British Journal of Applied Science & Technology
4(11): 1693-1717, 2014

SCIENCEDOMAIN *international*
www.sciencedomain.org

Environmental Impact of Metal and Metal Containing Wastes on the Cadmium and Lead Contents of Leachate and Soils of the Aba-Eku Dumpsite, Ibadan, Nigeria

A. A. Oni[1,2*] and A. T. Hassan[1]

[1]*Department of Zoology, University of Ibadan, Ibadan, Nigeria.*
[2]*Institute of Applied Ecology, Shenyang, China.*

Authors' contributions

This work was carried out in collaboration between all authors. Author ATH conceptualized and designed the study, author AAO managed the literature searches and wrote the protocol, carried out the experiments, performed the statistical analysis, and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

Original Research Article

Received 20th November 2013
Accepted 28th January 2014
Published 20th February 2014

ABSTRACT

Aims: This study evaluated the impact of metal and metal containing wastes (plastics, glass, miscellaneous and fines) on cadmium and lead contents in soil and leachate and the inter-relationships among the various waste categories dumped on the site, using Principal Component Analysis (PCA).

Study Design: Cadmium and lead contents in top soils of Sub-site WDA (Waste Dump Area) and LLA (Leachate Lagoon Area) (wdatscd, wdatspb; llatscd, llatspb); at 15-30cm depth i.e. sub-soil 1 (wdass1cd, wdass1pb; llass1cd, llass1pb); at 31-60cm depth i.e. sub soil 2 (wdass2cd, wdass2pb) and attenuated leachate cadmium and lead (alcd, alpb) were used along with the various waste fractions for PCA analysis.

Place and Duration of Study: Department of Zoology, University of Ibadan, Ibadan, Nigeria. January 2003-September 2004; Institute of Applied Ecology, Shenyang, China. May 2006-May 2007.

Methodology: Solid waste, leachate and soil were collected from two sub-sites (WDA and LLA and comparative control 600m away) from the Aba-Eku landfill site, Ibadan, Nigeria in February, April, August, October and December 2003; as well as in June 2004.

**Corresponding author: E-mail: adeyoni2006@yahoo.co.uk;*

They were analyzed for cadmium and lead contents using Inductively Coupled Plasma Spectroscopy after Hydrofluoric-Perchloric-Nitric acid digestion. Data obtained were subjected to PCA analysis.

Results: The tendency of the various metal containing waste categories to cluster with lead and cadmium in leachate and soil on more than one principal component is suggestive of the degree of input to lead and cadmium contamination in soil and leachate. Metals contributed the highest (cluster on all three PCs) followed by plastics and the miscellaneous fraction (cluster on two PCs), glass and the fines fraction (cluster on one PC). Results also revealed two main clusters of biodegradable (Food wastes, miscellaneous and fines or soil) and non-biodegradable wastes (Glass/ceramics and metals).

Conclusion: Based on these results, increased recovery and recycling of the metal, plastics and glass/ceramics waste fractions in particular, are suggested.

Keywords: Solid waste; soil; leachate; heavy metals; principal component analysis (PCA); Aba-Eku dumpsite.

1. INTRODUCTION

Among pollutants, heavy metals have been the subject of particular attention because of their long standing toxicity when exceeding specific thresholds. Their mobility in ecosystems and transfer in food chains are among the key issues in environmental research on heavy metals [1]. Technological developments and the increased consumer use of heavy metal containing materials have resulted in an increase in the extent of heavy metal contamination in the last fifty years [2]. Metal and metal containing wastes will ultimately require disposal. In most cases, this is via land filling, particularly in unlined landfills, as is common in many developing countries. The disposal of these wastes represents an important source of heavy metal contamination in soil, as well as in the leachates produced consequently. However, other anthropogenic sources of heavy metal contamination include mining, industrial and energy production, vehicle exhaust and coal and fossil fuel combustion. The level of heavy metals in urban soils has been shown to be useful tracers of environmental pollution [3,4].

Principal Component Analysis (PCA) is a method of Multi-Variate Data Analysis (MVDA), a statistical tool used for evaluating the correlations between several variables simultaneously. It is also useful for predictions [5]. Kylefors (2003) for instance, used MVDA to evaluate the possibility of predicting the content of specific organic substances (which are often expensive to analyse) in specific leachates from more common analyses [5]. The Aba-Eku landfill, Ibadan, Nigeria is the major repository of solid wastes in Ibadan, Nigeria. Ibadan has an estimated population of 3,847,500 million people according to 2007 census estimates [6] and is located 145km North-East of Lagos, Nigeria's commercial nerve centre. Studies carried out on the solid waste composition of the site revealed a sizeable proportion of metal and metal containing wastes such as plastics, fines and glass [7]. The implication of such waste types for solid waste leachates and the soil environment is the focus of this paper. This is important considering the fact that the soil also serves as a habitat for a great number of organisms. The impact on leachates and soil also has implications for groundwater quality in the vicinity of the landfill. This study was therefore conducted to determine the impact of metal containing wastes on leachate and soils of the landfill site using Principal Component Analysis (PCA) as a tool.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is the Akanran / Aba-Eku refuse landfill site, a major operational dumpsite in Ibadan, which is located at 13km, along Akanran – Ijebu Igbo road in Ona-Ara Local Government Area of Oyo state Fig. 1. Leachates from the landfill are drained through a system of pipes into a central leachate lagoon located approximately 250m down gradient of the active fill area, where the domestic and industrial solid wastes are dumped.

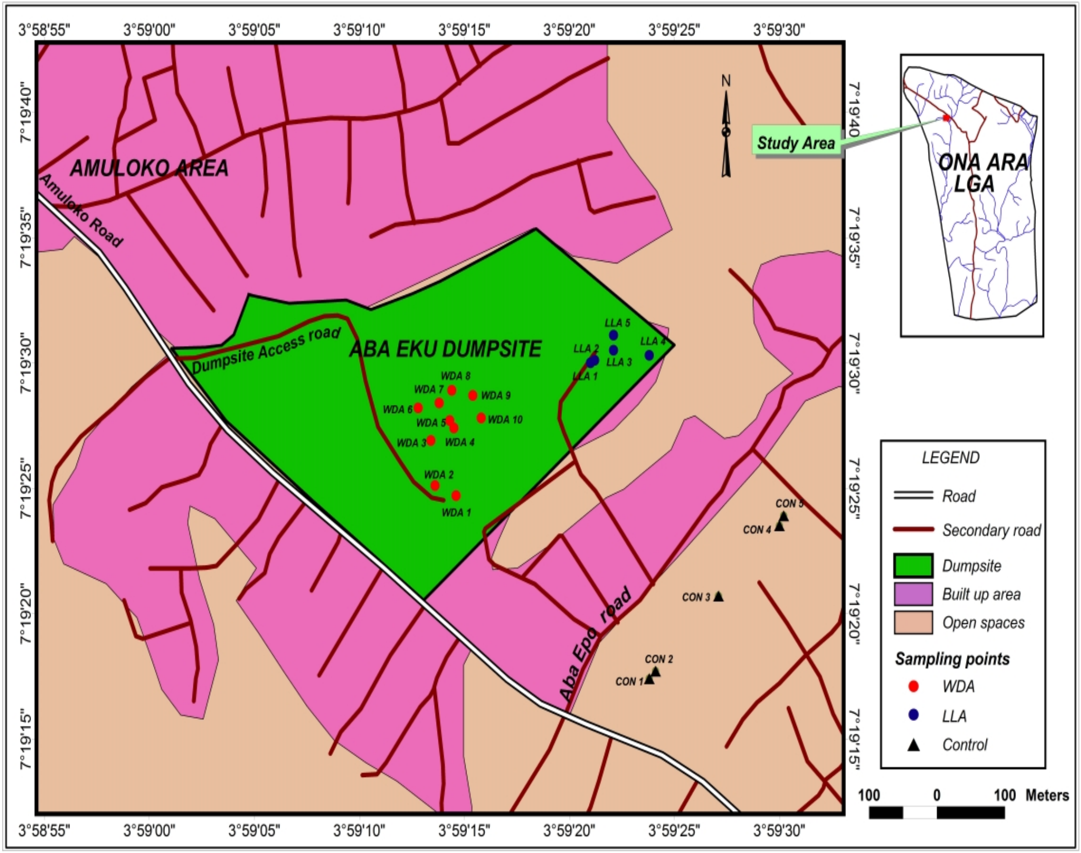


Fig. 1. Map of Ona-Ara LGA showing the Aba-Eku dumpsite

The study area was delineated into two sub-sites which were:

1. (1) The active fill area receiving the domestic and industrial wastes, otherwise known as the Waste Dump Area (WDA) and:
2. (2) The Leachate Lagoon Area (LLA) located approximately within 250m of the WDA.

A third site located approximately 600m from the landfill served as a comparative control site for reference purposes only and was designated CON. A Geographical Positioning System GPS 76 Garnier model was used to locate the sampling points.

2.2 Samples and Sampling

2.2.1 Sampling and sample processing for collected solid waste

Sampling of solid wastes was done at the site (WDA) monthly from January 2003 to September 2004. Solid waste samples were obtained from ten sampling points on the site WDA Fig. 1. The individual components of the collected solid wastes were sorted and weighed according to the site specific method of [8]. An average of 2.5kg of solid wastes was collected each month [2kg of solid waste samples is considered representative by the American Society of Testing and Materials – ASTM, [9]. The samples were collected in water-proof sacks and taken to the laboratory for sorting. Samples were thoroughly homogenized by mixing in the laboratory, prior to sorting. One kg representative sample was drawn out with the aid of a weighing balance and sorted into sixteen component parts. The percentage contribution of each solid waste category for each month as well as its overall percentage contribution was determined. The results are presented as means ± standard error of the mean (SEM).

2.2.2 Sampling, preservation and analytical methods for leachates

Leachates (attenuated as it passes through the landfill) were collected monthly between January 2003 and September 2004, in two 1.5 litre plastic containers from the leachate lagoon. However, only samples of February, April, August, October and December 2003; as well as in June 2004 were used for the PCA and presented in this paper. All the leachates were collected from the leachate lagoon in pre-washed polyethylene bottles and taken to the laboratory. They were stored at approximately 4°C until they were analysed. The metals were preserved and digested as stipulated by [10]. Thereafter, they were analyzed using an Inductively Coupled Plasma - Optical Emission Spectroscopy - ICP-OES Perkin Elmer Optima 3000 after nitric-perchloric acid digestion according to the method stipulated by [10]. Parameters analyzed were Cadmium (Cd) and Lead (Pb), two toxic metals shown to be elevated in adjoining groundwater of the site and linked to the solid wastes disposed on the site [7].

