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Full Length Research Paper

Investigation of dominating routes of personal particulates among workers of battery recycling workshops in a mixed urban industrial environment

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Monitoring of personal exposure of respirable particulate matter (RPM) or personal particulates among battery recycling workers was carried out to estimate the dominant routes of personal particulates. Three battery workshops have been identified and workshops were categorized depending on the number of batteries recycled/recharged per day. All workshops were lead acid battery recycling workshops. 5 workers were selected from different workshops and after formal consent a time-activity diary including sex, time spent in various microenvironments have been selected. Monitoring of personal exposure of RPM among workers engaged in selected workshops was carried out to evaluate the source contribution estimates of personal particulates using reported protocol. Longitudinal sampling has been done with a frequency of 10. Samples of personal, indoor, outdoor fine particulates have been collected using Personal Sampler (Envirotech Model APM 801) and Handy Sampler (Enviroteh Model APM 821). RPM measurement data have been documented as geometric mean and standard deviation of multiple measurements. Correlation coefficient between the RPM measurement of selected atmospheric levels has been carried out to investigate extent of dependence of personal particulate concentration on its major routes of exposure. Chemical analysis of the samples has been conducted and source and receptor profiles were prepared. Results were executed in the CMB8 model of USEPA to find out the dominant routes of personal particulates and has been observed that particulates of workshop indoor and road traffic were the main routes of exposure followed by residential indoor, ambient outdoor and soil.

Key words: Battery recycling, lead acid battery, personal particulates, RPM, CMB8.

INTRODUCTION

The increase in automotive vehicles on roads as well as in various other applications has increased the demand for lead acid batteries. With so many batteries in use, their disposal and recycling is of paramount importance. The spent battery is 99% recyclable if processed in a proper facility and under environmental friendly conditions. Lead is the most recycled metal and more than 50% world demand is met by the secondary lead itself. The spent battery has been seen as a lead resource, as in 1999-2000 approximately 110,000 MT of lead was available from automobile sector alone (Dubey, 1999). There is great utility of battery in our day to day life and it has mainly lead (70%), acid (20%) and plastic case (10%). It has been reported that about 55.3 Mg/Nm3 of fine particulate is released during recycling of lead acid

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batteries in unorganized sector in India, whereas 22.2 Mg/Nm3 of lead is the content of such huge emission of fine particulates (Dubey, 1999 and Dubey and Pervez 2008).

Lead acid battery workshops cause problems to the workers because of their exposure to lead and other respirable particulate matter (Pervez, 2006). There are a number of serious health problems that can result from exposure to leaking lead batteries. Routes of exposure include ingestion, inhalation and direct contact with skin. Battery recycling is an important source of exposure to inorganic lead. Battery recycling and manufacturing involves use of metallic lead for making grids, bearing and solder. Manufacturing process is usually manual and involves release of lead vapors, particles, debris and the lead oxides that cause considerable environmental pollution and severe lead poisoning. Absorption of lead ordinarily results in rapid urinary excretion. In a study conducted by Bhagwat et al (2008) in a battery recycling workshop, blood lead levels were considerably higher in the workers (53.63 ± 16.98 µg/dL; range 25.8 – 78 µg/dL) compared to the controls (12.52 ± 4.08 µg/dL; range 2.8 - 22 µg/dL). Chronic lead exposure in unregulated small scale industrial units together with low economic conditions has cumulative effects on deteriorating health of battery manufacturing workers (Sarnat et al, 2005). Elevated lead (Pb) exposure is of particular concern because of the ongoing exposure of thousands of workers in industrial plants. Of interest, the high risk occupations are those in which individuals directly inhaled Pb in environmental ambient air (Wiwanitkit, 2000). There are confusing reports on the effects of lead on liver functions (EHC, 1995). The workers engaged in such workshops are reported to facing chronic respiratory ailments (Matte et al, 2007).

The degree of spatial variability in fine particulates was likely to be region-specific and strongly influenced by region specific sources and meteorological and topographic conditions. Personal fine particulates have shown significant variation in relationship with their indoor and ambient components. PM concentration is complex because ambient pollutants can be lost through chemical and physical processes in microenvironments and the composition of PM can be modified during infiltration of outdoor air into microenvironments (Meng et al, 2007 and Sarnat et al, 2006). A lot of studies have been conducted to investigate the relationship of personal particulate with its ambient and non-ambient component in developed countries to assess impact assessment of ambient pollution on personal exposure levels (Ducret-Stich et al, 2009 and Reff et al, 2005).

During the study of Relationships of Indoor, Outdoor, and Personal Air (RIOPA*), 48-hour integrated indoor, outdoor, and personal air samples were collected between summer 1999 and spring 2001 in three different areas of the United States: Elizabeth NJ, Houston TX, and Los Angeles County CA. Personal PM2.5 concentrations were significantly higher and more variable than indoor and outdoor concentrations. Several approaches were applied to quantify indoor PM2.5 of ambient (outdoor) and non-ambient (indoor) origin (Adgate et al, 2007; Meng et al, 2007 and Turpin et al, 2007). Weisel et al (2005) have reported that the RIOPA study Part-I was undertaken to collect data for use in evaluating the contribution of outdoor sources of air toxics and particulate matter (PM) to personal exposure. The estimation of outdoor contributions to measured indoor concentrations provides insights about the relative importance of indoor and outdoor sources in determining indoor concentrations, the main determinant of personal exposure for most of the measured compounds.

Receptor models for source apportionment use the chemical and physical characteristics of gases and particles measured at source and receptor to both identify the presence and to quantify source contributions to the receptor. The particle characteristics must be such that: 1. they are present in different proportions in different source emissions; 2. these proportions remain relatively constant for each source type; and 3. changes in these proportions between source and receptor are negligible or can be approximated. Chemical mass balance is the fundamental receptor model, with all other approaches of Principal Component Analysis (PCA) and Multi Linear Regression (MLR) that based on the use of the mass balance concept. The CMB receptor model (Friedlander, 1973; Cooper and Watson, 1980; Gordon, 1980; Watson, 1984; Watson et al, 1984, 1990, 1991 and Hidy and Venkataraman, 1996) consists of a least squares solution to linear equations that express each receptor chemical concentration as a linear sum of products of source profile abundances and source contributions. The source profile abundances (i.e., the mass fraction of a chemical or other property in the emissions from each source type) and the receptor concentrations, with appropriate uncertainty estimates, serve as input data to the CMB model. The output consists of the amount contributed by each source type represented by a profile to the total mass and each chemical species. The CMB calculates values for the contributions from each source and the uncertainties of those values. The CMB is applicable to multi-species data sets, the most common of which are chemically-characterized PM10 (suspended particles with aerodynamic diameters less than 10 µm), PM2.5 (suspended particles with aerodynamic diameters less than 2.5 µm), and VOC (Volatile Organic Compounds).The CMB modeling procedure requires: 1) identification of the contributing sources types; 2) selection of chemical species or other properties to be included in the calculation; 3)estimation of the fraction of each of the chemical species which is contained in each source type(source profiles); 4) estimation of the uncertainty in both ambient concentrations and source profiles; and 5) solution of the chemical mass balance equations.

