2009, DST Report 2007-2008).

Carbon monoxide (CO) emission from open biomass burning is estimated about 16.5 Tg in 2000, of which more than 50% is from burning crop residue in mainland China (Yan, X., et al., 2006). The North China Plain is the major region for planting winter wheat in China, and is the major area to practice biomass burning. Large amount of pollutants due to straw burning lead to regional degradation of air quality (Zhao, Q Y, et al., 2003, Zhe ng, X Y, et al., 2005). Biomass burning generates large amounts of atmospheric particles, CO and PAHs, and even more serious pollution can be expected as well if combustion is incomplete (Haysa, M. D. et al., 2005, Dhammapala, R., et al., 2006). Burning of rice stubbles causes the serious air pollution with adverse effects on human and animal health (Gupta, P.K., et al. 2004) and increased GHG emissions. In Thailand and many other Asian countries, where rice is the major crop, open burning of rice straw after harvesting is a common practice. This activity releases a large amount of air pollutants, which can cause serious effects on the ambient air quality, public health and climate. During the intensive burning season (November-April) smoke plumes from rice straw burning in Pathumthani can be transported to Bangkok following the Northeast monsoon. Emission from open rice straw burning therefore may contribute significantly to air pollution levels in the surrounding areas including Bangkok and affect the air quality in the area significantly (Danutawat, T., et al., 2007).

Five primary sources are identified and quantified: diesel engine exhaust, gasoline engine exhaust, road dust, coal combustion, and biomass combustion and biomass combustion contributions to ambient $PM_{2.5}$ of 7-20% for Delhi, 7-20% for Mumbai, 13-18% for Kolkata, and 8% for Chandigarh (Chowdhury, Z., et al., 2007).

2.1 BURNING CONTRIBUTION TO GLOBAL EMISSION

Table 2.1 Comparison of global emission from biomass burning with emission from all sources, including biomass burning

Species	Biomass burning (Tg element/year)	All sources (Tg/year)	Biomass burning (%)
Carbon dioxide (gross)	3500	8700	40
Carbon dioxide(Net)	1800	7000	26
Carbon monoxide	350	1100	32
Methane	38	380	10
Non Methane Hydrocarbon[a]	24	100	24
Nitric oxide	8.5	40	21
Ammonia	5.3	44	12
Sulfur Gases	2.8	150	2
Methyl chloride	0.51	2.3	22
Hydrogen	19	75	25
Tropospheric ozone	420	1100	38
Total particulate matter	104	1530	7
Particulate organic carbon	69	180	39
Elemental carbon Soot	19	<22	> 86

a Excluding isoprene and tarpenes

Source: Andreae, M.O. 1991.

2.2 SOURCE OF POTASSIUM IN CROP RESIDUE

Among the cropping system commonly followed in the indo-Gangetic plain of south Asia and China, rice - wheat cropping system occupies more than 26 M ha of cultivated land and removes the highest amount of potassium (Singh, R.B., and Paroda, R.S., 1994, Aslam, M., 1998, Yadav, R.L., et al., 1998) and removes the highest amount of potassium (Singh, B., et al., 2003). Each harvest leaves the soil poorer with respect to potassium reserves of the soil. From 1960 to 1990, genetic improvement leading to development of highly fertilizer responsive rice and wheat varieties and improvement management strategies resulted in a dramatic rise in productive and production from rice-wheat system. Both rice and wheat are exhaustive feeders and the double cropping system is heavily depleting the soil of its nutrient contents. As rice –wheat sequence that yields 7 t ha^{-1} of rice and 5 t ha^{-1} of wheat removes more than 300 kg nitrogen, 30 kg phosphorus, and 300 kg $ha^{-}$of potassium from the soil (Singh B., et al., 2003).

The puddle and continued submerged soil in which rice is commonly transplanted differ from others in the control of acidity and alkalinity because the partial pressure of CO_2 flood water buffers carbonate and lower pH. The pH changes alter chemical equilibria and consequently the availability of different nutrients. As a result, a negative balance of the primary nutrients is developed particularly for the nitrogen and potassium. This causes the decline in production and rice- wheat cropping system no longer exhibiting increased production. Causes for the decline include changes in biochemical and physical composition of soil organic matter, and a gradual decline in the supply of soil nutrients causing macro- and micronutrient imbalances due to inappropriate fertilizer applications (Ladha, J.K., et al., 2000). Depletion of soil potassium seemed to be a general cause of yield decline in the 23 rice – wheat long turn experiments in the Indo –Gangetic plains investigated by Ladha, J.K., et al., 2003. Importance of potassium nutrition of rice – wheat systems stem from two facts : (1) The removal of potassium by above –ground plant parts and losses through leaching far exceeds the small addition through fertilizers and manures.

(2). Lack of balanced availability of nitrogen, phosphorus, and potassium to rice and wheat that may hinder achieving the potential yields (Singh, B., et al., 2003).

