Metal accumulation in surface sediment of the urban and industrial coastal area of the municipality of Moa (Cuba): distribution and pollution assessment

1. SUPPORTING INFORMATION I

SI. 1- Assessing the degree of pollution

The index value of geoaccumulation defined by Müller (1969) and used in several researches because of its importance as geoindicator of pollution (Amat *et al*. 2002; ONG *et al*. 2013) was used to assess sediment contamination.

The geoaccumulation index is defined by:

Igeo = log 2 (Cn / 1.5 Bn)

Where:

Cn = concentration of metal;

Bn = geochemical background value.

A company specialized in geographic and environmental solutions – CESIGMA - (1997) established the background values for Moa Bay Cay. They used as a reference by the same consultant in 2002 (Table 1).

Table 1. Values of background, mg g^{-1}

Al	Cr	Fe	Mn	Ni	Co	As	Cu	Pb	Zn
0,1	0,2	3	1,2	0,1	34	5*	7	20	15

*(Salomons & Förstener (1984))

In the case of arsenic the background value has not been identified in previous studies, so the value given as a world average in shallow water sediment, by Salomons & Förstener (1984), is reported.

According to Müller (1969), the value of Igeo allows to classify sediments according to the degree of pollution, as shown in Table 2.

Table 2. Quality of the sediment according to value of Igeo

Igeo	Class Igeo	Sediment quality
Around 0	0	Virtually no pollution
>0-1	1	A little polluted
>1-2	2	Moderately polluted
>2-3	3	Among moderately and strongly polluted
>3-4	4	Heavily polluted
>4-5	5	Very heavily polluted
>5	6	Extremely polluted

Source: Müller (1969)

References

AMAT, D.; PIERRA, A.; CASALS, I. & VÁZQUEZ, D. 2002: Estudio de la contaminación por metales pesados en sedimentos y ostiones de la bahía de Manzanillo, Cuba. Journal of the Mexican Chemical Society (ISSN 1665 – 9686), 46 (4): 357-361. Available on-line at: www.redalyc.org/pdf/475/47546411.pdf

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MÜLLER, G. 1969: Index of geoaccumulation in sediments of the Rhine River. *Geology Journal*, 2(3): 108–118.

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SALOMONS, W. & FÖRSTNER, U. 1984: *Metals in the Hydrocycle.* 352p, Springer-Verlag, Berlin, Germany. ISBN: 978-3642693274.

2. SUPPORTING INFORMATION II

SI. II - Data analysis based on quality criteria

In order to interpret the information based on ecotoxicological criteria the limits proposed by Long *et al*. (1995) were used. Two reference values for the concentration of metals in sediment are considered: the lowest concentration that may have adverse effects on living beings (ERL) and the

maximum tolerable level (ERM). Concentrations exceeding the latter values are considered very toxic (Accornero *et al*. 2008).

According to Long *et al.* (1995):

- If the metal concentration is below ERL, contamination is not significant.
- If the concentration of the metal exceeds ERL, but is below ERM, environment is polluted.
- If the concentration exceeds ERM, the environment is toxic.

These researchers identified and studied the effects on organisms and ecosystems of the accumulation of nine elements (As, Cr, Cd, Pb, Cu, Ni, Zn, Hg, and Ag) and their criteria have been widely accepted and based on studies conducted by the Environmental Protection Agency of the USA (USEPA) and by Accornero et al. (2008). Table 3 shows the limits for ecotoxicological assessment for As, Cr, Cu, Pb, Ni and Zn proposed by Long *et al.* (1995) for surface sediment.

Table 3. Limits of ecotoxicological assessment for surface sediments, Long *et al*. (1995), μg g^{-1}

Metal	ERL	ERM
Arsenic	8.2	70
Chromium	81	370
Copper	34	270
Lead	47	220
Nickel	20.9	51.6
Zinc	150	410

References

ACCORNERO, A.; GNERRE, R. & MANFRA, L. 2008: Sediment concentrations of trace metals in the Berre Lagoon (France): An assessment of contamination. *Archives of Environmental Contamination and Toxicology,* 54 (3): 372-385. DOI: 10.1007/S00244-007-9049-6

LONG, E.; MACDONALD, D.; SMITH, S. & CALDER, F. 1995: Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management,* 19 (1): 81-97. DOI: 10.1007/BF02472006.

