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# Environmental impact of heavy metal concentration in the Coatzacoalcos River, Veracruz, Mexico.

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## ABSTRACT

A quantitative environmental impact study on heavy metal concentration (Cr, Cu, Mn, Cd, Pb, Co and Ni) in the water, sediments and benthic fauna of the Coatzacoalcos River, Mexico was carried out to establish relationships between heavy metal concentration and human activity (urban and agricultural activities). The Coatzacoalcos River is characterized by one of the largest estuarine systems in the eastern coast of Mexico, and exhibits a large diversity of mangroves, palm trees and terrestrial invertebrates. However, the river has suffered from impacts of petrochemical activities in the past. Sediments, water and benthic fauna were collected during four sampling periods in September 1996 (rainy season), January 1997 (dry season), April 1997 (dry season) and August 1997 (rainy season). Dry sieving of the sediments was carried out. Also in situ measurements of organic matter content and heavy metal concentration were determined for seventeen river stations. The first and fourth samplings showed that most sediment in the Coatzacoalcos River is transported by suspension during the rainy season. The second and third sampling showed saltation as the main mode of transport during the dry season. Nine stations in the river were environmentally impacted by industrial and urban discharges leading to high Cu and Cr concentration values in water and sediments. Poor recovery of benthic organisms was observed for most Coatzacoalcos River stations. Depletion of benthic organisms was due to intensive dredging activity in the past decades as well as low $O_2$ values in the water column. Bivalves, *Rangia* concentrate 1.1 times more Cu than Cr than others *Polimesoda* from sediments. *Polimesoda carolineana, Rangia cuneata* and *Rangia flexuosa* concentrate 2.2 times more Cr than Cu from water. *Rangia* also concentrates 4.2 times more Cu than Cr in sediments. This suggests that the three species have an efficient excretory system to tolerate and eliminate the excess of Cu. A varimax rotated factor analysis showed that the highest impacted stations of the Coatzacoalcos River area

influenced by the lack of turbidness and depletion of $O_2$ with high water temperatures related to industrial discharges and high Cu and Cr values in sediments and water.
Key words: heavy metals, water, sediments, benthic fauna, Coatzacoalcos River

**RESUMO**

Realizou-se um estudo ambiental quantitativo das concentrações de metais pesados (Cr, Cu, Mn, Cd, Pb, Co e Ni) na água, sedimentos e fauna do benthos do Rio Coatzacoalcos, bem como uma relação entre as concentrações dos mesmos metais pesados, aliados as respectivas atividades humanas (petroquímica, urbana e agricultura). O Rio Coatzacoalcos possui um dos maiores sistemas estuarinos da costa oriental no Mexico, junto a uma grande diversidade de mangues, palmeiras e animais invertebrados terrestres. As amostragens de sedimentos, água e fauna benthônica foram realizadas durante quatro periodos de coleta entre setembro 1996 (período de chuvas)a janeiro 1997, abril 1997 (período de secas) a agosto de 1997 (período de chuvas). Logo em seguida, os sedimentos foram coletados, e logo em seguida fizeram-se medições "*in situ*" de conteúdo de matéria orgânica e concentração de metais pesados ao longo de dezessete estações no rio. A primeira e quarta amostragem mostraram que a maioria dos sedimentos no rio Coatzacoalcos foram transportados em suspensão durante a temporada de chuvas. Na segunda e terceira amostragem apontou-se que a saltação era a forma principal de transporte durante a temporada de seca. Nove estações no rio foram impactadas ambientalmente pelas descargas industriais e urbanas, elevando as concentrações de Cu e Cr na água e nos sedimentos. A pobre amostragem de fauna do rio se deve a excessiva dragagem efetuada ao longo de décadas , assim como a baixa concentração dos valores de $O_2$ na coluna de água. Os bivalvos: *Rangia* concentrou 1.1 vezes mais Cu que Cr que outros bivalvos como *Polimesoda* dos sedimentos. *Polimesoda carolineana, Rangia cuneata* e *Rangia flexuosa*, concentrou 2.2 vezes mais Cr que Cu da água. A *Rangia* também apresentou uma concentração 4.2 vezes maior que Cu e Cr nos sedimentos. Isto sugere que as trés espécies possuem um sistema excretor eficiente que tolera e elimina o exceso de Cu. A análise de fator rotatório "varimax" demonstrou que as estações mais impactadas do Rio Coatzacoalcos são influenciadas pela falta de turbidez e a baixa de $O_2$ com as altas temperaturas que tem relação com as descargas industriais, bem como aos altos valores de Cu e Cr nos sedimentos e na água.

Palavras chave: metais pesados, água, sedimentos, fauna benthônica, Rio Coatzacoalcos.

## INTRODUCTION

Fluvial and coastal resources are in serious risk due to human settlement increase and uncontrollability of agricultural and industrial activities partly cause by the excessive discharge input of heavy minerals in water and soil systems.

Some heavy metals like chrome (Cr), copper (Cu), iron (Fe) and manganese (Mn) are essential in living organisms but potentially hazardous in high concentrations. Others like lead (Pb), cadmium (Cd) and mercury (Hg) are highly toxic in low concentrations (**ESPINA AND VANEGAS, 1996**). Heavy metals concentrate in water, sediments and organisms throughout geological processes like weathering and volcanism. However, high concentrations of heavy metals are due to petrochemical, agricultural and metallurgical activity and lixiviation of solid residues in the water and sediments (**FÖRSTNER AND WITTMANN, 1979**).

The Coatzacoalcos River in the southeastern coast of Mexico has become a highly environmentally impacted river due to the petrochemical and agricultural activities in the past two decades (**FIGUEROA, 1986; BOTELLO AND PAÉZ, 1986; GALLEGOS, 1986**).

The river is characterized by one of the largest estuarine systems in the eastern coast of Mexico which groups a high diversity of mangroves, palm trees and marine and terrestrial invertebrates. Therefore, it is of our major concern to present a study of the environmental impact of human activity in the upper and lower reaches of the Coatzacoalcos River. The aims of this paper are to study the heavy metal concentration (Cr, Cu, Mn, Cd, Pb, Co and Ni) in the water, sediments and benthic fauna of the river and to establish their relationships with the human activity.

## STUDY AREA

The Coatzacoalcos River is located in the state of Veracruz, Mexico at $17^0$ 46´, $18^0$ 10´ N latitude and $94^0$ 25´, $94^0$ 31´W longitude (Fig. 1). The river basin has 26, 691 $Km^2$ with several converging tributaries. Using data from the Mexican Comisión Nacional del Agua, the combined volume of the measured Coatzacoalcos River runoff has been estimated in nearly $15 \times 10^9$ $m^3$ $year^{-1}$, although in an annual sampling cycle important variations have been detected of 1,251 $m^3$ $s^{-1}$ in September, 294 $m^3$ $s^{-1}$ in January, 129 $m^3$ $s^{-1}$ in April and 968 $m^3$ $s^{-1}$ in August (**ORTIZ *et al.* 2002**). The average evaporation rate in the river is 522 mm. The highest evaporation rate is 2510 mm (october) (**GARCÍA, 1988**).

