Distribution of chemical constituents according to particle size in torrential rivers of the Basque country

E Ruiz* and F Romero

Departamento de Ingeniería Química y del Medio Ambiente. Escuela Superior de Ingenieros. Alameda de Urquijo s/n. Bilbao, Spain.

Abstract

Surface sediment samples of the rivers Bidasoa, Lea and Oria (NE of Spain), with torrential character, were taken at 26 selected points, dried and sieved to eight fractions for size analysis (from >2 mm to <63 microns; first fraction >2 mm was rejected). Determined parameters include major (carbonates, organic carbon, Ca, Mg, Na, K, Si, Al and Fe) and microconstituents (Cu, Mn, Zn, Cr, Pb, Ni and Cd), measured mainly by AAS (flow spoiler and graphite furnace) and FIA. Results are discussed by calculation of factors of enrichment in the fine fraction and by graphs of correlation coefficients of parameters versus size fractions. Most microconstituents, organic carbon and Al (related to clays) were accumulated in the fine fractions of the sediments, suggesting pollution phenomena. The rest of the constituents seemed to be related to coarse fractions (Mg, carbonates) or not related to any particular size fraction. To discuss pollution phenomena, the comparison with major conservative elements (Al, Fe or Mg) was tried without success. A method was then proposed with the establishment of an index of quality for each pollutant constituent of sediments, based on the average earth's crust composition (or the average sedimentary rock content for organic carbon). With this method, fine samples show lower quality indices for most constituents, specially in the case of organic carbon, and total samples have much better indices suggesting organic carbon contamination only in seven cases.

Introduction

Sediment samples are often used as heavy metal pollution indicators in surface waters (Förstner and Salomons, 1980). The presence of heavy metals is affected by particle distribution of sediments (Thorne and Nickless, 1981). In this sense, Yamagata and Shigematsu (1970) pointed out that heavy metals should be analysed not only in total sediment, but also according to particle size. Oguna et al. (1979) showed that the concentration of a pollutant is distributed into two fractions of the sediments, i.e. the fine and the coarse. Salomons (1980) considered that both:

- the adsorption capacity by unit of weight usually increases as the particle size of the solids decreases; and
- the capacity of flow transport increases as the particle size decreases.

Förstner and Salomons (1980) also suggested that it is necessary to consider the distribution of size particle to estimate the natural metal levels of river sediments, because there is a marked decrease in the metal content as the particle size increases. Ackermann (1980) used an assay procedure to correct for different particle sizes on heavy metal content in estuarine and coastal sediments. He found that the best results are obtained using cesium for correction.

The comparison of the content of a heavy metal with a conservative element has been suggested to estimate sediment pollution at different depth levels. Magnesium (Hilton et al., 1985), iron (Allen and Brunskill, 1977) or aluminium (Bruland et al., 1974) have been mainly proposed as conservative elements. But the distribution of conservative elements according to sediment particle size may be variable because of changes in mineralogical constituents.

In this paper results are presented which form part of a broader study entailing the identification, origin and physico-chemical factors affecting pollution of torrential river sediments by heavy metals. This work is firstly focused on establishing relations between chemical parameters and size data for studied sediment samples, with special emphasis on estimating the distribution of pollutants in river sediments according to size particle. A second objective is to propose pollution criteria when considering river sediments which vary in both chemical composition and size particle.

Materials and methods

Sampling area

Sediments were collected from the Lea, Oria and Bidasoa Rivers with torrential regime, belonging to the hydrographic basin of the Cantabric Sea, Spain (Fig. 1). Geographic locations and characteristics are the following:

The Bidasoa River has its basin divided between Navarra and Guipuzcoa. It rises in the Lesete peak near the Izpegaray pass. It flows for 50 km in Navarra and for 11 km in Guipuzcoa, forming the border with France until it discharges in the Cantabric Sea (Fuenterrabia). The drainage area is 706 km^2 (681 km^2 in Navarra). The most important tributaries are the Ezcurra, Echalar, Marin and Ondalasco (where most of the industrial factories are located).

The Oria is the most important river in Guipuzcoa. It rises near Otzaurte (Aitzgorri mountain) and flows into the Cantabric Sea at the town of Orio. Its length is 63 km, with a catchment basin area of 850 km^2. Numerous tributaries, such as Araxes, Agaunza, Leizaran, Mutiloa and Estanda, feed into this river and may influence the characteristics of the main river.

The Lea River is quite short (22 km) and located in Vizcaya. It rises in the slopes of Oiz peak (1 026 m) and flows into the Cantabric Sea at the town of Lekeitio. Its elongated basin has an area of 80 km^2. Along its course many small streams are incorporated, but its main tributaries are the Zulueta, Telleria, Muxo and Murela.

