EFFECTS OF ORGANIC MATERIAL AND DISTRIBUTION OF FECAL COLIFORMS IN CHETUMAL BAY, QUINTANA ROO, MÉXICO

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Abstract. Most wastewater from the city of Chetumal is discharged into the adjoining bay without treatment through a pluvial sewer system. The bay also receives a high volume of vegetal organic material from the River Río Hondo. The average of biochemical oxygen demand (BOD) was 32.26 mg l^{-1}, it was low compared with other reports and should be indicative of self-depuration processes in Chetumal Bay. In the area most used by the public for recreational and fishing activities, concentrations of fecal coliforms above the limit established by Mexican Legislation were shown. The border between Mexico and Belize is Chetumal Bay, which recently was declared a protected area for manatees.

Keywords: organic material, fecal colifrms, BOD, wastewater

1. Introduction

Wastewater is considered as an important source of contamination in coastal areas. These areas are specially significant because two-thirds of the world's population and 60% of the big cities are located along the coast (Kocasoy, 1989). When the volume of organic wastes is increased, the capacities of treatment diminish until the oxygen is exhausted. The combination of the chemical and biological processes in which the aquatic environment mineralizes the organic load is called self-depuration (Leynaud, 1979; Bébin, 1988).

The city of Chetumal is located on the west coast of the bay, near the mouth of the River Río Hondo. The urban zone encompasses almost 10 km of littoral, and most wastewater from the oldest section of the city is channeled into the bay through a pluvial sewer system without previous treatment. The rest is deposited in deficient septic pits and the wastewaters are introduced into the aquifer by seepage. The most contaminated area is also the most popular for recreational and fishing activities. We calculated that approximately 200 m^3 of organic waste per day are discharged into the bay.

Some water quality studies have been done in Chetumal Bay to determine the degree of contamination with emphasis on bacterial contamination (Hernández, 1988; Cano and Flores, 1990; Flores and Cano, 1990; Chavira et al., 1992).

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1.1. Objective

In Chetumal Bay, this is the first study to show the real levels of organic material concentrations and bacterial contamination from pluvial sewer system and their levels up to 100 m from the shore line. It should be used as a quide for the responsible agencies to determine the areas of highest contamination and create rules or regulation for the disposition of wastewaters and population activities in the bay.

2. Study Area

Chetumal Bay (17°53′–18 °52′ N and 87°51′–88°23′ W) is located in the state of Quintana Roo, in the Yucatan Peninsula. The bay is formed in an 'S' shape, 67 km long, with a width of 12 km in the middle and a total area of 1100 km^2 (Delgado and Chavira, 1984; Flores and Cano, 1990). The communication to the sea is located in the southeast section of the bay. It is approximately 19 km wide and surrounded by keys and stand banks. The River Río Hondo, which runs along a geological fault (Escobar, 1992), starts in the Peten region of Guatemala. The River runs along the Mexican–Belizean border and finally flows into Chetumal Bay (Figure 1), with an approximate flow of 70–80 $m^3\ s^{-1}$ (R. Balmes, personal comm., National Commission of Water, Mexico).

Due to the influence of the River, the wetlands that surround it, and the influx of fresh water from the mainland by seepage, the bay presents estuarine characteristics. With an average salinity of 13‰ it is considered an hyposaline system (Gasca et al., 1994) with low productivity (Gasca and Castellanos, 1993). Due to its shallow depth (3.28 m average), water movement is determined mainly by the predominant trade winds. They are from the east and southeast most of the year with an average speed of 3 m s^{-1}, except for the intense northerly winds in winter; therefore the renovation and circulation of the waters are considered slow (Chavira et al., 1992). The climate is tropical with seasonal rains between March and August and an annual precipitation of 1249 mm on average. The mean annual temperature is 27 °C with a maximum of 32 °C and a minimum of 14 °C.

3. Materials and Methods

Samples were taken monthly from July 1993 to June 1994 (collection was done between 8:00 a.m. and 12:00 p.m.). Nine stations distributed along the length of the urban zone were chosen (Figure 1).