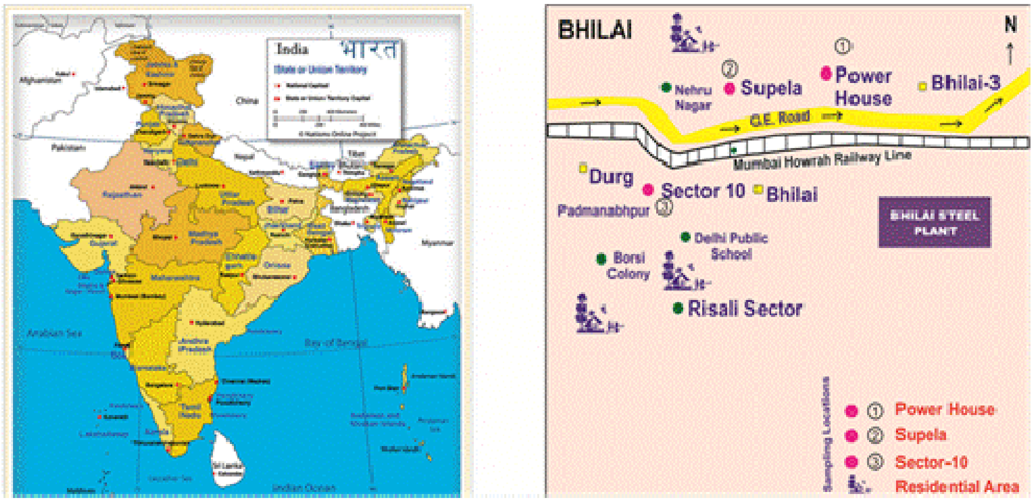


Figure1. Location map of selected battery recycling workshops in Durg-Bhilai area of Chhattisgarh.

The present study is focused on the source contribution estimates of personal RPM collected from battery recycling workshops, taking classified routes of exposure(workshop indoor, residential indoor, ambient outdoor, road traffic and soil)as source contributors in a mixed urban industrial environment.

MATERIALS AND METHODS

Study Design

The study has been designed in such a fashion that the impact evaluation of various other stationary industrial source emissions, temporary sources of toxic dust emissions located in urban areas along with workshop emissions on personal particulates will be possible. Location map of the sampling sites has been shown in Figure1.

The goal of the study is to conduct source apportionment of personal RPM in battery recycling workshops in relation to investigate the relative source contribution of various identified routes of exposure. Earlier studies in the field of relationship investigations between personal-indoor-outdoor particulate matter has shown that significant contribution from indoor and local outdoors in personal RPM compared to ambient RPM (Gadkari and Pervez, 2007, 2008). On the basis of these investigations, if regression analysis method (Geller et al, 2002) and chemical mass balance modeling (Watson et al, 1984) is applied on personal RPM source apportionment by taking indoor/outdoor routes of exposure, a comprehensive and more significant results of relative contribution of identified routes of exposure will be obtained. The objectives of the study were: 1. Measurement of RPM at personal levels of workers engaged in selected battery recycling workshops, 2. Measurements of RPM at workshop indoors, residential indoors, road-traffic outdoors, local ambient-outdoors and soil. 3. Evaluation of contribution from identified routes of exposure using regression analysis chemical mass balance (CMB8) model. To achieve the objectives of preliminary part of the study, a non-probability based stratified random sampling plan using longitudinal study design in space-time framework has been adopted (Gilbert, 1987 and USEPA, 2003). Since similar recycling process is involved in all three selected workshops and identified workers have similar house characteristics, single monitoring sites of routes of exposure has been decided for qualitative identification of possible contribution of routes in personal RPM (USEPA, 2003).

Sampling Plan

To achieve the objectives, a non-probability based longitudinal stratified random sampling plan in space–time framework. The environmental matrices chosen for samplings are personal, residential indoor RPM and local ambient outdoor RPM. Road-traffic and local-soils-borne RPM have also been sampled for preparation of possible source compositional profiles (Gilbert, 1987and USEPA, 2003).

Method of Personal RPM Sampling

To conduct the personal RPM measurements, a longitudinal stratified sampling plan in time-space framework have been adopted (Gilbert, 1987). Three battery recycling workshops have been identified, out of which two were located in downwind of steel plant and the third one was located cross-sectionally to wind direction from the steel plant. These workshops were

Table 1. Description of sampling units and characterization of selected subjects

Sl. No	Name and code	Average house characteristics	Mean age	Average experience	Surrounding environment
1	Power House-1(W1)	Well ventilated	30±8	15	In the vicinity of the steel plant
2	Supela-2 (W2)	Poor ventilation system	38±5	08	By the side of National Highway No:6
3	Sector-10 (W3)	Poorly ventilated	40±10	10	Away from plant and nearer to residential areas.

categorized depending on the number of batteries recycled/recharged per day: small scale below 50; medium 50-100: and large scales above 100 were handled. About 20 battery recycling workshops are situated in different parts of Durg-Bhilai. The present work has been conducted in small scale workshop, medium scale workshops and large scale battery recycling workshop in Durg-Bhilai area of Chhattisgarh. All workshops were lead acid battery recycling. The minimum temperature was 220C and maximum 350C during the sampling period. Similarly the humidity variation was from 66% -75%, rainfall 0.1mm-0.5mm and wind velocity varied from 4-6 km/h. Characterization of the selected workshops and subjects has been represented in Table 1.

Four personal respirable dust samplers (Envirotech, Model APM 801) attached with a cyclonic assembly (having cut off size five microns) have been used to collect RPM. Total daily exposure of a participant to particulate matter can be expressed as the sum of various microenvironments that the person occupies in the day (Envirotech, 2000 and USEPA, 2003). Participants wore the sampler continuously as they encounter different microenvironments and perform their daily activities (USEPA, 2003). Personal exposure data was collected for 24 h (12-h basis) in a sampling session of 2 days (48 h). In the first day, morning session (9a.m. to 9 p.m.) was completed and then battery of same sampler was set for electric recharge for 12 hr and evening session (9 p.m. to 9 a.m.) was conducted in next day. Ten sampling sessions (twice in a week) have been completed on each participant. The frequency of ten in longitudinal sampling has been adopted in many studies earlier and it has also been reported that longitudinal study is more susceptible to scientific justification of monitoring outcome (Wheeler et al, 2000). Personal RPM of selected battery recycling workers has been shown in Table 2 and regression graphs of the selected routes' RPM with personal RPM has been shown in Figure 2.

Method of Workshop and Residential Indoors, Ambient Outdoor and Road-Traffic RPM Sampling

Workshop indoors and participants' residential indoor RPM levels along with local ambient-outdoor RPM levels and road-traffic outdoor RPM levels have been measured simultaneously using a set of three handy samplers (Envirotech Model APM 821) attached with a cyclonic assembly (having cut off size less than five micron) under longitudinal stratified random sampling plan (USEPA, 2003). Indoor and traffic-outdoor monitoring has been conducted at a height of 4-5 ft, while monitoring of local ambient-outdoor has been conducted at a height of 12 ft. In case of RPM sampling at traffic-outdoors, sampler was positioned at a local heavy traffic junction close proximity to all selected workshops. Samples of RPM in all classified air receptors have been collected at an average flow rate of 1.1-1.2 L.Min-1 of the Personal and Handy samplers. Ten measurements (twice in a week) have been conducted during personal sampling period. The National Ambient Air Quality Standards have been formulated using PM10, henceforth a sampling plan of PM10 simultaneously with ambient RPM monitoring has been conducted using Respirable dust sampler (RDS) (Envirotech Model APM 460) with average flow rate of 1.1-1.3 m3.min-1. The results have shown that RPM (PM5)/PM10 ratio was 0.69 and comparable with earlier measurements (Gadkari and Pervez, 2007).