The three rivers have much reduced flows during the summer

---

*To whom all correspondence should be addressed.
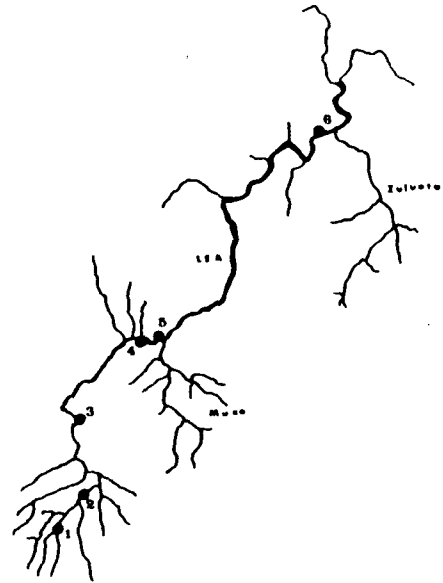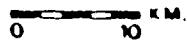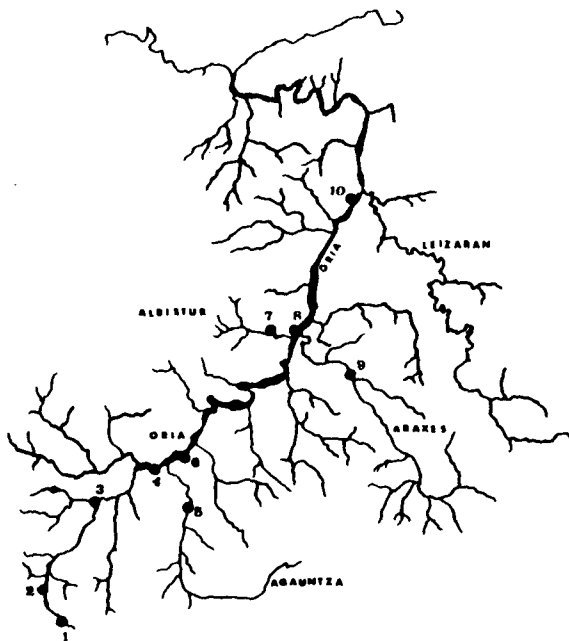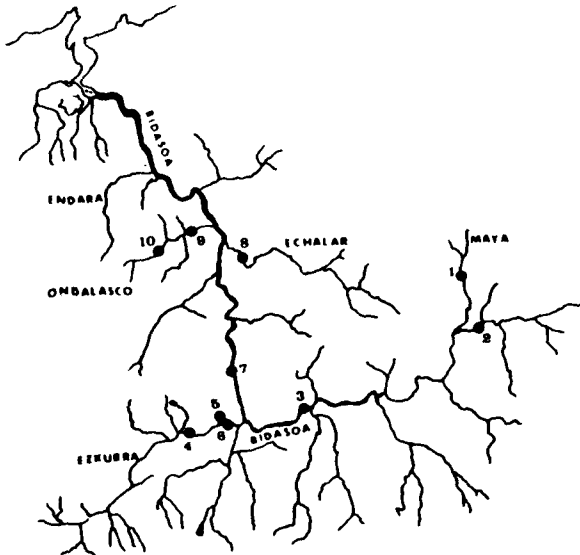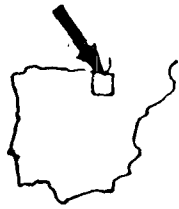
and quite strong flows in autumn and spring. Mean annual rainfall, for the period 1940/41 to 1982/83, is 1 564 mm for the Lea River area, 2 148 mm for the Bidasoa and 1 680 mm for the Oria (CHNE, 1986). The main human activity, along the Lea and Bidasoa Rivers (Ondalasco area was not considered) is agriculture with a few industrial factories in the Lesaca and Vera de Bidasoa areas. Oria River is subject to a high degree of industrial and urban pollution. The most important pollutants include suspended solids, cyanides, Zn, Ni, Cr, solvents, oils and fats. Data published (Basque Government, 1986) attribute 80,6 per cent of the COD content to industrial pollution.

Collection, sieving and chemical analysis

Surface sediment samples were taken at 26 points along the three rivers (ten for Bidasoa/Oria, and six for Lea) using 500 ml polyethylene bottles, previously washed with 20% HCl and distilled water. Sediments were dried at low temperature, for 24 to 48 h and later homogenised. Three representative parts were obtained to carry out size distribution and chemical analyses of both total (<2 mm) and fine (<0,063 mm) samples.

For particle size analysis eight fractions were obtained, namely F-1 (>2 mm, rejected), F-2 (2 to 1 mm), F-3 (1 to 0,75 mm), F-4 (0,75 to 0,5 mm), F-5 (0,5 to 0,25 mm), F-6 (0,25 to 0,1 mm), F-7 (0,1 to 0,063 mm) and F-8 (<0,063 mm), and depicted as differential and accumulatives curves. The mean particle diameters (Perry, 1966) were also calculated as functions of volume (D_V) and surface area (D_{SA}) of particles.