Water samples were collected from discharges and transects at 1, 50 and 100 m from the shoreline at stations 1, 2, 4, 5, 6, 7, and 8. In the stations 3 and 9, only the transect points were sampled, because in these stations there were no discharges. The sediments were sampled along nine transect lines perpendicular to the shore,

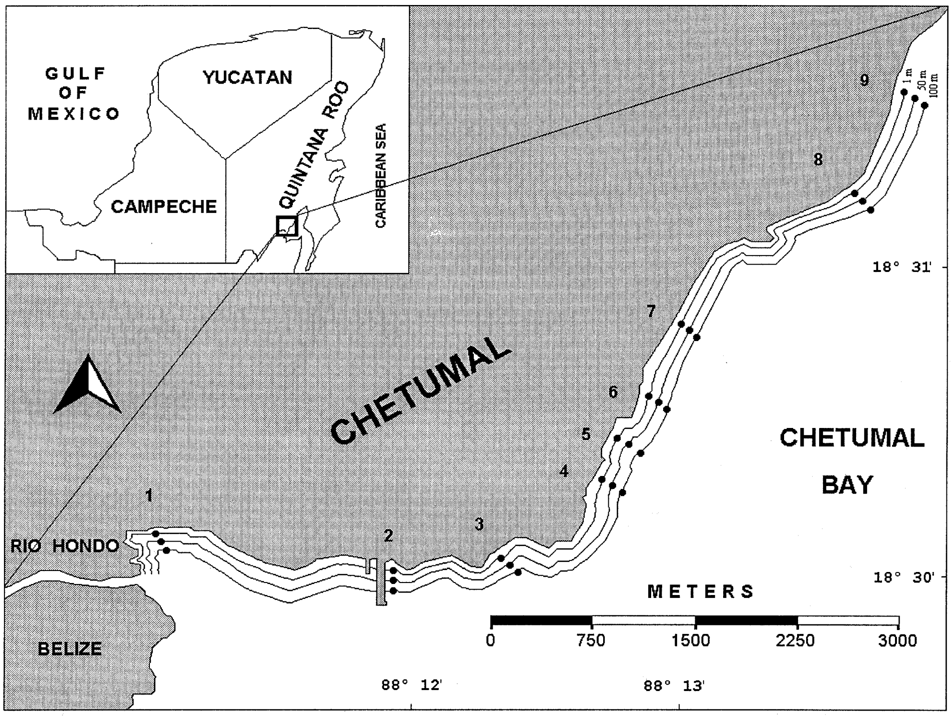

Figure 1. Study area and sampling stations with their transects.

at 50 m intervals, from 1 to 100 m in front of each discharge. The water samples in transects were collected at the surface with a Van Dorn bottle and the sediments with a Ekman dredge. The water samples were held on ice until analysis in the laboratory about 2 h after collection; the sediments were freeze-dried.

The volume of organic waste per day discharged from pluvial sewer system into the bay was determinated by measuring the flow per minute from several discharges.

The temperature, pH, total dissolved solids (TDS), and conductivity was determined *in situ* using a Corning Check-mate type 90. The dissolved oxygen (DO) was also measured *in situ* with an oxymeter/YSI type 58 and by the standard Winkler procedure (Strickland and Parsons, 1972). The salinity was obtained from conductivity conversion, the chemical oxygen demand (COD) by the dichromate reflux method and the biochemical oxygen demand (BOD) with the 5 d incubation method (APHA-AWWA-WPCF, 1990). The content of organic carbon in sediments was determined using the chromic acid oxidation technique (Buchannan, 1984; Páez-Osuna et al., 1984). Fecal coliforms (FC) were counted by the membrane filtration technique (0.45 μm pore size) with culture media M-FC broth (APHA-AWWA-WPCF, 1990). All methods are based on the Official Norm Mexican.