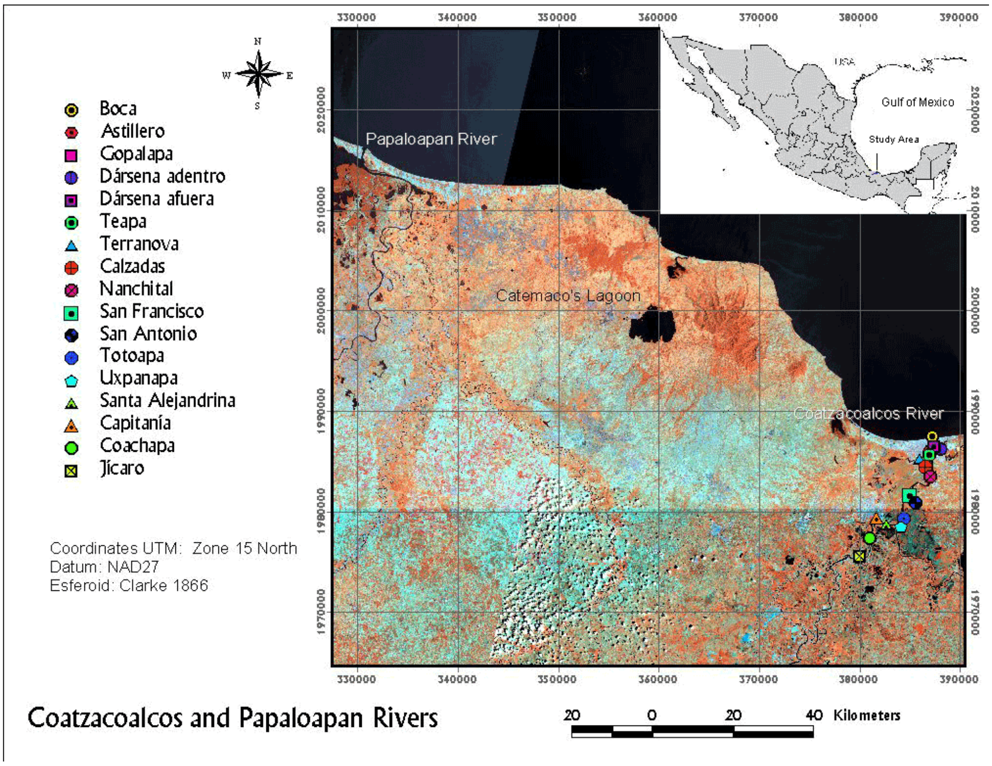


*Fig 1. Study area and sampling sites.*

The climate in the area is humid with average temperatures of 25.5$^0$ C in spring and summer. In winter the average temperature is 22.2$^0$ C. Northeastern and northwestern winds with average velocities of 3.2 to 5.5 m/s are dominant in may, august and december respectively (**García**, 1996). Hurricanes are common in summer and fall. The river is surrounded by a low relief of small hills and flat terrains composed of Miocene sedimentary rocks and Quaternary alluvial deposits (**INEGI**, 1980a)

## EQUIPMENT AND METHODS

*Field work*

Sediments, water and benthic fauna were collected during september 1996 (rainy season, first sampling), january 1997 (dry season, second sampling), april 1997 (dry season, third sampling) and august 1997 (rainy season, fourth sampling) in boats using a 1 lt. capacity sedimentary dredge and polyethylene flasks to collect water. Fourteen, sixteen and seventeen sampling stations were considered during the first, second, third and fourth field sampling respectively. A Trimble GPS and topographic charts 1:50 000 (E15-A85) of the **INEGI** (**1980b**) were used for sample site positioning.

In situ physical parameters measurements were carried out (Table 1) using a Hidrolab YSI Model 3800 portable field equipment. Sediment subsampling (300 g) was done

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transferring the samples into plastic bags with $HNO_3$ for 72 hours to avoid contamination. Water samples were stored at 40° C in flasks adding $HNO_3$ for preservation. Benthic organisms were collected from 2 to 10 lt of sediment and preserved in plastic bags.

*Table 1. In situ physical parameters of the Coatzacoalcos River during one annual cycle (1996-1997)*

| Station | pH | T | $O_2$ | S o/oo | Eh | Turbidness | Cu | Cr |
|---|---|---|---|---|---|---|---|---|
| **Boca sep 96** | 8.19 | 28.3 | ND | 24.8 | 143 | 49 | ND | ND |
| **Astillero sep 96** | 7349 | 26.4 | ND | 0.10 | 234 | 75 | ND | ND |
| **Gopalapa sep 96** | 7.59 | 26.4 | ND | 0.10 | 238 | 342 | ND | ND |
| **Terranova sep 96** | 7.07 | 28.0 | ND | 0.10 | 161 | 27 | ND | ND |
| **Calzadas sep 96** | 7.54 | 26.5 | ND | 0.10 | 225 | 250 | ND | ND |
| **Nanchital sep 96** | 7.48 | 26.7 | ND | 0.10 | 210 | 46 | ND | ND |
| **S. Francisco sep 96** | 7.50 | 26.8 | ND | 0.10 | 205 | 57 | ND | ND |
| **S. Antonio sep 96** | 7.53 | 26.7 | ND | 0.10 | 203 | 118 | ND | ND |
| **Totoapa sep 96** | 7.64 | 26.3 | ND | 0.10 | 198 | 136 | ND | ND |
| **Uxpanapa sep 96** | 7.70 | 26.1 | ND | 0.10 | 212 | 69 | ND | ND |
| **Sta. Alejandrina sep 96** | 7.41 | 27.0 | ND | 0.10 | 220 | 117 | ND | ND |
| **Capitanía sep 96** | 7.45 | 27.0 | ND | 0.10 | 222 | 55 | ND | ND |
| **Coachapa sep 96** | 7.48 | 27.0 | ND | 0.10 | 231 | 69 | ND | ND |
| **El Jícaro sep 96** | 7.46 | 27.1 | ND | 0.10 | 225 | 72 | ND | ND |
| **Boca jan 97** | 8.51 | 23.1 | ND | 35.10 | 202 | 2.0 | 6.36 | 3.55 |
| **Astillero jan 97** | 8.32 | 21.9 | ND | 2.20 | 2.15 | 3.0 | 7.00 | 3.24 |
| **Gopalapa jan 97** | 8.46 | 23.2 | ND | 33.90 | 211 | 6.0 | 2.21 | 2.97 |
| **D. adentro jan 97** | 8.52 | 23.1 | 2.70 | 33.90 | 200 | 2.0 | 2.24 | 7.79 |
| **Teapa jan 97** | 8.42 | 22.9 | ND | 27.10 | 207 | 1.0 | 4.66 | 2.65 |
| **Terranova jan 97** | 7.9 | 22.7 | ND | 0.8 | 245 | 11.0 | 0.71 | 4.60 |
| **Calzadas jan 97** | 8.05 | 21.8 | ND | 2.10 | 222 | 5.0 | 2.01 | 0.86 |
| **Nanchital jan 97** | 8.53 | 23.2 | ND | 33.80 | 219 | 4.0 | 4.36 | 3.65 |
| **S. Francisco jan 97** | 8.01 | 22.0 | ND | 1.30 | 252 | 5.0 | 0.43 | 1.12 |
| **S. Antonio jan 97** | 8.0 | 24.5 | ND | 29.70 | 177 | 3.0 | 2.20 | 2.81 |
| **Totoapa jan 97** | 7.96 | 21.7 | ND | 0.10 | 264 | 9.0 | 3.08 | 0.44 |
| **Uxpanapa jan 97** | 8.08 | 21.7 | ND | 0.10 | 264 | 7.0 | 3.46 | 0.91 |
| **Sta. Alejandrina jan 97** | 7.75 | 22.0 | ND | 0.10 | 270 | 9.0 | 2.67 | 0.49 |
| **Capitanía jan 97** | 8.17 | 22.1 | ND | 0.10 | 275 | 11.0 | 2.91 | 0.41 |
| **Coachapa jan 97** | 7.69 | 22.5 | ND | 0.10 | 199 | 13.0 | 0.91 | 0.30 |
| **El Jícaro jan 97** | 8.58 | 22.5 | ND | 0.10 | 324 | 8.0 | 1.11 | 0.92 |
| **Boca apr 97** | 7.83 | 25.5 | 5.99 | 32.40 | 167 | 4.0 | 3.60 | 3.04 |
| **Astillero apr 97** | 7.93 | 25.5 | 5.81 | 33.20 | 182 | 9.0 | 1.26 | 8.98 |
| **Gopalapa apr 97** | 7.9 | 25.6 | 5.60 | 32.80 | 73.0 | 11.0 | 1.94 | 6.41 |
| **D. adentro apr 97** | 7.9 | 26.7 | 5.33 | 30.80 | 151 | 5.0 | 2.93 | 3.19 |
| **Terranova apr 97** | 7.41 | 26.3 | 4.30 | 9.60 | 184 | 13.0 | 5.90 | 1.93 |
| **Nanachital apr 97** | 7.88 | 25.6 | 5.16 | 32.50 | 102 | 13.0 | 2.66 | 4.96 |
| **S. Francisco apr 97** | 7.65 | 26.4 | 3.30 | 25.30 | 169 | 5.0 | 0.22 | 3.95 |
| **S. Antonio apr 97** | 7.63 | 26.1 | 2.69 | 28.20 | 118 | 14.0 | 0.88 | 5.47 |
| **Totoapa apr 97** | 7.35 | 25.4 | 0.41 | 24.60 | -35.0 | 6.0 | ND | 5.99 |
| **Uxpanapa apr 97** | 7.43 | 26.3 | 2.03 | 20.80 | 95.0 | 27.0 | ND | 3.93 |
| **Sta. Alejandrina apr 97** | 7.55 | 27.3 | 5.64 | 4.80 | 119 | 4.0 | 4.99 | 4.44 |
| **Capitanía apr 97** | 7.23 | 25.9 | 0.11 | 26.30 | -27.0 | 3.0 | 0.56 | 5.32 |
| **Coachapa apr 97** | 6.89 | 26.9 | 0.20 | 17.30 | 385 | 3.0 | 4.55 | 2.25 |
| **El Jícaro apr 97** | 7.21 | 26.1 | 6.48 | 0.10 | 559 | 9.0 | 3.78 | 0.35 |
| **Boca aug 97** | 6.77 | 28.7 | 4.56 | 5.20 | 245 | 11.0 | 3.38 | 1.0 |
| **Astillero aug 97** | 6.96 | 28.5 | 4.80 | 0.70 | 137 | 22.0 | 0.49 | 1.30 |
| **D. adentro aug 97** | 7.26 | 28.8 | 6.28 | 1.80 | 166 | 12.0 | 0.13 | 1.43 |
| **Teapa aug 97** | 6.83 | 28.6 | 4.69 | 0.70 | 144 | 17.0 | 0.93 | 1.45 |
| **Terranova aug 97** | 6.72 | 29.2 | 3.01 | 0.20 | 127 | 44 | 1.72 | 2.59 |
| **Calzadas aug 97** | 6.83 | 28.5 | 4.06 | 7.40 | 139 | 12.0 | 1.17 | 2.05 |
| **Nanachital aug 97** | 6.81 | 28.6 | 3.36 | 0.30 | 153 | 18.0 | 0.93 | 0.95 |
| **S. Francisco aug 97** | 6.61 | 28.8 | 3.46 | 0.10 | 133 | 47.0 | 0.93 | 2.45 |
| **S. Antonio aug 97** | 6.51 | 28.9 | 4.42 | 0.10 | 184 | 20.0 | 2.57 | 1.06 |
| **Totoapa aug 97** | 6.69 | 28.5 | 5.00 | 0.10 | 173 | 21.0 | 4.22 | 1.23 |
| **Uxpanapa aug 97** | 6.87 | 28.1 | 4.97 | 0.10 | 168 | 23.0 | 21.77 | 1.11 |
| **Sta. Alejandrina aug 97** | 6.74 | 28.6 | 4.33 | 0.10 | 158 | 96.0 | 9.52 | 0.95 |
| **Capitanía aug 97** | 6.72 | 28.5 | 4.26 | 0.10 | 107 | 62.0 | 10.33 | 0.99 |
| **Coachapa aug 97** | 6.4 | 28.0 | 3.07 | 0.10 | 148 | 106 | 1.14 | 0.07 |
| **El Jícaro aug 97** | 6.76 | 27.4 | 1.64 | 0.10 | 88.0 | 167 | 0.78 | 0.71 |