Standard analytical methods for soils (ASA-SSSA, 1982), with some modifications, were applied after calibration with a certified sediment sample (NBS, 1988). These methods are summarised in Table 1 and have been described in detail (Ruiz et al., 1991). Conventional statistical techniques were used for data treatment as described by Calvo (1978). The critical value for the

Figure 1
Location of sampling points

TABLE 1
EXPERIMENTAL METHODS

Parameter	Procedure	Reference
Size distribution	Wet sieving	ASA-SSSA (1982)
Carbonates, as $CaCO_3$	Gas evolution	MAPA, 1981
Organic carbon	Direct titration	MAPA, 1981
Cation exchange capacity	NH_4^+ replacement	MAPA, 1981
Sample solutions	Wet digestion	FAO, 1979; Zazoski and Burau, 1977; Christensen et al., 1982
Major constituents (%):		
Ca, Mg	AAS	
Na, K	Flame photometry	
Si	Spectrophotometric. FIA.	Borggaard and Jorgensen, 1985.
Al	Spectrophotometric.	Rios et al., 1985; Zaki and El-Didamony, 1988.
Fe	Spectrophotometric. FIA.	Mortatti et al., 1982
Microconstituents (mg/kg):		
Cu, Mn, Zn	AAS	Zazoski and Burau, 1977; Pagenkopf and Cameron, 1979
Cr, Pb, Ni, Cd	AAS, graphite furnace	Nielsen and Hrudey, 1984; Ramondetta and Harris, 1978

Pearson correlation coefficient is $r_{critic} = 0,388$ at 95% confidence level (two-sided).

See also Table 1 for experimental methods.

Results and discussion

Analytical results

Table 2 includes mean values for studied rivers, and average values, standard deviations and extreme values of measured parameters for all collected samples. Individual results (more than one thousand data) are omitted for brevity, but can be obtained from the author on request.

Differences in mean data for each river, including particle size and composition of total or fine fractions, are evident. When total contents are considered in estimating metal pollution: Lea River is almost unpolluted; most of the samples from Bidasoa River are polluted by Pb and two samples from the tributary Ondalasco also by Zn, Mn and Cd, due to industrial activities; and Oria River, with smaller particle size, is the most contaminated one, especially by Pb, Cd, Zn and Cu.

Particle size differences

Mean results of sieve analysis for the studied rivers are shown as accumulative curves in Fig. 2, and it is evident that Oria sediments are finer than the other ones. An additional comparison of particle size, based on average particle diameters derived from volume and surface area, is made in Table 3. Again the smaller size of Oria River sediments can be seen clearly. There are no substantial differences between the sediments of the other two rivers, which have consequently greater sizes than average data.

Composition of fine sample and distribution of chemical constituents according to size particle

From Table 2, it is evident that there is an average enrichment of most of the chemical parameters in the fine sample, relative to the total sample, in the following order of percentages:

$$C_{org} (360) > CEC (285) > Cd (270) > Na (195) >$$
$$Cr (175) > Cu (155) > Mg (145) > K (135) >$$
$$Zn, Al, CO_3 (125) > Ni, Mn (115)$$
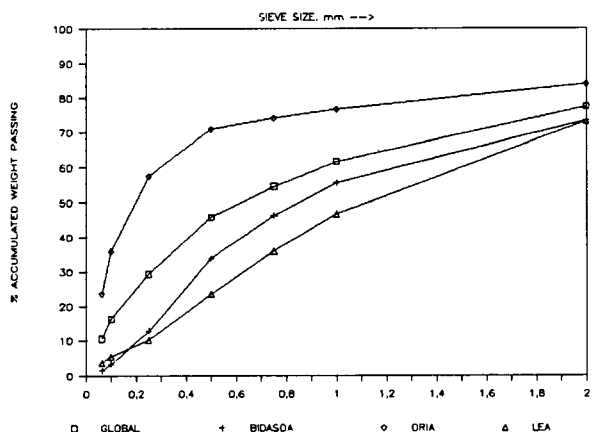
Figure 2
Mean values for studied rivers, average data, standard deviations and intervals of parameters for collected samples