2.2 A) POTASSIUM FERTILIZER USE IN THE RICE-WHEAT CROPPING SYSTEMS

On average more than 25kg ha^{-1} of potassium is being applied to both rice and wheat in China, the range in the Indo-Gangetic plain is 0.4- 8.3 kg ha^{-1}(Source IFA, and FAO (2002) FAO and IFA, (1999). In the Indo-Gangetic plains in India, the general recommendation for rice is to apply 25 kg $ha^{-1}$of potassium in Punjab (Trans-Gangetic plains) and up to 50 kg ha^{-1} in the middle and lower Gangetic plains (Uttar Pradesh and West Bengal) (Singh, B., et al., 2003). For wheat, the range for potassium application is 21- 58 kg ha^{-1} (Tiwari, K.N., 2000). Fertilizer use pattern for rice – wheat system in the Indo-Gangetic plains varies greatly from one part to another. For example, in out of 36 districts in Punjab and Haryana states in northwestern India, 34 districts consumed more than 100 kg ($N+P_2O_5$ $+K_2O$) ha^-. On the other hand, 95 out of 155 districts of the eastern part comprising Utter Pradesh, Bihar and West Bengal consumed 100 kg ($N+P_2O_5$ $+K_2O$) ha^- or less (Singh, B., et al., 2003).

2.2 B) SOIL UNDER RICE –WHEAT CROPPING SYSTEM

Total potassium in alluvial soils of the Indo-Gangetic plains in India ranges from 1.28 to 2.77%; the range for exchangeable potassium contents is from 78 to 273 mg k kg^{-1} (Tandon, H.L.S., et al., 1998). Soil in the Indus plain in Pakistan contained 2.65-3.55% potassium (Zia, M.S., et al., 1998), rice and wheat crop supporting soil of china show variation in potassium contents from 1.06 to 2.02 % (Cao, Z., et al.1995). Potassium feldspars and micas are the potassium minerals present in the soils of Indo-Gangetic alluvial plains in India (Sidhu, P.S., 1984). Potassium feldspar species present in these soils are microcline and orthoclase. Mica minerals present are muscovite and biotite in the coarser fractions and illite in the finer fractions. The illite is predominantly dioctahedral (Kapoor, B.S., et al., 1982, Sidhu, P.S., et al., 1977). A study of mineralogical composition of soil of rice –wheat regions in the Indo - Gangetic plain in India was carried by Sekhon, G.S., et al (1992) reveal that illite is the dominant clay mineral in the soil of Punjab (Nabha), Uttar Pradesh, and Bihar and contained 39-70 mg K kg^{-1}.Soil potassium is often considered to exist in solution, and in exchangeable and non-exchangeable (fixed and structural potassium) forms. The amount of solution and exchangeable potassium is usually a small fraction of total potassium (1- 2% and 1-10%); the bulk of soil potassium exists in potassium bearing micas and feldspars (Sekhon, G.S., et al. 1995).

Potassium nutrition of crops is a function of the amounts of different forms of potassium in soil, their rates of replenishment and the degree of leaching. The forms of soil potassium in Nabha (Punjab) is 27 mg kg^{-1} water soluble, exchangeable potassium is 57 mg kg^{-1} and non exchangeable potassium is 1334 mg kg^{-1} Sekhon ,G.S., et al. (1992). Rice and wheat absorbed a large proportion of the potassium from slowly available potassium in soils, 60 to 80% potassium absorbed by crops came from slowly available potassium (Xie J., et al., 1987). Increased plant growth due to application of organic manures and NH_4^+ forming fertilizer applied to rice and wheat encourage acidification which in turn results in release of non –exchangeable potassium. Leaching as well as potassium removal by rice and wheat in large quantities enhances release of potassium from micas by removing the reaction products. Field crops generally absorb potassium faster than they absorb nitrogen or phosphorus or build up dry matter. The removal of potassium depends on the production level, soil type and whether crop residue are removed or recycled in the soil. When crop residues are retained in the field, large amount of potassium is recycled. The amount of potassium removed by rice – wheat cropping systems from the soil can be as high as 325 kg K ha^{-1} in the Indo-Gangetic plains (Singh, Y., et al., (2001); Dobermann, A., et al.(2000). Out of the total potassium uptake by rice, about 55% of potassium is absorbed during the early panicle initiation stage. About 60% of potassium uptake is completed by the heading stage (Pillai, K.G., et al., 1993). Several studies have shown, however, that intensive rice-based cropping systems, including rice-wheat (RW) (Timsina, j., et al., 2001), may cause heavy depletion of soil K (Tiwari, K.N., et al., 1985; Dobermann, A., et al.,1999; Gami S.K., et al., 2001; Singh, B., et al., 2003; Singh, Y., et al., 2005). Extraction is especially large in these systems because straw is often harvested as well as grain, or is burnt to facilitate tillage (Timsina, J., 2001).

