# Water pollution in the Rio Conchos of northern Mexico

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## Abstract

The Rio Conchos originates in the Sierra Madre Occidental in northern Mexico. Its flow is the largest contributor to the Rio Bravo, which serves as part of the border between Mexico and the United States. Therefore, water quality and quantity have implications on both sides of the United States and Mexico border. The objective was to determine the water quality of the Rio Conchos. Six sampling sites were selected along 560 km of the river. Physical-chemical characteristics as well as heavy metals (As, Cd, Cu, Cr, Fe, Mn, Hg, Pb and Zn) were determined. In addition, microbiological and epidemiological tests were performed. Discharge was estimated and ranged from 0.0931 $m^{-3}sec^{-1}$ in the Rio Chuviscar to 2.8348 $m^{-3}sec^{-1}$ in Valle de Zaragoza. Water samples at Ojinaga, in the Rio Florido and in the Rio Parral exceeded the Maximum Permissible Levels with respect to turbidity. Total Dissolved Solids were highest in the Ojinaga and Rio Florido samples, exceeding the maximum permissible limit. The pH varied from 7.71 in Ojinaga to 9.47 in Rio Florido. The most contaminated point was Ojinaga. *Helminto, Cryptosporidium, and Giardia* eggs were not detected in any sample, but total coliform and fecal coliform were present in all samples.
*Keywords: water quality, physical characteristics, chemical characteristics, heavy metals, discharge.*

## 1 Introduction

The concern for water resources in terms of quantity and quality has increased in the last decade worldwide. The Mexican Republic has not escaped this problem, but has aggravated it, especially in arid and semiarid environments. The state of

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Chihuahua, the largest in Mexico, is located north with about 24 million hectares. The most important watershed is associated with the Rio Conchos, which is the most important river and about 560 km long. It is estimated that this river's water supports, direct and indirectly, the needs of more than a million inhabitants along with livestock and wildlife throughout the watershed. In addition, the Rio Conchos is the major tributary of the Rio Bravo/Rio Grande, which serves as the natural boundary between two nations: The United States of America (USA) and Mexico.

The state of Chihuahua has grown in terms of industry, agriculture, and forestry as well as very dynamic human settlement. These factors may provoke different levels of water contamination by the discharge of industrial water, raw sewage, irrigation drainages, and other sources of pollution. This problem might be enlarged because the water resource does not present a deterministic tendency due to low and erratic precipitation, recurrent drought episodes of different magnitudes, high evaporation as well as transpiration rates, and the abuse of natural resources.

The contaminating products may be classified in eight different categories [1] that potentially may cause human health problems to the producers [2]. To date 70 heavy metals are recognized and some of them are related to cancer problems [3, 4] or different sort of diseases like the "Itai Itai" syndrome that was first diagnosed in Japan and that was associated to cadmium contamination [5]. Other heavy metals of concern are mercury that is acknowledged as one of the most toxic [6,7,8] and lead [9] that can be transferred to the placenta of pregnant women [10].

The results presented in this paper offer an overall assessment of the degree of contamination of the Río Conchos, and may be seen as a diagnosis of this area. This information is necessary for acquiring knowledge for authorities at the federal, state and municipal levels of government in Mexico for establishing preventive and reclaimed actions.

## 2 Materials and methods

Water flow of the Rio Conchos originates in the municipality of Bocoyna about 2,700 meters above sea level (masl). The headwater have plant communities dominated by pine (*Pinus durangensis; Pinus herrerae, and Pinus engelmannii*) with a mean precipitation of 750 mm. Stream flows descend to the great plains about 1,000-1500 masl represented by short grass communities and brush land growing in an environment with 235 mm mean precipitation. The Rio Conchos water joins the Rio Bravo/RioGrande water at 720 masl in a very arid zone where mean precipitation is 150 mm. The most important tributaries are The Rio Florido and the Rio Parral in the south region whose flows are stored in the Boquilla Dam (2,903 million $m^3$ capacity); the tributaries San Pedro and the Rio Conchos in central part of the state whose main flows are stored in Las Virgenes Dam (348 million $m^3$ capacity) and the Río Chuviscar whose water is stored in El Granero Dam (356 million $m^3$ capacity) which is located downstream from

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the Boquilla Dam and the Virgenes Dam, before joining the Rio Bravo/Rio Grande.