3. SUPPORTING INFORMATION III

SI. III - Factorial analysis (Use *SPSS STATISTICS* software)

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FACTOR
  /VARIABLES Al Cr Fe Mn Ni Co As Cu Pb Zn
  /MISSING LISTWISE
  /ANALYSIS Al Cr Fe Mn Ni Co As Cu Pb Zn
  /PRINT UNIVARIATE INITIAL CORRELATION SIG DET KMO INV REPR AIC
EXTRACTION ROTATION FSCORE
  /FORMAT SORT
  /CRITERIA MINEIGEN (1) ITERATE (25)
  /EXTRACTION PC
  /CRITERIA ITERATE (25)
  /ROTATION VARIMAX
  /METHOD=CORRELATION.
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Table 4. Correlation matrix

	Al	Cr	Fe	Mn	Ni	Co	As	Cu	Pb	Zn
Al	1,000									
Cr	0,807	1,000								
Fe	0,815	0,840	1,000							
Mn	-0,348	-0,689	-0,566	1,000						
Ni	0,901	0,602	0,755	-0,145	1,000					
Co	-0,093	-0,420	-0,251	0,661	0,135	1,000				
As	0,051	0,112	0,325	-0,029	0,088	0,052	1,000			
Cu	0,121	-0,153	-0,087	0,143	0,213	0,604	0,160	1,000		
Pb	0,236	0,249	0,236	-0,061	0,255	0,437	0,607	0,600	1,000	
Zn	-0,118	-0,432	-0,286	0,501	-0,019	0,822	0,040	0,814	0,345	1,000

a. Determinant = 2.10E-008

KMO and Bartlett test

Kaiser-Meyer-Olkin sampling adequacy		0,238
Bartlett's test of sphericity	Approx. Chi - squared	120,811
	gl	45
	Sig.	0,000

Table 5. Rotated component matrix

	Component		
	1	**2**	**3**
Al	0,975	0,006	0,004
Ni	0,923	0,198	-0,021
Fe	0,865	-0,272	0,259
Cr	0,829	-0,417	0,189
Co	-0,070	0,929	0,069
Zn	-0,120	0,917	0,105
Cu	0,130	0,784	0,338
Mn	-0,420	0,645	-0,238
As	0,014	-0,023	0,893
Pb	0,239	0,388	0,810

Extraction method: Principal component analysis.

Rotation method: Varimax with Kaiser normalization.

4. SUPPORTING INFORMATION IV

SI. IV - Average, standard deviation and ranges of values for the elements studied

Elements	Average	Standard deviation	Range (sample)
Al (mg g^{-1})	47,4	24,5	15,7 (MP 10) – 83,5 (MP 5)
Cr (mg g^{-1})	8,2	6,1	1,4 (MP 10) – 17,9 (MP 4)
Fe (mg g^{-1})	129,4	128,4	22,8 (MP 8) – 379,5 (MP 3)
Mn (mg g^{-1})	19,7	17,6	1,5 (MP 1) – 56,2 (MP 11)
Ni (mg g^{-1})	2,8	1,6	0,9 (MP 10)– 6,2 (MP 2)
Co (µg g^{-1})	388,4	287,4	56 (MP 4) – 1094 (MP 7)
As (µg g^{-1})	63,8	30,6	6,3 (MP 4) – 126 (MP 3)
Cu (µg g^{-1})	79,6	36,6	17 (MP 4) – 146 (MP 5)
Pb (µg g^{-1})	29,1	20,3	6 (MP 4) – 66 (MP 1)
Zn (µg g^{-1})	286,8	151,1	64 (MP 4) – 576 (MP 7)