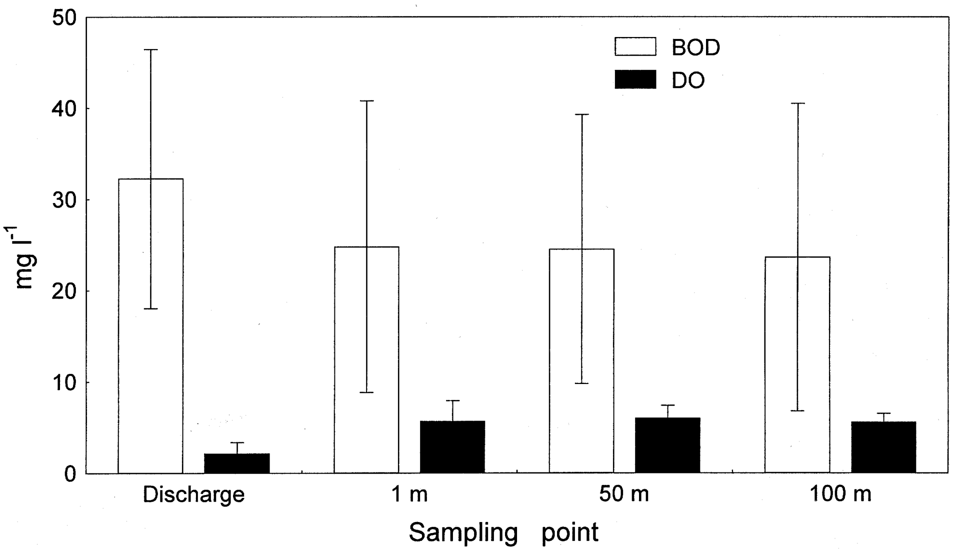

Figure 2. Mean concentrations of BOD and DO in discharges and transects. The bars indicate ± 1 deviation standard.

Statistical analysis were performed using three-way analysis of variance (ANOVA), using distance, station, and month as factors; and Tukey comparison multiple test ($p < 0.05$). These methods are considered to be robust (Sokal and Rohlf, 1980; Zar, 1984; Potvin and Roff, 1993), and although were not carried out by replicates, the sampling size was considered large. Also, simple linear regression was applied ($p < 0.05$), where appropriate, in order to determine the relationship between some parameters. In some cases, it was not possible to take samples, so the relationship between BOD and pH, for example, was carried out only in the coincident months.

4. Results and Discussion

The wastewater discharged in Chetumal Bay registered a BOD mean of 32.26 mg l^{-1} and ranged from 22.61–38.96 mg l^{-1}; the discharge points did not present significant differences ($p = 0.3882$). The DO concentrations in the transects showed that the organic load did not reach a level to flatten the oxygen levels.

The usual BOD values for domestic wastewaters ranged between 100 and 500 mg l^{-1} (SARH, 1986; Bébin, 1988). Mexican Legislation has not determined the maximum values permissible for urban wastewater. The BOD values founded in this study were within the maximum range permissible (30–45 mg l^{-1}) for legislation of California and Oregon, U.S.A. (Sañudo and Suárez, 1982; P. DeVito, personal comm., Oregon Department of Environmental Quality).

At the mouth of the discharges, the DO mean was 2.63 mg l^{-1}, with a range from 0.47–3.73 mg l^{-1}. In discharges, the ANOVA indicated that the DO was