Six points along the Rio Conchos were selected for analysis in December 2002. Point 1 was located in the Rio Chuviscar (latitude 28° 49' 23.7"; longitude 105° 54' 57.0"; 1,279 masl) about 15 km below the city of Chihuahua, which has a population of 750,000. Point 2 was located in the Rio San Pedro (latitude 27° 57' 13.2"; longitude 106° 06' 35.9"; 1,375 masl) approximately 5 km below the municipality called Satevo. Sampling point 3 was in the Rio Conchos near the municipality called Valle de Zaragoza (latitude 27° 28' 15.5"; longitude 105° 42' 25.4"; 1,329 masl). Point 4 was located in the Rio Parral (latitude 27° 40' 03.4"; longitude 105° 12' 33.8"; 1,228 masl) about 30 km below the city of Parral, which has a population of about 100,000 inhabitants and mining operations. Point 5 was located in the Rio Florido (latitude 27° 40' 36.6"; longitude 105° 08' 37.4"; 1,225 masl). Point 6 was located near the city of Ojinaga (latitude 29° 34' 02.1"; longitude 104° 26' 46.1"; 786 masl) about 3 km above the junction with the Rio Bravo/Rio Grande. These sites will be referred as sites 1,2,3,4,5 and 6 as they were mentioned.

Water samples were collected from surface water, conserved in sterilized bags, preserved in a cool place (about 4° C) and transported to the laboratory for analysis according to international standards [11]. Arsenic (As), cadmium (Ca), copper (Cu), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), mercury (Hg), lead (Pb), sodium (Na), and zinc (Zn) were analyzed with an atomic adsorption spectrophotometer. Hexavalent Cr, detergents, and phenols were estimated by colorimetric analysis. Total alkalinity, bicarbonates, and carbonates were determined by titration techniques. Chlorides were determined by argentometric procedures. Color was determined with a platinum-cobalt scale. Conductivity was determined with a conductivity device. Biological Oxygen Demand was measured using incubation techniques for a five day period. Calcium hardness (as CaCO3) and magnesium hardness (as CaCO3) were estimated by hand calculation. Phosphates were determined with ascorbic acid, while nitrate and nitrites were measured with spectrophotometer techniques. Ammonium-N, organic-N, and total-N were determined by micro kjeldahl procedures. Sulfates and turbidity were determined by a turbidimetric method. Total Dissolved Solids were determined by a gravimetric method. The pH was measured with a potentiometer. Total coliforms as well as fecal coliform were counted with the most probable number, while *Helminto* eggs (*Cryptosporidium* and *Giardia*) were counted with the microscopic-concentration technique.

Stream flow (Q) was estimated by measuring stream velocity (V) and cross-sectional area (A) of the river channel using the following formula:

$$Q[m^{-3}\ seg^{-1}] = V[m\ seg^{-1}] \times A[m^2]$$

Velocity was determined with a hydrometric device. Total water flow (Q) was calculated by adding the partial flows of each segment. Water temperature, air temperature, and river width were determined *in situ* for each sampling point.

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Values from water analysis were compared with those presented in the Mexican Official Norm (NOM–001-ECOL-1996) that establishes the Maximum Limiting Values of contaminants in the discharge of residual waters in national waters. In some cases the results, as an indicator, were compared with the Mexican Official Norm (NOM-127-SSAI-1994) that establishes water for human uses and consumption.

## 3 Results and discussion

Table 1 shows the values for stream flow, water temperature, air temperature, river width and total dissolved solids (TDS). Maximum stream flow was observed at site 3 while minimum flow was noted at site 1. It can be noted that water temperature ranged from 19°C to 22°C. These water temperature values were similar to air temperatures which ranged from 18°C to 25°C. River width was greater in site 5 with 44.0 m in comparison with site 4 with 4.5 m. High values of TDS were noted for sites 5 and site 6. These values exceeded those reported for the Congo in Africa (33 mg $l^{-1}$) [12] and for the Río Bravo/Río Grande in Laredo (881 mg $l^{-1}$) as well as those reported for the Atlixco River with a higher value of 1,019 mg $l^{-1}$ [13]. It is generally believed that water with 500-1000 TDS values can have detrimental effects on some sensitive agriculture crops.

