

MATUTE CREEK, CARTAGENA, COLOMBIA: DETERIORATION OF WATER QUALITY BY HUMAN IMPACT

ARROYO MATUTE, CARTAGENA, COLOMBIA: DETERIORO DE LA CALIDAD DEL AGUA POR IMPACTO HUMANO

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INTRODUCTION

Matute Creek, Arroyo Matute, rises in Loma de Piedra, northwest of Turbaco City, Bolivar, Colombia, and flows northwest. The river basin has 1594ha, a length of 9.7km and ends through the Chupundún and Calicanto channels in the Ciénaga de la Virgen, Cartagena (Calderón & Suarez, 2006). Arroyo Matute was the first aqueduct that supplied Cartagena (Colombia) and worked from 1907-1940; currently, the upper part of the river is an important source of water used in swimming pools and agricultural activities.

The creek has been under anthropogenic pressure. Turbaco lacks an adequate sewerage, and sewage is mainly done through non-waterproofed septic tanks polluting the ground waters that supplies this stream. Moreover, the low coverage of the aqueduct, has prompted people to groundwater reservoirs built without technical criteria that, being abandoned, are used to eliminate waste of all kinds, which also pollute the creek. The high riverbed is a source of water for farming and touristic pools but its flow rate has been reduced by agricultural activities that concentrate contaminants. From its middle part, Matute is used as household waste and garbage receiver in Cartagena (Figure 1) and floods several substandard neighborhoods of this city in the rainy season (Figure 1) where the river spreads diseases transmitted by insects and rodents. In this research, the waters of Arroyo Matute were evaluated by physicochemical and organoleptic analyses. This Report is important because establishes a baseline to compare with future studies in this creek, to monitor its deterioration and to alert the environmental authorities.

MATERIALS AND METHODS

Sampling Five sampling stations were established:

- Station A, Los Lagos, the river source 10°20'58"N; 75°25'49"O (Reference Station) where the water is expected to be less contaminated.
- Station B, Hacienda Matute, 10° 20'58"N; 75°25'57"O, middle reach.
- Station C, Hacienda el Cortijo, 10°22'00"N; 75°27'00"O, middle reach.
- Station D, San Buenaventura University, 10°23'16"N; 75°27'56"O, low reach.
- Station E, Las Palmeras neighborhood, 10°24'05"N; 75°28'25"O, low reach.

Stations D and E were in the urban area of Cartagena, where most pollution was expected. Physical and chemical indicators of contamination were used: pH; concentration of NO₂⁻, NH₄⁺ and NO₃⁻, and biochemical oxygen demand (BOD). Samplings were conducted in the rainy, September 1999, and in the dry seasons, February 2000. At each station, specific surface water samples were collected and analyzed in triplicate by standard methods (APHA, 2016). Average monthly precipitation was provided by IDEAM (2016). Samples were taken from the water surface up to 1m deep, stored in plastic or glass bottles, depending on the analytical requirements, and kept at 4°C. In the laboratory, samples were analyzed immediately or frozen until analysis, while not exceeding two days.

Methods. The tests were from Standard Methods for the Examination of Water and Wastewater (ASTM): Hardness (2340 C, Volumetric EDTA), alkalinity (2320 B, Titration),