TABLE 2
SIZE DISTRIBUTION AND CHEMICAL COMPOSITION OF STUDIED SEDIMENTS

Size fractions	Bidasoa River	Oria River	Lea River	Average n=26	σ	Maximum	Minimum
% 2-1 mm	17,89	7,33	26,62	15,80	12,5	42,5	0,23
% 1-0,75 mm	9,44	2,50	10,72	7,07	5,17	21,7	0,48
% 0,75-0,5 mm	12,4	3,24	12,33	8,86	7,14	22,7	0,98
% 0,5-0,25 mm	21,01	13,42	13,42	16,30	13,6	42,8	0,57
% 0,25-0,1 mm	9,39	21,79	4,58	13,10	13,6	43,7	0,59
% 0,1-0,063 mm	1,78	12,17	1,74	5,77	7,6	29,1	0,12
% <0,063 mm	1,57	23,54	3,77	10,50	17,9	78,2	0,16
Sample <63 μ							
% C_{org}	3,28	1,61	1,25	2,17	1,46	5,70	0,51
% Carbonates*	6,97	12,84	8,99	9,69	4,99	24,7	2,05
% Na	0,50	0,46	1,81	0,79	0,70	2,98	0,15
% K	2,29	1,66	1,69	1,91	0,86	3,38	1,07
% Ca	1,04	4,37	1,83	2,50	2,23	7,30	0,34
% Mg	1,29	0,49	0,52	0,80	0,57	2,75	0,17
% Al	7,59	6,51	10,11	7,76	2,31	13,3	4,06
% Fe	3,51	5,69	4,96	4,69	1,98	11,2	1,61
% Si	22,88	27,66	25,19	25,30	3,59	32,3	18,4
CEC (meq/100g)**	25,54	13,51	16,85	18,90	8,92	39,0	7,89
mg/kg Cr	59,18	105	58,95	76,70	37,4	195	30,4
mg/kg Pb	38,43	64,06	38,58	48,30	27,6	140	9,9
mg/kg Ni	44,32	70,0	33,93	51,80	23,8	130	27,6
mg/kg Cu	55,96	123,2	27,48	75,20	85,7	465	14,1
mg/kg Zn	187	336	171,4	240	140	580	9,97
mg/kg Mn	972	723,2	1172	920	380	1660	270
mg/kg Cd	0,54	0,69	0,27	0,54	0,53	2,7	0,2
Total sample (<2 mm)							
% C_{org}	0,43	1,00	0,24	0,61	0,69	3,38	0,10
% Carbonates*	1,28	15,2	6,66	7,88	9,05	41	0,38
% Na	0,34	0,37	0,59	0,41	0,19	0,96	0,17
% K	1,71	1,30	1,02	1,39	0,43	2,60	0,64
% Ca	0,48	5,76	3,47	3,20	3,93	13,2	0,04
% Mg	0,80	0,35	0,53	0,56	0,37	1,56	0,17
% Al	6,18	7,33	4,21	6,17	3,05	14,1	1,62
% Fe	4,61	5,71	6,91	5,56	2,73	12,8	1,56
% Si	32,76	26,89	30,28	29,90	4,40	36,0	15,6
CEC (meq/100g)**	4,82	8,51	6,68	6,67	3,19	19,3	3,62
mg/kg Cr	42,73	59,84	20,00	44,10	46,2	262	9,90
mg/kg Pb	44,78	90,08	11,73	54,60	52,5	250	6,0
mg/kg Ni	35,94	59,53	33,88	44,50	22,2	110	13,6
mg/kg Cu	30,78	76,96	32,70	49	40,0	180	14,6
mg/kg Zn	121	296,3	132,8	190	140	495	38,3
mg/kg Mn	812	631,5	1320	860	720	289	150
mg/kg Cd	0,05	0,43	0,07	0,20	0,23	0,80	0,0

* As $CaCO_3$
** CEC cation exchange capacity

TABLE 3
MEAN CALCULATED PARTICLE DIAMETERS (mm) FOR STUDIED RIVERS

	D_V	D_{SA}
Bidasoa	0,12	0,43
Oria	0,05	0,09
Lea	0,09	0,38
Global	0,07	0,18

Only four constituents were lower:

Pb (90) > Si, Fe (85) > Ca (80)

Such ordering suggests the following comments:

* Very large increments of the organic carbon and the cation exchange capacity for the fine samples.
* Considerable enrichment in the fine sample of metallic microconstituents (all those studied except Pb), clay minerals (as a consequence of increments of Al) and carbonates (but not Ca).
* Relative impoverishment of the contents of Si, Fe and Ca (also Pb) in the fine samples.

In searching for the relation between contituents and particle size, the correlation coefficients between each chemical constituent and the weight percentage of each size fraction were calculated for total (<2 mm) samples from individual data (26 sediments). The relationship becomes apparent when the correlation coefficients of a selected fraction (and related constituents) with all size fractions are depicted versus size fractions, from F-2 (2 to 1 mm) to F-8 (<63 microns). From these graphs, it can be concluded that:

* There are eight parameters (Al, C_{org}, CEC, Pb, Cu, Zn, Cd and probably Ni) whose correlation coefficients with particle size fractions follow an evolution paralled to the correlation coefficients of the finest fractions (F-7 or F-8) (Figs. 3 and 4). This would indicate that the organic matter, clay minerals (related with Al content) and most of the metallic microconstituents should be found in the two finest fractions of the total sample. The cation exchange capacity (depending on the organic carbon and the clay fraction) follows a parallel trend. The behaviour found for most of the microconstituents (Ni, Cu, Cd, Zn and Pb) suggests the possibility of pollution phenomena.
* The distribution of Mn and most of the major constituents of the sediments does not show any statistical relation at 95% confidence level with particle size fractions, except for Mg which is significantly related to the F-4 fraction (0,75 to 0,5 mm) and carbonates, negatively related to the same fraction. This fact (not presented in graphs for the sake of simplicity) suggests an origin mainly natural for the mentioned constituents in the total samples.