2.3 POTASSIUM AS A MAIN COMPONENT OF CROP RESIDUES

Crop residues are good sources of plant nutrients. These are the primary source of organic material added to the soil and are important components for the stability of agriculture ecosystems. It is not a waste but rather a tremendous natural resource. About 25% of nitrogen (N) and phosphorus (P), 50% of sulfur (S), and 75% of potassium (K) uptake by cereal crops are retained in crop residues, making them valuable nutrients sources (Singh, Y., et al.2003). Because of its role in productivity, potassium nutrition is important in rice-wheat cropping systems. A filed experiment on the RW cropping system at three site in Bangladesh by Panaullah, G.M., et al., 2006, shows that majority of potassium uptake was in straw and the proportion in grain varied little across sites (range: 11%-29%). At all sites, the majority of the K removal was in straw, and the proportion varied significantly among sites, with 70%-82%,88%-94%,and 84%-88%,at Joydebpur, Ishwordi, and Nashipur, respectively.

Rice straw contains about 65% of total potassium in water soluble form. The incorporation of rice residue caused a smaller but more significant increase in available K content in the soil than did the residue removal treatment. On average, rice residue added about 175 kg K ha^{-1}anuually and wheat residue added 65 kg K ha^{-1} (Singh, Y., et al., 2004). Gaur, A.C., et al (1984) estimated the nutrient supply potential of cereal residues in India at 2.1×10^{6}t K_2O. Sarkar, A., et al. (1999) reported an annual crop residue production of 356 Mt having potential of supplying 7.4 Mt of

$N + P_2O_5 + K_2O$. For the ICP-OES analytic results, potassium is the major element comprising 7.2% for wheat straw and 6.9% for maize stover while all other elements are below 1%. Xinghua Li, et al .2007, when studied the particulate and trace gases emission from open burning of wheat straw and corn stover in china find out the carbon content wheat and corn stover is between 40% and 45%. The moisture content of wheat and maize stover is less than 10%. Si and K are present in relatively high concentration in elemental compositions of the fuels. Si accounts for 3.01% and 2.49%, and K accounts for 1.75% and 1.85% in wheat straw and maize stover, respectively. Leaving straw in the field also returns nutrients valuable to crop growth back to the soil. These nutrients include carbon, nitrogen, phosphorus, potassium, sulfur, calcium and magnesium. When straw is burned, about 90% of these nutrients are lost (Heard, J., et. al., 2001).

2.4 POTASSIUM (K) AS MARKER OF BIOMASS BURNING

Soil dust and vegetative burning are often the only sources of K in many urban environments (Park, S.S., et al., 2005). Non- soil potassium from a source other than soil, has been shown to be important sources of biomass burning, wood burning, and meat stoke (Lewis, C.W., et al., 1988; Miranda, J., et al., 1994). Cl^- and K^+ are an important anion and cation in PM from open burning of agricultural wastes; their ratios for wheat straw and maize stover are 1.4 and 2.7, respectively (Xinghua Li et al.2007). Zarate's research shows their ratio is about 0.8 for cereal waste (Zarate I.O. et al. 2000). In Jenkis- Turn's data, the ratios range from 0.33 to 2.0 for herbaceous fuels (Jenkins, B. M.; Turn S.Q.; et al 1996). From Hays's study, the ratios are 1.1 for wheat straw and 2.8 for rice straw, respectively (Haysa, M. D.; 2005). Potassium and chlorine were predominant, and accounted for 18±4 % of the $PM_{2.5}$ mass in wheat smoke and 9±1% in Kentucky bluegrass smoke (Jimenez, J., et al., 2006). It can be concluded that Cl-/K+ ratios vary considerably, possibly because of varying content of K and Cl in the individual fuels. Duan et al. investigated the effect of biomass burning on ambient air quality in Beijing and concluded that the particularly high

K^+/OC value (_0.2) could be representative of on-field wheat open fire (Duan, F.et al 2004). Andreae, et al., presented that a high K_{excess}/soot ratio is a tracer of biomass burning, with observed values between 0.7-0.9 in aerosols mainly from agricultural burning and brush fire (Andreae, M. O., 1983). Turn et al. reported the value from herbaceous fuels was 0.95 (Turn, S. Q.; et al 1997**)**. A high value (2.83) was also found in wheat straw burning in Haysa data (Haysa, M. D.; 2005). Sarkar, A., et al. (1999) reported an annual crop residue production of 356 Mt having potential of supplying 7.4 Mt of N + P_2O_5 + K_2O. The soluble potassium concentration appeared the highest in June. It is 2－3 times as much as that in May (Duan, F. K., et al. 2001) displaying a significant role of straw burning in Beijing air pollution (LI Ling Jun et al March 2008.). The burning treatment also caused significant increase in yield components as well as grain yield due to substantial nutrient contribution through ash as most of the elements will be left in the ash, rendered water soluble and are readily available to plants due to incomplete burning of cereal crop residues as the temperature necessary to cause complete burning (>800 C) may not be achieved during burning of cereal crop residues (Kumar, K., et al., 2000). During straw burning, there is a rapid conversion of nutrients in organic form to inorganic N, P, K, Ca and Mg. Biederbeck, V.O., et al. (1980) reported that straw burning tended to increase yields in the early years but depressed yields in later years. Potassium is commonly used as a tracer for biomass burning (Echalar, F., et al., 1995). The majority of the PM 2.5 mass found in the smoke was made of organic compounds (OC) (POM ~64% wheat and ~52% for Kentucky bluegrass (KBG), respectively), followed by EC, potassium (K), and chlorine (Cl) (Jimenez, J. et al., 2006). Besides, burning of crop residues produces gaseous and non-gaseous matter which pollutes the atmosphere. Hence, burning of crop residues is an undesirable practice and should be discouraged (Biederbeck, V.O., et al., 1980).