Sample Pre-treatment and Analysis

All the samples/sampled filters collected from different sites of different sources/routes and personal exposure assessment were digested with (1:3) H2O2 and HNO3 mixture (AnalR grade, Merck) using Teflon digestion bombs having capacity of 100 mL (Envrotech, 2000). The samples were digested at 180oC for 12 hours in a temperature controlled muffle furnace (Labtech Model

Table 2. Personal RPM levels (µg/m^3) of workers engaged in battery recycling workshops along with its component of indoor–outdoor matrices

Receptor (subjects)	Subject characteristics	Workshop category	Personal RPM	Workshop indoor RPM	Residential Indoor RPM	Road Traffic RPM	Ambient outdoor RPM
BBH1	41/M/√	Small	425.88±101.24	178.90±42.09	244.26±67.39	208.19±48.15	240.9±56.05
BBH2	42/M/√	Small	555.69±114.27		205.06±42.68		
BBH3	35/M/√	Medium	698.87±164.32	317.57±149.37	190.23±49.76	213.79±46.79	
BBH4	24/M/√	Medium	830.98±106.41		199.71±34.49		
BBH5	33/M/×	Large	857.90±94.10	359.30±97.87	263.06±50.00	216.12±38.00	

Subject characteristics: Age, M-male, √-Smoking, and ×- Non-smoking

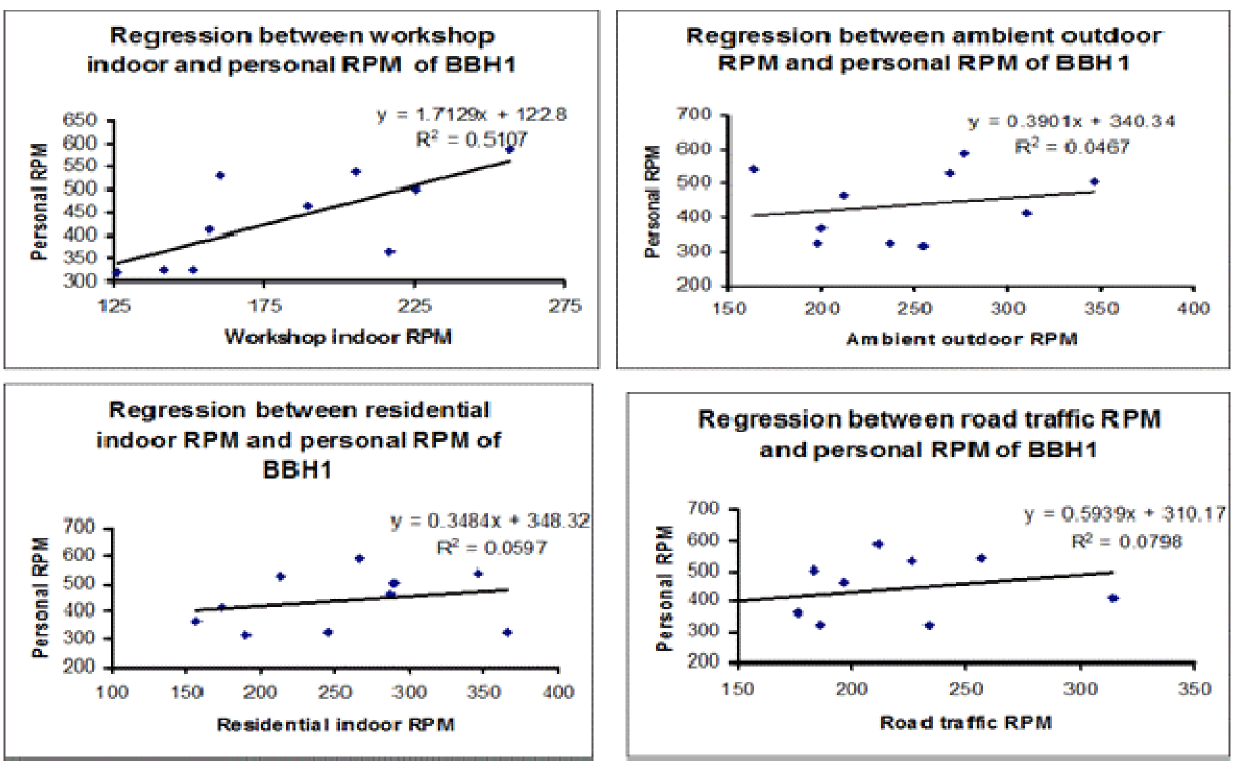


Figure 2. Regression graphs of the RPM of different exposure routes with the personal RPM of BBH1

TIC 4000). The samples were then cooled and filtered through Whatman filter paper No: 42. The final volume is made up to 50 mL by double distilled water (Envirotech 2000). The digested samples were then transferred into cleaned glass bottles. The digested samples were then subjected to chemical analysis for the selected elements

Table 3. Regression analysis of personal RPM with selected routes of exposure among battery workers.

Sources / Receptors	Battery recycling workshop indoor (S1)			Residential indoor (S2)			Ambient outdoor (S3)			Road traffic (S4)		
	m	c	r^2	m	c	r^2	m	c	r^2	m	c	r^2
BBH1	1.71	122.8	0.51	0.35	348.3	0.06	0.39	340.4	0.05	0.59	310.2	0.08
BBH2	1.58	276.0	0.34	0.77	406.0	0.08	0.19	517.2	0.009	0.90	373.3	0.15
BBH3	0.77	422.9	0.59	0.39	611.3	0.02	0.34	634.56	0.01	0.50	578.5	0.02
BBH4	0.52	649.7	0.56	0.34	762.0	0.01	0.12	801.6	0.004	0.81	653.2	0.13
BBH5	0.47	672.5	0.24	0.58	706.5	0.10	0.52	735.47	0.09	1.21	596.9	0.24

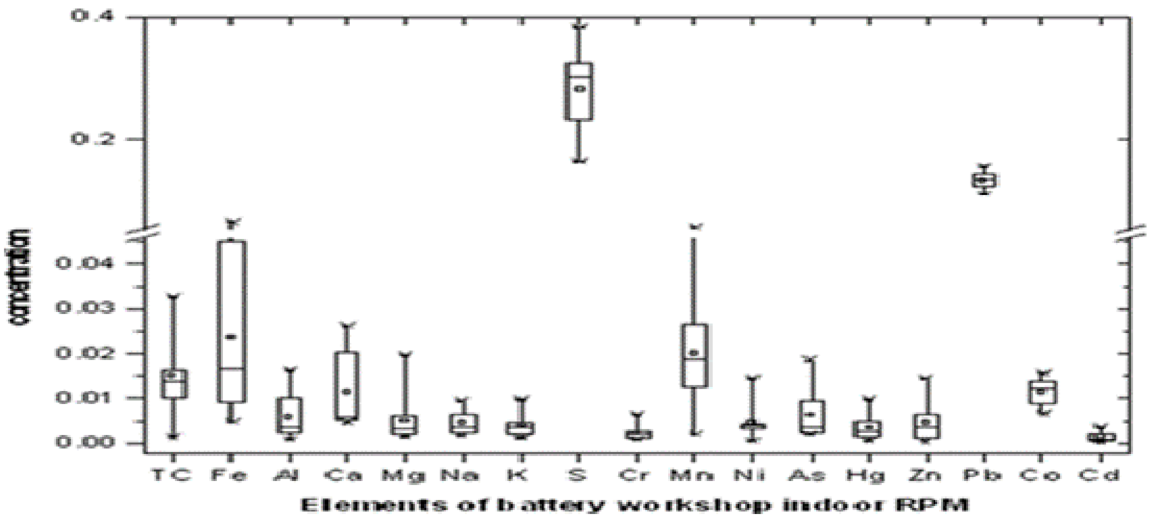
(Fe, Al, Ca, Mg, Hg, Cd, Co, Mn, Cr, Zn, Pb, Ni) using ICP-AES (JOBIN–YVON HORIBA ICP Spectrometers Version 3.0) at Sophisticated Analytical Instrumentation Facility (SAIF), IIT, Mumbai (Montaser and Golightly, 1987). Total carbon was analyzed using conventional thermo gravimetrically (ignition-loss) method and sodium and potassium were determined flame photo metrically (Bassett et al, 1978; CPCB, 2007 and Katz, 1977). Details of the regression analysis have been given in Table 3. Box plot diagrams of selected sources and receptors have been diagrammatically shown in Figure. 3 and 4.