Pollution of sediment samples

To estimate pollution in the studied sediments, the increase in the content of a metal relative to suggested conservative elements was rejected, because of very important variations in Al, Fe or Mg contents or their molar accumulations for the first total samples (unpolluted or scarcely contaminated) of the studied rivers, as can be seen in the following data:

	%Al	%Fe	%Mg	(Al+Fe)	(Al+Mg)	(Fe+Mg)	(Al+Fe+Mg)
				mol/100 g			
Bid-1	7,81	2,99	1,05	0,3248	0,3325	0,0967	0,3860
Ori-1	13,8	8,48	0,31	0,6629	0,5239	0,1646	0,6757
Lea-1	1,81	1,56	0,17	0,0950	0,0740	0,0350	0,1020

This method would require establishing different pollution criteria for each river, or even each tributary.
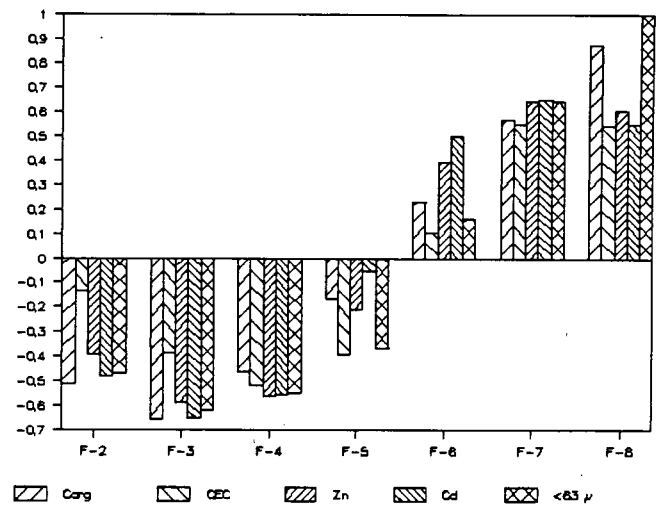

Figure 3
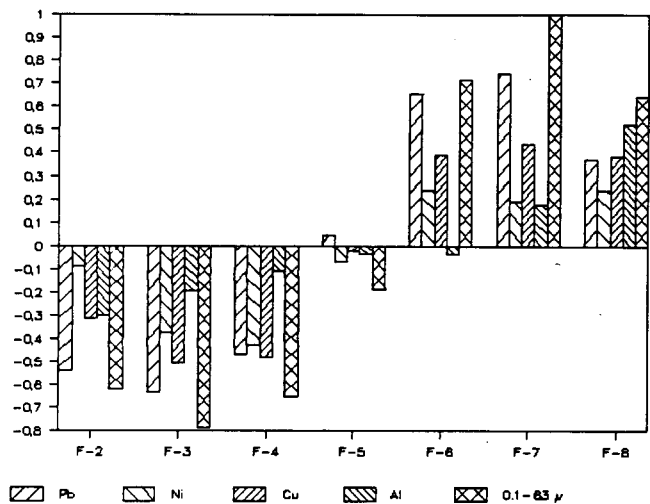*Chemical constituents related to particles <63 µm in total samples*

Figure 4
Chemical constituents related to particles with size in the interval 0,1 to 0,063 mm in total samples

The enrichment of a metal in the fine fraction, relative to a conservative element was also tried. According to data included in the former paragraph and considering any major constituent from Mg to Fe as conservative element, average contamination would be expected for the constituents C_{org}, Cd, Cr and Cu, following an increase in CEC due to the organic matter content.

This second method was also rejected because almost 50 per cent of the samples with total cadmium content below or close to detection limit (0,01 ppm) had to be classified as contaminated as a consequence of accumulation, possibly natural, of Cd in the finest fractions.

The comparison of each element with a mean natural value seems to be therefore the best method. As average values the amounts in the earth's crust for metals and the content in sedimentary rocks for organic carbon (CRC, 1973-1974) were selected. The following data in parts per million:

