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ASSESSMENT OF THE HEAVY METAL POLLUTION IN THE SEDIMENT SAMPLES OF MAJOR CANALS IN DHAKA CITY BY MULTIVARIATE STATISTICAL ANALYSIS

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ABSTRACT

In this study, the levels of selected metals (Cd, Cr, Cu, Mn, Fe and Pb) concentrations were measured by Flame Emission Atomic Absorption Spectrophotometer (FL-AAS) in sediment (sludge) samples collected from 10 different Canals in and around the Dhaka City Corporation (DCC) area of Bangladesh. The analysis result shows that Cr, Cu and Pb were present as major pollutants in the some canals in the DCC area with high concentration levels, while Cd, Mn and Fe emerged as minor pollutants. Principal Component Analysis (PCA) and Cluster analysis were used to assess the metal contamination in the canals. Positive correlations were found between Mn–Fe ($r = 0.860$), Pb–Cu ($r = 0.786$), Pb–Cd ($r = 0.398$) and Cu-Cd ($r = 0.227$) pairs. The present metal concentration in the canal sediments data shows that Cr, Pb and Pb levels are higher than recommended sediment quality guideline by USEPA but pollutants concentrations in the sludge are below the prescribed hazard limit provided by USEPA for land application of sludge.

KEYWORDS: Canals, Sludge, Heavy metal, Principal component analysis, Cluster analysis**.**

INTRODUCTION

In the current decades the heavy metal accumulation in the soils is a growing concern due to its potential health risks as well as its detrimental effects on soil ecosystems (McLaughlin et al., 1999; Qishlaqi & Moore, 2007). Heavy metals have characteristics including that they are non-biodegradable (Facchinelli et al. 2001) and they can be necessary or beneficial to plants at certain levels, but can be toxic when exceeding specific thresholds (Qishlaqi & Moore, 2007; Bilos et al., 2001) Sources of these elements in soils mainly include natural occurrence derived from parent materials and anthropogenic activities. Anthropogenic inputs are associated with industrialization and agricultural activates, deposition, such as atmospheric deposition, waste disposal, waste incineration, emissions from traffic, fertilizer application and long-term application of wastewater in agricultural land (Qishlaqi & Moore, 2007; Bilos et al., 2001; McLaughlin et al., 2001; Koch et al., 2001).

For the present day's environmental researchers, knowledge of the heavy metal accumulation in soil, the potential source of heavy metals and their possible interactions with soil are one of the prime focuses. Different statistical analysis tools can provide such knowledge and can be very helpful for the interpretation of environmental data (Tuncer et al., 1993; Sena et al., 2002; Einax et. al 1999). In recent times, the statistical methods (univariate or multivariate) have been applied widely to investigate heavy metal concentration, accumulation and distribution in soils. (Vega et al. 1998; Wunderlin et al., 2001; Grande et al., 2003; Simeonov et al., 2003; Pekey et al., 2004; Singh et al., 2004; Astel et al., 2006; Kowalkowski et al., 2006; Shrestha & Kazama, 2007 Salman et al., 1999).

Once, Dhaka City, the capital of Bangladesh had excellent natural drainage system even 40 years ago. The city was interlaced with numerous natural channels/canals and wetlands. It is estimated that there were up to 45 natural drainage canals that span the city. In the course of rapid expansion of the city, most of the natural drainage canals as well as wetlands has been intervened and destroyed. Now only few canals exist but these have become contaminated wetland because of disposal of solid waste, toxic industrial waste which are the potential sources of heavy metal pollution (Subramanian, 2004; Karn & Harada, 2001). Now even after a medium size rainfall, the streets of the city get flooded for hours at a time because water has no way to drain out easily. Although some drainage structures have been built over the last two decades, they are woefully inadequate. In addition, due to haphazard design and construction of these drainage structures and lack of proper maintenance, over the years these have lost their carrying capacity due to severe clogging. The effects of water logging causes serious suffering of the city dwellers as well as damage the roads and thereby increasing the road maintenance cost. On the other hand, water supply and sanitation infrastructures have been being become ineffective due to unwanted water logging in the city. There is thus an immediate need for rehabilitation and development of the natural drainage network and find ways to properly operate and maintain the already constructed drainage structures, such as box culverts and drain lines. For the restoration of these canals in Dhaka city, it is very important to explore the current pollution status of the sludge deposited at the bottom of canals over the year. The present study stems from the above concerns, with the primary focus on the current status of distribution of some selected toxic metals in the sludge sample collected from 10 major canals in the Dhaka city Corporation (DCC) area by multivariate statistical analysis.