T=temperature ($^{O}C$); $O_2$ = dissolved oxygen (mg/l); S= salinity (o/oo); Cu= dissolved Cu (mg/l); Cr= dissolved Cr (mg/l), ND=undetermined

## METHODOLOGY AND LABORATORY WORK

### *Sediments*

Dry sieving of the sediments was carried out for the sand fraction (-1 to 4 $\phi$). Fractions > to 4 $\phi$ (silts and clays) were separated and the pipette method was used (**KRUMBEIN AND PETTIJOHN, 1938**). Grain-size parameters were determined according to **FOLK (1974)**

(Tables 2, 3, 4 and 5). Mode of sediments transport distributions (rolling, saltation and suspension) (**VISHER, 1969**) were determined by reading on probability plots and the results presented in percentages (Tables 2, 3, 4 and 5). This was done by each site during different sampling cycles to correlate between mode of sediment transport and heavy metal concentration. Determination of organic matter was based on the method by **GAUDDETE and FLIGHT (1974)** (Tables 2, 3, 4 and 5).

*Table 2. Grain-size, mode of sediment transport and organic matter content of the Coatzacoalcos River sediments (september 1996)*

| Station | Mz | σ | Roll (%) | Salt (%) | Susp (%) | OM (%) |
|---|---|---|---|---|---|---|
| **Boca** | 6.39 | 3.38 | 1.20 | 64.80 | 34.00 | 1.55 |
| **Astillero** | 5.86 | 1.48 | 0.28 | 34.72 | 65.00 | 1.09 |
| **Terranova** | 5.50 | 1.53 | 0.56 | 45.44 | 54.00 | 1.52 |
| **Gopalapa** | 1.88 | 0.99 | 0.80 | 91.96 | 7.24 | 0.19 |
| **Calzadas** | 5.73 | 1.41 | 1.30 | 46.70 | 52.00 | 1.02 |
| **Nanchital** | 5.36 | 1.77 | 1.00 | 49.00 | 50.00 | 1.36 |
| **San Francisco** | 5.92 | 1.44 | 0.15 | 35.85 | 64.00 | 1.19 |
| **San Antonio** | 5.91 | 1.46 | 4.00 | 30.00 | 66.00 | 1.24 |
| **Uxpanapa** | 5.63 | 1.72 | 0.50 | 65.50 | 34.00 | 1.67 |
| **Totoapa** | 5.86 | 1.48 | 0.20 | 39.80 | 60.00 | 1.26 |
| **Santa Alejandrina** | 6.44 | 1.62 | 0.28 | 23.72 | 76.00 | 1.53 |
| **Capitanía** | 6.29 | 1.60 | 0.14 | 92.86 | 7.00 | 0.44 |
| **Coachapa** | 5.92 | 1.42 | 0.02 | 35.98 | 64.00 | 1.41 |
| **Jícaro** | 5.65 | 1.55 | 0.14 | 39.86 | 60.00 | 1.55 |

Mz= grain-size, σ= sorting; Roll= rolling (%); Salt= saltation (%), Susp= suspension (%); OM= organic matter content (%)

*Table 3. Grain-size, mode of sediment transport and organic matter content of the Coatzacoalcos River sediments (january 1997)*

| Station | Mz | σ | Roll (%) | Salt (%) | Susp (%) | OM (%) |
|---|---|---|---|---|---|---|
| **Boca** | 2.23 | 0.74 | 0.00 | 66.00 | 34.00 | 1.30 |
| **Dársena** | 2.20 | 0.45 | 0.00 | 98.00 | 2.00 | 3.80 |
| **Astillero** | 3.70 | 3.55 | 0.00 | 72.00 | 28.00 | 0.92 |
| **Teapa** | 5.60 | 1.71 | 0.40 | 69.60 | 30.00 | 1.16 |
| **Terranova** | 5.92 | 1.85 | 0.00 | 78.00 | 22.00 | 1.43 |
| **Gopalapa** | 1.56 | 1.38 | 0.00 | 91.00 | 9.00 | 1.65 |
| **Calzadas** | 6.92 | 1.47 | 0.06 | 25.94 | 74.00 | 1.28 |
| **Nanchital** | 4.91 | 2.13 | 0.10 | 49.90 | 50.00 | 0.47 |
| **San Francisco** | 4.87 | 2.19 | 0.28 | 79.72 | 20.00 | 0.97 |
| **San Antonio** | 4.91 | 2.04 | 5.00 | 35.00 | 60.00 | 0.70 |
| **Uxpanapa** | 4.90 | 1.30 | 0.04 | 88.96 | 11.00 | 0.20 |
| **Totoapa** | 6.50 | 1.34 | 0.02 | 39.98 | 60.00 | 1.99 |
| **Santa Alejandrina** | 5.62 | 1.84 | 0.20 | 57.80 | 42.00 | 1.56 |
| **Capitanía** | 6.22 | 1.87 | 0.15 | 45.85 | 54.00 | ND |
| **Coachapa** | 5.27 | 2.08 | 0.08 | 61.92 | 38.00 | 0.57 |
| **Jícaro** | 5.61 | 1.66 | 0.15 | 79.85 | 20.00 | 1.55 |