2.2.3 Sampling, processing and analytical methods for collected soil

Samples were obtained bimonthly between January 2003 and September 2004 from the two sub-sites (WDA; LLA) and the Control (CON) site using a soil auger at the following depths: Top-soils, 0-15cm; Sub-soils, 15-30 cm and 30-60cm. As with the leachate, only samples of February, April, August, October and December 2003; as well as in June 2004 were used for the PCA. These were selected months in which complete solid waste, soil and leachate sampling was carried simultaneously. In determining the number of sampling cores to be taken from the landfill, the suggestion of [11] was considered. Fifteen sampling cores were taken from the landfill area at each sampling period (i.e. monthly) as follows: WDA (10); LLA (5). Five cores were also taken at the control site (CON). In sampling soils of the WDA, ten soil cores were obtained from underlying soils of the dumpsite, at similar points from where the solid wastes were collected. Core samples at similar depths within each of the three sub-sites were bulked to form a composite sample for each depth at each sampling period. The soil samples were collected in well labeled polyethylene bags and taken to the laboratory for processing and analysis.

In the laboratory, soil samples were air-dried for 48 to 72 hours and pulverized using a porcelain mortar and pestle. Metals determined were cadmium and lead. They were determined on an ICP-OES Perkin Elmer Optima 3000 after Hydrofluoric – Perchloric - Nitric acid digestion according to the method of [12]. All analytical procedures were carried out at the Shenyang Institute of Applied Ecology, Shenyang, China. Data were analysed using PCA on the statistical package SPSS 15.0. Samples from selected months were used for the PCA. Cadmium and lead contents in top soils of Sub-site WDA and LLA (wdatscd and wdatspb; llatscd and llatspb); at 15-30cm depth i.e. sub-soil 1 (wdass1cd and wdass1pb; llass1cd and llass1pb); at 31-60cm depth i.e. sub soil 2 (wdass2cd and wdass2pb) and attenuated leachate cadmium and lead (alcd and alpb) were used along with the various metal and metal containing wastes for PCA analysis. Data obtained and used for the PCA are presented in Tables 1-2, while data obtained from the control site is presented in Table 3.

Table 1. Dataset for PCA of selected solid waste fractions

MONTHS	PAP	FW	SOIL	MISC.	PE	GC	MET
JAN.03	*26.37*	4.79	3.01	4.63	8.43	0.17	28.18
FEB.03	8.58	0.28	3.80	6.11	2.89	20.10	*44.11*
MAR.03	17.8	0.18	0.05	0.54	4.43	**23.51**	39.9
APR.03	**36.35**	2.57	5.34	7.86	12.50	12.00	17.41
MAY.03	7.50	0.38	7.40	8.38	7.50	13.96	**51.27**
AUG.03	11.72	**19.56**	7.88	13.22	8.26	0.00	28.66
OCT.03	20.14	4.30	1.77	10.60	8.03	*20.80*	23.34
NOV.03	25.34	8.90	**15.96**	10.96	8.27	0.00	13.19
DEC.03	7.30	3.40	8.20	10.17	6.70	19.71	34.1
JAN.04	21.70	5.01	3.74	9.10	13.47	0.10	9.58
FEB.04	14.96	5.14	5.50	14.15	14.90	0.00	31.48
MAR.04	19.21	*17.71*	8.70	*14.40*	10.94	2.03	6.56
APR.04	25.73	1.50	3.83	3.54	16.20	0.00	19.64
MAY.04	21.47	2.01	7.03	11.33	12.80	0.28	30.81
JUN.04	9.36	6.44	2.93	6.74	15.76	5.40	36.72
JUL.04	19.52	12.32	2.38	7.67	*18.03*	0.26	19.9
AUG.04	20.24	15.87	*11.26*	**18.10**	**27.10**	0.00	0.27
SEP.04	3.32	6.4	6.66	9.06	10.7	0.91	11.02

Highest / High amounts of each variable are highlighted in bold / italics respectively. No solid waste samples were obtained in June, July and September 2003. All values are in % (Values for each month sum less than 100% as data excludes the waste fractions not used for the PCA).

Table 2. Dataset for PCA of lead and cadmium in metal containing waste fractions, soil and leachates

Variable name	Abbr.	Unit	Feb.03	Apr. 03	Aug. 03	Oct. 03	Dec. 03	Jun.04
Metals (S.W)	swmet	%	44.11	17.41	28.66	23.34	34.10	*36.72*
Glass/cer. (S.W)	swgc	%	20.10	12.00	0.00	20.80	19.71	5.40
PE Plastics (S.W)	swpe	%	2.89	12.*50*	8.26	8.03	6.70	15.76
Misc. (S.W)	swmisc	%	6.11	7.86	13.22	10.60	10.17	6.74
Soil (S.W)	swsoil	%	3.80	5.34	*7.88*	1.77	8.20	2.93
WDA;topsoil;cd	wdatscd	mg/kg	22.15	21.98	28.17	18.38	17.22	34.81
WDA;topsoil;pb	wdatspb	mg/kg	*253.2*	273.06	235.48	161.47	244.98	187.52
WDA;15-30cm;cd	wdass1cd	mg/kg	6.15	12.99	*15.71*	17.48	14.70	13.47
WDA;15-30cm;pb	wdass1pb	mg/kg	199.3	156.65	251.39	211.88	*335.54*	356.80
WDA 30-60cm;cd	wdass2cd	mg/kg	11.81	11.26	*22.20*	16.73	19.14	23.59
WDA;30-60cm;pb	wdass2pb	mg/kg	196.5	*218.50*	189.70	204.10	281.32	191.45
LLA;topsoil;cd	llatscd	mg/kg	BDL	BDL	*2.60*	1.67	BDL	4.31
LLA;topsoil;pb	llatspb	mg/kg	157.*50*	163.06	32.77	122.50	1.17	BDL
LLA;15-30cm;cd	llass1cd	mg/kg	1.*23*	0.58	BDL	BDL	2.19	BDL
LLA;15-30cm;pb	llass1pb	mg/kg	9.55	81.39	BDL	4.58	0.83	85.28
Lcht;cd	alcd	mg/l	*0.19*	0.09	0.07	BDL	0.08	0.21
Lcht;pb	alpb	mg/l	0.09	0.03	*0.05*	0.02	0.04	0.03

Highest / High amounts of each variable are highlighted in bold / italics respectively; BDL – Below Detection Limits. Paper and Food Wastes were not considered as metal containing wastes.

Table 3. Data for control site

Variable name	Observations					
	Feb. 03	Apr. 03	Aug. 03	Oct. 03	Dec. 03	Jun.04
CON;topsoil;cd	1.42	2.55	1.71	0.94	BDL	2.00
CON;topsoil;pb	53.89	101.65	89.44	65.28	30.56	47.22
CON;15-30cm;cd	0.00	0.50	2.58	3.04	1.50	2.58
CON;15-30cm;pb	40.56	27.78	64.17	126.10	47.22	27.78
CON;30-60cm;cd	2.17	BDL	2.00	BDL	1.42	BDL
CON;30-60cm;pb	67.29	101.38	37.50	37.50	35.28	82.49

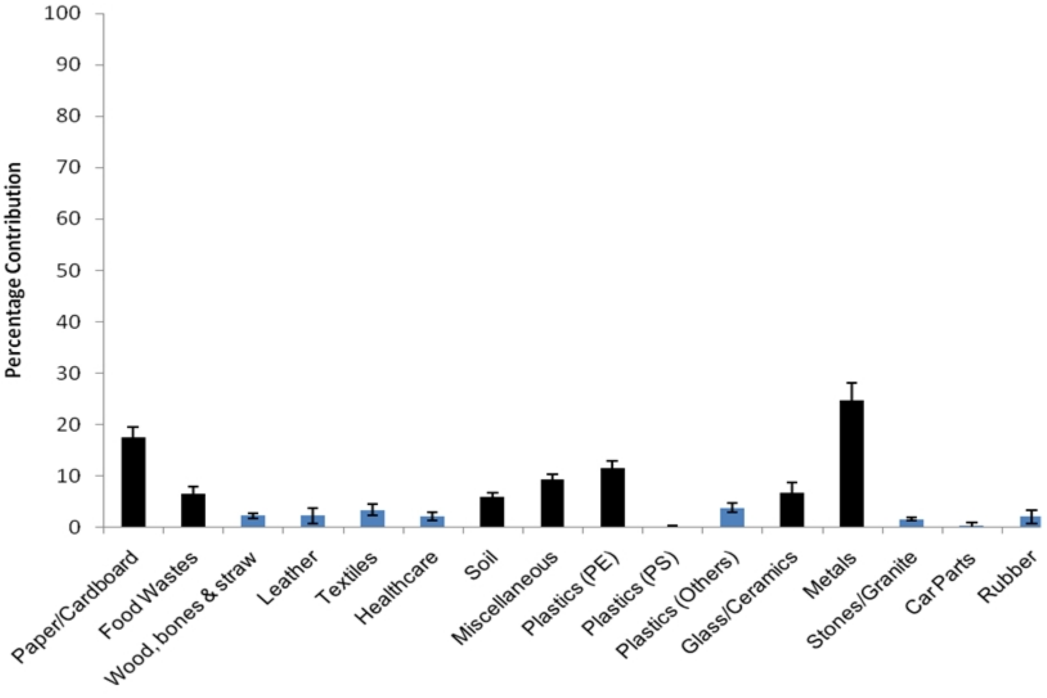
All values are in mg/kg; BDL – Below Detection Limits

3. RESULTS

3.1 Composition of the Solid Wastes

3.1.1 Mean percentage contribution of the various solid waste fractions

The mean percentage contribution (±SEM) of each waste category to the overall waste composition of the landfill site over the study period is illustrated in Fig. 2. Of the sixteen waste fractions observed in the solid wastes at the landfill site, seven of these contributed ≥ 5% to the overall waste composition of the Aba-Eku landfill site, and together, these seven fractions accounted for over 80% of the total waste composition of the landfill site. They were paper/cardboard, food wastes, biodegraded humus (soil or fines), polyethylene plastics, glass/ceramics, metals and the miscellaneous fraction (comprised of wastes difficult to assign to a category). The other nine fractions each contributed less than 5% and altogether accounted for a mean of less than 20% of the total waste composition of the landfill site Fig. 2. The seven waste fractions considered significant are highlighted in black color Fig. 2, and were used for the PCA to determine the inter-relationships amongst them. Table1 shows the solid waste fractions selected for the PCA. These results also showed a dominance of the metal waste fraction on nine out of the eighteen month sampling period for the solid wastes.