MAJOR CANALS IN DCC AREA AND THEIR PRESENT CONDITIONS

The major canals (Khals) are located in the various part of the city and their other particulars are shown in the Table 1.

Table: 1. Major Canals in the DCC Area

Serial No.	Canal's Name	Location	Length(Km)
1	Kalyanpur main khal	Western part of the city	3
2	Kalyanpur branch khal - Ka	Western part of the city	1.5
3	Kalyanpur branch khal - Kha	Western part of the city	2.4
4	Kalyanpur branch khal - Gha	Western part of the city	1.56
5	Kalyanpur branch Khal - Umo	Western part of the city	1.78
6	Kalyanpur branch Khal - Cha	Western part of the city	0.98
7	Baunia Khal	North western part	8.8
8	Digun Khal	North eastern part	4.5
9	Mohakhali Khal	Central city	2.3
10	Hazaribagh Khal	South-western part.	0.7
11	Shegunbagicha khal	Central-eastern part	1
12	Manda khal	Central-eastern part	1
13	Shangbadik Colony	North western part	1
14	Section 2 to Digun Canal through Section 6 and Rupnagar	North western part	3.5
15	Mirpur Housing Canal	North western part	1
16	Kashaibari - Boalia to Balu river	North eastern part	3
17	Gerani khal	Central-eastern part	5

Source: Study of storm water drainage system by JICA in 1990

From our field survey, it was found that illegal encroachment and nearby pollution activities are the major concerns to maintain the natural conditions in most of the canals in Dhaka city. A variety of small industries are building up near the bank of the canals. Various Residential plots are now under construction on the different parts of the canals. The water of the canals water gets polluted and become blackish with lots of waste including construction debris, vegetations, chemical waste, polythene sheets and as a result there is partial drainage blocking. Some photographs, which were taken during our field survey, are presented in Fig. 1

(a) Northern part of Kayallanpur Main khal (canal) beside ACME

(b) Kayallanpur '*Ka' khal(canal) near Bosupara*

(c) End point of Shegunbagicha khal (canal)before the Kadamtala bridge

(d) Mirpur Housing khal (canal)

(e) Hazaribagh khal (canal) beside the Leather Technology College

(f) Mohakhali khal (canal) near Mohakhali rail crossing

Fig. 1: Photographs of Some Canals in and Around the Dhaka City Depicting the Current Pollution Scenario

MATERIALS AND METHODS

For the present study, sediment (sludge) samples were collected from 10 canals (name of the canal mentioned in Table 2) on the months of March and April, 2011 and samples were analyzed for the metals, Cd, Cr, Cu, Mn, Fe and Pb. Above mentioned metals concentration in the collected sludge samples were determined by total extraction with Aqua-Regia. The extracted aqueous solution was analyzed for Cd, Cr, Cu, Mn, Fe and Pb by using Flame Emission Atomic Absorption Spectrophotometer (FL-AAS, Model: Shimadzu, Japan, AA6800). Standard QA/QC protocol was followed throughout, including replicate analysis (1 in every 5 samples), checking of method blanks (1 in every 10 analysis) and standards (1 in every 10 analysis). The estimated metal levels were compared with the permissible safe levels for the sediment sample proposed by USEPA. Multivariate statistical techniques (Lin et al. 2002; Facchinelli et al. 2001; Nolte 1988; Tahri et al. 2005; Yeung 1999; Lin et al. 2004; Sandhu et al. 1976) were adopted to assess the metal contamination in the sludge. For this purpose, the well founded techniques of Pearson correlation analysis, Principal Component Analysis (PCA), and Cluster Analysis (CA) were jointly used, the first affording a direct measure of interdependence of the set of variables under investigation while the latter two provides the visual grouping of the data to help understand the interrelated metal clusters produced (Hopke 1992). SPSS software (Version 16.0) was used to perform the multivariate statistical analyses.