TABLE 4
QUALITY INDICES FOR EACH POLLUTANT CONSTITUENT OF SEDIMENTS

Muestra				IQS				
	Cr	Pb	Ni	Cu	Zn	Mn	Cd	C_{org}
Bid-1	89,7	34,6	76,2	72,1	64,4	69,2	100	79,5
Bid-2	77,30	20,00	78,30	73,10	76,50	81,40	100,0	86,80
Bid-3	79,50	21,40	74,30	71,40	63,70	83,80	100,0	68,00
Bid-4	83,60	19,20	73,30	64,80	62,90	41,50	100,0	40,00
Bid-5	86,6	34,40	65,20	69,60	56,70	69,10	100,0	60,6
Bid-6	81,90	43,50	66,90	77,60	69,80	72,40	88,20	63,5
Bid-7	85,00	46,50	64,40	79,70	55,50	75,40	100,00	86,80
Bid-8	83,50	34,00	62,60	73,00	52,60	67,10	83,30	33,00
Bid-9	78,00	16,20	62,20	57,00	25,50	38,30	42,90	71,00
Bid-10	80,50	26,80	70,50	62,90	42,90	27,90	42,90	72,50
Oria-1	88,20	40,70	62,70	73,80	53,00	71,10	33,30	75,00
Oria-2	88,10	35,70	66,50	73,80	48,50	70,90	42,90	75,00
Oria-3	89,00	21,30	69,00	52,80	24,20	54,90	20,00	30,60
Oria-4	43,30	17,60	42,20	35,20	34,40	52,10	27,30	62,90
Oria-5	76,10	10,20	43,20	28,10	21,10	47,60	20,00	62,30
Oria-6	78,60	6,00	55,90	39,10	23,00	54,30	23,10	34,70
Oria-7	90,70	34,30	72,50	82,70	64,60	86,90	60,00	52,40
Oria-8	74,80	12,00	49,10	37,80	21,50	59,20	23,10	16,30
Oria-9	92,00	19,30	66,40	70,90	41,00	68,40	15,80	42,60
Oria-10	84,80	12,70	66,30	46,10	26,70	65,90	33,30	36,30
Lea-1	95,00	65,00	85,40	82,20	77,50	77,60	78,90	65,30
Lea-2	93,90	61,50	71,60	67,80	55,90	66,70	75,00	70,20
Lea-3	92,20	72,70	67,20	63,10	46,80	53,30	100,0	78,60
Lea-4	87,90	71,50	69,90	63,30	33,90	30,80	93,80	81,50
Lea-5	89,60	41,60	65,40	69,20	47,80	47,20	42,90	75,00
Lea-6	87,20	46,60	65,40	66,70	55,90	25,70	60,00	73,30

Cd	Cr	Cu	Mn	Ni	Pb	C_{org}
0,15	200	70	1 000	80	16	6 600

were used to propose for each constituent an index of quality of sediment (IQS) by the expression:

$$IQS = 100 \,[1-\{x/(x+av)\}]$$

where:

x = content of a constituent in a particular sample; and
av = its average natural value.

The proposed method leads to IQS in the range 0 to 100 with the following values according to the ratio of the content to natural average value:

x/av	0	1	1,5	2	3	4	7	9	n
IQS	100	50	40	33,3	25	20	12,5	10	->0

For calculating a global IQS for a sample sediment, two procedures can be followed, namely:

* To obtain the arithmetic mean value (used in this work)
* To establish differences among constituents by using ponderation factors for each one (not tried in this work)

The application of the proposed method to studied total samples of sediments led to results included in Table 4. By considering

that a sample is contaminated when its content exceeds 1,5 times the natural average (an IQS lower than 40), the following deduction can be made on total samples:

* No contamination was found in the case of two metals, namely Cr and Ni.
* Total sediments of the Lea River are almost unpolluted, with the exception of two samples contaminated by Mn and just one by Zn.
* Bidasoa River is polluted by Pb, Zn and Mn in several samples, particularly in the cases of sediments from the tributary Ondalasco (Samples 9 and 10), where most of the industrial activities are located. A sample (Number 8) is also contaminated by organic matter. This pollution can be attributed to an urban origin, as it is situated after quite a big town, Tolosa.
* Oria River, the most polluted one, has quite a low IQS for Pb, Cu, Zn, Cd and organic carbon in many samples. These results are probably consequences of urban, farming and industrial activities alongside the basin.

For the fine samples (<63 microns) an analogous treatment was carried out because of the probable influence of sediment composition on aquatic life. Condensed results from this calculation, expressed by the interval of variation of IQS and percentage of polluted samples (exceeding 1,5 times natural averages), are the following:

	-----Bidasoa-----		-----Oria------		--------Lea--------	
Cr	71,8 - 81,3	0	80,8 - 50,5	0	68,9 - 86,8	0
Pb	16,4 - 61,8	70	10,3 - 35,6	100	24,5 - 37,9	100
Ni	61,1 - 73,8	0	38,1 - 69,2	10	67,5 - 74,3	0
Cu	43,6 - 71,8	0	13,0 - 62,6	40	52,9 - 83,2	0
Zn	21,5 - 57,0	20	18,5 - 47,0	60	33,2 - 52,0	17
Mn	37,6 - 58,9	20	41,8 - 78,7	0	38,2 - 65,1	33
Cd	5,3 - 42, 9	60	8,6 - 33,3	100	33,3 - 42,9	67
C_{org}	10,4 - 40,2	90	14,3 - 41,8	90	26,4 - 56,4	67
Mean	33,5 - 61,0	33	28,2 - 52,3	50	43,1 - 62,3	35

Again Oria River has the lower IQS and the greater mean percentage of contaminated fine samples. The percentages of contaminated fine samples are almost coincident for the Lea and Oria Rivers but mean intervals of IQS suggest greater pollution in the case of the Bidasoa River.