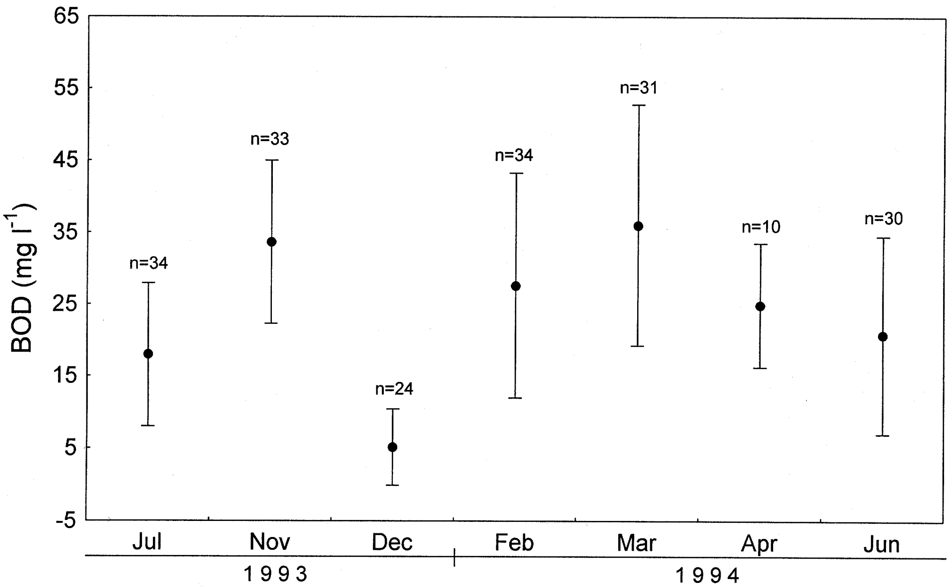

Figure 3. Temporal variation of BOD values. The bars indicate ± 1 deviation standard.

significantly lower (p <0.0001) compared with the concentrations obtained at 1, 50, and 100 m which ranged from 5.92–6.37 mg l^{-1} (Figure 2). The low oxygen values in the discharges could be by lack of residual water aeration due to slight contact the atmosphere and/or the consumption required by the bacterial activity in the degradation of the organic material. In fact, Ortiz and Sáenz (1997) founded high concentrations of nutrients like NO_3, NO_2, and PO_4^{-3} in discharges. They considered that the presence of detergents was the principal source of orthophosphates in Chetumal Bay.

Chetumal Bay is a system with low energy, which infers a slow renewal of water, although probably the residence time is variable in its different zones. The BOD range at 1, 50 and 100 m was from 11.89–35.24 mg l^{-1}. The concentrations were not significantly different (p = 0.5969) because the conditions in the system permitted that the organic material was diluted (Figure 2).

During the sampling period, BOD variations were significantly lower in December (p <0.0001) (Figure 3). In this month, an inverse relationship between BOD and pH (Figure 4a) and temperature and pH was registered (Figure 4b). This could be attributed to a decrease in temperature which diminishes bacterial metabolism and development as well as the oxidation rate, therefore pH increases (Parsons et al., 1979; Sañudo and Suárez, 1984).

COD values from the discharges were significantly lower (p <0.0001) compared to those at 1, 50, and 100 m, which indicated that the contribution of chemically oxidable material from discharges was low. The COD values increased with the distance and BOD values diminished, therefore at the discharges a BOD–COD