RESULTS AND DISCUSSIONS

The Sludge samples analysis results for different heavy metals are presented in *Table 2.* The comparison between the metals concentration present in the sludge samples of DCC canals with permissible metal concentration limit proposed by USEPA for the sediment sample shows that some canals in DCC area are facing heavy metal pollution.

Table 2: Present Status of the Heavy Metals Concentration in Sludge Samples Collected from 10 Different Canals of Dhaka City Area

Sl.No.	Canal's name and (sampling location)	Heavy metals concentration (mg/kg)					
		Cd	Cr	Cu	Mn	Pb	Fe
1	Hazaribagh Khal (Sikder Medical)	0.3	61.8	3.8	0.72	1.9	0.11
2	Kalyanpur 'Kha' khal (Navana CNG pump)	BDL	70.6	6.6	1.6	11.1	0.22
3	Kalyanpur main khal (Darussalam)	0.1	48.6	2.8	0.63	0.1	0.09
4	Section-2 Digun khal (Rupnagar)	0.1	45.2	2.6	0.67	0.2	0.08
5	Baunia khal (Section-13)	0.2	117	5.4	0.51	0.1	0.08
6	Kalyanpur Shakha 'Gha" (Shewrapara)	BDL	191	6.2	0.79	2.7	0.06
7	Mohakhali Khal (Near Bus Stand)	0.4	72.4	116	0.62	51.1	0.15
8	Mirpur Housing Khal (Mirpur-10)	0.2	48.8	187	0.23	69.1	0.07
9	Segunbagicha Khal (Kamalapur Stadium)	0	78.6	166	1.51	24.9	0.22
10	Jirani Khal (Kadamtola)	0.2	75.4	304	0.66	37.3	0.06
	EPA Guideline for Sediments (Mg/Kg)						
Not Polluted	….	<25	<25	<300	<40	….	
Moderately Polluted	….	25-75	25-50	300-500	40-60	….	
Heavily Polluted	**>6**	**>75**	**>50**	**>500**	**>60**	**….**	
	EPA Limit for Land Application of Sludge (Mg/Kg)						
		85	….	4300	….	840	….

Note: BDL- Below Detection Limit

According to USEPA guideline, the sludge samples of Mohakhali Khal, Mirpur Housing Khal, Segunbagicha Khal, Jirani Khal are heavily polluted with Cu. Baunia Khal, Kalyanpur Shakha 'Gha" (Shewrapara), Segunbagicha Khal, Jirani Khal are heavily polluted with Cr. Pollution level of Pb in Mirpur Housing Khal is also exceed the USEPA heavily polluted criteria. Pollution level of Hazaribagh Khal, Kalyanpur "Kha" Khal , Kalyanpur main Khal ,Digun Khal are comparatively low for all tested heavy metals except Cr. By reviewing the pollutant limits of USEPA against the result from sludge samples analysis, it can be easily stated the pollutants concentration in the sludge of the selected canals are below the prescribed hazard limit for land application but some canals exceed the EPA guideline for heavily polluted sediments for some metal.

Before forming a judgment on the observed distribution of metal levels and interrelationship among them, the metal data was first examined on the basis of linear correlation between metal pairs in terms of significant positive correlation coefficient. Strong positive correlations were observed for Mn – Fe (r = 0.860), Pb – Cu (r = 0.786), Pb – Cd (r = 0.398) and Cu - Cd (r = 0.227) pairs (Correlation matrix is shown in *Table 3*), indicating the existence of a common source/origin of these metals in the sludge sample.