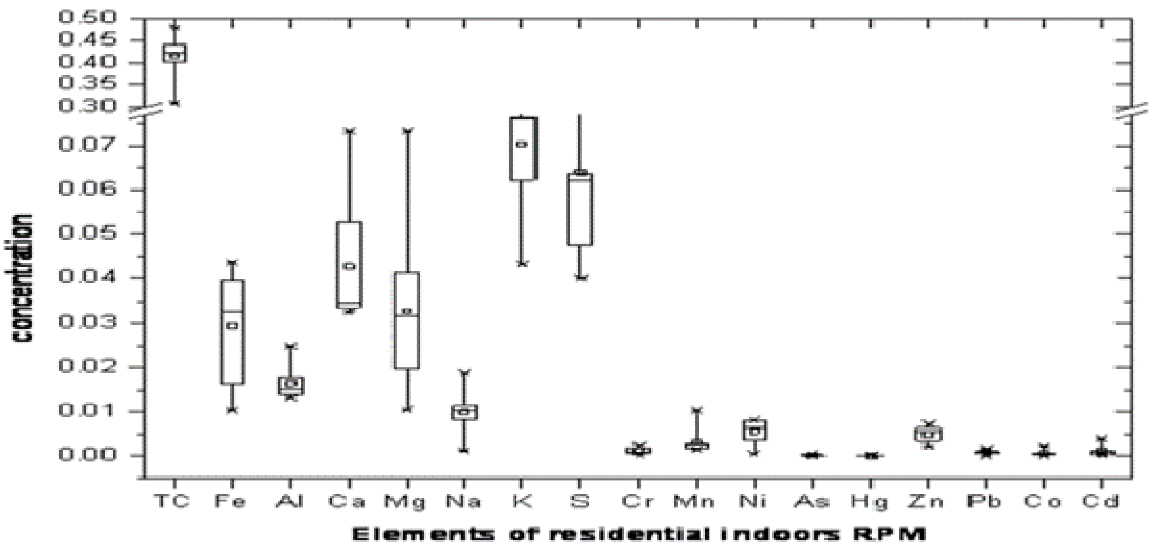
Source apportionment studies

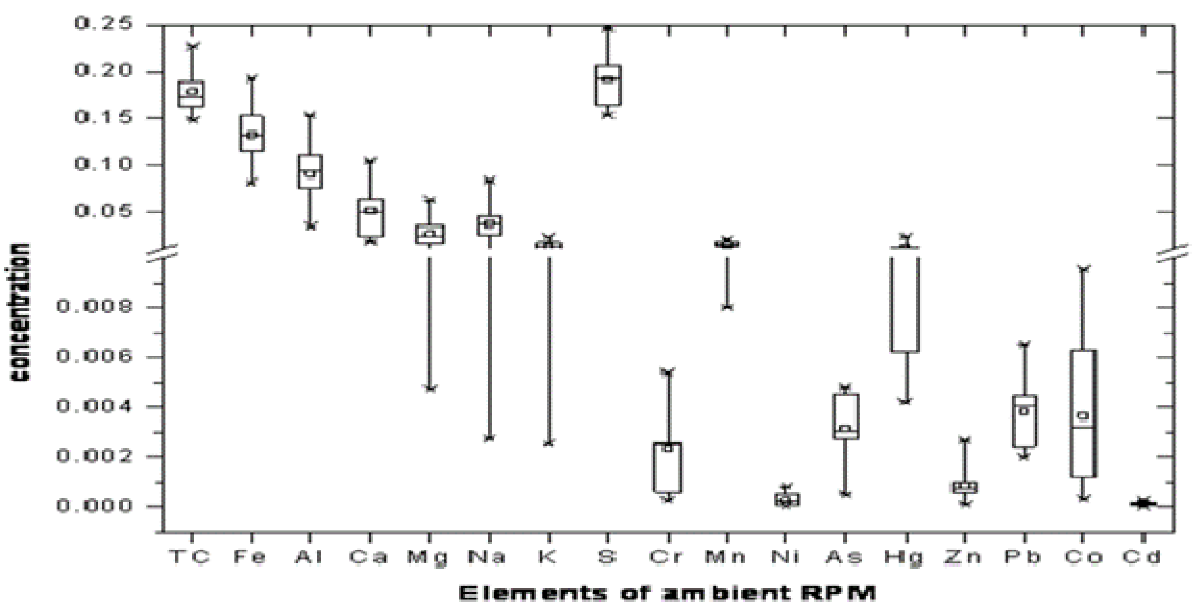
Researchers have examined the factors influencing indoor- outdoor ratios or penetration and deposition coefficients using elemental mass data on personal, indoor and outdoor PM data (Yakovleva, 1999) in the accumulation mode particles with stationary or mobile combustion have greater potential for penetration into homes. Source apportionment receptor modeling has been applied to the personal exposure data to understand the relationship between personal and ambient source of particulate matter (USEPA, 2002).

Most important task of any receptor modeling is to develop receptor profiles along with susceptible source profiles. USEPA has developed comprehensive source profiles of various stationary, mobile and area sources that include anthropogenic and natural origin. A large collection of various source profiles has been reported in Speciate 4.0 (Speciate 4.0, 2005). The work being presented here is focused on development of chemical compositional profiles of selected sources (welding indoor RPM, welders' residential-indoor RPM, road-traffic outdoors and local ambient-outdoors) along with characterization of personal RPM of selected welders using similar chemical constituents. The chemical species known for selected source indicators were chosen for the development of source-receptor profiles.

A non-probability based representative sampling plan using longitudinal study design has been adopted for development of source-receptor compositional profiles (Gilbert, 1987). Except local ambient-outdoors, all other source/routes profiles have been formulated on average basis using representative samples of RPM from workshops, residential indoors, road-traffic outdoors. A single ambient monitoring station has been decided for source profile of ambient-outdoor level. Apart from these routes, soils have also been identified as one of the major routes of exposure in urban conditions. Soil samples were collected by a laboratory manual method using a Handy Sampler attached with a cyclonic assembly(cut off point 5.0 mm size particulates) (Envirotech Model APM 821). In this method, 10 kg of surface soils were dug out from locations surrounding the residential houses of each colony. Soil samples were collected from depth of 6 inches and transferred to laboratory. Soils have been smashed in a milling machine and blown in a closed glass chamber (size 1.5m3) using a pressure fan. The cyclonic attachment of Handy Sampler has been placed in the chamber and operated during dispersion of soil dusts in the chamber (Gadkari and Pervez, 2007). The method of soil sampling and extraction of RPM has been repeated 10 times throughout the period of personal sampling. The data of source and receptor profiles were incorporated in the CMB software by making files as per the execution protocol of CMB8 model (Watson et al, 1998; Friedlander, 1973 and Cooper and Watson, 1984). The results so obtained, have explained the parameters of the source contribution estimates. The important good fit parameters of CMB8 model are t- stat, r2 and chi2. T-Statistic (TSTAT) is the ratio of the source contribution estimate (SCE) to its standard error. A high TSTAT suggests nonzero SCE, [Target > 2.0]. R-square is r-square variance in receptor species concentrations explained by the calculated species concentrations. A low r2 (<0.8) indicates that the selected source profiles have not accounted for the variance in the selected receptor concentrations. It ranges from 0 to 1.0. [Target 0.8 to 1.0]. Chi2 (CHI SQUARE) is similar to R-SQUARE except that it also considers the uncertainties of the calculated species concentrations. A large CHI SQUARE (>4.0) means that one or more of the calculated species concentrations differs from the measured concentrations by several uncertainty intervals. Source contri-bution estimate of detected sources has been shown


0.4
0.2
0.04
0.03
0.02
0.01
0.00
concentration
TC Fe Al Ca Mg Na K S Cr Mn Ni As Hg Zn Pb Co Cd
Elements of battery workshop indoor RPM


0.50
0.45
0.40
0.35
0.30
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
concentration
TC Fe Al Ca Mg Na K S Cr Mn Ni As Hg Zn Pb Co Cd
Elements of residential indoors RPM


0.25
0.20
0.15
0.10
0.05
0.008
0.006
0.004
0.002
0.000
concentration
TC Fe Al Ca Mg Na K S Cr Mn Ni As Hg Zn Pb Co Cd
Elements of ambient RPM