PE = Polyethylene; PS = Polystyrene; Other Plastics/Rigid Plastics; Waste fractions contributing ≥ 5 % are highlighted in black color. Values represent mean ± SEM, n = 18.

Fig. 2. Mean percentage contribution of the various solid waste fractions at Aba-Eku dumpsite

3.2 Analysis of Results on Solid Wastes-Leachates-Soil Relationship Using PCA

3.2.1 Principal component analysis for the solid waste fractions

Seven waste fractions with a total contribution of over 80% were selected for the PCA Fig. 3. Of these seven, metal and metal containing waste fractions (plastics, glass, soil or fines and the miscellaneous fraction) were subsequently used along with soil and leachate results to determine the relationship to metal contaminants in leachate and soil. Cadmium and Lead were the elements of focus in both soil and leachates, based on results on impact on groundwater adjoining the site. Six months of complete collection of solid wastes, soil and leachates were selected and used for the PCA.

PCA was first carried out on the seven solid waste fractions to determine the inter-relationship between these waste fractions. Results of the PCA for the solid waste fractions showed that about 70% of the total variance was due to two factors. The first factor explained about 37% of the variance and had strong positive loadings from the miscellaneous fraction, food wastes and biodegraded humus (or soil). Glass/ceramics and metals had fairly negative loadings on this factor as well. The second factor explained about 32% of the variance (cumulative of both factors - 69%) and had strong positive loadings from paper/cardboard and polyethylene plastics, while metals and the glass/ceramics fraction had strong negative loadings respectively.

Information from the rotated component matrix and factor score loadings generated by the PCA was used to generate loading and scatter plots for the solid waste fractions which is shown in Fig. 3. The results of the loading plots Fig. 3 highlighted two main clusters of closely related waste fractions - glass/ceramics (GC) and metals (MET) which are non-biodegradable wastes while food wastes (FW), biodegraded humus (SOIL) and the miscellaneous fraction (MISC) clustered together possibly indicative of their biodegradable nature. Paper/Cardboard (PAP) and polyethylene plastics (PE) were outliers and as such did not cluster with the other waste fractions Fig. 3.

The scatter plots which are basically plots of the observations used for the PCA are also presented in Fig. 3. The results showed that observations with high amounts of the variables (waste fractions) in the corresponding corners of the loading plot tend to scatter in a similar pattern. Sample observations with high amounts of polyethylene plastics, miscellaneous, food wastes and biodegraded humus all located in the upper right of the loading plots, influence the locations of the observations in the upper right of the scatter plots. Similarly, glass/ceramics and metals are located in the lower left of the loading plot, which influenced the observations with high amounts of these waste fractions to also locate in the lower left of the scatter plots. A similar pattern was observed for the other waste fractions as shown in Fig. 3.

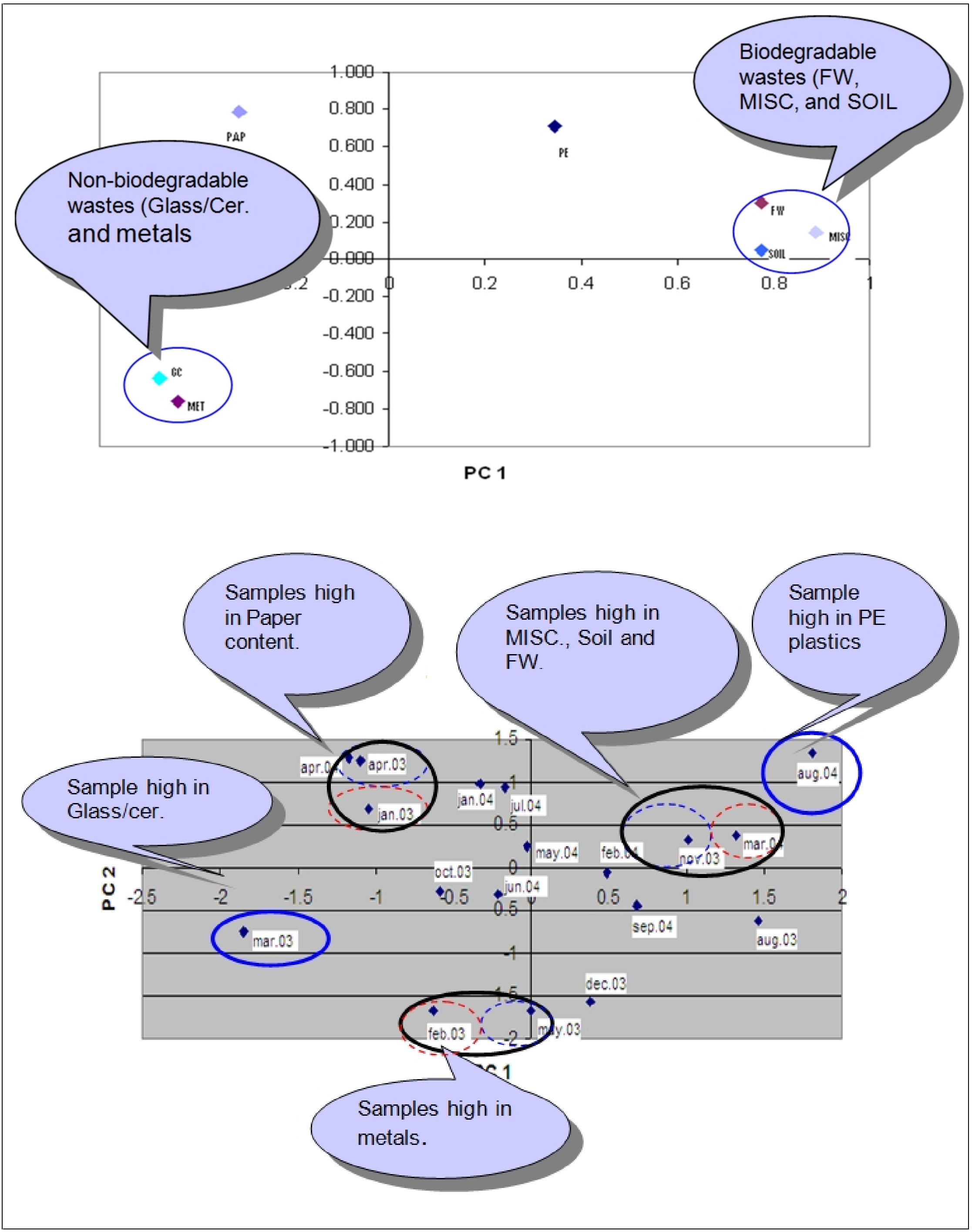


Fig. 3. Component loading (top) and scatter plots (bottom) for the solid waste fractions

3.2.2 PCA of Pb and Cd in solid waste fractions, soil and leachates

3.2.2.1 Metals (SW MET)

Results of the PCA using the metals fraction, soil and leachates showed that four components were extracted, which explained a cumulative of about 95% of the total variance. The first factor which explained about 31% of the variance had strong positive loadings from lead in sub-soils (15-30cm depth) of the waste dump area (WDA) – i.e. WDA/SS1/PB; cadmium at 30-60cm depth in WDA – i.e. WDA/SS2/CD and strong negative loadings from lead in top soils of LLA. The second factor which explained 26% of the variance (cumm. 57%) had strong positive loadings from the metal fraction of solid wastes (SW/MET), cadmium and lead in the leachate (AL/CD and AL/PB) and a strong negative loading from cadmium at 15-30cm depth in WDA - WDA/SS1/CD.

The third factor explained about 25% of the variance (cumm. 81%), had strong positive loadings from lead in 30-60cm depth in WDA (WDA/SS2/PB), cadmium at 15-30cm depth in LLA (LLA/SS1/CD) and a moderately positive loading from lead in top soils of WDA (WDA/TS/PB). There were also strong negative loadings on this factor from cadmium in top soils of both LLA and WDA (LLA/TS/CD and WDA/TS/CD). The fourth factor explained about 14% of the variance (cumm. 95%) and had a strong positive loading from lead at 15-30cm depth in LLA (LLA/SS1/PB) and moderately positive loadings from cadmium in top soils of WDA (WDA/TS/CD) and in the leachate - AL/CD.

Information obtained from the rotated component matrix and factor score loadings generated by the PCA were used to obtain scatter and loadings plots for the observations (months) and variables - the metal fraction of solid wastes, soil and leachate contaminants. Figs. 4–6 shows the scatter and loading plots for the metals, soil and leachate contaminants. It is important to note that for the metals fraction, all the three principal components highlighted clusters with the contaminants of focus in contrast to metal containing wastes which showed less clusters on all PCs. The loading plot in Fig. 5 highlights a cluster of the metals fraction with cadmium in leachates. The scatter plot (top) shows that the location of variables in the loading plot influences how the observations in the scatter plot are located.

The highest amounts of WDA/TS/CD; WDA/SS1/PB and AL/CD as well as next highest amounts of the metals fraction were obtained in June 2004. These variables are located in the upper right of the loading plot in Fig. 4 and explain why the observation of June 2004 locates on the upper right of the scatter plot. A similar pattern was observed for February 2003 which has the highest amounts of AL/PB and the next highest amounts of WDA/TS/PB and LLA/TS/PB, which in turn influence this observation to locate in the upper left of the scatter plot. Similarly the highest amounts of WDA/SS2/PB were obtained in December 2003 and this influences the location in the lower right corner of the scatter plot Fig. 4.