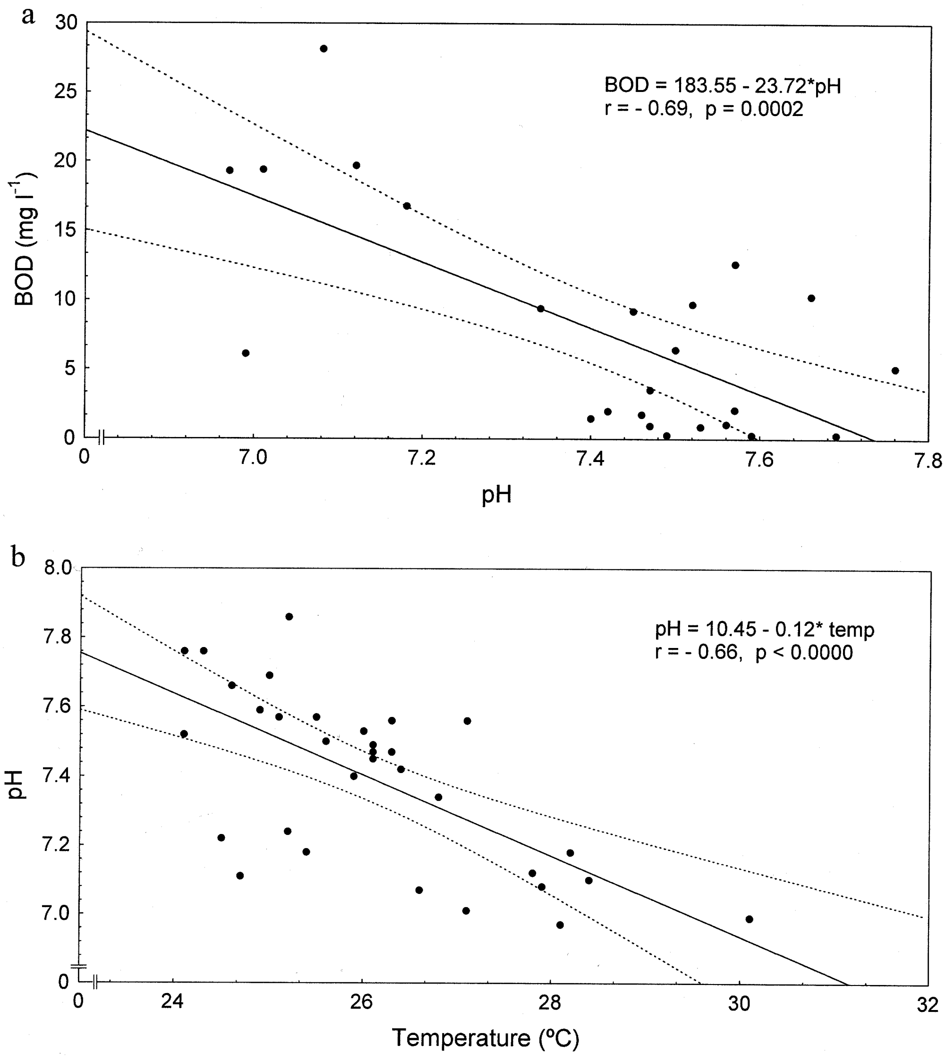

Figure 4. Relationships between (a) BOD vs. pH and (b) pH vs. temperature in December. The broken lines indicate 95% confidence limits.

ratio of 1 : 1.6 was obtained while in the transects the BOD–COD ratio was 1 : 6.8 (Figure 5).

The presence of limestone and other carbonates (Lesser, 1978), apart from the presence of nitrites in the environment, create a COD inorganic, which interfere with the test; these conditions increased the inorganic COD values in the transects. A significant correlation (p <0.05) between COD and TDS was observed at 1, 50 and 100 m (r = 0.67, r = 0.45, and r = 0.65 respectively), but not at the discharges. According to the New York State Department of Health (1986), 60% of TDS val-