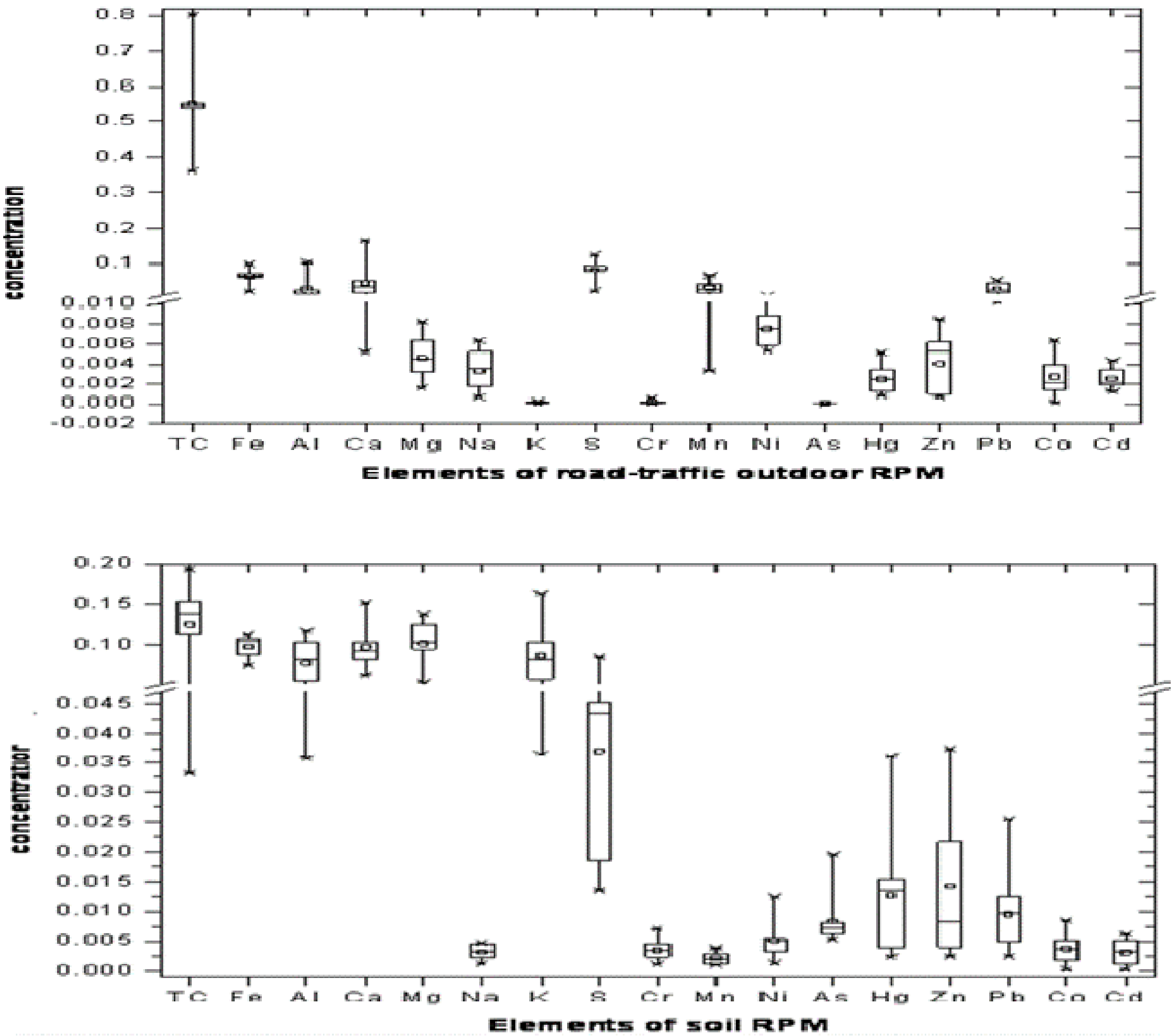
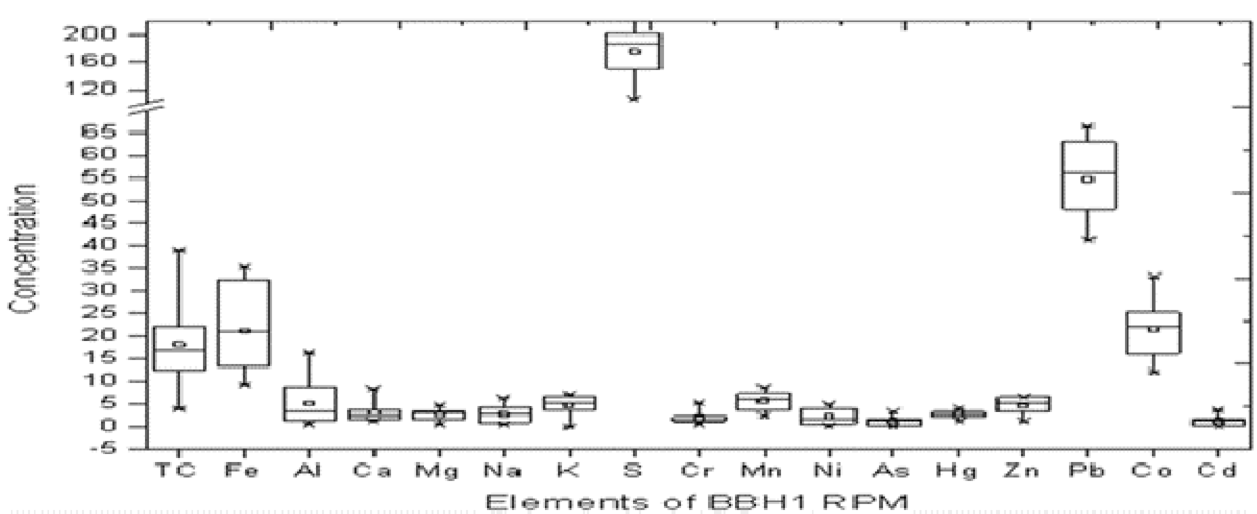
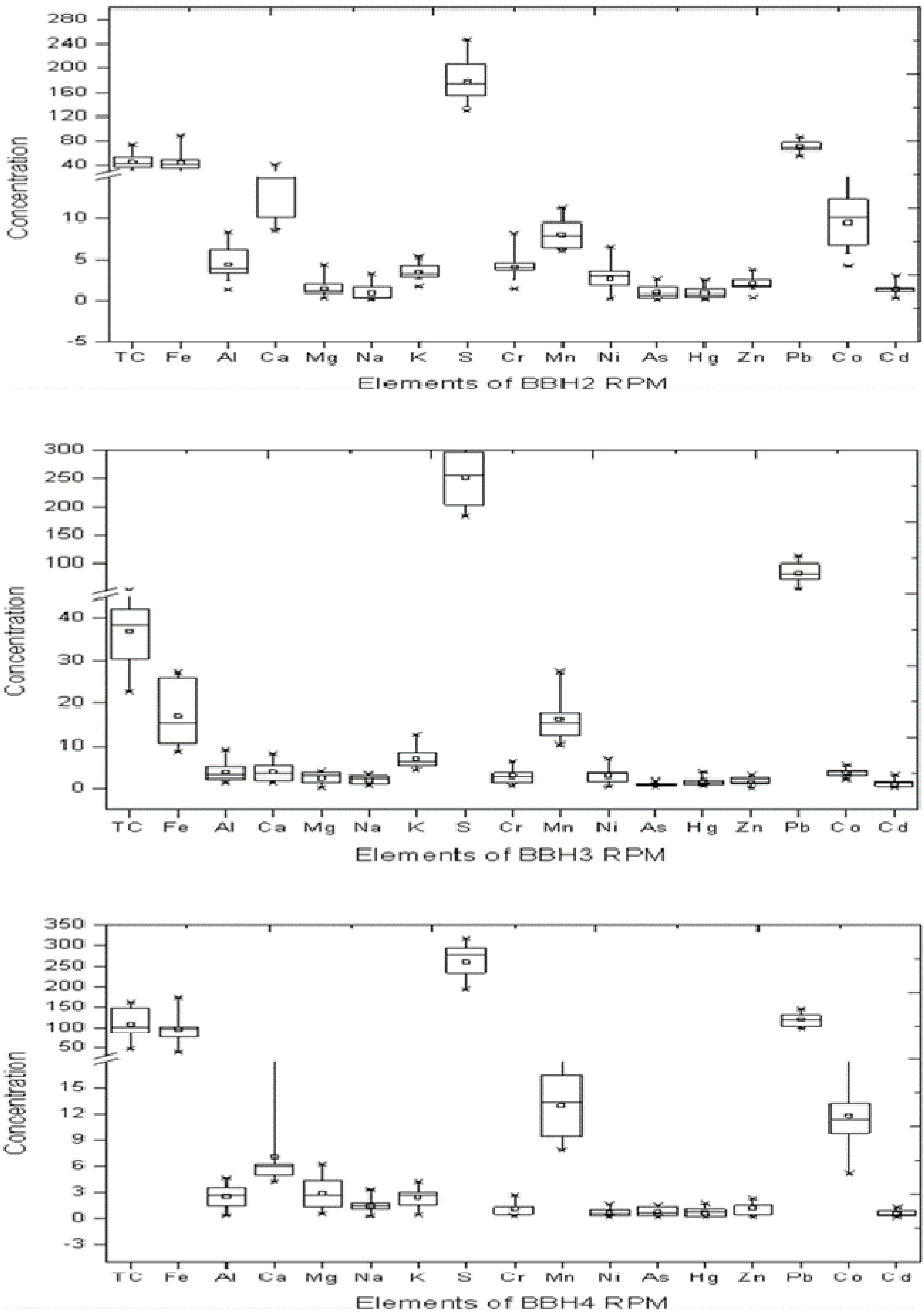