See Table 2 for symbols, ND= undetermined

*Table 4. Grain-size, mode of sediment transport and organic matter content of the Coatzacoalcos River sediments (april 1997)*

| Station | Mz | σ | Roll (%) | Salt (%) | Susp (%) | OM (%) |
|---|---|---|---|---|---|---|
| **Boca** | 6.34 | 2.64 | 0.30 | 46.70 | 53.00 | 0.16 |
| **Dársena** | 6.73 | 3.38 | 0.40 | 57.60 | 42.00 | 4.52 |
| **Dársena adentro** | 8.79 | 4.30 | 0.80 | 61.20 | 38.00 | 1.19 |
| **Astillero** | 6.95 | 3.47 | 0.40 | 57.60 | 42.00 | 1.72 |
| **Teapa** | 7.15 | 2.43 | 4.37 | 73.63 | 26.37 | 0.92 |
| **Terranova** | 7.55 | 2.94 | 0.28 | 27.72 | 72.00 | 1.72 |
| **Gopalapa** | 5.33 | 2.62 | 0.80 | 61.20 | 38.00 | 1.28 |
| **Calzadas** | 4.16 | 2.25 | 0.00 | 76.63 | 26-37 | 0.50 |
| **Nanchital** | 8.18 | 2.34 | 0.39 | 15.61 | 84.00 | 2.02 |
| **San Francisco** | 5.16 | 2.18 | 0.14 | 69.86 | 30.00 | 0.88 |
| **San Antonio** | 4.82 | 2.97 | 2.50 | 58.50 | 39.00 | 2.44 |
| **Uxpanapa** | 7.28 | 2.57 | 1.00 | 51.00 | 48.00 | 1.57 |
| **Totoapa** | 4.26 | 3.34 | 0.40 | 80.60 | 19.00 | 1.57 |
| **Capitanía** | 5.84 | 3.33 | 0.00 | 40.00 | 60.00 | 1.07 |
| **Coachapa** | 2.52 | 1.20 | 0.04 | 88.96 | 11.00 | 0.33 |
| **Jícaro** | 7.48 | 2.69 | 0.50 | 25.50 | 74.00 | 1.61 |

See Table 2 for symbols

*Table 5. Grain-size, mode of sediment transport and organic matter content of the Cotzacoalcos River sediments (august 1997)*

| Station | Mz | σ | Roll (%) | Salt (%) | Susp (%) | OM (%) |
|---|---|---|---|---|---|---|
| **Boca** | 6.82 | 3.71 | 1.0 | 67.00 | 32.00 | 1.49 |
| **Dársena** | 2.24 | 0.61 | 0.60 | 23.10 | 76.30 | 0.29 |
| **Dársena adentro** | 1.18 | 2.26 | 0.80 | 44.70 | 54.50 | 0.53 |
| **Astillero** | 6.94 | 3.10 | 0.60 | 23.10 | 76.30 | 1.68 |
| **Teapa** | 6.50 | 3.17 | 13.80 | 68.45 | 17.75 | 0.29 |
| **Terranova** | 7.17 | 3.92 | 0.40 | 31.60 | 68.00 | 2.42 |
| **Gopalapa** | 5.96 | 2.52 | 0.80 | 44.70 | 54.50 | 1.59 |
| **Calzadas** | 3.86 | 2.16 | 3.80 | 68.45 | 27.75 | 1.68 |
| **Nanchital** | 8.00 | 3.28 | 0.22 | 13.28 | 86.50 | 2.11 |
| **San Francisco** | 6.09 | 2.91 | 0.15 | 45.85 | 54.00 | 1.25 |
| **San Antonio** | 8.42 | 2.95 | 0.20 | 9.30 | 90.50 | 1.73 |
| **Uxpanapa** | 6.73 | 3.22 | 1.00 | 45.00 | 55.00 | 1.54 |
| **Totoapa** | 6.40 | 3.41 | 0.22 | 42.78 | 57.00 | 1.54 |
| **Santa Alejandrina** | 7.61 | 3.00 | 0.32 | 10.68 | 89.00 | 1.58 |
| **Capitanía** | 7.60 | 2.84 | 0.45 | 11.55 | 88.00 | 1.78 |
| **Coachapa** | 5.01 | 3.65 | 2.63 | 45.22 | 52.15 | 0.67 |
| **Jícaro** | 7.34 | 2.69 | 0.10 | 37.50 | 62.40 | 1.35 |

See Table 2 for symbols

## *Heavy metal concentration in sediments*

Determination of heavy metal concentration (Cu, Cr) in the Coatzacoalcos River sediments was carried out in a microwave oven following the Manual of Microwave Digestion System (**CEM, 1994**) using a Spectr AA-10 plus varian Atomic Absorption Spectrophotometer (Table 6). The sediment was dried at 55ºC and grinded. The total concentration of each element was obtained in a microwave oven extracting the acid residue with 10 ml of bidistilled water, 5 ml of $HCO_3$ and 2 ml of HCl (**BAHENA, 1999**). The residues were centrifuged. A Northern Sea sediment classified as SDN 1/2 and certified by the Marine Radioactive Laboratory, Monaco was used for calibration. The accuracy of the method showed a relative error of 10 % for Cd, 11.57% for Co, 3.87% for Cu and 1.62% for Ni (**BAHENA, 1999**). Heavy metal bioavailability (non-residual trace elements) was also determined by continuous extract of 1 g. of sediment in 10 ml of HCl. The samples were centrifuged and trace elements (Cu, Cr) were detected with a Spectr AA-10 plus varian Atomic Absorption Spectrophotometer (Table 6).

*Table 6. Total average Cu and Cr concentration and bioavailability values in the Coatzacoalcos River sediments*

| Station | Total average Cu and Cr concentration | | Average Cu and Cr bioavailability | | Non-residue heavy metal contribution to the total | |
|---|---|---|---|---|---|---|
| | Cu | Cr | Cu | Cr | Cu | Cr |
| **Boca** | 26.83 | 59.74 | 10.80 | 5.00 | 40.47 | 8.40 |
| **Astillero** | 26.02 | 71.47 | 7.70 | 4.20 | 29.77 | 5.99 |
| **Gopalapa** | 16.55 | 49.04 | 6.30 | 3.70 | 35.76 | 7.60 |
| **Dársena adentro** | 65.26 | 25.50 | 46.40 | 5.00 | 71.19 | 19.75 |
| **Dársena afuera** | 21.39 | 50.25 | 5.00 | 1.90 | 23.38 | 3.95 |
| **Teapa** | 59.35 | 54.05 | 36.60 | 6.60 | 61.70 | 12.25 |
| **Terranova** | 29.51 | 69.99 | 10.50 | 7.00 | 35.74 | 10.07 |
| **Calzadas-Coatzacoalcos** | 16.61 | 51.87 | 5.10 | 4.10 | 30.77 | 7.91 |
| **Nanchital** | 44.61 | 59.07 | 8.60 | 4.40 | 19.31 | 7.50 |
| **San Francisco** | 38.54 | 49.0 | 6.10 | 2.60 | 15.89 | 5.47 |
| **San Antonio** | 45.05 | 65.68 | 9.10 | 3.90 | 20.36 | 5.93 |
| **Totoapa.** | 46.81 | 64.33 | 6.00 | 4.30 | 20.39 | 5.95 |
| **Uxpanapa** | 15.16 | 50.30 | 9.50 | 3.80 | 39.94 | 8.72 |
| **Santa Alejandrina** | 24.97 | 54.52 | 8.90 | 3.40 | 36.0 | 6.27 |
| **Capitanía** | 13.97 | 45.79 | 4.80 | 2.00 | 34.40 | 4.52 |
| **Coachapa** | 6.77 | 25.15 | 3.40 | 2.00 | 43.56 | 8.08 |
| **Jícaro** | 23.21 | 41.31 | 5.50 | 1.70 | 23.69 | 4.19 |
| **Average** | 30.62 | 52.18 | 11.90 | 3.86 | 32.14 | 7.79 |

Cu, Cr values in ppm; non-residue contribution values in %

*Heavy metals in water*

Disolved metals (Cu, Cr) in the water column were determined with a Spectr AA-10 plus varian Atomic Absorption Spectrophotometer following the standard methods (3131B), **APHA**, (1995) (Table 1).