Table 1: Variables of the water of the Rio Conchos in Chihuahua, Mexico.

| Sampling Point | Stream Flow ($m^{-3}$ $seg^{-1}$) | Water temperature (C degrees) | Air Temperature (C degrees) | River width (m) | TDS (mg $l^{-1}$) |
|---|---|---|---|---|---|
| Site 1 | 0.0931 | 21 | 20 | 10.0 | 10 |
| Site 2 | 0.5410 | 22 | 25 | 6.5 | 220 |
| Site 3 | 2.8348 | 19 | 23 | 19.0 | 56 |
| Site 4 | 0.7467 | 21 | 19 | 4.5 | 671 |
| Site 5 | 0.2721 | 20 | 18 | 44.0 | 1425 |
| Site 6 | 0.1855 | 21 | 25 | 6.90 | 2397 |

Table 2 shows values for six more variables of waters in the Rio Conchos. Water color values (units in platinum-cobalt scale) were highest in sites 1 and 5. It is assumed that in site 1 inorganic matter was responsible for this value while in site 5 organic material from decaying vegetation could be responsible for this value of 10. Turbidity values were highest in sites 4 and 5 with 8.3 and 11.6 units, respectively. Turbidity in excess of 5.0 units is usually objectionable for aesthetic reasons. Although the pH ranged from 8.0 in sites 2 and 4 to 9.4 in site 5, these are considered safe according to NOM-001 (pH range from 5-10). The pH in site 5 can affect aquatic organisms that are adapted to live within pH ranges higher than 9.0. In fact some results established a pH range of 6.5-8.5 criteria for aquaculture [14]; hence, site 5 may have water quality problems. Other research found pH values higher than 10 in Sanguesa, Spain [15]. In general, the results reported here with respect to pH values agree with those reported by others who found pH ranged from 7.7 to 8.4 in the Rio Conchos near the city of Camargo, Chihuahua [16].

The highest sulfate value was observed at site 6 with 1,033 mg $l^{-1}$, which is higher than the recognized value in the NOM-127 (400 mg $l^{-1}$). The lowest value was noted in site 3 with 24 mg $l^{-1}$. Fluoride concentrations range from 0.08 mg $l^{-1}$ in site 6 to 1.84 mg $l^{-1}$ in site 3. The NOM-127 established a value of 1.5 mg $l^{-1}$. It can be noted that fluoride content is negatively correlated with water hardness (Ca) that is shown in Table 5. With respect to phosphate, the highest level was noted in site 1 with 2.89 mg $l^{-1}$. Site 1 is close to the city of Chihuahua, thus, high phosphorous content in water may be due to human wastes and industrial wastes as well as from phosphate based power detergents.

Table 2: Some characteristics of the water of the Rio Conchos en Chihuahua, Mexico.

| Sampling Point | Water color | PH | Turbidity (NTU) | Sulfates (mg $l^{-1}$) | Fluorides (mg $l^{-1}$) | Phosphates (mg $l^{-1}$) |
|---|---|---|---|---|---|---|
| Site 1 | 10 | 8.1 | 0.46 | 224 | 1.63 | 2.89 |
| Site 2 | <5 | 8.0 | 0.57 | 40 | 0.99 | 0.50 |
| Site 3 | <5 | 8.2 | 0.33 | 24 | 1.84 | 0.39 |
| Site 4 | <5 | 8.0 | 8.3 | 333 | 1.32 | 0.62 |
| Site 5 | 10 | 9.4 | 11.6 | 540 | 1.35 | 0.05 |
| Site 6 | <5 | 7.7 | 7.6 | 1033 | 0.08 | 0.41 |

Table 3 shows the different fractions of nitrogen detected in waters of the Río Conchos. Total nitrogen was greatest in sites 1 and 5, and it was observed that in site 1 most of the total-N was present in the ammonia-N form (4.28 mg $l^{-1}$) in comparison with site 5 where most of the total-N was present as organic-N (3.75 mg $l^{-1}$). It is generally known that high values of nitrates-N can cause eutrophication of surface water. The sources of nitrate-N are through the processes of mineralization and nitrification that occur in inorganic fertilizers, animal manures, municipal sewage wastes, agricultural and industrial wastes, atmospheric deposition and nitrogen fixation. Site 5 had the highest value for nitrate-N with 10.53 mg $l^{-1}$. This value is slightly higher than that given in NOM-127, which establishes a value of 10.0 mg $l^{-1}$. As already noted it is well known that high nitrate levels in drinking water may cause the blue baby syndrome or methemoglobinemia. In addition, sites 1 and 4 had high values of nitrate-N if it is considered that some authors have reported methemoglobinemia from cattle drinking water containing more than 2.79 mg $l^{-1}$ of nitrate. Other authors have reported that high levels of nitrate increased abortions in lab animals and cattle [17]. Actually, methemoglobinemia in animals is caused by nitrite toxicity because once nitrate is ingested by a ruminant animal, it undergoes a chemical reduction action to nitrites, a process carried out by rumen

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microorganisms. Nitrite values were not detectable in sites 2 and 3, and very low values were observed in the other sampling points.