Figure 3. Statistical graphs of the chemical profile of the RPM of different routes of battery recycling workers (Concentration in %)




Concentration
TC Fe Al Ca Mg Na K S Cr Mn Ni As Hg Zn Pb Co Cd
Elements of BBH2 RPM
Concentration
TC Fe Al Ca Mg Na K S Cr Mn Ni As Hg Zn Pb Co Cd
Elements of BBH3 RPM
Concentration
TC Fe Al Ca Mg Na K S Cr Mn Ni As Hg Zn Pb Co Cd
Elements of BBH4 RPM

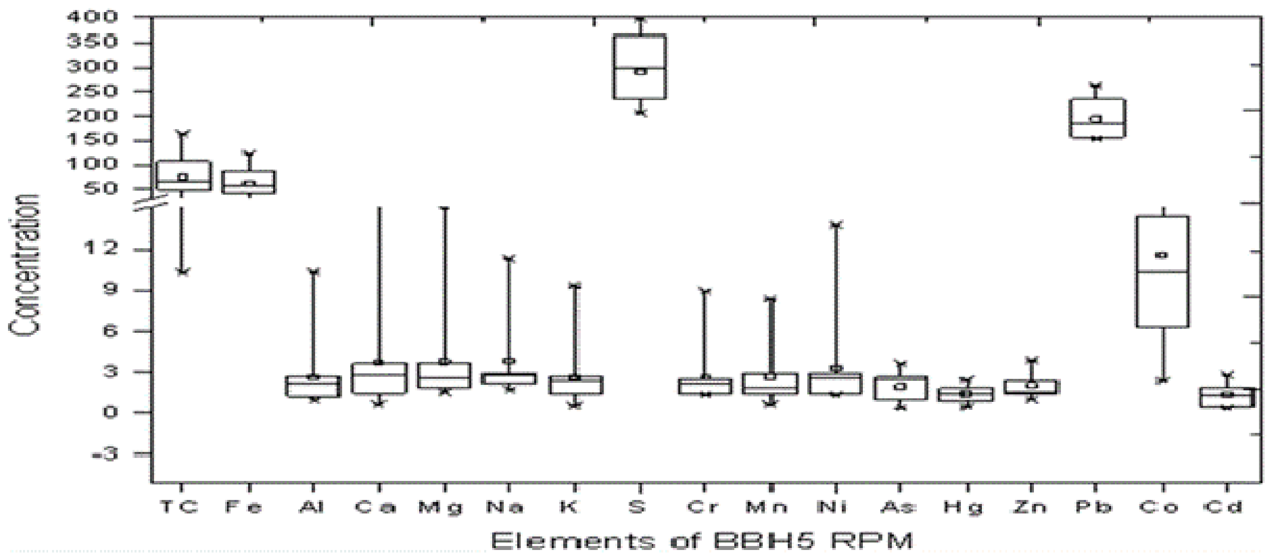
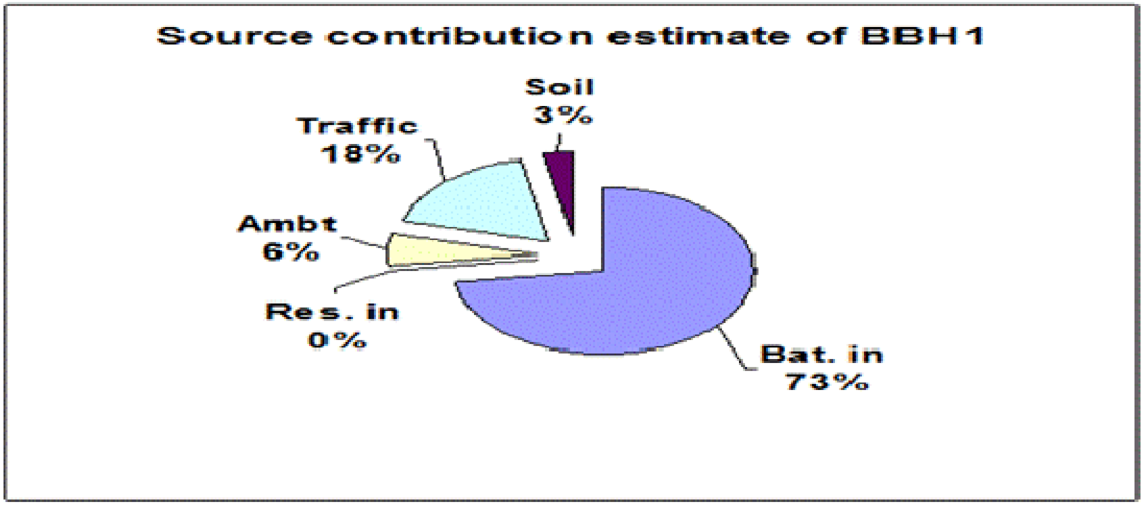


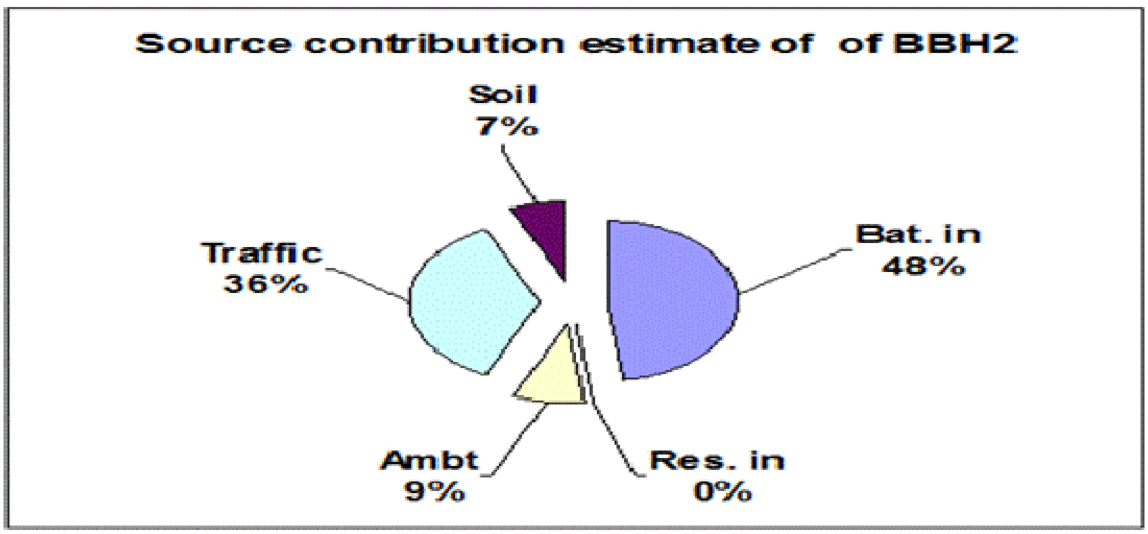
Figure 4. Statistical graph of the chemical profile of the personal RPM of battery recycling workers (Concentration in µg/m^3).