*Heavy metals in benthic fauna*

Samples were prepared with 0.5 of biogenic residues following the Manual of Microwave Digestion System (**CEM**, **1994**). Mn, Cr, Cd, Pb, Co, Cu and Ni were determined using a Spectr AA-10 plus varian Atomic Absorption Spectrophotometer which was previously calibrated with Merk standards.

## RESULTS AND DISCUSSION

The results showed that the Coatzacoalcos River sediments are composed of silts (average Mz=5.65 $\phi$) that are transported mainly by suspension (Tables 2, 3, 4 and 5). Some sampling sites also showed sediments transported by saltation (Tables 2, 3, 4 and 5) especially during the second and third sampling cycles. Saltation takes place during low discharge cycles in dry seasons were the water unables the threshold of finer sediments as suspended loads. Most of the sampled sites were located downstream of the Coatzacoalcos River which concentrates finer sediments than the upstream. Nearby rivers to the Coatzacoalcos (i.e. Papaloapan River) also concentrate fine-grained sediments downstream and in the river mouth (**ALVAREZ-RIVERA *et al*., 1986; ROSALES *et al*., 1986**).

*Heavy metals in sediments*

The Coatzacoalcos River sediments are potentially capable of trapping heavy metals since they are composed mainly by silts (**YASUO, 1993**).

Total average concentration of Cr and Cu in fine sediments of the Coatzacoalcos River was 52.18 μg/g and 30.62 μg/g respectively. The highest average values were reported for the Dársena Adentro, Teapa, Astillero and Nanchitlan locations (Table 6). Both values exceeded those found by **ROSALES-HOZ AND CARRANZA-EDWARDS** (**1998**) in the Coatzacoalcos River of 25.70 μg/g in sands and 39.35 μg/g in silts for Cr and 4.66 μg/g in sands and 25.46 μg/g in silts for Cu. The highest concentration of Cr and Cu in sediments reported in this study is related to industrial sewage discharges close to the Dársena Adentro and Teapa locations (Table 6). The highest Cr concentration value alone was found in the Astillero station where ship maintenance activities are carried out. Also, the Nanchital station showed high concentration values for Cr (59.07 ppm) and Cu (44.61ppm) (Table 6) probably due to the petrochemical activity of PEMEX (Mexican Oil Industry).

The highest average Cr and Cu bioavailability concentration values for the Dársena station were 5 ppm and 46.40 ppm respectively. The Teapa station reported 6.6 ppm and 36.60 ppm for Cr and Cu respectively (Table 6). Both localities are impacted by industrial and urban discharges.

*Multiple correlation*

A multiple correlation at 95% significance level between the sediments, grain-size parameters, modes of sediment transport, organic matter, total Cu and Cr concentrations and Cu and Cr bioavailability values was carried out (Tables 7, 8, 9 and 10).

The first sampling (september 1996) showed a positive correlation between Mz, suspension, total Cu and Cr concentrations and bioavailability and organic matter content (Table 7). This suggests that during the rainy season sediments in the Coatzacoalcos River are transported mainly by suspension and that high Cu and Cr values are related to high percentages of silt and clay fractions and organic matter in the sediments. Antrophogenic influence is controlling the high Cu and Cr values in the sediments. A positive correlation is also shown between the silt and clay fraction, organic matter content and Cu and Cr values (Table 7).

The second sampling (january 1997) showed little correlation with the rest of the parameters (Table 8). Only the clay fraction has a positive correlation with the suspension (Table 8). This implies that during intermittent storms in january, clays might be resuspended into the water column due to heavy discharge inputs.

The third sampling (april 1997) showed that the sand and silt fractions have a positive correlation with saltation and suspension respectively (Table 9). There is also a high correlation between total Cu and Cr in bottom waters and organic matter content (Table 9). This indicates that finer sediments concentrate higher organic matter content (**ORTIZ-ZAMORA AND CARRANZA-EDWARDS, 1997**) which also allows high concentration of heavy metals.

The fourth sampling (september 1997) showed that Mz has a positive correlation with suspension, Cr concentration and organic matter content (Table 10). Also, the silt and clay fractions correlates with suspension, Cr concentration and organic matter content (Table 10). These correlations followed a similar pattern to those showed during the first sampling in september (Tables 7 and 10).

*Table 7. Multiple correlation among sediments, mode of sediment transport, Cu and Cr concentration and bioavailability values and organic matter content (september 1996).*

| | Sand | Silt | Clay | Mz | σ | Roll | Salt | Susp | Total Cu | Total Cr | Cu Bio | Cr Bio | OM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sand** | 1.00 | -0.96 | -0.42 | -0.94 | -0.18 | -0.05 | 0.82 | -0.82 | -0.71 | -0.84 | -0.45 | 0.15 | -0.78 |
| **Silt** | | 1.00 | 0.16 | 0.81 | -0.07 | 0.05 | -0.82 | 0.82 | 0.55 | 0.78 | 0.25 | -0.23 | 0.66 |
| **Clay** | | | 1.00 | 0.69 | 0.90 | 0.02 | -0.24 | 0.24 | 0.76 | 0.46 | 0.81 | 0.23 | 0.64 |
| **Mz** | | | | 1.00 | 0.47 | 0.04 | -0.76 | 0.76 | 0.84 | 0.86 | 0.68 | -0.02 | 0.85 |
| σ | | | | | 1.00 | 0.05 | 0.10 | -0.11 | 0.50 | 0.35 | 0.73 | 0.38 | 0.54 |
| **Roll** | | | | | | 1.00 | -0.11 | 0.05 | 0.11 | 0.02 | 0.37 | 0.38 | -0.05 |
| **Salt** | | | | | | | 1.00 | -1.00 | -0.72 | -0.68 | -0.41 | 0.20 | -0.48 |
| **Susp** | | | | | | | | 1.00 | 0.72 | 0.68 | 0.39 | -0.22 | 0.49 |
| **Total Cu** | | | | | | | | | 1.00 | 0.68 | 0.77 | 0.14 | 0.69 |
| **Total Cr** | | | | | | | | | | 1.00 | 0.65 | 0.03 | 0.69 |
| **Cu Bio** | | | | | | | | | | | 1.00 | 0.59 | 0.59 |
| **Cr Bio** | | | | | | | | | | | | 1.00 | 0.12 |
| **OM** | | | | | | | | | | | | | 1.00 |

See Table 2 for symbols; Bio=bioavailability; 95% confidence level

*Table 8. Multiple correlation among sediments, mode of sediment transport, Cu and Cr concentration and bioavailability values and organic matter content (january 1997).*

| | Sand | Silt | Clay | Mz | σ | Roll | Salt | Susp | Total Cu | Total Cr | Cu Bio | Cr Bio | Cu wat | Cr wat | OM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sand** | 1.00 | -0.95 | -0.62 | 0.33 | -0.34 | 0.08 | 0.35 | -0.45 | 0.16 | 0.12 | 0.13 | -0.15 | 0.23 | 0.53 | 0.40 |
| **Silt** | | 1.00 | 0.37 | -0.27 | 0.14 | -0.10 | -0.21 | 0.31 | -0.15 | -0.22 | -0.11 | 0.19 | -0.27 | -0.63 | -0.37 |
| **Clay** | | | 1.00 | -0.26 | 0.39 | 0.03 | -0.58 | 0.66 | -0.04 | 0.18 | -0.09 | -0.02 | -0.24 | -0.06 | -0.20 |
| **Mz** | | | | 1.00 | -0.35 | -0.08 | -0.12 | 0.17 | -0.06 | -0.06 | 0.07 | 0.01 | 0.47 | 0.23 | -0.07 |
| σ | | | | | 1.00 | 0.13 | -0.20 | 0.13 | 0.44 | -0.16 | -0.40 | -0.24 | 0.13 | 0.4 | -0.55 |
| **Roll** | | | | | | 1.00 | -0.44 | -0.15 | -0.41 | 0.03 | 0.01 | 0.02 | -0.13 | 0.12 | -0.23 |
| **Salt** | | | | | | | 1.00 | -0.82 | 0.16 | -0.20 | 0.15 | 0.20 | -0.03 | 0.24 | -0.48 |
| **Susp** | | | | | | | | 1.00 | 0.15 | 0.20 | -0.14 | -0.22 | 0.10 | -0.36 | 0.20 |
| **Total Cu** | | | | | | | | | 1.00 | 0.20 | 0.14 | 0.03 | -0.03 | 0.17 | -0.08 |
| **Total Cr** | | | | | | | | | | 1.00 | 0.32 | 0.48 | 0.09 | 0.34 | -0.08 |
| **Cu Bio** | | | | | | | | | | | 1.00 | 0.54 | 0.33 | 0.30 | 0.34 |
| **Cr Bio** | | | | | | | | | | | | 1.00 | 0.17 | 0.41 | 0.42 |
| **Cu wat** | | | | | | | | | | | | | 1.00 | 0.38 | -0.11 |
| **Cr wat** | | | | | | | | | | | | | | 1.00 | 0.03 |
| **OM** | | | | | | | | | | | | | | | 1.00 |