Conclusions

Results are included in this paper on three rivers of torrential regime from the NE of Spain. The variations in size particle and composition among samples, even from the same basin, are so great that the treatment of data by conventional methods for estuarine, lake or coastal sediments was not adequate.

For estimating the distribution of chemical constituents among size fractions a method based on correlation coefficients between total content and percentages of size particle fractions was tried. This method may probably be used with success for most sediments.

The comparison with a natural background content was necessary to establish pollution phenomena in this type of river. For that, an index of quality of sediment, based on average earth's crust metal amounts and sedimentary rocks content was designed and applied. Calculated indices agree with considerations derived from presumably urban, agricultural and industrial inputs for the studied zones, and may probably also be applied to most types of sediments.

References

ACKERMAN, F (1980) A procedure for correcting the grain size effect in heavy metal analyses of estuarine and coastal sediments. *Environ. Tech. Lett.* Vol. 1 518 pp.

ALLEN, RJ, and BRUNSKILL, GJ (1977) Relative atomic variation (RAV) of elements in lake sediments; Lake Winnipeg and other Canadian lakes. In: Golterman, HL (ed.) *Interactions Between Sediments and Fresh Water.* 108-120.

ASA-SSSA (1982) *Methods of Soil Analysis. Part 2-Chemical and Microbiological Properties* (2nd edn.) Page, AL, Miller, RH and Keeney, DR (eds.) ASA-SSSA. Madison, Wisconsin. USA.

BASQUE GOVERNMENT (1986) Resumen del estado actual del medio ambiente en Euskadi. Departamento de Política Territorial y Transportes.

BORGGAARD, OK and JORGENSEN, SS (1985) Determination of silicon in soil extracts by flow injection analysis. *Analyst* 110 177-180.

BRULAND, KW, BERTINE, K, KOIDE, M and GOLDBERG, ED (1974). History of metal pollution in Southern California coastal zone. *Environ. Sci. Tech.* 8 425-430.

CALVO, F (1978) Estadística Aplicada. Cap. 13. Ediciones Deusto S.A. Bilbao.

CHRISTENSEN, TH, PEDERSEN, L AND TJELL, JC (1982) Comparison of four methods for digestion of sewage sludge by samples for analysis of metals by atomic absorption spectrophotometry. *Intern. Environ. Anal. Chem.* 12 41-50

CHNE, (1986) Recursos hidraúlicos de las cuencas del Norte de España. Síntesis. Estudios previos de planificación hidrológica. Confederación Hidrográfica del Norte de España.

CRC (1973-1974) *Handbook of Chemistry and Physics* (54th edn.) 1973-1974.

FAO (1979) European Research Network on Trace Elements. Presentado en Consultation Meeting Mach in Ghent. Bélgica.

FÖRSTNER, U and SALOMONS, W (1980) Trace metal analysis on polluted sediment. *Environ. Tech. Lett.* 1 494.

HILTON, J, DAVISON, W and OCHSENBEIN, U (1985) A mathematical model for analysis of sediment core data: Implications for enrichment factor calculations and trace-metal transport mechanisms. *Chemical Geology* 48 181-191.

MAPA (1981) Métodos oficiales de análisis de suelos y plantas. Ministerio de Agricultura, Pesca y Alimentación. Madrid.

MORTATTI, F, KRUNG, FJ, PRESSENDA, CR, ZAGATTO, EAG and JORGENSEN, SS (1982) Determination of iron in natural waters and plant material with 1.1 - Phenanthroline by flow injection analysis. *Analyst* 107 659-663.

NBS (1988) Standard Reference Material 2704. Buffalo River Sediment. Office of Standard Reference Materials, Chemistry Building, National Bureau of Standards, Galthersburg, MD 20899, USA.

NIELSEN, JS and HRUDEY, SE (1984) Rapic methods for the digestion of sewage and sludge metal analyses. *Environ. Sci. Tech.* 18(2) 130-132.

OGUNA, H, YARITA, I, KOBAYASHI, S and NAKAJIMA, J (1979) Mechanism of metal accumulation of sediments of Edogawa and Muratagawa Rivers; a consideration on the basis of grain size distributions. *Jap. J. Water. Pollut. Res.* 2 173-180.

PAGENKOPF, GK and CAMERON, D (1979) Deposition of trace metals in stream sediments. Department of Chemistry, Montana State University, Bozeman, USA.

PERRY, JH (1966) Manual del Ingeniero Quimico. Uteha, México. Tomo II. 1734 pp.

RAMONDETTA, PL and HARRIS, WH (1978) Heavy metals distribution in Jamaica bay sediments. *Environ. Geol.* 2(3) 145-149.

RIOS, A, LUQUE DE CASTRO, MD and VALCARCEL, M 91985) New approach to the simultaneous determination of pollutants in waste water by flow injection analysis. *Analyst* 110 277-281.