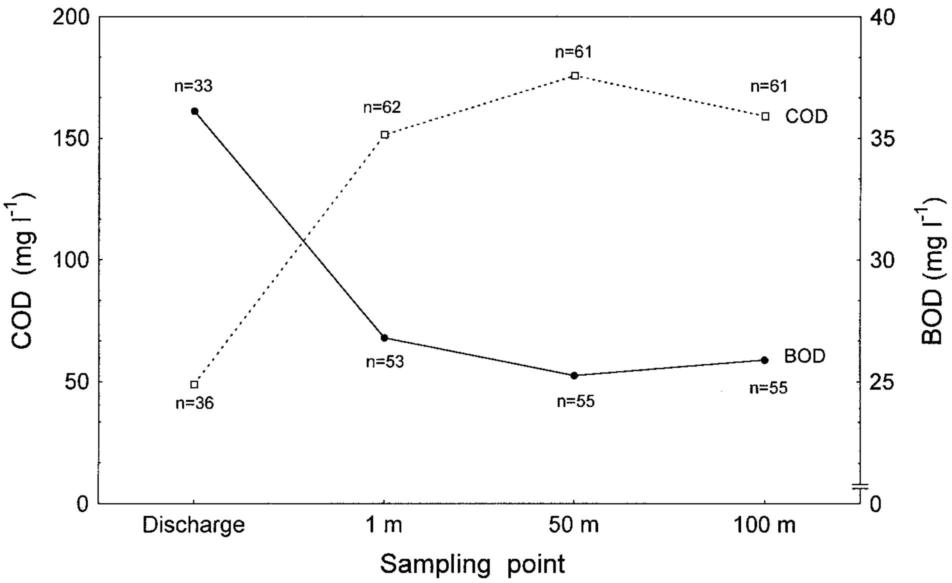

Figure 5. Relation between COD and BOD values by distances.

ues correspond to dissolved inorganic solids; this leads us to conclude that in the transects the measures are mainly of inorganic type.

Organic carbon in the sediments decreased with increasing distance from the mouth of the River Río Hondo, because there are important contributions of refractable materials into Chetumal Bay. This tendency is shown in the Figure 6a where all values were lumped; this is opposed to the relation of COD and TDS values (Figures 6b, and c) because, as mentioned, these measures are essentially of inorganic type. Also, there is an inverse relation between the organic material in sediments and DO values (Figure 6d), which increases toward the North while the organic material diminishes.

In the zone closest to the river a significant part of organic carbon is probably trapped in sediments and could provide electron donors for mineralization processes in the environment. This indicates that the amount of vailable organic material in sediments is crucial in controlling the status of dissolved oxygen in the water column (de la Lanza and Arenas, 1986; He et al., 1989; Rysgaard et al., 1994). In fact, we found that the stations farthest from the River Río Hondo presented values of DO significantly higher (p <0.0001) than those closer to the river.

4.1. BACTERIOLOGY

Total and fecal coliforms (FC) have correlated well with the presence of fecal contamination because *Escherochia coli* is associated exclusively to the mammal intestinal tract (Babinchak, et al., 1977; Rees, 1993). In this study 258 samples of