Table 3: Fractions of nitrogen observed in six sites of the water of the Rio Conchos.

| Sampling Point | N-total (mg $l^{-1}$) | Nitrates (mg $l^{-1}$) | Nitrite (mg $l^{-1}$) | Ammonia-N (mg $l^{-1}$) | Organic-N (mg $l^{-1}$) |
|---|---|---|---|---|---|
| Site 1 | 5.97 | 2.55 | 0.19 | 4.28 | 1.69 |
| Site 2 | 4.35 | 0.89 | No detectable | 0.90 | 3.44 |
| Site 3 | 2.02 | 0.62 | No detectable | No detectable | 2.02 |
| Site 4 | 1.83 | 2.97 | 0.03 | 0.03 | 1.81 |
| Site 5 | 4.43 | 10.53 | 0.01 | 0.68 | 3.75 |
| Site 6 | 2.22 | 1.08 | 0.01 | 0.56 | 1.66 |

Table 4 shows Ca, Mg, total alkalinity, bicarbonate and carbonate levels in water of the Rio Conchos. High Ca levels were found in sites 4, 5 and 6. These Ca values were reflected in calcium hardness as $CaCO_3$ that are presented in Table 5. With respect to Mg levels, highest values were observed in sites 1, 3 and 6. Highest total alkalinity values were observed in sites 1, 4, and 6. It can be noted that the buffering capacity of water defined as alkalinity resulted in higher values for the bicarbonate component. In fact, the carbonate component was no detectable in sites 2, 3, 4, and 5.

Table 4: Levels of Ca, Mg, total alkalinity, bicarbonate and carbonate levels in water of the Rio Conchos.

| Sampling Point | Calcium (mg $l^{-1}$) | Magnesium (mg $l^{-1}$) | Alkalinity (mg $l^{-1}$) | Bicarbonates (mg $l^{-1}$) | Carbonates (mg $l^{-1}$) |
|---|---|---|---|---|---|
| Site 1 | 13.71 | 106.33 | 351.17 | 326.76 | 24.41 |
| Site 2 | 5.73 | 45.00 | 201.00 | 201.00 | No detectable |
| Site 3 | 3.24 | 29.13 | 149.30 | 149.30 | No detectable |
| Site 4 | 136.34 | 16.10 | 215.02 | 215.02 | No detectable |
| Site 5 | 165.44 | 31.70 | 51.64 | 51.64 | No detectable |
| Site 6 | 278.53 | 35.23 | 305.64 | 294.55 | 11.08 |

Table 5 shows that chloride presence was very high reaching values of 263.03 mg $l^{-1}$ at site 6 and 82.50 mg $l^{-1}$ at site 1. Maximum chloride limit in the NOM-127 is 250 mg $l^{-1}$. High chloride concentration in water has been responsible for deaths of Israeli carp [18]. Water hardness was higher at site 6 (840 mg $l^{-1}$) in comparison with 94.73 mg $l^{-1}$ detected at site 3. Calcium hardness as $CaCO_3$ was classified as very hard water at sites 4, 5, and 6, while magnesium hardness as $CaCO_3$ was highest at sites 1, 2, and 6.

Sites 1 and 5 showed the highest levels of biochemical oxygen demand (BOD) while sites 5, 6 and 1 reached values of chemical oxygen demand (COD) of 71.90, 39.05 and 31.7, respectively.

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Table 5: Six variables measured in water of the Rio Conchos in Chihuahua, Mexico.

| Sampling Point | Chloride (mg $l^{-1}$) | Calcium hardness (mg $l^{-1}$) | Magnesium hardness (mg $l^{-1}$) | BOD (mg $l^{-1}$) | COD (mg $l^{-1}$) | Detergents (mg $l^{-1}$) |
|---|---|---|---|---|---|---|
| Site 1 | 82.50 | 34.23 | 437.87 | 4.60 | 31.70 | 0.158 |
| Site 2 | 9.71 | 14.31 | 185.31 | 1.50 | 8.50 | 0.053 |
| Site 3 | 8.74 | 8.09 | 119.96 | <1.00 | 14.40 | 0.082 |
| Site 4 | 24.26 | 341.93 | 66.29 | 1.63 | 9.47 | 0.212 |
| Site 5 | 82.50 | 413.10 | 130.54 | 7.98 | 71.90 | 0.186 |
| Site 6 | 263.03 | 695.48 | 145.07 | <1.00 | 39.05 | 0.102 |