Table 3: Correlation Matrix between Different Heavy Metal Pairs

	Cd	Cr	Cu	Mn	Fe	Pb
Cd	1					
Cr	-0.292	1				
Cu	**0.227**	-0.2	1			
Mn	-0.547	0.1	-0.11	1		
Fe	-0.207	-0.2	-0.05	**0.9**	1	
Pb	**0.398**	-0.3	**0.77**	-0.3	0.031	1

Further confirmation of this hypothesis of 'different heavy metals may have common origin' was secured through multivariate methods of statistical analysis (Hair et al. 1988). In this study, two multivariate techniques were applied: Principal Component Analysis (PCA) and Cluster Analysis (CA). The PCA has emerged as a useful tool for better understanding the relationships among the variables (e.g., metal concentrations in this study) and for revealing groups (or clusters) that are mutually correlated within a data body (Qishlaqi & Moore, 2007). This procedure reduces overall dimensionality of the linearly correlated data by using a smaller number of new independent variables, called principal components (PC), each of which is a linear combination of originally correlated variables. On the other hand, Cluster Analysis (CA) exclusively classifies a set of observations into two or more unknown groups based on combination of internal variables. Therefore, the purpose of CA is to discover a system of organized observations where a number of groups/variables share properties in common, and it is cognitively easier to predict mutual properties based on an overall group membership (Everitt 1993; Jolliffe 1986). This helps define source profiles of variables, such as metal concentrations, and their interpretation in terms of possible sources (Jobson 1991).

Principal Component Analysis (PCA) using Varimax normalized rotation was conducted for common source identification. The variables are correlated with two principal components in which 70.3% of the total variance in the data was found. The rotated Principal Component Loadings are given in *Table 4*. Principle component plot in a rotated space is shown in Fig. 2. The first component with 40.92% of variance comprises Pb, Cu (bold figures in Table 4) with high loadings. This association strongly suggests that these variables have a strong interrelationship. The second component (PC2) contributes Mn and Fe at 29.40 % variance, which also infers the strong correlation between this metal pair. The corresponding cluster analysis Dendrogram is shown in Fig. 3. From the cluster analysis result it can be said that there is a strong correlation between Fe-Mn metal pair, which is a good agreement with PC2, but cluster analysis results did not show a good agreement between Cu-Pb pair. This result suggests that the strong relationship between Cu-Pb pair does not confirm.

Table 4: Rotated Principal Matrix

(Rotation Method: Varimax with Kaiser Normalization)

	Component	
	PC1	**PC2**
Cd	0.511	-0.5
Cr	-0.585	-0.1
Cu	**0.812**	-0.1
Mn	-0.14	**1**
Fe	0.184	**0.9**
Pb	**0.89**	-0.1