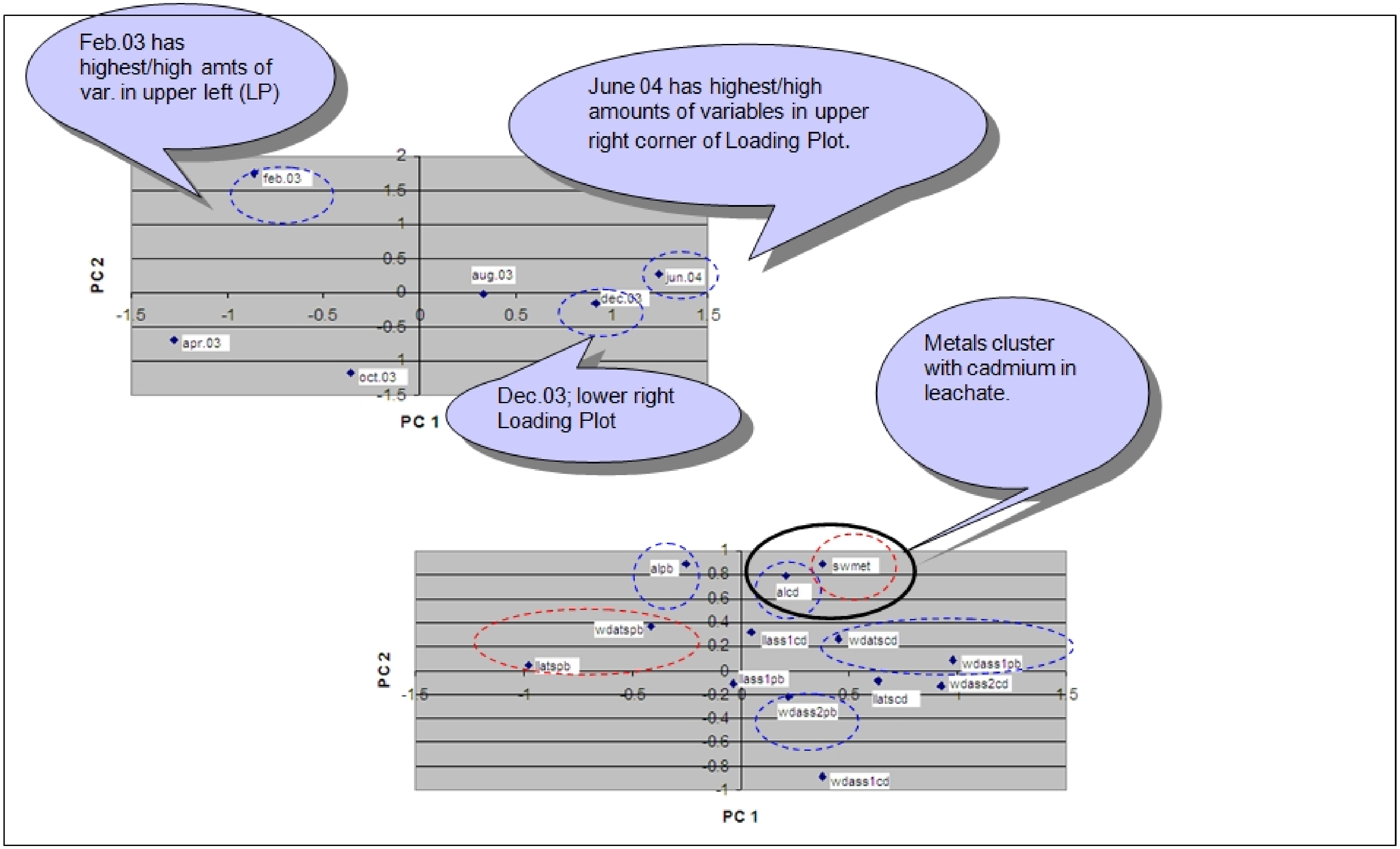
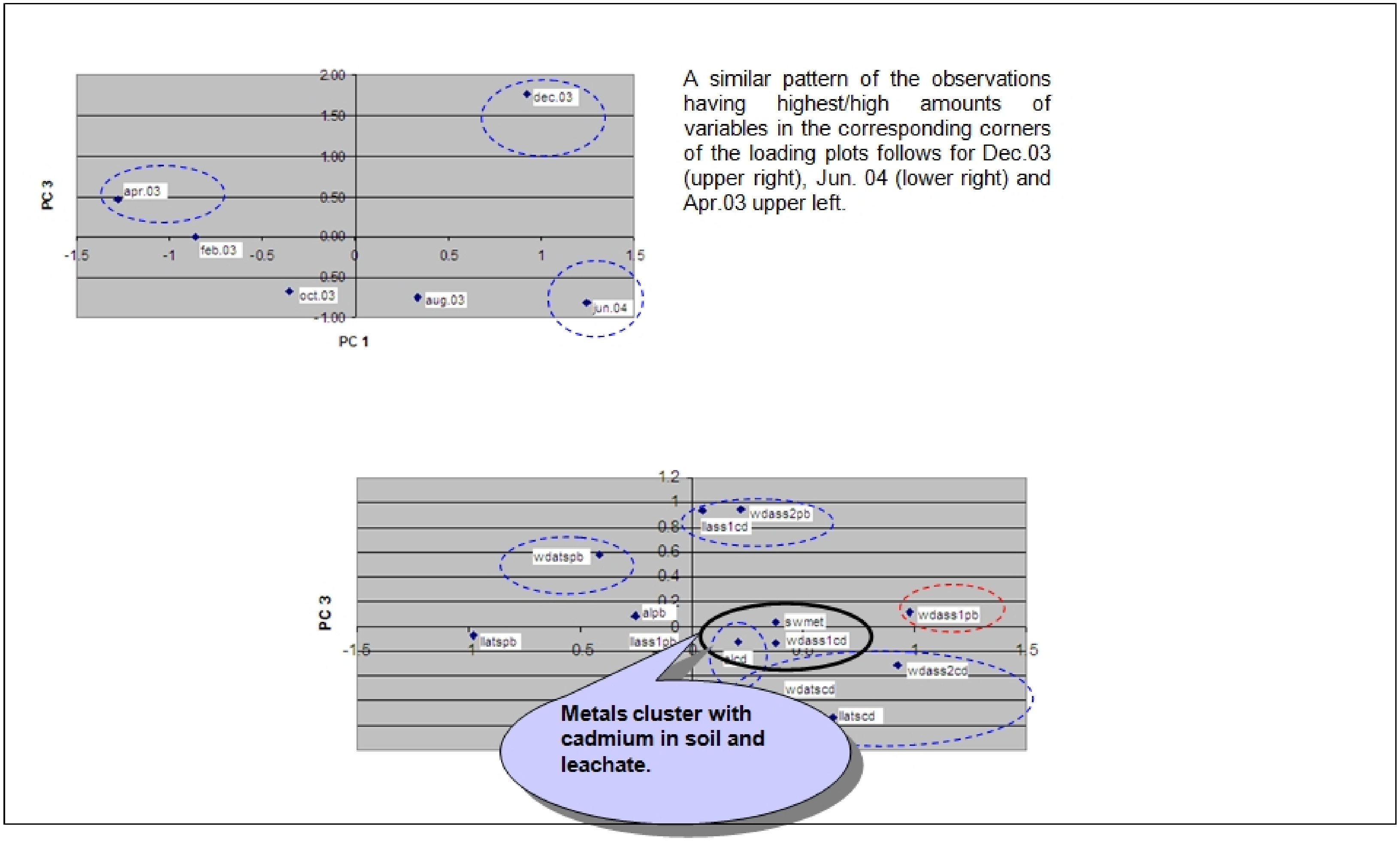


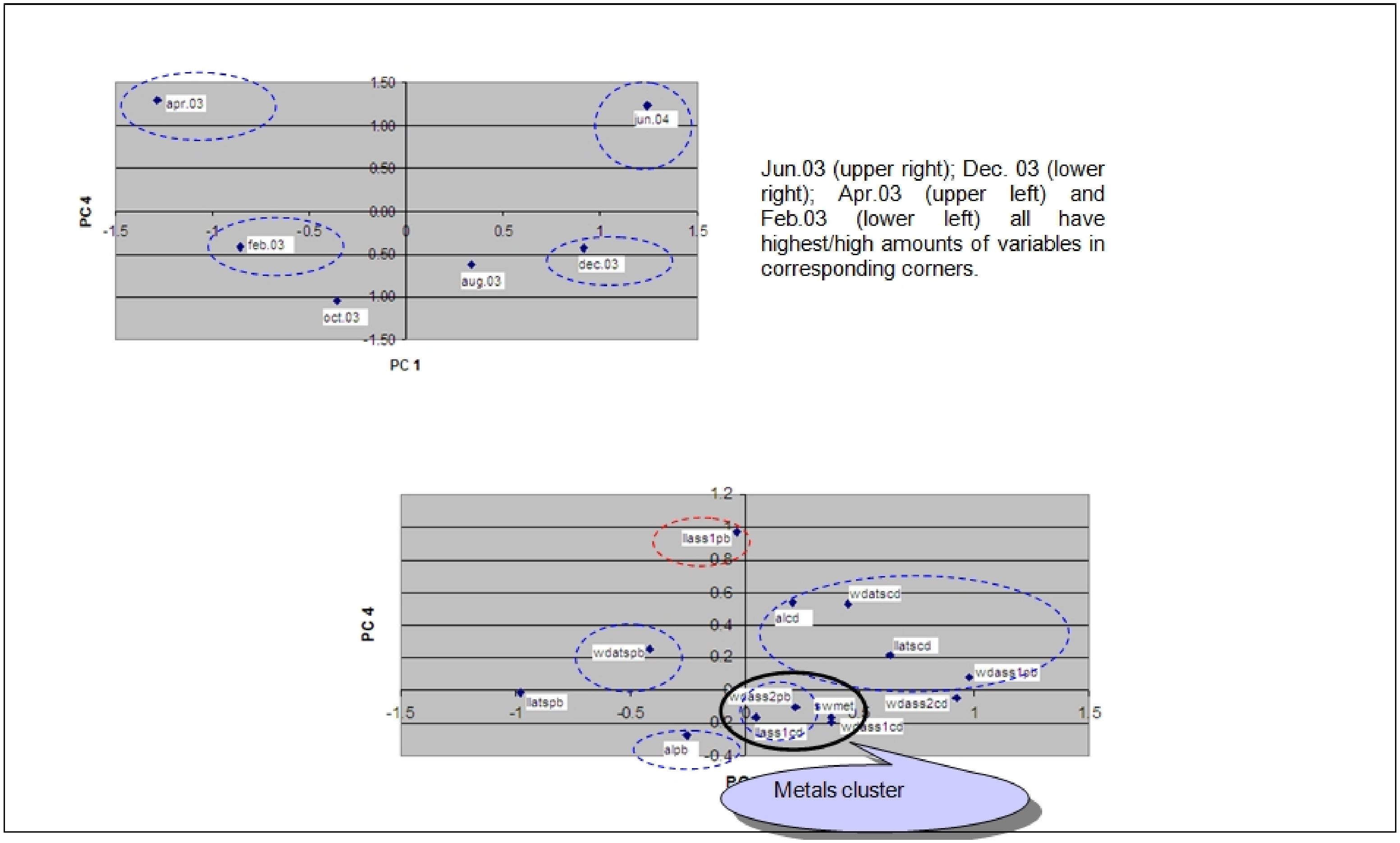
Fig. 4. Scatter (top) and loading plots (bottom) for metals, soil and leachates (PC 1/2)



A similar pattern of the observations having highest/high amounts of variables in the corresponding corners of the loading plots follows for Dec.03 (upper right), Jun. 04 (lower right) and Apr.03 upper left.