See Table 2 for symbols; Bio=bioavailability; wat=bottom water

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*Table 9. Multiple correlation among sediments, mode of sediment transport, Cu and Cr concentration and bioavailability values and organic matter content (april 1997).*

| | Sand | Silt | Clay | Mz | σ | Roll | Salt | Susp | Total Cu | Total Cr | Cu Bio | Cr Bio | Cu wat | Cr wat | OM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sand** | 1.00 | -0.95 | -0.93 | -0.71 | -0.63 | 0.21 | 0.67 | -0.68 | -0.53 | -0.26 | -0.43 | -0.38 | -0.24 | 0.01 | -0.26 |
| **Silt** | | 1.00 | 0.77 | -0.57 | 0.58 | -0.34 | -0.56 | 0.56 | 0.41 | 0.25 | 0.31 | 0.34 | 0.21 | -0.02 | 0.16 |
| **Clay** | | | 1.00 | 0.80 | 0.60 | -0.09 | -0.74 | 0.74 | 0.61 | 0.23 | 0.52 | 0.38 | 0.24 | -0.01 | 0.34 |
| **Mz** | | | | 1.00 | 0.32 | -0.21 | -0.81 | 0.81 | 0.70 | 0.02 | 0.64 | 0.33 | 0.59 | -0.35 | -0.15 |
| **σ** | | | | | 1.00 | -0.27 | -0.33 | 0.33 | 0.62 | 0.08 | 0.60 | -0.05 | -0.20 | 0.26 | 0.34 |
| **Roll** | | | | | | 1.00 | -0.04 | 0.03 | -0.26 | 0.21 | -0.26 | 0.06 | -0.15 | 0.21 | 0.05 |
| **Salt** | | | | | | | 1.00 | -1.00 | -0.40 | -0.16 | -0.32 | -0.44 | -0.24 | 0.28 | -0.12 |
| **Susp** | | | | | | | | 1.00 | 0.40 | 0.17 | 0.33 | 0.44 | 0.25 | -0.29 | 0.11 |
| **TotalCu** | | | | | | | | | 1.00 | -0.16 | 0.98 | 0.12 | 0.18 | -0.13 | 0.15 |
| **TotalCr** | | | | | | | | | | 1.00 | -0.33 | 0.65 | -0.08 | 0.49 | 0.59 |
| **Cu Bio** | | | | | | | | | | | 1.00 | -0.03 | 0.11 | -0.14 | 0.03 |
| **Cr Bio** | | | | | | | | | | | | 1.00 | 0.39 | 0.11 | 0.30 |
| **Cu wat** | | | | | | | | | | | | | 1.00 | -0.68 | -0.38 |
| **Cr wat** | | | | | | | | | | | | | | 1.00 | 0.68 |
| **OM** | | | | | | | | | | | | | | | 1.00 |

See Table 8 for symbols

*Table 10. Multiple correlation among sediments, mode of sediment transport, Cu and Cr concentration and bioavailability values and organic matter content (august 1997).*

| | Sand | Silt | Clay | Mz | σ | Roll | Salt | Susp | Total Cu | Total Cr | Cu Bio | Cr Bio | Cu wat | Cr wat | OM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sand** | 1.00 | -0.96 | -0.95 | -0.93 | -0.67 | 0.36 | 0.86 | -0.87 | -0.35 | -0.49 | -0.19 | 0.10 | -0.15 | 0.25 | -0.70 |
| **Silt** | | 1.00 | 0.87 | 0.92 | 0.65 | -0.35 | -0.80 | 0.80 | 0.41 | 0.57 | 0.23 | -0.15 | 0.16 | -0.14 | 0.69 |
| **Clay** | | | 1.00 | 0.93 | 0.62 | -0.36 | -0.92 | 0.92 | 0.29 | 0.50 | 0.14 | -0.17 | 0.18 | -0.37 | 0.65 |
| **Mz** | | | | 1.00 | 0.65 | -0.20 | -0.90 | 0.88 | 0.37 | 0.65 | 0.19 | -0.24 | 0.25 | -0.17 | 0.77 |
| **σ** | | | | | 1.00 | -0.07 | -0.56 | 0.54 | 0.27 | 0.09 | 0.23 | 0.13 | 0.09 | -0.12 | 0.60 |
| **Roll** | | | | | | 1.00 | 0.32 | -0.44 | -0.32 | -0.18 | -0.23 | -0.14 | 0.37 | 0.11 | 0.09 |
| **Salt** | | | | | | | 1.00 | -0.99 | -0.31 | -0.48 | -0.18 | 0.18 | -0.19 | 0.21 | -0.71 |
| **Susp** | | | | | | | | 1.00 | 0.34 | 0.48 | 0.21 | -0.15 | 0.12 | -0.21 | 0.65 |
| **TotalCu** | | | | | | | | | 1.00 | 0.32 | 0.97 | 0.34 | -0.09 | 0.10 | 0.32 |
| **TotalCr** | | | | | | | | | | 1.00 | 0.13 | -0.26 | 0.21 | 0.20 | 0.56 |
| **Cu Bio** | | | | | | | | | | | 1.00 | 0.45 | -0.14 | 0.07 | 0.22 |
| **Cr Bio** | | | | | | | | | | | | 1.00 | -0.31 | 0.40 | 0.16 |
| **Cu wat** | | | | | | | | | | | | | 1.00 | -0.18 | 0.21 |
| **Cr wat** | | | | | | | | | | | | | | 1.00 | 0.36 |
| **OM** | | | | | | | | | | | | | | | 1.00 |

See Table 8 for symbols

### *Physical parameters and heavy metal concentrations.*

The physical parameters (pH, TºC, $O_2$, S º/oo, Eh, turbidness) measured in the Coatzacoalcos River and metal concentrations (Cu, Cr) are shown in Table 1.

Average extreme pH values were reported for august 1997 (pH=6.76) and january 1997 (pH=8.18). The highest pH value was observed for the Dársena Adentro station in january 1997 (pH=9.27) (Table 1) which exceeded the values reported in Canada for life protection (pH=6.5-9.0) (**CHAPMAN AND KIMSTACH, 1992**).

The water temperature varied from 21.7º C in january to 29.2º C in august. **Guerra** (1990) and **GONZALES, M.** ***et al*****., 1994**) reported temperature values of 21.3º C in february and 31.3º C in august in the river which do not show high discrepancies to the values found in this study (Table 1). However high water temperatures are probably associated to industrial discharges (**MÉNDEZ, 1998**)

Low dissolved $O_2$ values (0-6.48 mg/l) in the water column of the Coatzacoalcos River were determined in april and august (Table 1). The locations with the lowest $O_2$ dissolved values were the Capitanía and Coachapa stations (0.11-0.20 mg/l respectively) (Table 1).

Low dissolved $O_2$ values in the water column are due to little turbulence in the water column, organic matter oxidation and microbial activity (**CHAPMAN AND KIMSTACH, 1992**). In general, the average dissolved $O_2$ values in the water of the Coatzacoalcos River were 3.82 mg/l in april and 4.06 mg/l in august. Similar average values were determined by **MÉNDEZ (1998)** in april 1998 (3.62 mg/l) in the Coatzacoalcos River. This probably indicates little turbulence in the water during the dry season (april) and also high microbial activity due to industrial discharges (**CHAPMAN AND KIMSTACH, 1992; MÉNDEZ, 1998**). A low dissolved $O_2$ value in the water column of the river has also depleted the number of benthic organisms as it will be reported further in this study.