RUIZ, E, ECHEANDIA, A and ROMERO, F (1991) Microanalysis determination of metallic constituents of river sediments. *Fresenius J. Anal. Chem.* 340 223-229.

SALOMONS, W (1980) Adsorption processes and hydrodynamic conditions in estuaries. *Environ. Tech. Lett.* 1 356-365.

THORNE, LT and NICKLESS, G (1981) The relation between heavy metals and particle size fractions within the Severn Estuary (U.K. inter-tidal sediments). *Sci. Total Environ.* 19 207-213.

YAMAGATA, N and SHIGEMATSU, I (1970) Cadmium pollution in perspective. *Bull. Inst. Publ. Hlth.* 19 1-27.

ZAKI, MTK and EL-DIDAMONY, AM (1988) Use of haematoxylin in an improved method for the determination of ultramicro amounts of aluminium. *Analyst* 113 577-580.

ZAZOSKI, RJ and BURAU, RG (1977) A rapic nitric-perchloric acid digestion method for multi-element tissue analysis. *Commum. Soil Sci. Plant Anal.* 8(5) 425-436.

GUIDE TO AUTHORS

AIMS AND SCOPE

This journal publishes refereed, original work in all branches of water science, technology and engineering. This includes water resources development; the hydrological cycle; surface hydrology; geohydrology and hydrometeorology; limnology; mineralisation; treatment and management of municipal and industrial water and wastewater; treatment and disposal of sewage sludge; environmental pollution control; water quality and treatment; aquaculture; agricultural water science; etc.

Contributions may take the form of a paper, a critical review or a short communication. A paper is a comprehensive contribution to the subject, including introduction, experimental information and discussion of results. A review may be prepared by invitation or authors may submit it for consideration to the Editor. A review is an authoritative, critical account of recent and current research in a specific field to which the author has made notable contributions. A short communication is a concise account of new and significant findings.

GENERAL

Submission of manuscripts

The submission of a paper will be taken to indicate that it has not, and will not, without the consent of the Editor, be submitted for publication elsewhere. Manuscripts should be submitted to: **The Editor, WATER SA, PO Box 824, Pretoria, 0001, South Africa.**

Reprints

One hundred free reprints of each paper will be provided. Any additional copies or reprints must be ordered from the printer (address available on request).

Language

Papers will be accepted in English or Afrikaans. Papers written in Afrikaans should carry an extended English summary to facilitate information retrieval by international abstracting agencies.

Abstracts

Papers should be accompanied by an abstract. Abstracts have become increasingly important with the growth of electronic data storage. In preparing abstracts, authors should give brief, factual information about the objectives, methods, results and conclusions of the work. Unsubstantiated viewpoints should not be included.

Refereeing

Manuscripts will be submitted to and assessed by referees. Authors bear sole responsibility for the factual accuracy of their publications.

Correspondence

State the name and address of the author to whom correspondence should be addressed on the title page.

SCRIPT REQUIREMENTS

Lay-out of manuscripts

An original typed script in double spacing together with three copies should be submitted. Words normally italicised should be typed in italics or underlined. The title should be concise and followed by authors' names and complete addresses. A paper may be organised under main headings such as **Introduction, Experimental, Results, Discussion (or Results and Discussion), Conclusions, Acknowledgements and References.**

Contents of manuscripts

The International System of Units (SI) applies. Technical and familiar abbreviations may be used, but must be defined if any doubt exists.

Tables

Tables are numbered in arabic numerals (Table 1) and should bear a short but adequate descriptive caption. Their appropriate position in the text should be indicated.

Illustrations and line drawings

One set of original figures and two sets of copies should accompany each submission. Photographs should be on glossy paper (half-tone illustrations should be kept to a minimum) and enlarged sufficiently to permit clear reproduction in half-tone. All illustrations, line-drawings and photographs must be fully identified on the back, numbered consecutively and be provided with descriptive captions typed on a separate sheet. Authors are requested to use proper drawing equipment for uniform lines and lettering of a size which will be clearly legible after reduction. Freehand or typewritten lettering and lines are not acceptable. The originals should be packed carefully, with cardboard backing, to avoid damage in transit.

References

Authors are responsible for the accuracy of references. References to published literature should be quoted in the text as follows: Smith (1982) or (Smith, 1982). Where more than two authors are involved, the first author's name followed by *et al.* and the date should be used.

All references are listed alphabetically at the end of each paper and not given as footnotes. The names of all authors should be given in the list of references. Titles of journals of periodicals are abbreviated according to Chemical Abstracts Service Source Index (Cassi).

Two examples of the presentation of references are the following:

Grabow, WOK, Coubrough, P, Nupen, EM and Bateman, BW (1984) Evaluations of coliphages as indicators of the virological quality of sewage-polluted water. *Water SA* 10(1) 7-14.

Wetzel, RG (1975) *Limnology*. WB Saunders Company, Philadelphia. 324.