Metals cluster with cadmium in soil and leachate.

Fig. 5. Scatter (top) and loading plots (bottom) for metals, soil and leachates (PC 1/3)



Jun.03 (upper right); Dec. 03 (lower right); Apr.03 (upper left) and Feb.03 (lower left) all have highest/high amounts of variables in corresponding corners.

Fig. 6. Scatter (top) and loading plots (bottom) for metals, soil and leachates (PC 1/4)

Another important observation is that the variables with the strongest loadings on each principal component locate towards the extremes of that principal component which in turn influences the observations with the highest amounts of these variables to locate accordingly. PC 1 (corresponding to the x-axis), which had strong positive loadings of WDA/SS1/PB and WDA/SS2/CD influenced the June 2004 observation to locate towards the extreme along PC 1 in the scatter plot. Similarly, LLA/TS/PB which loads strongly but negatively on PC 1 influenced the April 2003 observation to locate on the left (negative) side of PC 1 Fig. 5.

The most important observation was however the cluster of the metals fraction with cadmium in the leachate Fig. 4. A similar cluster was observed on the loading plots of PC 1 and PC 3, as well as on the plot of PC 1 and PC 4 Figs. 5-6. The metals fraction clustered with both leachate cadmium and cadmium at 15-30cm depth in WDA – WDA/SS1/CD Fig. 5. Similarly, the loading plots of Fig. 6 show another cluster of the metals fraction with WDA/SS1/CD; cadmium at 15-30cm depth in LLA – LLA/SS1/CD and lead at 31-60cm depth in WDA – WDA/SS2/PB. Furthermore, the locations of the various observations in the scatter plots as influenced by the locations of these variables in the loading plots hold accordingly Figs. 5-6.

3.2.2.2 Glass/ceramics (SW G/C)

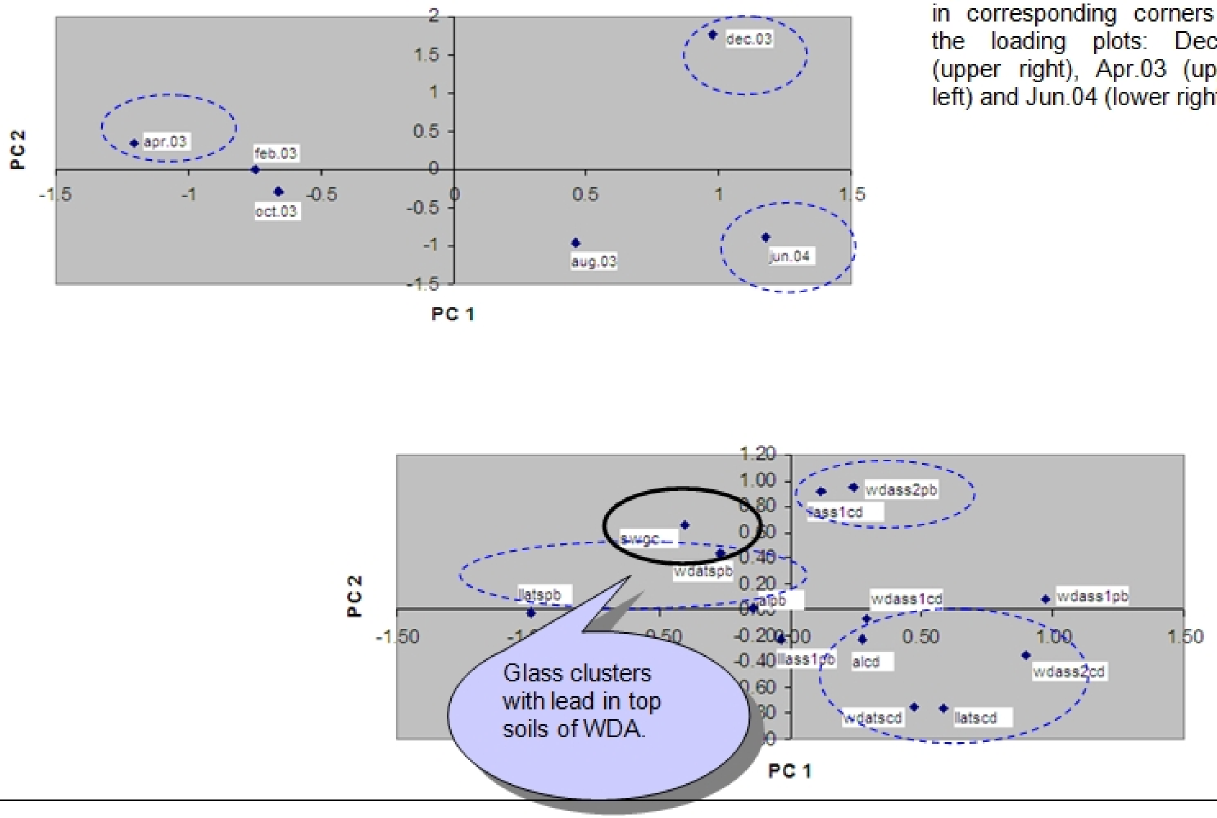
Results of the PCA for the glass/ceramics waste fraction, soil and leachates also extracted four components which explained 92% of the total variance. Loading plots generated from the PCA analysis showed only one cluster of the glass/ceramics fraction (with lead in top soils of WDA – WDA/TS/PB) on the loading plots of PC 1 and PC 2 Fig. 7. Results of the other principal components are not shown. However, there were no clusters of this waste fraction with cadmium and lead in soil or leachate on the loading plots of PC 1 and PC 3, as well as on PC 1 and PC 4.

3.2.2.3 Polyethylene plastics (SW PE)

Scatter and loading plots of polyethylene plastics are presented in Fig. 8-9. The results obtained show two clusters of polyethylene plastics with cadmium and lead in soil and leachates. Loading plots of PC 1 and PC 2 show a cluster with cadmium at 15-30cm depth in WDA – WDA/SS1/CD and in the leachates – AL/CD Figure 8. Loading plots of PC 1 and PC 3 show a cluster with lead at 30-60cm depth in WDA – WDA/SS2/PB Fig. 8-9. There was no cluster observed on PC 1 and PC 4 with polyethylene plastics. The four components extracted by the PCA explained 96% of the variance and similar patterns of scatter of the observations as influenced by the locations in the loading plots were observed.

3.2.2.4 Miscellaneous fraction (SW MISC.)

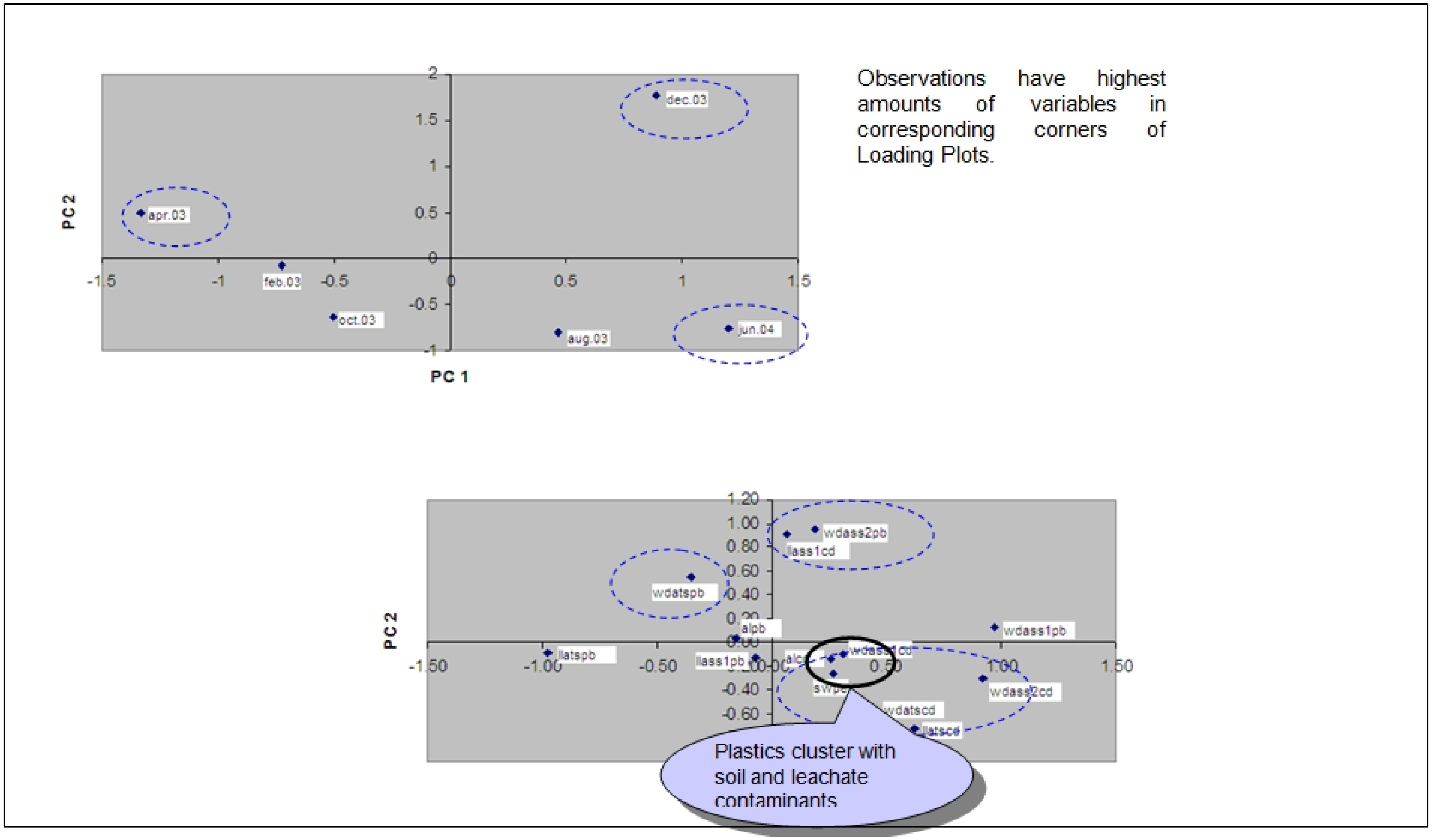
Similarly scatter and loading plots for the miscellaneous fraction are presented in Figs. 10-11. Two clusters of the miscellaneous fraction were observed with AL/CD and WDA/SS1/CD were observed on the loading plot of PC 1 and PC 2, while it clustered with WDA/SS2/PB on the loading plot of PC 1 and PC 3. Similar to the observation on the polyethylene plastics fraction, there was no cluster observed on the loading plots of PC 1 and PC 4. As with the previous fractions, four components were extracted and this explained 94% of the total variance. The loading plots also influenced the observations in the scatter plot as indicated in the Figs. 10-11.