Average salinity values were 0.85 °/oo and 22.02 °/oo in august and april respectively (Table 1). Highest salinity values in the water column are associated to the dry season.

Redox potential (Eh) values showed inconsistencies especially in areas of industrial discharges like Dársena Adentro and Totoapa (Table 1).

The highest average disolved Cr and Cu values in the water were observed during the dry season (april 1997) for the Nanchital (Cr= 4.96 mg/l), Astillero (Cr= 8.98 mg/l), Sn. Antonio (Cr= 5.47 mg/l), Totoapa (Cr= 5.99 mg/l) and Boca (Cu= 6.36 mg/l), Dársena Adentro (Cu= 9.10 mg/l), Nanchital (Cu= 4.36 mg/l), Terranova (Cu= 5.90 mg/l), Teapa (Cu= 4.66 mg/l in january 1997), Astillero (Cu=7.0 mg/l) and Sta. Alejandrina (Cu= 4.99 mg/l and 9.52 mg/l in august 1997) (Table 1). These stations exceeded the Cu and Cr values in water reported in Canada for life protection (4.00 mg/l) (**CHAPMAN AND KIMSTACH, 1992**), and those reported in polluted-free waters (< 0.5 mg/l) (**SADIQ, 1992**) (Table 1). The highest dissolved Cr and Cu values in water were determined in april (dry season) with the exception of one station (Uxpanapa) (Fig. 2) in which a dissolved Cu value of 21.77 mg/l was observed in august 1997 (Table 1). **KONHAUSER *et al.*** (**1997**) reported dissolved Cu values of 2.5 mg/l to 17.9 mg/l in the Mahanadi River and dissolved Cr values of 2.6 mg/l to 18.6 mg/l for the Brahmani River in India. Both rivers are impacted by industrial and urban discharges.

*Benthic fauna*

A systematic count of benthic fauna was carried out for the january 1997 sampling since little recovery of organisms was achieved for the rest of the sampling cycles (Table 11).

*Table 11. Benthic fauna in the Coatzacoalcos River*

| Station | Family | Genera | Number recovered |
|---|---|---|---|
| Dársena | Corbulidae * | *Corbula (Caryocorbula)* | 4 |
| Dársena | Semelidae * | *Abra aequalis* | 1 |
| Dársena | Pilargidae *** | *Parandalia vivianneae* | 37 |
| Astillero | Mytilidae * | *Modiolus americanus* | 7 |
| Astillero | Neritidae ** | *Neritina reclivata* | 88 |
| Astillero | Neritidae ** | *Neritina virginea* | 20 |
| Astillero | Ostreidae * | *Crassostrea virginica* | 15 |
| Astillero | Poliqueto *** | *Nereis sp* | 3 |
| Astillero | Corbiculidae * | *Polymesoda caroliniana* | 7 |
| Astillero | Ostreidae * | *Rangia flexuosa* | 14 |
| Astillero | Corbulidae * | *Corbula spp* | 1 |
| Teapa | Corbulaide * | *Corbula (Caryocorbula)* | 2 |
| Teapa | Cuspidariidae * | *Cuspidaria sp* | 3 |
| Teapa | Neritidae ** | *Neritina reclivata* | 1 |
| Teapa | *** | *Nereis sp* | 1 |
| Teapa | Semelidae * | *Abra aequalis* | 1 |
| Terranova | Parapseudidae **** | *Discapseudes holthuisi* | 7 |
| Terranova | *** | *Nereis sp* | 1 |
| Terranova | | *Crustacean debri* | 1 |
| Gopalapa | Corbulidae * | *Corbula (Caryocorbula)* | 3 |
| Gopalapa | Apseudidae | | 1 |
| Calzadas | Neritidae ** | *Neritina reclivata* | 52 |
| Calzadas | Ostreidae * | *Crassostrea virginica* | 2 |
| Calzadas | Apseudidae | | |
| Nanchital | Neritidae ** | *Neritina reclivata* | 1 |
| Nanchital | Apseudidae | | 4 |
| Nanchital | Pilargidae *** | *Parandalia vivianneae* | 5 |
| San Francisco | Parapseudidae **** | *Discapseudes holthuisi* | 4 |
| San Francisco | Pilargidae *** | *Parandalia vivianae* | 8 |
| San Antonio | Apsudidae | | 1 |
| San Antonio | Neritidae ** | *Neritina reclivata* | 14 |

* bivalve; ** gastropod; *** polychaete; **** crustacea

The low preservation of benthic fauna is due to the intense dredging activity in the last two decades and $O_2$ poor waters that have depleted the benthic communities in the Coatzacoalcos River (**GONZALES *et al.*, 1994**). Therefore only heavy metal concentration was determined in *Rangia cuneata, Rangia flexuosa and Polimesoda carolineana* at Astillero station. These three species concentrated 300.28 µg/g and 93.93 µg/g of Mn respectively (Tables 12 and 13). **BOTELLO *et al*.** (1996) found 148 µg/g and 172 µg/g of Mn values in *Rangia flexuosa* and *Polimesoda carolineana*. The Mn values obtained in this study exceeded in 100% the Mn values obtained by **BOTELLO *et al*. (1996**). The Mn values in *Rangia cuneata* and *Rangia flexuosa* are below the values obtained by the same author. High Mn values can be hazardous for human consumption although no legislation has been issued for Mn in organisms (**VILLANUEVA AND PAEZ-OSUNA, 1996**).

The Pb concentration value in *Rangia cuneata* and *Rangia flexuosa* was 16.38 µg/g and 4.94 µg/g in *Polimesoda carolineana* (Tables 12 and 13). The three species exceeded the values allowed by the Health Department of Australia of 2.5 µg/g for Pb concentration in organisms.

The Co concentration value in *Rangia cuneata* and *Rangia flexuosa* was 10.92 µg/g and 9.89 µg/g in *Polimesoda carolineana* (Tables 12 and 13). **BOTELLO *et al*. (1996)** reported for Co in *Melongena melongena* a concentration value of 13.57 µg/g. Nevertheless, these values are not considered hazardous since similar Co concentration values in organisms have been reported in polluted-free areas (**BOTELLO *et al*, 1996**)

The Ni concentration value in *Rangia cuneata* and *Rangia flexuosa* was 10.92 µg/g and 4.94 µg/g in *Polimesoda carolineana* (Tables 12 and 13). Since Ni is a highly mobile element it is less capable of being accumulated in organisms (**SADIQ, 1992**). In this study Ni values in the organisms can be related to Ni values concentrated in the sediments.

The Cu concentration value in *Rangia cuneata* and *Rangia flexuosa* was 10.92 µg/g and 9.89 µg/g in *Polimesoda carolineana* (Tables 12 and 13). The highest Cu concentration value in organisms allowed by the Health Department of Australia is 150µg/g. The values obtained in this study are within the normal standard range.

The Cr concentration value in *Rangia cuneata* and *Rangia flexuosa* was 10.92 µg/g and 9.89 µg/g in *Polimesoda carolineana* (Tables 12 and 13). Cr concentration value in the water and sediments in the Astillero station were 3.24µg/g and 71.47 µg/g respectively (Tables 1 and 6) Cr concentration values in the water, sediments and organisms exceeded the values allowed by the Urban Services Department Headquarters of Japan of 1.0 µg/g (**NAUEN, 1996**). However some organisms like oysters can tolerate between 100 and 300 µg/g of Cr concentration (**ROSAS *et al.* 1983; VILLANUEVA *et al.*, 1996**).

No Cd values were detected in the benthic fauna of the Coatzacoalcos River (Tables 12 and 13).