Ambient air sampling was done at two locations, simultaneously by a research group for the sponsored research project of department of science and technology (GOI) (06-07/72) in and around Patiala city using two high volume samplers (HVS) (APM-430, Envirotech Instruments Pvt. Ltd.) under natural conditions of temperature and pressure from September 2006 to December 2007. Glass Micro Fiber (GMF/A, 20×25 cm^2size, Whatmann) and Quartz Micro Fiber (QMF) sheets (Whatman /A, 20 _ 25 cm^2) were used as a filter media for the collection of aerosols. SPM samples for analysis of potassium were taken from this project.

3.1 CHARACTERISTICS OF STUDY AREA AND SAMPLING SITES

Patiala (Figure 3.1, courtesy Google Earth) is a princely city of the state of Punjab, India with no major industry in and around its vicinity. It has head quarters of 15

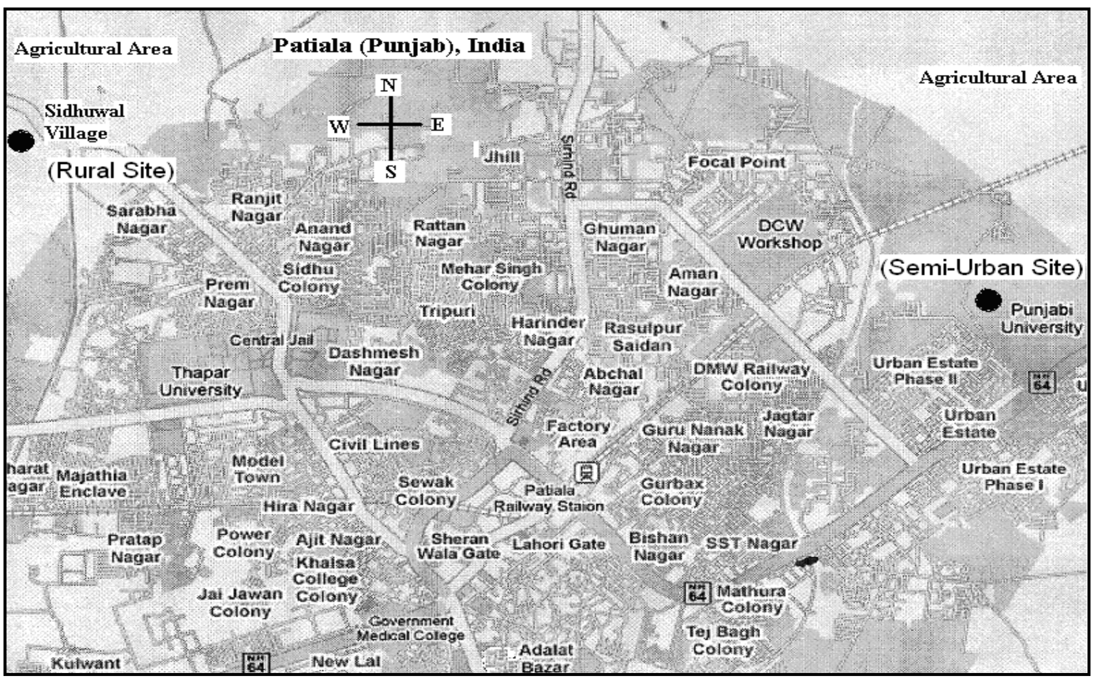

Figure 3.1 Map showing the location of urban (Punjabi University) and rural (Sidhuwal Vllage) sampling sites in and around Patiala city

state government offices including that of Punjab Pollution Control Board (PPCB), and has a railway and a bus terminus. It is located in the southeastern part of the Punjab state of Northern India (latitude between 29°49' and 30°47' N, longitude between 75°58' and 76°54' E). The area around Patiala city is predominantly agricultural (rural) and wheat and rice (paddy) crops are the two major crops of the district with a combined cropping area of more than 86%. Farmers usually burn crop residue after crop harvesting during April–May (wheat crop harvesting period) and October–November (rice crop harvesting period). The climate here is typical of the Punjab plain, i.e., very hot in summer (max. temp. 43±2° C) and very cold in winter (min. temp. 2±2°C). On an average there are 61 rainy days with annual average rainfall of 650±30 mm. The variation in rainfall is appreciable. May is the hottest month and January is the coldest month (TERI, 2003).