The observations have the highest amounts of variables in corresponding corners of the loading plots: Dec.03 (upper right), Apr.03 (upper left) and Jun.04 (lower right).

Glass clusters with lead in top soils of WDA.

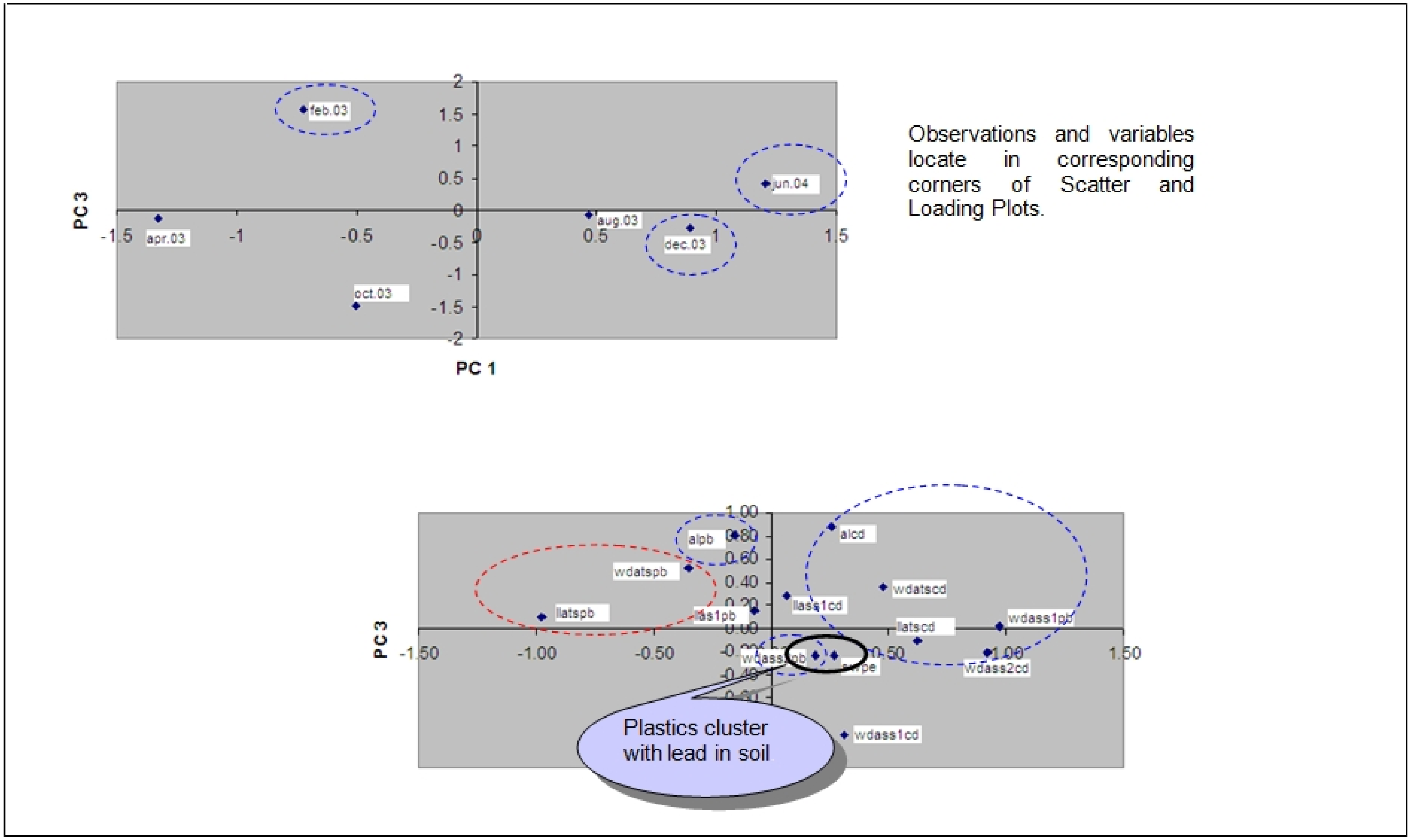
Fig. 7. Scatter (top) & loading plots (bottom) for glass, soil and leachates (PC 1/2)



Observations have highest amounts of variables in corresponding corners of Loading Plots.

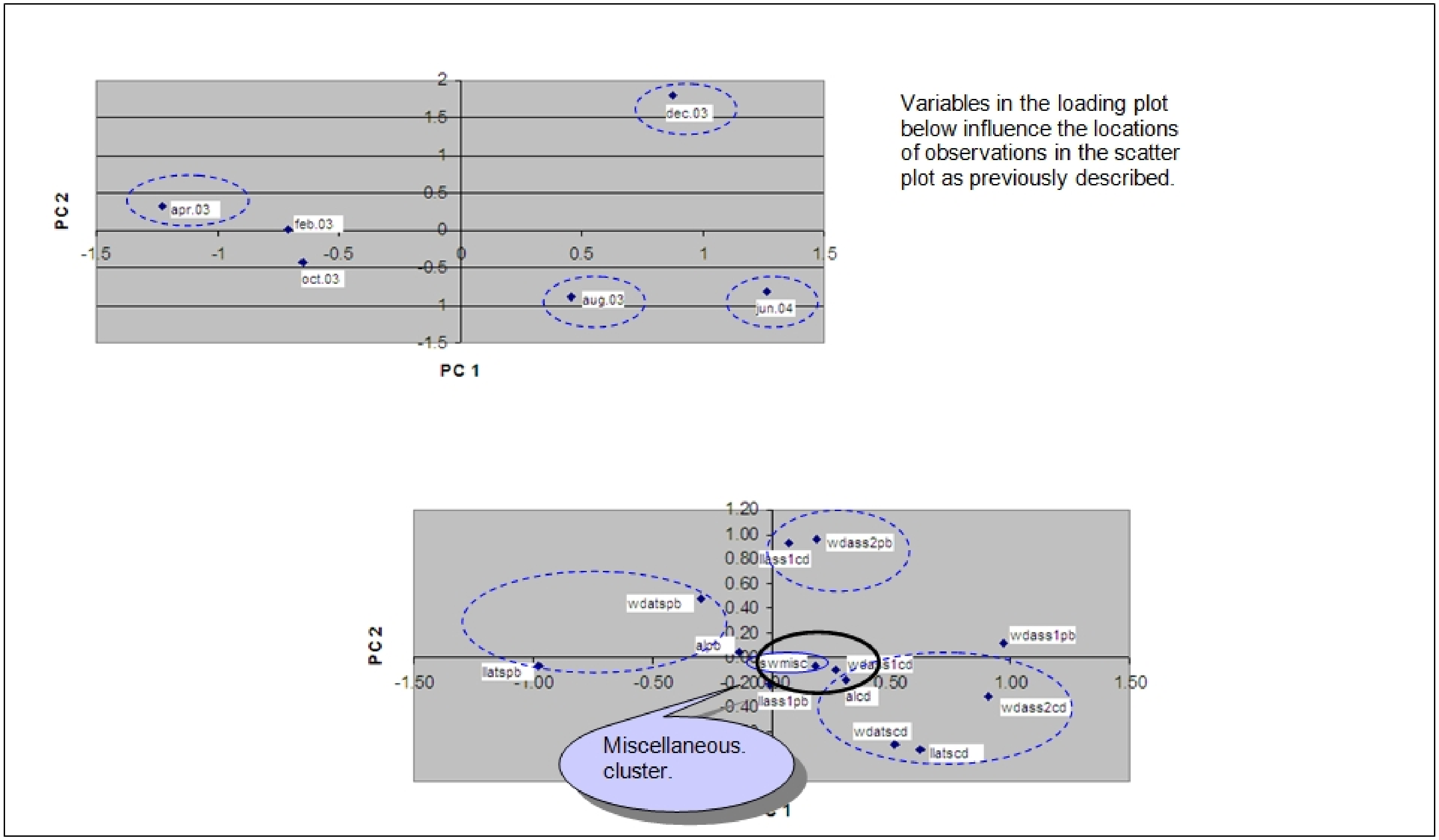
Plastics cluster with soil and leachate contaminants

Fig. 8. Scatter (top) and loading plots (bottom) for plastics, soil and leachates (PC 1/2)



Observations and variables locate in corresponding corners of Scatter and Loading Plots.

Fig. 9. Scatter (top) and loading plots (bottom) for plastics, soil and leachates (PC 1/3)



Variables in the loading plot below influence the locations of observations in the scatter plot as previously described.

Miscellaneous. cluster.

Fig. 10. Scatter (top) and loading plots (bottom) for misc., soil and leachates (PC 1/2)