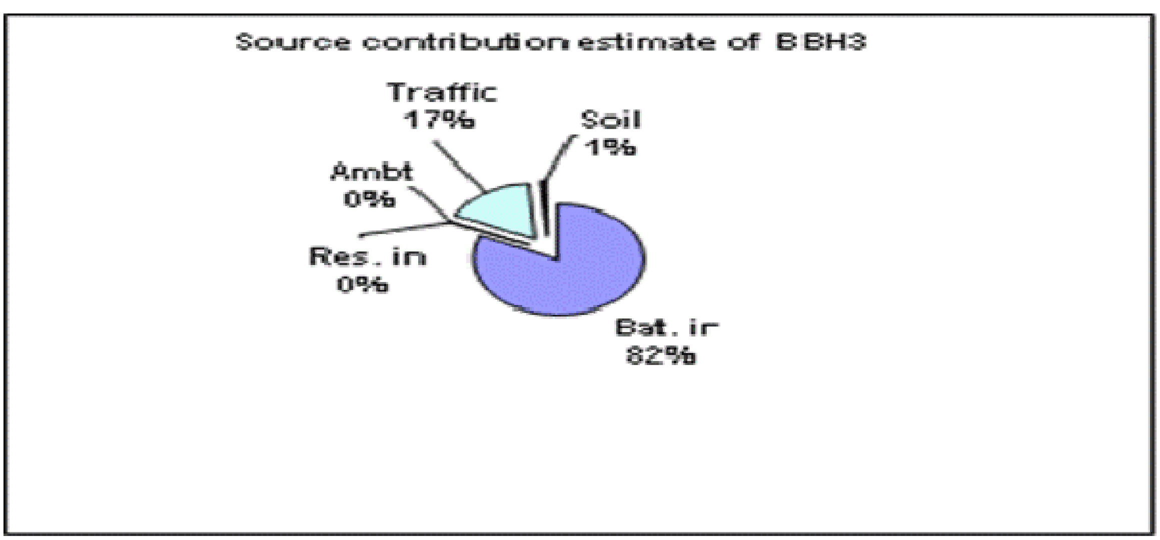
in Figure 5 and good fit parameters have been tabulated in Table 4.

RESULTS AND DISCUSSION

Most of the battery workers were in the mean age of 30-40 with minimum 08 years experience. The workshop W1 was well ventilated but the other two W2 and W3 were of poor ventilation. First two subjects BBH1 and BBH2 belonged to the first workshop, BBH3 and BBH4 belonged to the second workshop and BBH5 belonged to the third workshop. The personal RPM values in all the five subjects were significantly higher compared to the National Ambient Air Quality Standards (NAAQS). It varied from 10.2-20.7 times higher. The workshop indoor RPM was 4.29-8.67 higher, residential RPM varied from 4.58-6.35, the road traffic RPM was 5.02-5.21 times more and the ambient air RPM was 5.79 fold higher than the values prescribed by the Central Pollution Control Board (CPCB). Taking into account the contribution phenomena of personal RPM from selected routes, in case of BBH1, 75% contribution comes from the workshop indoor itself with an r2 value of 0.51, from the residential indoor the contribution is 18.2%, from ambient outdoor 20% and from road traffic the contribution came at 27% with higher deviations in all cases showing the variation of the source contribution and except the workshop indoor the remaining sources gave poor correlation. In case of BBH2 the workshop indoor contribution was 50.2%, the residential indoor contributed 4.65%, the ambient outdoor contribution was 6.8% while the road traffic contributed to 32.1%. Both BBH1 and BBH2 have decidable contribution is from the workshop indoor followed by the road traffic .This might be due to the proximity of the workshops with the National Highway and also due to the presence of steel plant in the surrounding area of the first workshop. In case of BBH3 the workshop indoor contribution was 33.4%, from residential indoor 12.3%, from ambient outdoor 9.2% and road traffic contribution was 17.2%. The less values in the case of workshop indoor and road traffic might be due to the varying workload everyday and changing wind conditions around W2. In case of BBH4 the workshop indoor contribution was 21.8% the residential indoor contribution was 8.2% the ambient outdoor contribution was 3.5% and the road traffic's share was 21.3%. BBH3 and BBH4 subjects the correlation coefficient value is above 0.5 which shows the significance of the workshop indoor in the source contribution estimate. In the personal RPM of BBH5 the workshop indoor contribution was 22.8%, residential indoor 17.65%, ambient outdoor 14.2% and road traffic contribution was 30.4%. It has been clearly observed that r2 values in all cases except workshop indoor is comparatively weaker which shows the weak correlation between these sources and personal RPM and the good correlation of the workshop indoor with personal RPM. The workshop indoor r2 value in BBH5 is 0.24 only and the road traffic r2 is 0.24 even though the road traffic contribution was more than the workshop indoor share. In this case the ambient outdoor correlation coefficient was 0.09, perhaps due to the prevailing wind condition. Among the different subjects BBH3 has given the strongest positive correlation with the workshop indoor with an r2 value of 0.59 followed by BBH4, BBH1, BBH2 and BBH5. In case of residential indoor r2 was comparatively stronger for BBH5 and weaker in other cases. The regression analysis of personal RPM and different sources' RPM has supported the report of the severe impact of traffic emissions in Asian countries


Source contribution estimate of BBH1
Soil
3%
Traffic
18%
Ambt
6%
Res. in
0%
Bat. in
73%


Source contribution estimate of of BBH2
Soil
7%
Traffic
36%
Bat. in
48%
Ambt
9%
Res. in
0%


Source contribution estimate of BBH3
Traffic
17%
Soil
1%
Ambt
0%
Res. in
0%
Bat. in
82%