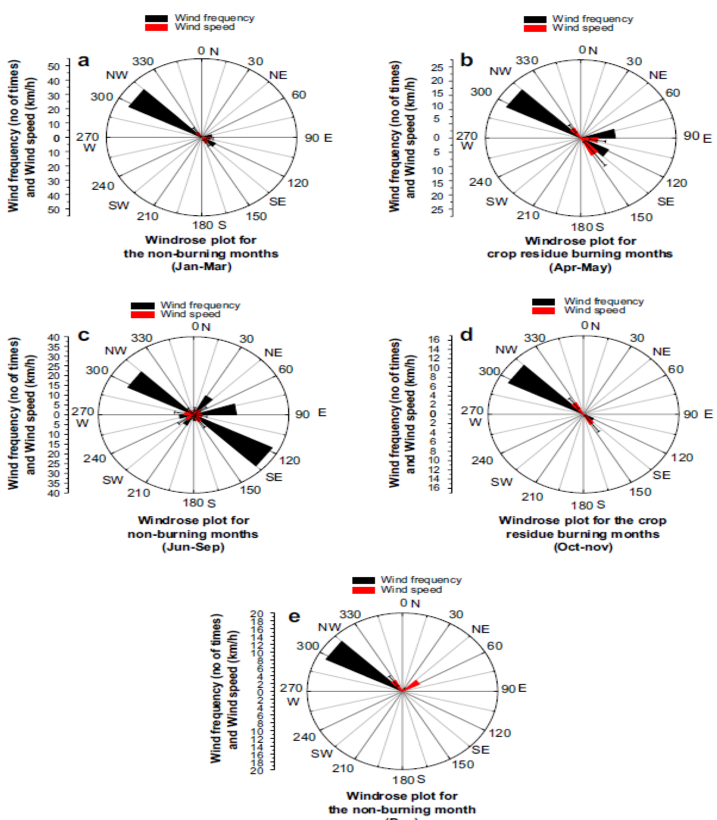

Figure 3.2 (a-e) Wind rose plots showing wind direction, wind speed and wind frequency in Patiala during burning and non-burning months of the study campaign in 2007

Wind direction of Patiala is North-West (NW) for most of the time period (Mittal, S.K., et al., 2009). Two sampling sites Punjabi University (30°21′28.10″ N, 76°27′02.57″ E) and Sidhuwal Village (30°22′42.14″ N, 76°20′31.52″ E) were selected representing urban and rural sites respectively. These sampling sites were located in downwind direction with a distance of 10 km to each other.

3.2 MONITORING AND ANALYSIS OF SPM

To get entire coverage of ambient SPM and metal concentrations emanating from CRB activities and other activities, two High Volume Samplers (HVS, Envirotech, India), were operated actively during the year 2006-2007 at both rural and semi urban sites over Patiala. SPM samples were collected twice in a week during harvesting period and biweekly during rest of the period on pre-weighed Glass Micro Fiber Sheets (GMF/A, 20 ×25 cm^2 size, Whatmann) with an average air flow rate of 1.5 m^3 min^{-1} for 24 hours (Marrero, J., et al 2005). In order to determine the mass of the collected particles, sampled sheets were reweighed after sampling and subsequent conditioning to remove any moisture. The concentrations of particulate matter in ambient air were then calculated by dividing mass by the total volume of air sampled (IS: 5182 (Part XV), 1974, IS: 5182 (Part XIV), 1974) (Katz, M., (1977).

3.3 CHARACTERIZATION OF SPM FOR K METAL

For the determination of K concentration in the ambient air, the collected SPM samples were prepared (55 samples from urban area site and 75 samples from rural area site) by digesting ¼ portion of each filter sheet a mixture of concentrated nitric acid (HNO_3) and concentrated hydrochloric acid (HCl) (3:1 ratio) at 70° C temperature for one and half hour using hot plate digestion system. The content was filtered through What man filter paper No. 42 and final volume was made up to 100 mL by adding deionized water. The filtrate was used to determine the K metal concentration by Flame Photometer (Zhuang, G., et al., 1992, 2001; Park, S.S., et al., 2001, 2005; Sun. Y., et al., 2004). Filters used to collect SPM samples may comprise impurities. The concentration of K metal was also measured by flame photometer in solutions of blank filters that were treated as the filters loaded with SPM to establish a baseline and the concentration of K (0.382 μgm^{-3}) was subtracted to the concentration of true samples (Marrero, J., et al., 2005).

Sampling sites were selected in the downwind direction to the burning fields to get full exposure of ambient SPM emanating from crop residue burning activities and other activities. At Punjabi University Site (Semi Urban Area), average monthly concentration of SPM varied between 109 µgm^{-3} to 510 µgm^{-3} whereas at Sidhuwal Village Site (Rural Area), it varied between 111 µgm^{-3} to 491 µgm^{-3} during the period of study. High SPM levels were obtained during April-May in 2007 (421 µgm^{-3}, 380 µgm^{-3}; respectively) and October-November (491 µgm^{-3}; October 2006, 449 µgm^{-3}; November 2006, 456 µgm^{-3}; October 2007 and 467 µgm^{-3}; November 2007) (Figure4.1) due to CRB in these months after harvesting of crops. Higher level of SPM was obtained at Punjabi University Site due to the mixed influence of CRB and vehicular emission. The levels of SPM were high during the burning months at both the locations and exceeded the standards set by the regulatory bodies of the government. Vehicular activities and domestic emission may be contributing to high levels of SPM at the urban location. The monthly average concentrations of SPM and K metal are shown in Figures 4.1-4.6.