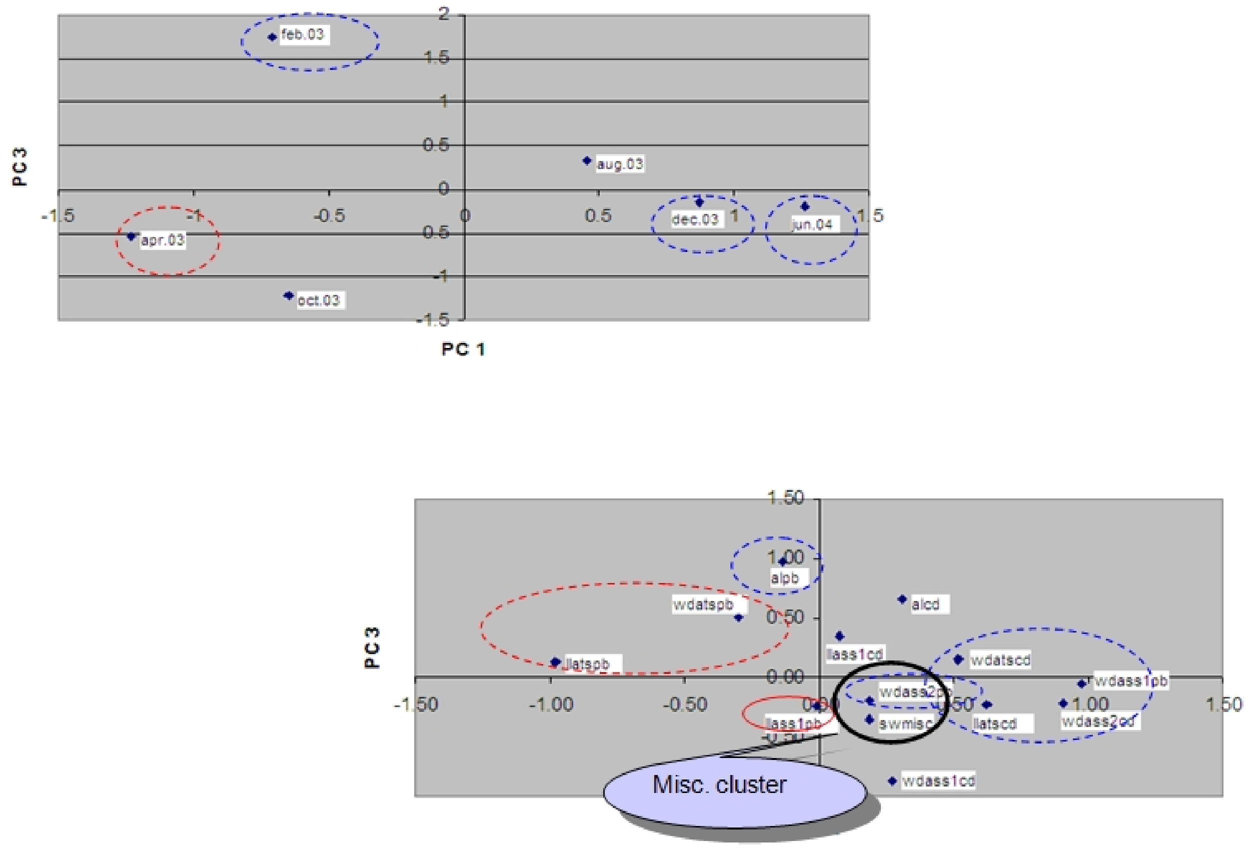


Fig. 11. Scatter (top) and loading plots (bottom) for misc., soil and leachates (PC 1/3)

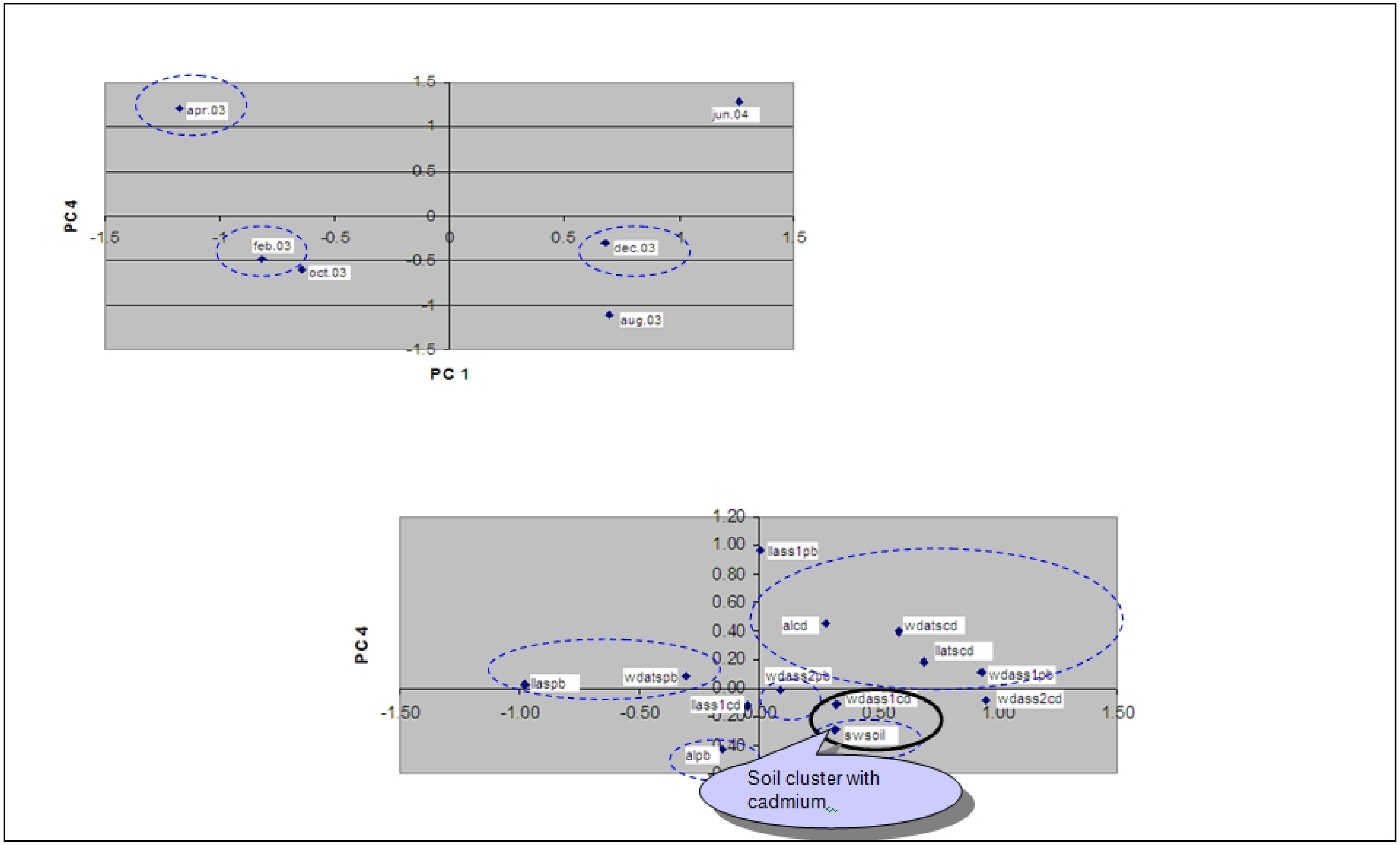


Fig. 12. Scatter (top) and loading plots (bottom) for degraded humus (soil) and leachates (PC 1/4

3.2.2.5 Biodegraded humus (SW SOIL)

The scatter and loading plots for the PCA are presented in Fig. 12. Four components were extracted which explained 92% of the total variance, with strong positive loadings from WDA/SS1/PB, WDA/SS2/CD, moderate positive loadings from LLA/TS/CD and WDA/TS/CD and a strong negative loading from LLA/TS/PB on PC 1. Results of the scatter and loading plots in Fig. 12 showed that biodegraded humus only clustered on the loading plot of PC 1 and PC 4 with WDA/SS1/CD, while the loading plots of PC 1 and PC 2, as well as PC 1 and PC 3 did not highlight any clusters.

4. DISCUSSION

4.1 Solid Waste – Soil - Leachate Inter-Relationships Using PCA

The order of percentage contribution to the total waste composition of Aba-Eku landfill was: metals > paper/cardboard > polyethylene plastics > miscellaneous > glass/ceramics > food wastes > biodegraded humus (soil) > other plastics > textiles > leather > wood, bones & straw > healthcare & rubber > stones/granite (construction wastes) > car parts (excluding the metal parts) > polystyrene plastics. Only the first seven fractions were used for PCA. In selecting waste fractions for the PCA, only waste fractions with a high frequency of occurrence (i.e. observed on at least twelve out of the eighteen - month sampling period) and which had greater than or equal to five percent mean contribution to the total waste composition of Aba-Eku landfill, were assumed to be significant contributors to the waste composition of Aba-Eku landfill, and thus were used for the PCA analysis. A total of nine waste fractions were excluded for reasons of low frequency of occurrence and / or low percentage contribution (i.e. less than five percent).

It is common in PCA analysis to exclude certain variables. Kylefors [5] in the use of PCA for leachate characterization excluded as many as 24 variables that had results on less than five or six observations as they had low variability. Forty-nine variables were subsequently used for PCA. Critto et al. [13] similarly excluded certain variables for similar reasons. The pollutants of focus were the pollutants of health concern at the landfill site, as determined by mean values exceeding the regulatory standards - cadmium and lead in groundwater [7].

The emphasis was however on the identification of the patterns in the data as stated by [5]. The clusters which are indicative of associations or similarities are of particular interest. PCA for the seven wastes fractions identified two clusters which have been identified as biodegradable wastes and non-biodegradable wastes. The loading plots also highlighted the patterns of the data, in particular clusters with the pollutants of focus. The mean percent contribution of each waste category as well as its tendency to cluster with the pollutants of focus (lead and cadmium) on more than one principal component was taken as a measure of the degree of association (or contribution) of that particular waste fraction with lead and cadmium in both soil and the leachate.

Most of the wastes tended to cluster more with cadmium rather than with lead, possibly due to the fact that cadmium levels were several orders of magnitude higher than natural background levels in soils of the site compared to lead. The groundwater also indicated a more pronounced pollution of cadmium than lead as both wells in the area exceeded both the World Health Organization (WHO) and Nigeria’s Federal Ministry of Environment (FMEnv.) limits in contrast to lead which exceeded only WHO limits [7]. The metals waste fraction tended to cluster around cadmium in soils and leachate suggestive of significant input of this waste fraction to cadmium pollution at the landfill site. Waste materials that were observed in the landfill and classified under the metals category included ferrous metals, battery wastes, circuit boards of consumer electronics, recyclable cans, foils and soft drink caps. Ferrous metals have been reported by [14] to contribute mainly cadmium. Batteries have been reported to be sources of cadmium and lead – [15,16]. Richard and Woodbury, [17] reported that battery wastes contributed up to 50 and 70% of the total cadmium and lead content in landfills; even after 80% of the battery wastes had been recovered. Circuit boards of consumer electronics tend to contribute higher amounts of lead than cadmium [14,15]. Foil contains lead [17], while recyclable cans were assumed by [18] to contribute only iron. Contaminants contained in soft drink caps were not specified in the literatures reviewed.

Plastics tended to cluster more with cadmium in the soils and the leachate and to a lesser extent with lead in the soil, suggesting that polyethylene plastics may contribute more to cadmium pollution and to a lesser extent lead pollution at the landfill site. Plastics contain additives such as colorants, stabilizers and plasticizers that may include toxic constituents such as cadmium and lead. High concentrations of cadmium and lead are found in plastics [19]. Plastics contribute significantly to cadmium in MSW landfills and to a lesser extent lead. The percentage contributions vary from 28% of the total cadmium and approximately 2% of the total lead content in landfills, 30% of cadmium, [17] to 39 - 49% of cadmium, [14]. The "other plastics" fraction which comprised rigid plastics was not considered a significant contributor to the total waste contribution at the landfill as its mean percentage contribution was low at 3.76% and it also had low frequency of occurrence.