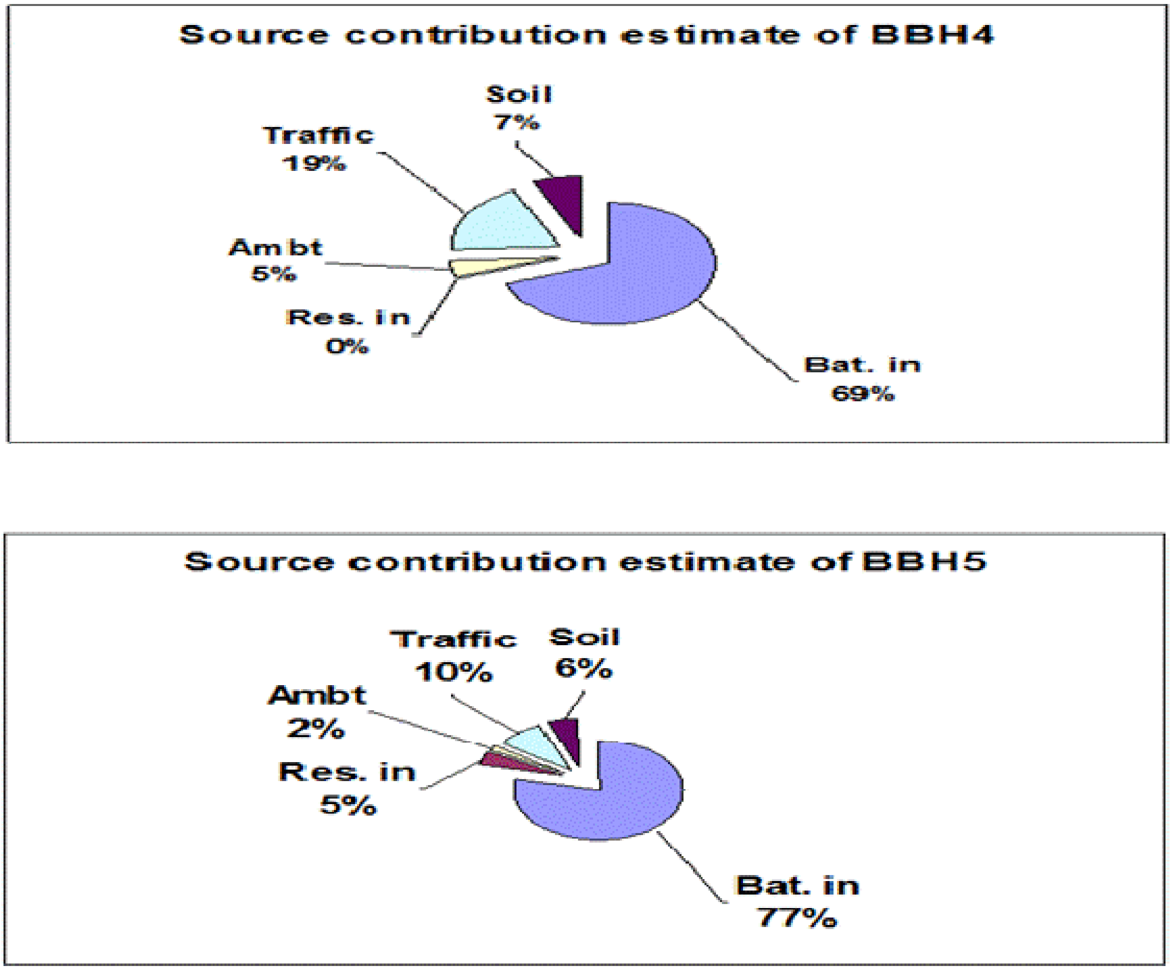


Figure 5. Source contribution estimate of the personal RPM of battery recycling workers

Table 4. Good fit parameters obtained by the execution of CMB8 model.

Receptor Code	Date	R^2	χ^2	TSTAT				
				S1	S2	S3	S4	S5
BBH1	08/10/05	0.82	1.01	6.13	-0.80	0.50	0.83	0.32
BBH2	14/11/05	0.92	0.52	5.27	-1.37	0.69	1.63	0.71
BBH3	25/11/05	0.94	0.26	5.22	-0.42	0.03	0.76	0.07
BBH4	02/01/06	0.92	0.59	6.25	-1.86	0.43	0.61	0.61
BBH5	15/01/06	0.81	0.53	3.71	0.38	0.19	0.71	-0.50

(Pervez et al, 2006 and USEPA, 2008). The results of the exchange phenomena have been further investigated using chemical mass balance (CMB8) to assess the precise source contribution estimates.

Source of Battery Workshop Indoors: It has been observed that lead and sulphur were found in higher concentration compared to other species. Lead has already been reported in earlier investigations (Bhagwat et al, 2008). Its concentration was 13.2%. Sulphur constituted 27.3%. Total carbon was 1.1% and iron constituted 1.7%. Cobalt was present with concentration level of 1.1%. In case of sulphur, and cobalt the mean value lies below the 50th percentile and in all other cases it is above the 50th percentile. The outlier observations are lying closer to 75th percentile in case of sulphur, lead and cobalt. In all other cases of outlier observations have shown tendency towards the 25th percentile. The marker element lead has mean and median value very close to each other showing its generation by the indoor activity itself due to the processing materials. In case of calcium, mercury and zinc the outliers are very much closer to the 25th percentile. Except sulphur and lead all elements have come within 10% of the total RPM indicating a clear demarcation between the major and the minor elements.

Personal RPM

Total carbon was found in the range of 3.6%-12.3% of the total RPM with lower value of standard deviations compared to the mean values. Iron was in the range of 2.24%-9.97% of the total RPM. Sulphur was in the range 30.8% -40.44% with lower value of the uncertainty showing its predominance in the personal RPM of the battery recycling worker. From the boxplot graph of the personal RPM it is clear that sulphur has been generated by the indoor activity itself. The concentration of lead varied from 11.6% -22.1% and in all the cases the mean value and the median are coming close to each other showing its predominance in the battery recycling industry. Unexpectedly cobalt also has shown a similar trend with RPM concentration varying from 0.5 -4.85%. Potassium which is the marker of residential RPM has been found in the range of 0.22%-0.88%. Aluminium concentration varied from 0.23% -0.72%, calcium from 0.23-2.86%, the amount of which was comparatively higher in the case of BBH2. Magnesium varied from 0.18-0.5% sodium from 0.11-0.46% chromium from 0.11-0.67%, manganese from 0.25-2.235, nickel from 0.05-0.41%, arsenic from 0.06-0.2%, mercury from 0.05-0.2%, zinc from 0.10-0.93% and cadmium from 0.04-0.22% in the longitudinal measurements of the personal RPM of battery recycling workers. The outliers in BBH1 are in the proximity of the 75th percentile and in other subjects it is in the vicinity of the 25th percentile. The good fit parameters of all CMB execution for selected personal RPMs are in agreement within the prescribed values of the model. All personal RPM have shown comparatively higher contributions from workshop indoors compared to other sources and represent the dominant source of personal exposure of RPM among battery recycling workers, the least was in the case of BBH2 with 48%. All personal RPM have shown more than one/third contributions from workshop indoors compared to other sources and represent predominant source of personal exposure of battery recycling worker. The contribution varied from 48-82% in five different subjects. Road traffic contributions varied from 10-36% except in one subject where it was nil. Residential indoor contributed less and it was almost negligible except in the case of BBH5. Ambient outdoor contributions varied from 2-9% and soil contribution was in the range of 3-7%. In all cases the workshop indoor and road traffic are the major sources for the battery worker, which shows that other microenvironments are also the deciding factors through which the subject passes in his day to day activities.

The r2 value varies from 0.81-0.94, nearer to 1, the best fitting the parameters are (Watson et al, 1998). Similarly chi2 values vary 0.26-1.01 where the best values will be nearer to 1and can go up to 4. BBH2 has shown the best fitting r2 value (0.96) and BBH1 has shown the best fit chi2 value (1.01). The TSAT values are considerably less in the case of residential indoor where the contribution is less. This may be due to the better domestic environments of the workers. Comparatively the soil contributions are better because of the proximity of the area with the integrated steel plant and National Highway.

CONCLUSION

This study has proved that the total personal exposure to particulate matter of a battery recycling worker is from his work environments as well as other ambient and non-ambient sources. The regression analysis between the RPMs of various sources have revealed that the main contributor to the workers' exposure is the battery workshop indoor, even though other factors especially road traffic adds to this component. The source profile contained about 13% of Pb in the RPM. The receptors' overall exposure is the factor to be taken into account. The study on five receptors at different sites have also proved that exposure factor varies in accordance with the load they expose themselves in the workshops. The number of years also adds to the problem. All receptors have shown higher concentration of Pb and S.

Execution of the source and receptor profiles of selected species in the CMB8 model has given the source contribution estimate (SCE) of various contributing routes of the battery worker which was in good agreement with the regression analysis studies. The good fit parameters were on the expected lines of the model. All the five subjects have shown considerably higher contribution from workshop indoor and in the case of BBH3 it was as high as 82%. It also has given the best r2 value but a less 2 value. The different subjects have shown different contribution but from different sources but it should be related to the working load, the surroundings of the workshop and residence as well as the serving years in a respective workshop.

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