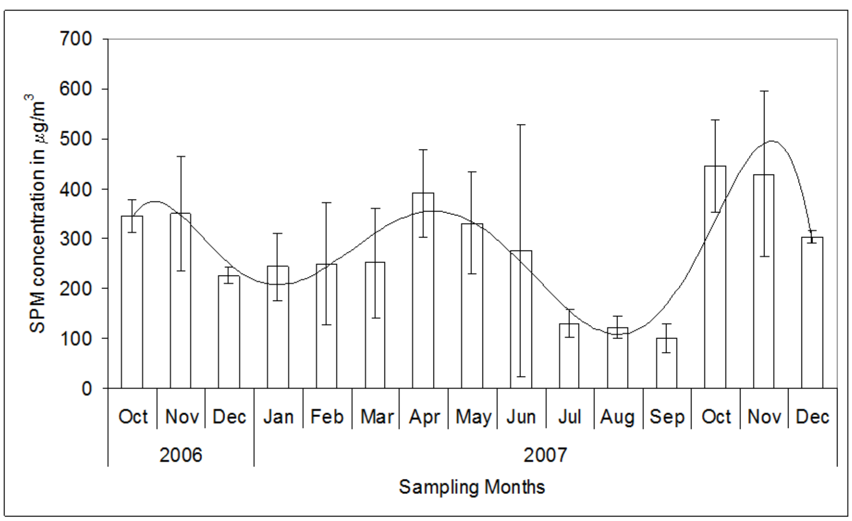

Figure 4.1 Variation in monthly average concentration of SPM during 2006-2007 at Punjabi University (semi-urban) Site, Patiala

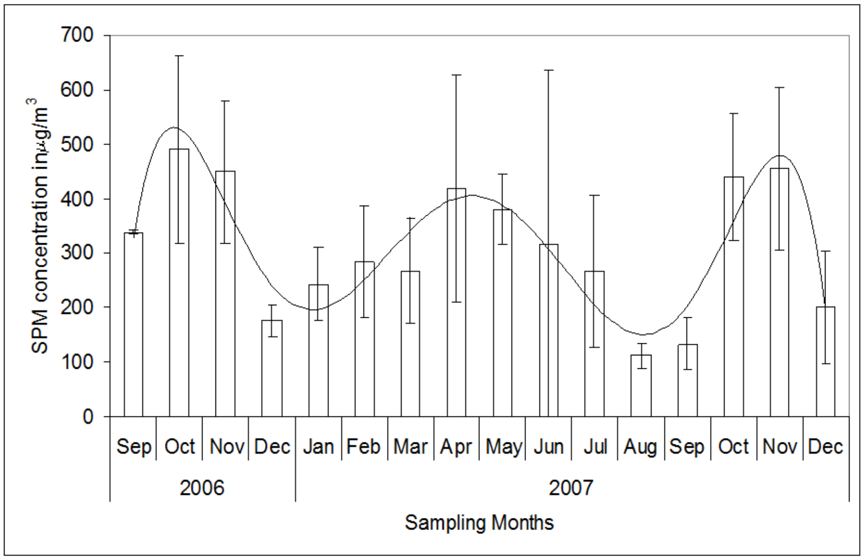

Figure 4.2 Variation in monthly average concentration of SPM during 2006-2007 at Sidhuwal Village (rural) Site, Patiala

SPM monitoring was carried out at the selected sites, representing rural and urban sites in Patiala. The study revealed that monthly average of SPM ranged from 100–510 μgm^{-3} at semi-urban site and 100-491 μgm^{-3} (Figures 4.1 and 4.2) at rural site. A high level concentration of SPM was observed at Sidhuwal Village Site (Rural Site) during the study period as compared to the Punjabi University Site (Urban Site) especially during CRB months. Monthly average Potassium (K) concentration varied between 3.3 μgm^{-3} to 11.1 μgm^{-3} and 4.7 μgm^{-3} to 28.9 μgm^{-3} at urban and rural area sites, respectively. Peak K concentration (28.96 μgm^{-3}) was obtained at rural area site during October 2007 indicating the dominating effect of CRB at this site, however at semi-urban area site, highest K concentration was obtained in the month of October 2006 again showing the effect of CRB (Figures 4.3-4.4). Use of NPK fertilizers for the wheat and rice crops may be the source of K in the ambient air. Potassium can be used as a marker in the analysis of ambient air SPM to investigate the effect of CRB.