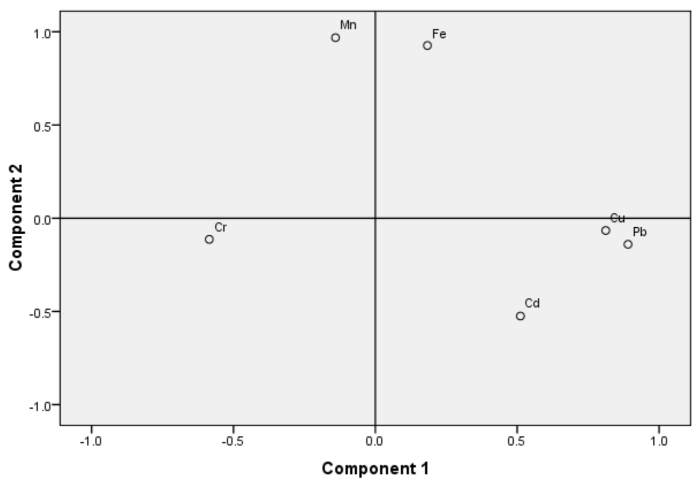

Fig. 2: Principal Component Plot in a Rotated Space

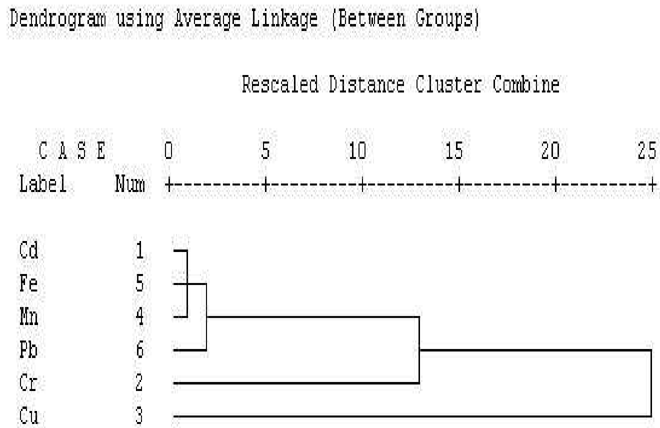

Fig. 3: Dendrogram of Cluster Analysis

CONCLUSIONS

The present study showed that Cr, Cu and Pb were present as major pollutants in the some canals in the DCC area with high concentration levels, while Cd, Mn and Fe emerged as minor pollutants. Strong positive linear correlations were found between Mn, Cu and Pb from linear regression analysis. Principal component analysis summarizes (reduces) the data set into two major components representing the different interrelationship among the elements. Strong interrelation between Cu - Pb pair and Mn - Fe pair was found from principle component analysis. Corresponding cluster analysis result confirms the relationship between Mn - Fe metal pair but, does not confirm the strong interrelationship between the Cu – Pb metal pair. Comparison with USEPA guideline for sediment showed that Cr, Pb and Cu levels are in far excess of the recommended safe limits for some canals but pollutants concentration in the sludge are below the prescribed hazard limit for land application of sludge.

REFERENCES

1. Astel, A., Biziuk, M.,Przyjazny, A., and Namiesnik, J. (2006). Chemometrics in monitoring spatial and temporal variations in drinking water quality. Water Research 8: 1706-1716

2. Bilos C., Colombo, J.C. Skorupka, C.N. and Rodriguez, P.M.J. (2001). Sources, distribution and variability of air borne trace metals in La Plata city are, Argentina. Environ. Pollu., 11: 149-158.

3. Einax, J.W. and Soldt, U. (1999). Geostatistical and multivariate statistical method for the assessment of polluted soils; Merits and limitations. Chemometrics Intell. Lab., 46: 79-91.

4. Everitt, B. S. (1993). Cluster analysis. London: Heineman.

5. Facchinelli, A., E. Sacchi and L. Mallen (2001). Multivariate statistical and GIS-based approach to identify heavy metals sources in soils. Environmental Pollution, 114: 313-324.

6. Grande, J. A., Borrego, J., Morales, J. A., and de la Torre, M. L. (2003). A description of how metal pollution occurs in the Tinto-Odiel rias (Huelva-Spain) through the application of cluster analysis. Marine Pollution Bulletin 46: 475-480.

7. Hopke, P. K. (1992). Factor and correlation analysis of multivariate environmental data. In C. N. Hewitt (Ed.), Methods of environmental data analysis (pp. 139–180).London, UK: Elsevier.

8. Hair, J. F., Jr., Anderson, R. E., Tatham, R. L., & Back, W. C. (1988). Multivariate data analysis (5th ed.). Englewood Cliffs, NJ: Prentice-Hall.

9. Jolliffe, I. T. (1986). Principal component analysis. New York: Springer.

10. Jobson, J. D. (1991). Applied multivariate data analysis. NewYork: Springer.

11. Karn, S.K. and Harada, H. (2001). Surface water pollution in three urban territories of Nepal, India, and Bangladesh. Environ Manage 28(4):483–496

12. Koch, M. and Rotard, W. (2001). On the contribution of background sources to the heavy metal content of municipal sewage sludge. Water Sci. Technol., 43: 67-74.