Table 6 shows the levels of As, Cd, Cu, Cr, Mn, Fe, Pb and Hg in the Rio Conchos. The highest As concentration was found at site 1 with 0.0192 mg $l^{-1}$, which is considerably above that for the NOM-001 value of 0.2 mg $l^{-1}$ for aquatic life. However, according to one source [19] this element potentially can be a problem because they showed that As levels increment with time. Levels of Cd, Cu and Cr did not exceed values of NOM-001. Manganese levels in site 6 were higher than those established in NOM-127 (0.15 mg $l^{-1}$). It is recognized that long term exposure to Mn will cause several problems, but specifically, drinking water with high Mn content (14 mg $l^{-1}$) has long been recognized as causing the manganese syndrome [20]. This disease mostly affects elderly people because they are more sensitive than younger people [21]; these facts have obligated some institutions to lowering the limit of Mn in water to levels of 0.5 mg $l^{-1}$ [22].

Iron levels were highest at sites 4, 5, and 6 with levels that exceeded the limit value established in the NOM-127 (0.3 mg $l^{-1}$). These data represent an irony due to the fact that in the upper region (mountain area) of the state of Chihuahua, where more than 80,000 Tarahumara Indians are living, they have iron deficiency problems [23]. Lead levels at site 6 were close to that established in NOM-001 (0.4 mg $l^{-1}$) for aquatic life, hence, it might become critical in the short time. These results show that in the case of Hg the levels did not represent a problem where the highest value was found in site 4.

Table 6: Levels of some metals in water of the Rio Conchos in Chihuahua, Mexico.

| Sampling point | As (mg $l^{-1}$) | Cd (mg $l^{-1}$) | Cu (mg $l^{-1}$) | Cr (mg $l^{-1}$) | Mn (mg $l^{-1}$) | Fe (mg $l^{-1}$) | Pb (mg $l^{-1}$) | Hg (mg $l^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Site 1 | 0.0192 | 0.0014 | 0.036 | 0.0031 | 0.0220 | 0.014 | 0.0137 | <0.0050 |
| Site 2 | 0.0046 | 0.0002 | 0.029 | 0.0006 | <0.010 | <0.010 | 0.0018 | <0.0050 |
| Site 3 | 0.0089 | 0.0003 | 0.044 | 0.0030 | <0.010 | 0.087 | 0.0041 | <0.0050 |
| Site 4 | 0.0164 | 0.0021 | 0.057 | 0.0041 | 0.1315 | 0.625 | 0.0122 | 0.0086 |
| Site 5 | 0.0092 | 0.0030 | 0.048 | 0.0032 | 0.0610 | 0.598 | 0.0164 | 0.0059 |
| Site 6 | 0.0049 | 0.0033 | 0.033 | 0.0065 | 0.2413 | 0.406 | 0.0333 | 0.0052 |

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Fecal coliform counts were highest at sites 3 and 6, with values of 500 and 240 cfu/100 ml, respectively; even though they do not exceed the NOM-001 values (1000 cfu/100 ml). Sites 1 and 2 showed the lowest values with 22 and 23 cfu/100 ml, respectively. With respect to total coliform counts the highest values were detected in sites 3, 4, and 6 with values of 500, 500, and 900 cfu/100 ml respectively. On the other hand, site 2 reported the lowest amount of total coliforms with 34 cfu/100 ml. In a study of the Atlixco river [13] that is located in the central part of Mexico, levels of fecal were 814 cpu/100 ml in summer and 7,823 cpu/ml in spring, and total coliforms were 671 cpu/100 ml in summer and 16,923 cpu/100 ml in spring, which exceeded values of NOM-127.

No presence of *Helminto*, *Cryptosporidium* and *Giardia* eggs were detected in any sample. However, a long-run monitoring needs to be conducted because waterborne outbreaks of cryptosporidiosis and giardiasis have been reported in several countries [24, 25, 26].

## 4 Conclusions

This study showed that the Rio Conchos undergoes considerable spatial changes in terms of physical-chemical-heavy metal contents throughout its length. It is extremely difficult to establish a general pattern as well as cause-effect relationships; however, these results might shed light to follow up studies for focusing on specific variables or specific elements of the stream. It is clear that the results reported here illustrate the general Rio Conchos´s pollution problems, although it is recognized that great efforts by the federal government have been implemented to diminish them.

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