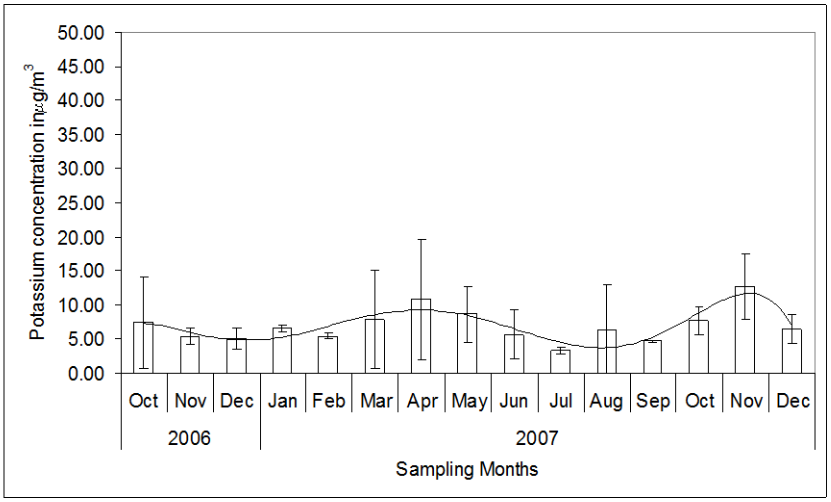

Figure 4.3 Variation in monthly average concentration of potassium (K) during 2006-2007 at Punjabi University Site, Patiala

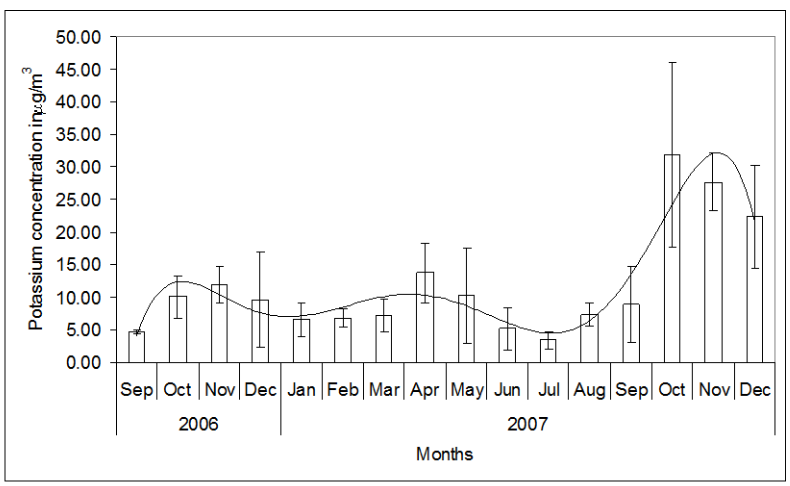

Figure 4.4 Variation in monthly average concentration of potassium (K) during 2006-2007 at Sidhuwal Village Site, Patiala

K in the atmosphere originates from the combustion of crop residue at high temperature and may include earth-crust like some other sources (Chow, J.C., et al., 1992, Begum, B. A., et al, 2004). Monthly mean concentration of K varies from 10 μgm^{-3} to 50 μgm^{-3} at rural sites and 10 μgm^{-3} to 40 μgm^{-3} at semi-urban site.

Concentrations of K and corresponding SPM with their standard deviations are presented in Table 4.1.

Table-4.1 Potassium and SPM concentration in different sampling months at Semi-urban and Rural Area Site during 2006-2007

CRB*	Year	Month	Concentration± standard deviations (SD) in μgm^{-3}			
			Semi-urban site		Rural Area Site	
			K	SPM	K	SPM
NO	2006	Sep	--	--	4.7±0.2	339±4
YES		Oct	11.1±6.8	372±32	10.0±3.1	491±173
YES		Nov	5.9±0.2	369±115	11.8±2.8	449±132
NO		Dec	6.4±0.4	269±73	9.6±7.2	176±30
NO	2007	Jan	6.5±0.4	244±68	14.1±13.6	257±61
NO		Feb	9.3±6.7	241±104	18.3±17.5	283±103
NO		Mar	9.6±8.1	247±100	10.2±7.0	268±96
YES		Apr	9.6±8.5	291±149	19.2±12.6	421±170
YES		May	7.2±4.5	297±89	9.0±7.6	380±65
NO		Jun	5.6±3.6	277±252	5.1±3.2	316±321
NO		Jul	3.3±0.5	109±3	12.4±0.2	267±139
NO		Aug	6.2±6.6	109±41	12.3±8.8	111±22
NO		Sep	3.9±1.0	418±178	8.9±5.7	133±48
YES		Oct	5.6±1.3	510±48	28.9±16.1	456±122
YES		Nov	9.9±1.4	293±6	24.7±9.3	467±142
NO		Dec	6.5±2.1	303±12	19.8±12.9	201±103

* Crop residue burning (CRB)

At rural area sampling site, during non-CRB months of 2006-2007, the highest K concentration (19.8±12.9 μgm^{-3}) was obtained in December 2007, whereas during CRB months highest K concentration (28.9±16.1 μgm^{-3}) was obtained in the month of October 2007 (Figure 4.5). Average K concentration during non-CRB and CRB months was 11.7 µgm^{-3} and 17.3 µgm^{-3}, respectively, indicating higher concentration during CRB months.