13. Kowalkowski, T., Zbytniewski, R., Szpejna, J., and Buszewski, B. (2006). Application chemometrics in river water classification. Water Research 40: 744-752.

14. Lin, Y.P., Teng, T.P. and Chang,T.K. (2002) Multivariate analysis of soil heavy metal pollution and landscape pattern in Changhua county in Taiwan. Landscape and Urban Planning, 62: 19-35.

15. McLaughlin, M.J., Parker, D.R. and Clarke, J.M. (1999). Metals and micronutrients-food safety issues. Field Crops Res., 60: 143-163.

16. McLaughlin, M.J., Hammon, R.E. Mclaren, R. Speir G. and Rogers, T.W. (2000). A bioavailability-based rationale for controlling metal and metalloid contamination of agricultural land in Australian and New Zealand. Aust. J. Soil Res., 38: 1037-1086.

17. Nolte, J. (1988). Pollution source analysis of river water and sewagesludge. Environmental Technology Letters, 9, 857–868.

18. Pekey, H., Karakas, D., and Bakog, L. M. (2004). Source apportionment of trace metals in surface waters of a polluted stream using multivariate statistical analyses. Marine Pollution Bulletin 49: 809-818.

19. Qishlaqi, A. and Farid Moore, F.(2007).Statistical Analysis of Accumulation and Sources of Heavy Metals Occurrence in Agricultural Soils of Khoshk River Banks, Shiraz, Iran ,American-Eurasian J. Agric. & Environ. Sci., 2 (5): 565-573

20. Salman, S.R. and Abu Rukah, Y.H., (1999). Multivariate and principal component statistical analysis of contamination in urban and agricultural soils from north Jordan. Environmental Geology, 38: 256-270.

21. Sandhu, S. S., Warren, W. J., and Nelson, P. (1976). Trace inorganics in rural potable water and their correlation to possible sources. Water Research, 12, 257–261.

22. Sena, M.M., Frighetto, R.T.S., Valarini, P.J., Tokeshi H., and Poppi, R.J. (2002). Discrimination of management effects on soil parameters by using principal component analysis: A multivariate analysis case study. Soil and Tillage Research, 67: 171-181.

23. Simeonov, V., Stratis, J.A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., Sofoniou, M., and Kouimtzis, T.H. (2003). Assessment of the surface water quality in Northern Greece. Water Research 37: 4119-4124.

24. Singh, K. P., Malik, A., Mohan, D., and Sinha, S. (2004). Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India), a case study. Water Research 38: 3980-3992.

25. Shrestha, S., and Kazama, F. (2007). Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. Environmental Modelling and Software 22: 464-475.

26. Subramanian, B.2004. Water quality in South Asia. Asian J Water Environ Pollut. 1(1–2):41–54 Statistical year book (SYB), 2007

27. Tahri, M., Bounakhla, M., Bilal, E , Gruffat, J.J. , Moutte J. and Garcia, D. (2005).Multivariate Analysis of heavy metal contents in soils, sediments and water in the region of Meknes (Central Morocco). Environmental Monitoring and Assessment, 102: 405-417.

28. Tuncer, G.T., Tuncel, S.G. and Balkas, T.I. (1993). Metal pollution in the Golden Horn, Turkey- Contribution of natural and anthropogenic components since 1913. Water Science and Technology, 28: 50-64.

29. Vega, M., Pardo, R., Barraado, E., and Deban, L. (1998). Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. Water Research 32: 3581-3592.

30. Wunderlin, D.A., Diaz, M.P., Ame, M.V., Pesce, S.F., Hued, A.C., and Bistoni, M.A. (2001). Pattern recognition techniques for the evaluation of spatial and temporal variations in water quality. A case study: Suquia river basin (Cordoba-Argentina). Water Research 35:2881-2894.

31. Yeung, I. M. H. (1999). Multivariate analysis of the Hong Kong Victoria harbour water quality data. Environmental Monitoring and Assessment, 59, 331–342.