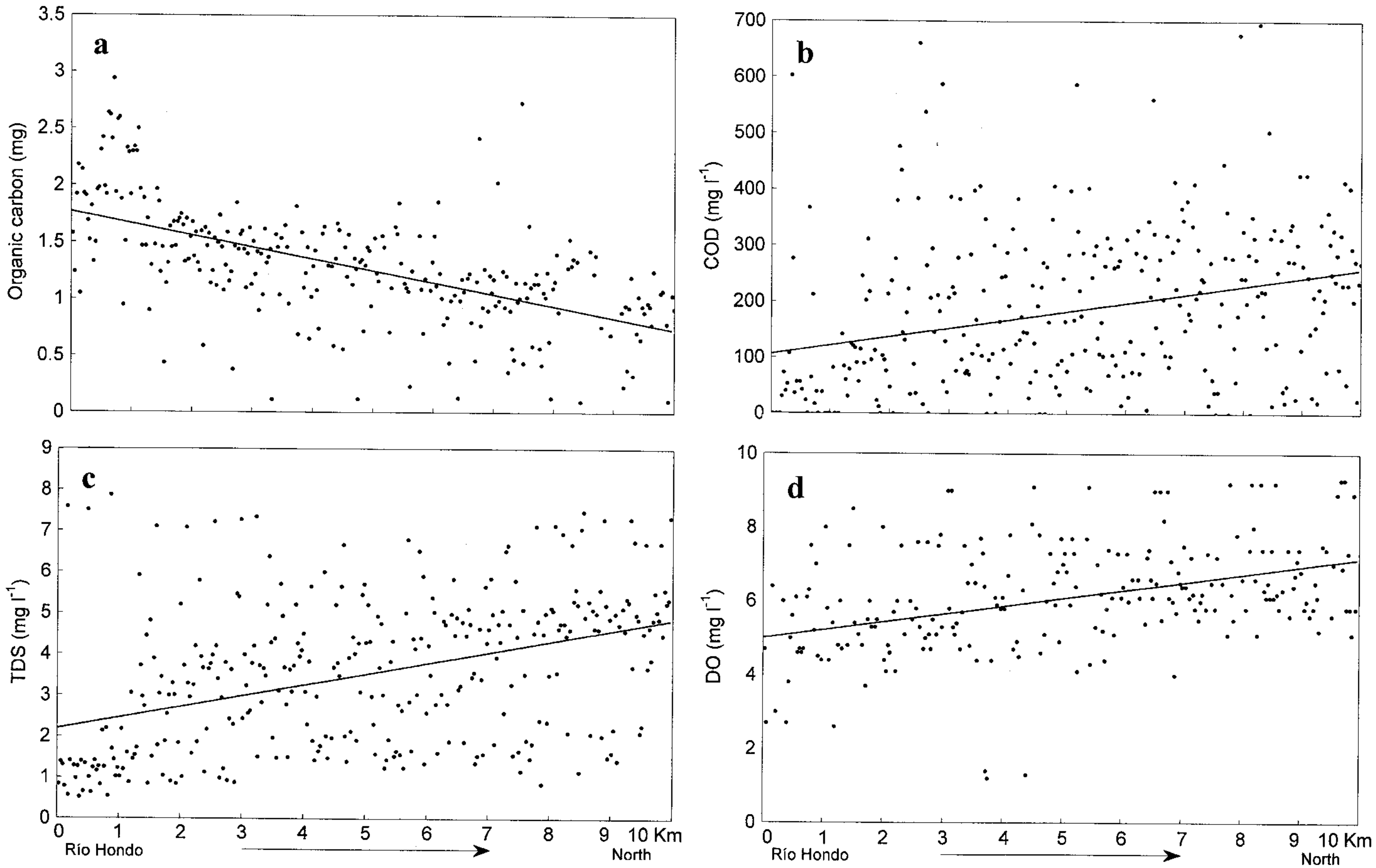

Figure 6. Influence of the river Río Hondo on: (a) Organic carbon in sediments; (b) COD in water column; (c) TDS in water column; (d) DO in water column.

TABLE I

Distribution of fecal coliform densities per 100 ml of water by distances in Chetumal Bay

Ranges of	Number of samples				
FC/100 ml	Discharge	1 m	50 m	100 m	Total
0–99	17	38	50	48	153
100–200	4	7	5	4	20
201–1000	8	9	6	11	34
1001–10000	11	4	8	5	28
10001–20000	4	6	0	2	12
>20000	7	4	0	0	11
Total	51	68	69	70	258

FC were analyzed, of which 33% were above the values established by Mexican Legislation (200 Most Probable Number (MPN)/100 ml) for swimming and recreational purposes (Diario Oficial de la Federación, 1989). Eleven samples registered values of $>2\times10^4$ org/100 ml at the discharge and 1 m (Table I). The highest average FC was recorded at the discharge and 1 m sampling point at stations 2, 4, 7 and 8. In Figure 7, a monthly average of FC concentration is shown; there was an evident decrease of FC at 50 and 100 m, except for a peak in October (2.4×10^3 org/100 ml) at the 100 m sampling point.

Chavira et al. (1992) found the highest total coliform densities at a station located 200 m from the urban zone in Chetumal Bay, and at the mouth of the River Río Hondo (>240 (MPN)/100 ml), but they did not find fecal coliforms. However, Hernández (1988) recorded maximum densities of 22×10^3 (MPN)/100 ml 200 m off the coast in front of the city of Chetumal, *E. coli* being the most abundant.

The environmental conditions that affect the coliforms presence are solar radiation, turbidity, temperature, and the salinity. Rains can cause runoff of pollutants, increase turbidity and decrease the salinity (Kocasoy, 1989). In this study, precipitation produced an increased in FC at sampling points located 1 m from shoreline (Figure 7). The sampling points located 50 and 100 m from shoreline FC's density has decreased; this decrease could be due to dispersion by tide and winds; however, the variations of temperatures and salinity did not affect their densities. Cano and Flores (1990) found, at three points close to the coast line of the city of Chetumal, that the salinity was not a determinant in the densities of FC, although they were influenced by tides and solar radiation.