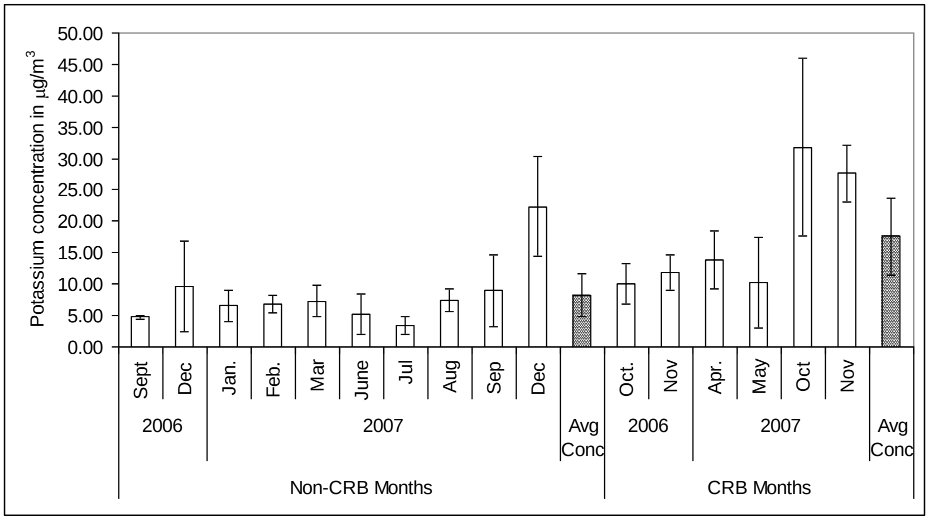

Figure 4.5 Variation in monthly average concentration of potassium (K) during CRB and non-CRB months in 2006-2007 at Sidhuwal Village Site, Patiala

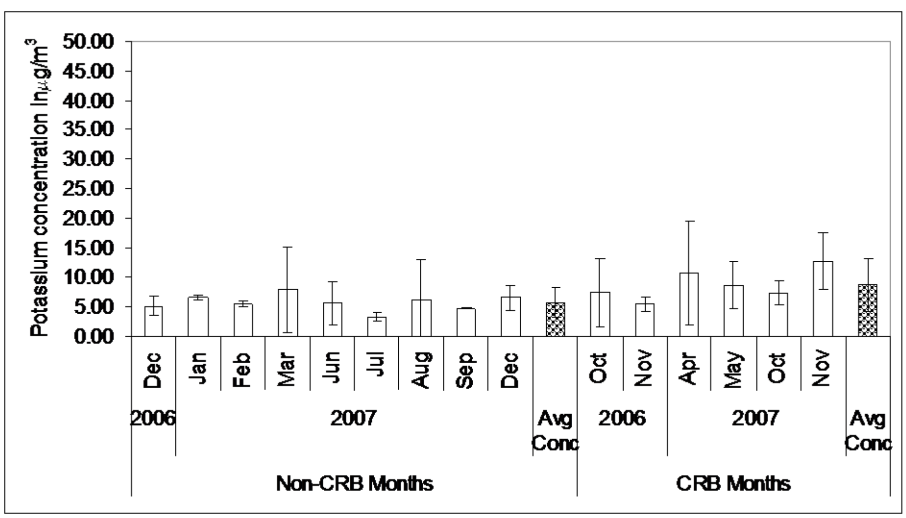

Figure 4.6 Variation in monthly average concentration of potassium (K) during CRB and non-CRB months in 2006-2007 at Punjabi University Site, Patiala

At semi-urban area site, during non-CRB months of 2006-2007, the highest K concentration (9.6±8.1 μgm^{-3}) was obtained in March 2007 whereas during CRB months, highest K concentration (11.1±6.8 μgm^{-3}) was obtained in the month of October 2006. Average K concentration during non-CRB and CRB months was 6.4 μgm^{-3} and 8.2 μgm^{-3} respectively at this site, indicating higher concentration during CRB months (Figure 4.6).

CONCLUSIONS

Crop residue burning (CRB) was identified an important source of SPM pollution in and around Patiala city integrated with the contribution of vehicular emissions. There was no positive relationship between K and SPM. Their concentrations varied independently at two selected sites during the different sampling months but high concentration of K was obtained at rural area site as compared to the semi-urban area site especially near CRB months indicating the contribution from crop residue burning episodes. K metal was found as a marker metal in the source apportionment of CRB. CRB was dominating source at rural site in increasing the SPM load whereas automobile exhaust was dominating source for SPM at semi-urban area site. In Patiala, ambient air quality with respect to SPM was found deteriorated and metals has moderate problem as compared to other big cities of India. However, CRB, increased vehicular traffic and swelling of urban population in and around the city will lead to severe air pollution problem in near future. Consequently, it is supported that air quality management especially for CRB should be formulated. Raising public awareness about dangers of SPM in ambient air will help in the improvement of urban air quality. It is also advocated to grow plantation along the roadsides to capture the pollution from mobile sources.

Finally, this work can be used in receptor models like chemical mass balance to improve our current understanding of air quality impacts from agricultural field burning in the populated areas of this region, and could provide substantial information for short and long-term studies on community exposure to pollution from agricultural field burning. This information could also help in developing future control strategies for field burning management and air quality improvement.

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