The results of the PCA for the solid waste fractions suggested that the miscellaneous fraction was comprised mainly of organic wastes. Organics have been shown to contain varying amounts of heavy metals – cadmium (5ppm), lead (188ppm), chromium (310ppm), mercury (<0.1ppm) and Arsenic (67ppm), all values are on dry weight basis [20]. However, the percentage contribution of this waste fraction to the total metal content when compared to the other waste fractions is generally low [20].

The results suggest that the miscellaneous fraction may have a significant input to lead and cadmium levels at the landfill site judging by the degree of clustering with these contaminants. The possible reasons for this may be that the dissolved organic matter, a primary degradation product of organics, [21,22] may form complexes with the heavy metals [21], particularly lead. This may perhaps explain this association as this waste fraction clustered with both cadmium and lead. It is also possible that tiny bits of polyethylene plastics and metals which could not be sorted out of this waste category may also have contributed to the association of this waste fraction with the pollutants in the soil and leachate. Lastly, burnt wastes in the miscellaneous fraction may likely contain ash which had been stated to contain heavy metals such as lead and cadmium [23,24].

Glass has been shown to contain high levels of lead. Waste glass particularly from discarded electronics such as television and computer monitors contains high amounts of lead [25,26]. Studies by [14] showed that the glass fraction contributed about 8% of the lead in the wastes studied while the contribution of cadmium was low at 1%. Glass showed a little degree of clustering with lead levels in top soils of the Waste dump area (WDA), possibly suggestive of some input of lead and no cluster with cadmium, possibly suggesting no input to this pollutant.

The soil fraction is categorized in literature as degraded components or fine particles [14,15,27]. Some studies state that this fraction contributes mainly to metals, particularly lead and cadmium in solid wastes, though contribution ratios were found to be low - 8% and 1% respectively [14]. Rotter et al. [15] obtained similar results. However, results of [27] showed that degraded components or fine particles contributed mainly to the organic matter levels rather than metal contaminants. Similarly, Jain et al. [28] characterized the heavy metal content of residues reclaimed from a municipal landfill. The fine fraction which was more soil-like had the lowest concentrations of various heavy metals. The results of this study support the above observation which suggests that this fraction is mainly organic in nature. The cluster on only one of three principal components and low percentage contribution (5.86%) suggest little input to the main pollutants of concern at the landfill site.

It is important to note that although the form of digestion used may also extract Cd and Pb from the soil mineral phase, the magnitude of Cd and Pb in dumpsite soils versus the control Tables 2-3, suggests that the bulk of the Cd and Pb input originates from the solid wastes dumped, particularly the metal fraction. This is attested to by the dominance of this waste fraction over the sampling period i.e. on nine out of the eighteen months recorded, its high percentage contribution at approximately 25% Table 1; Fig. 2 and the cluster on all three principal components for this waste fraction (as opposed to two and one for the other waste fractions, as shown by the results of the PCA. Hence, the degree of contribution to the Cd and Pb contents of the soil and leachate is in the order: metals > plastics > miscellaneous > glass/ceramics and fines or soil.

On the basis of the obtained results, the prioritization of the different waste categories might aid the development of simple and sustainable waste management strategies for better management of solid wastes at the landfill site. These results confirm that the high amount of metals in the Aba-Eku landfill is a major contributor to cadmium and lead pollution in soils, leachate and ultimately groundwater at the landfill. Similarly, polyethylene plastics and other waste fractions may also contribute. There is therefore a need to evolve waste management strategies with specific focus on the prioritized wastes.

The study highlights the urgent need for increased metals recovery / recycling at the landfill site. More recyclable tins and cans in particular, can still be recovered, in addition to other categories of metal and metal-containing wastes such as plastics and glass. Offering higher incentives to scavengers for all, not selective categories of metal and metal containing wastes, as is currently the practice, may encourage this. A limitation of this study was the inability to assess the contribution of wastes recovered by the scavengers for sale to recyclers. These wastes are also dumped on site pending their relocation for sale. Such wastes will ultimately have an input hence prompt relocation of such recovered wastes is necessary. Proper management of solid wastes may lie with the sorting of the wastes at source before their disposal in the landfill. The waste management operators can forge a partnership with the informal recycling sector at this site (i.e. the scavengers) to extend their area of coverage to include some waste originating points. This will enhance the recovery and subsequent recycling of certain categories of solid wastes. This may also benefit the waste scavengers from the economic standpoint, as well as provide more job opportunities. For example, food wastes from originating points such as markets and restaurants (which generate large quantities of such wastes) may serve as feed points for the composting plants in the state after non – biodegradables like metals, glass and plastics have been recovered. This will decrease the volume of wastes diverted to the landfill site as well as encourage waste-to-wealth initiatives.

The study also highlighted the need for proper management of Polyethylene plastics, another waste of concern at this site. Some of these plastics, particularly the "pure water" sachets are usually recovered for sale to recyclers. However the rate of recovery is still low, owing to the cumbersome nature of sorting out such wastes. The state government may need to offer higher incentives for this category of wastes, considering the impact of their disposal on the environment and the nuisance value they sometimes constitute. Alternatively, the "polluter pays" principle may be considered.

5. CONCLUSION

This study evaluated the contribution of various categories of wastes, particularly metal and metal containing wastes to Cd and Pb contamination in soil and leachates of the Aba-Eku landfill site, Ibadan, Nigeria using PCA, a tool of MVDA. The tendency of the various waste categories to cluster on more than one principal component is suggestive of the degree of input. Metals contributed the highest (cluster on three PCs) followed by the plastics, miscellaneous (two PCs), glass and the fines fraction (one PC). Based on these results, increased recovery and recycling of the metal, plastics and glass/ceramics waste fractions in particular, are suggested.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Coskun M, Steinnes E, Viladimirovna M, Sjobakk T, Demkina S. Heavy metal pollution of surface soil in the Thrace region, Turkey. Environ. Monit. Assess. 2006;119:545-556.
2. Majid A, Argue S. Remediation of heavy metal contaminated solid wastes using agglomeration techniques. Miner. Eng. 2001;14(11):1513-1525.
3. Martin AC, Rivero VC, Marin MTL. Contamination by heavy metals in soils in the neighborhood of a scrap yard of discarded vehicles. Sci. Total Environ. 1998;212:142-152.
4. Li XD, Poon CS, Pui SL. Heavy metal contamination of urban soils and street dusts in Hong Kong. Appl. Geochem. 2001;16:1361-1368.
5. Kylefors K. Evaluation of leachate composition by multivariate data analysis (MVDA). J. Environ. Manage. 2003;68:367-376.
6. National Population Census 2007. Nigeria.
7. Oni AA. Physico-chemical parameters and toxicity of solid waste and leachates on selected animals at Aba-Eku landfill site, Ibadan, Nigeria. Ph.D thesis. Dept. of Zoology. University of Ibadan. xii + 330pp. 2010.
8. United States Environmental Protection Agency 1998. Characterization of municipal solid waste in the United States. Accessed November 2002, Available: www.epa.gov/epaoswer/non-hw/muncpl/msw98.htm
9. Perket CL, Kruegger JR, Whitehurst DA. The use of extraction tests for deciding waste disposal options. Trends Analyt. Chem. 1982;1(14):342-347.
10. American Public Health Association. Standard methods for the examination of water and wastewater 20th ed. Washington D.C: American Public Health Association. 1998;1149.

11. Odu CTI, Babalola O, Udo EJ, Ogunkunle AO, Bakare TA, Adeoye GO. Laboratory manual for agronomic studies in soil, plant and micro-biology. Department of Agronomy, University of Ibadan, Ibadan. 1986;9.
12. Lu R. 1999. Analytical methods of agricultural and chemical soils. China: Agriculture, Science and Technology of China. 1999;638.
13. Critto A, Carlon C, Marcomini A. Characterization of contaminated soil and groundwater surrounding an illegal landfill (S. Giuliano, Venice, Italy) by principal component analysis and kridging. Environ. Pollut. 2003;122:235-244.
14. Burnley SJ. The use of chemical composition data in waste management planning - a case study. Waste Manag. 2007;27:327-336.
15. Rotter VS, Kost T, Winkler J, Bilitewski B. Material flow analysis of RDF-production processes. Waste Manag. 2004;24:1005-1021.
16. Nnorom IC, Osibanjo O. Determination of lead and cadmium contents of dry cell batteries available in Nigeria. J. Appl. Sci. Environ. Manag. 2006;10(3):37-41.
17. Richard TL, Woodbury PB. Strategies for separating contaminants from composts (Fact Sheet). Biomass Bioenergy. 1993;3(3-4):195-211.
18. Jung CH, Matsuto T, Tanaka S. Flow analysis of metals in a municipal solid waste management system. Waste Manag. 2006;26(12):1337-1348.
19. He P, Xiao Z, Shao L, Yu J, Lee D. In-situ distributions and characteristics of heavy metals in full-scale landfill layers. J. Hazard. Mater. 2006;137:1385-1394.
20. Otte PF. Analysis of metals and caloric values in household waste composition (in Germany) 1988-1992. Rapportnummer 776201012. 1995.
21. Christensen TH, Kjeldsen P, Bjerg PL, Jensen DL, Christensen JB, Baun A, Albrechtsen H, Herom G. Biogeochemistry of landfill leachate plumes. Appl. Geochem. 2001;16:659-718.
22. Kjeldsen P, Barlaz MA, Rooker AP, Baun A, Ledin A, Christensen TH. Present and long-term composition of MSW landfill leachate: A review. Crit. Rev. Environ. Sci. Technol. 2002;32(4):297-336.
23. United States Environmental Protection Agency 1989. Characterization of products containing lead and cadmium in municipal solid waste in the United States, 1970 to 2000. Executive Summary. Washington D.C: EPA Office of Solid Waste EPA/530-SW-89-015c.
24. Kylefors K. Predictions of leaching from municipal solid waste and measures to improve leachate management at landfills. PhD. Thesis. Department of Environmental Engineering, Division of Waste Science and Technology, Lulea University of Technology, Lulea, Sweden. 2002;8:55.
25. Schmidt CW. E-junk explosion. Environ.l Health Perspect. 2002;110(4):188-194.
26. Mear F, Yot P, Cambon M, Ribes, M. The characterization of waste cathode-ray tube glass. Waste Manag. 2006;26:1468-1476.
27. Francois V, Feuillade G, Skhir, N, Lagier T, Matejka G. Indicating the parameters of the state of degradation of municipal solid waste. J. Hazard. Mater. 2006;137(2):1008-1015.
28. Jain P, Kim H, Townsend TG. Heavy metal content in soil reclaimed from a municipal solid waste landfill. Waste Manag. 2005;25:25-35.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=434&id=5&aid=3760