The use of fecal streptococci as a contamination indicator for human fecal presence may be the best enteric indicator for assessing the quality of water; these organisms are more resistant to environmental stress than FC and also could in-

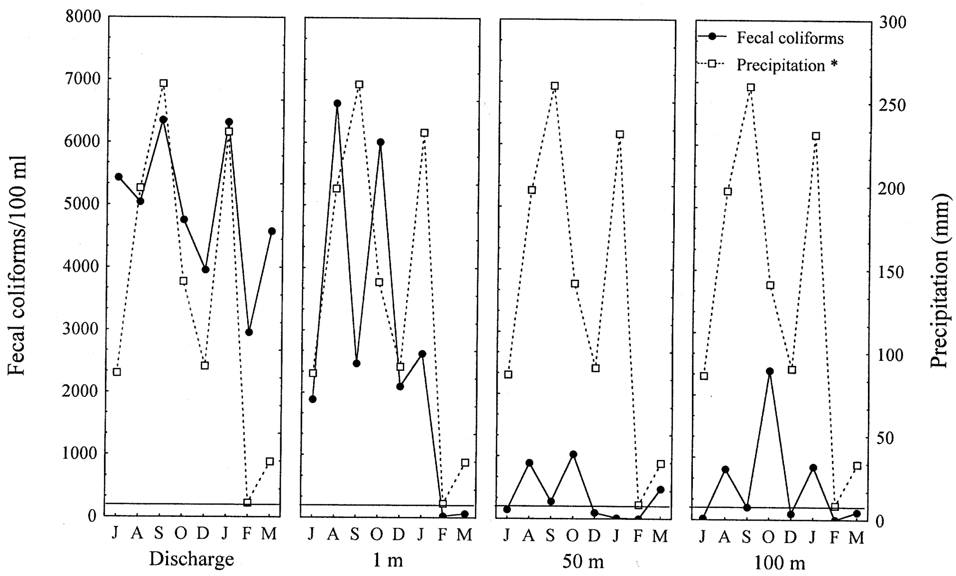

Figure 7. Average sampling stations of fecal coliform densities and precipitation, (1993–1994) by month. The inferior line indicates maximum values (200 org/100 ml) established by Mexican Legislation. *Source:* National Commission of Water, Mexico.

dicate the presence of virus (Rees, 1993). On the other hand, de Vicente et al. (1991) established that the presence of *Pseudomona aeruginosa* is closely related to high levels of FC. The inclusion of fecal streptococci and total fungi testing with total and fecal coliform sampling could provide better studies of water quality (Papapetropoulou and Rodopoulou, 1994).

5. Conclusions

Our results suggest that the most important source of water pollution was attributable to wastewater discharges; however, the environmental conditions allowed dilution and dispersion of organic material from discharges and the river. The organic carbon in sediments, COD, TDS and DO concentrations were influenced by the River Río Hondo.

The densities of FC were highest in discharge samples and decreased with increasing distance from the discharge. The most contaminated area is used by the public for swimming and recreational activities; this may eventually result in a public health problem. Currently Mexican Legislation has not considered other water quality tests which can detect microorganisms that can produce skin, ear, nose and throat infections. Counts of fecal streptococci are an alternative for FC counts and are being considered in other parts of the world (Cabelli et al., 1984), e.g. in Oregon State the bacterial standard recently changes from FC to a limit on enterococci (P. DeVito, personal comm., Oregon Department of Environmental Quality, U.S.A.).

Because this study did not involve economic and political considerations, no recommendations were made for decision makers; however, we did provide scientific information that must be used in order to detect any increase in contaminant concentrations by anthropegenic inputs and, therefore, appropriate actions could be taken.

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