*Table 12. Heavy metal concentration in benthic fauna at the Astillero station (january, 1997)*

| Benthic fauna | Mn | Cr | Cd | Pb | Co | Cu | Ni |
|---|---|---|---|---|---|---|---|
| ***Rangia cuneata* and *R. flexuosa*** | 300.28 | 10.92 | ND | 16.38 | 10.92 | 10.92 | 10.92 |
| ***Polimesoda carolineana*** | 93.93 | 9.89 | ND | 4.94 | 9.89 | 9.89 | 4.94 |

ND= undetermined; values in ppm

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*Table 13. Heavy metal concentration in water, sediments and benthic fauna from the Astillero and Jícaro Stations (january 1997).*

| Element | Bottom Water Astillero | Bottom Water Jícaro | Total sediment Astillero | Total sediment Jícaro | *Polimesoda carolineana* | *Rangia cuneata* and *R. flexuosa* |
|---|---|---|---|---|---|---|
| **Mn** | NS | NS | 500 | 200 | 93.93 | 300.28 |
| **Cr** | 3.24 | 0.92 | 57.30 | 19.18 | 9.89 | 10.92 |
| **Cd** | NS | NS | 4.67 | 2.30 | ND | ND |
| **Pb** | NS | NS | 49.83 | 52.98 | 4.94 | 16.38 |
| **Co** | NS | NS | 17.44 | 18.43 | 9.89 | 10.92 |
| **Cu** | 7 | 1.11 | 13.7 | 4.70 | 9.89 | 10.92 |
| **Ni** | NS | NS | 24.90 | 16.45 | 4.95 | 10.92 |

ND= undetermined NS= unsampled; Bottom water=μg/l; Total sediment = mg/Kg *Polimesoda carolineana*= mg/Kg; *Rangia cuneata and R. flexuosa*= mg/Kg

*Rangia* concentrates 1.1 times more Cu than Cr than *Polimesoda* in sediments (Table 14). *Polimesoda carolineana, Rangia cuneata* and *Rangia flexuosa* concentrate 2.2 times more Cr than Cu in water (Table 15). *Rangia* also concentrates 4.2 times more Cu than Cr in sediments (Table 16).

This probably indicates that the three species have an efficient excretory system to tolerate and eliminate the excess of Cu (**BRYAN and HUMMERSTON, 1971; GRANT *et al.*, 1989**)

*Polimesoda carolineana* concentrates 0.91 times more Cr than *Rangia cuneata* and *Rangia flexuosa. Polimesoda carolineana* bioconcentrates 0.24 times more Cr than Cu in the sediments (Tables 14 and 16). This is associated to the total Cr concentration values in the sediments at Astillero station that is proportional to the Cr bioconcentration in organisms (**BRYAN and LANGSTON, 1992**).

In summary only the Astillero station was evaluated for heavy metal concentration in benthic fauna due to the depletion of organisms in the rest of the stations of the Coatzacoalcos River.

*Table 14. Total Cr y Cu concentration and bioavailability values in sediments, water and benthic fauna (january1997*

| | Total Sediment | Bioavailable | Water | *Polimesoda* mg/l | Rangia |
|---|---|---|---|---|---|
| Cu | 13.7 | 5.99 | 7.0 | 9.89 | 10.92 |
| Cr | 57.3 | 3.32 | 3.24 | 9.89 | 10.92 |

Total sediment = mg/l; Bioavailable =mg/l; Water=µg/l; *Polimesoda carolineana*= mg/Kg; *Rangia cuneata y R. flexuosa*= mg/Kg

*Table 15. Ratio of Cu and Cr concentration values in benthic fauna and water*

| | Benthic fauna / water | |
|---|---|---|
| | *Polimesoda* | *Rangia* |
| Cu | 1410 | 1560 |
| Cr | 3050 | 3370 |

*Table 16. Ratio of Cu and Cr concentration values in benthic fauna and sediments*

| | Benthic fauna / sediment | |
|---|---|---|
| | *Polimesoda* | *Rangia* |
| Cu | 0.72 | 0.80 |
| Cr | 0.175 | 0.19 |

*Factor analysis for the impacted stations.*

A varimax rotated factor analysis (FA) was carried out to find the coefficients and proportions of six variables (pH, Tº, $O_2$, turbidness, Cu and Cr) for the highest impacted stations of the Coatzacoalcos River. A previous Kolmogorov-Smirnov normality test for the six variables entered in the FA was carried out (Table 17) due to the fact that multivariate procedures required data which do not departure markedly from the normal distribution (Swan and Sandilands, 1995). For the FA, the Kaiser criterion was used for factor retention (i.e. eigenvalues > 1.00) (**LINDERMAN *et al*., 1980**). The data were arranged in the form of a N x n matrix in which N= number of stations (N= 12) and n= number of variables (n= 6). The results showed that pH, Tº, $O_2$ and turbidness were the highest variable loads in the first component (Table 18). The first component accounted for the 57.84 % of the total variance. The second component, account for the 27.81 % of the total variance, with Cu and Cr as highest variable loads (Table 18).

The Kolmogorov-Smirnov test for normality shows that the null hypothesis of normality is accepted at the $\rho$=0.05 level of significance (Table 17). This implies that the variables entered in the FA followed a normal distribution.

Furthermore, the FA suggests that the highest impacted stations of the Coatzacoalcos River are influenced by the lack of turbidness and depletion of $O_2$ with high temperatures related to industrial discharges (**MÉNDEZ, 1998**). Also, a high Cu and Cr concentrations seems to play a role in the impact that the river shows when water and sediments are analyzed. Hence, the FA supports the previous analyzed data results which suggest that little turbidness, depletion of $O_2$, high temperatures and high Cu and Cr concentration in water and sediments are parameters which are contributing to the environmental impact of the Coatzacoalcos River.

*Table 17. Kolmogorov-Smirnov test summary*

| Variables | N | D | D´ | mean | variance | ρ |
|---|---|---|---|---|---|---|
| **pH** | 12 | 0.13 | 0.37 | 7.9 | 0.28 | 0.05 |
| **Tº** | 12 | 0.12 | 0.37 | 24.8 | 4.43 | 0.05 |
| **$O_2$** | 12 | 0.18 | 0.37 | 2.6 | 6.04 | 0.05 |
| **Turbidness** | 12 | 0.15 | 0.37 | 7.8 | 45.65 | 0.05 |
| **Cu** | 12 | 0.26 | 0.37 | 5.4 | 32.65 | 0.05 |
| **Cr** | 12 | 0.09 | 0.37 | 4.4 | 5.43 | 0.05 |

N= number of observations; D= Kolmogorov-Smirnov computed value; D´= Kolmogorov-Smirnov critical value; ρ= level of significance

*Table 18. Factor analysis summary*

| Variables | Factor 1 | Factor 2 |
|---|---|---|
| **pH** | -0.87 | 0.28 |
| **Tº** | 0.96 | -0.06 |
| **$O_2$** | 0.87 | 0.21 |
| **Turbidness** | 0.84 | -0.35 |
| **Cu** | 0.25 | -0.87 |
| **Cr** | 0.05 | -0.94 |
| **Total variance** | 57. 89 % | 27.81 % |
| **eigenvalues** | 3.47 | 1.90 |

## CONCLUSIONS

1. - The first and fourth samplings showed that most of the sediments in the Coatzacoalcos River are transported by suspension during the rainy season. In contrast saltation is the main mode of sediment transport during the dry season (second and third sampling).

2.- The stations with higher environmental impact due to industrial and urban discharges in the river were Teapa, Darsena Adentro, Astillero, San Antonio, Terranova, Sta. Alejandrina, Uxpanapa, Boca and Nanchital. Higher Cu and Cr concentration values in sediments and water were observed in these stations. The Astillero station was the only site with efficient recovery of benthic fauna with high heavy mineral concentration. Depletion of organisms is due to the intensive dredging activity in the past decades and low $O_2$ values in the water column of the majority of the stations in the Coatzacoalcos River.

3. - Organisms like *Rangia* concentrate 1.1 times more Cu than Cr than *Polimesoda* in sediments. *Polimesoda carolineana, Rangia cuneata* and *Rangia flexuosa* concentrate 2.2 times more Cr than Cu in water. *Rangia* also concentrates 4.2 times more Cu than Cr in sediments. This probably indicates that the three species have an efficient excretory system to tolerate and eliminate the excess of Cu.

4. - Organisms like *Polimesoda carolineana* concentrate 0.91 times more Cr than *Rangia cuneata* and *Rangia flexuosa. Polimesoda carolineana* bioconcentrates 0.24 times more Cr than Cu in the sediments. This is associated to the total Cr concentration values in the sediments at Astillero station that is proportional to the Cr bioconcentration in organisms.

5. - A varimax rotated factor analysis suggests that the highest impacted stations of the Coatzacoalcos River are influenced by the lack of turbidness and depletion of $O_2$ with high temperatures related to industrial discharges and high Cu and Cr values in sediments and water.

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