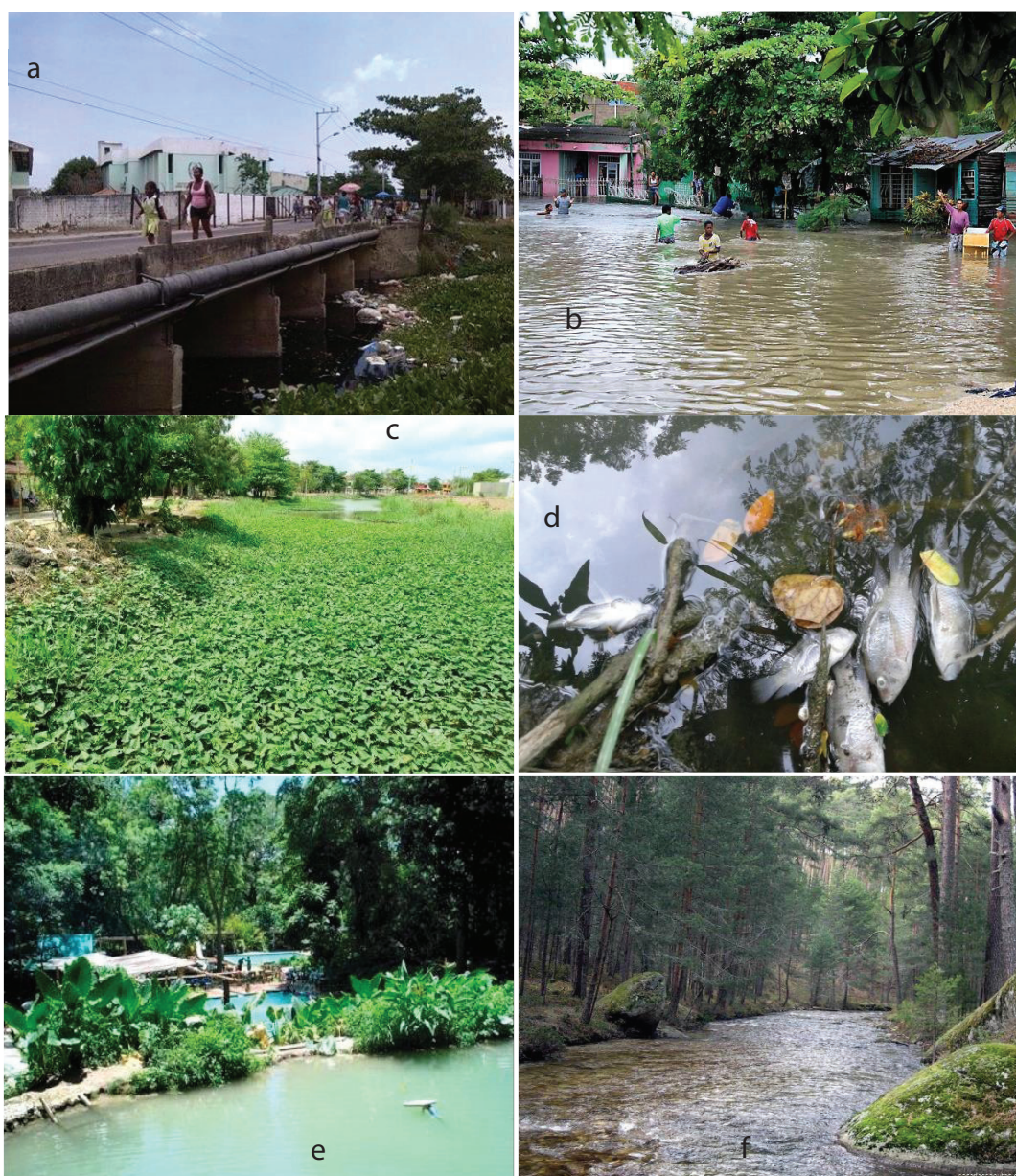


Figure 1. (a) Garbage in Arroyo Matute, station E; (b) Flooding caused by Arroyo Matute by station E; (c) Eutrophication in station E; (d) Fish Kill in station E; (e) Station B; (f) Station C. In internet. [Accessed 11/02/17] from the newspaper El Universal, Cartagena Colombia, except (f) from Alcaldía de Turbaco – Bolívar, Nuestro Municipio, Turismo. <http://www.turbaco-bolivar.gov.co/turismo.shtml>

a) http://ciudadano.eluniversal.com.co/sites/default/files/imagecache/550x400/maguilera/18-06-2014/puente_de_la_pedro_romero_-_arroyo_matute_-_reinaldo_manjarre.jpg&imgrefurl 16/09/2015 b) <http://www.eluniversal.com.co/cartagena/local/%C2%A1inundacion-historica-49238>, 04/08/2009. c) <http://ciudadano.eluniversal.com.co/problemas-comunitarios/nada-que-lo-limpian.html>. d) <http://www.eluniversal.com.co/cartagena/epa-investiga-causas-de-mortandad-de-peces-en-cano-matute-en-ternera-205143> 08/09/2015. e) <http://www.eluniversal.com.co/cartagena/rutas-del-encanto/conozca-el-paraiso>. 04/08/2009

chloride (4500- Cl⁻ C, Mercuric nitrate), total solids (2540 B, Total solids dried at 103-105°C), dissolved solids (2540 C, Total dissolved solids dried at 180°C), suspended solids (2540 D, Total suspended solids dried at 103-105°C), oils and fats (5520 B, Partition gravimetric), BOD (5210 B, BOD), chemical oxygen demand (COD) (5220 C, closed reflux titrimetric method), phosphates (4500-PE, ascorbic acid), nitrates (4500 E, cadmium reduction), nitrites (4500 B, colorimetric), ammonium (4500 D, indophenol), and sulfates (4500-SO₄ D, turbidimetric).

Data processing. Statgraphics (Statistical Graphics System) was used; statistical significance tests were held at the 95% confidence level to determine differences between stations and the reference site or between the seasons. Results were reported as the mean of triplicate analyses and those with RSD>20% were rejected. Correlations (r) were calculated for each parameter to obtain the trend over the course of the stream. Results were compared to quality criteria for natural waters as defined in national or international legislation aimed to flora and fauna preservation (Minsalud, 2016; WHO, 2008).

RESULTS AND DISCUSSION

Significant differences were found in physicochemical parameters with the reference station in both seasons (Table 1) and also between stations ($p < 0.05$) in most cases. **Alkalinity**, primarily determined by carbonate (CO₃²⁻) and bicarbonate (HCO₃⁻) content, is important because acts as a pH stabilizer (Patil *et al.* 2012) and determines the acceptability of a water for irrigation (WHO, 2008). In all seasons, alkalinity exceeded the maximum permissible levels (MPL), indicating high concentrations of carbonates due to the type of soil the stream crosses, a mass of coral limestone resting on a clay stratum (Berna & Orjuela, 1992).

Water hardness has a natural character and also corresponds to the washing of the soil. The harder the water, the higher the cost to prepare it for its use; a hardness of 80 to 100mg/L can be considered satisfactory. In all stations and seasons, the waters were of acceptable quality although hardness exceeded all MPL (WHO, 2008). The concentration of **chlorides** increased with the distance from the source. The high chloride content in station E may be due to sewage contamination, the influence of seawater by the low height above the sea level and the proximity of the salty Ciénaga de la Virgen. **BOD** is important because it determines the oxygen required to oxidize organic matter by biological means. BOD increased with the distance from the source, without exceeding the MPL established by WHO, consistent with the deterioration of the river water when approaching the mouth. **COD** indicates the organic matter content and the quality of waters, dissolved or suspended. COD values,

higher than the WHO guidelines, also increased with the proximity of the stream mouth indicating anthropogenic pollution; COD's MPL were exceeded in the rainy season, and in both seasons in stations D and E.

The solubility of **dissolved oxygen (DO)** in water depends on the temperature, atmospheric pressure, salinity, presence of vegetation, oxidizable organic materials, organisms and aerobes, and disturbance of the interface by wind, fats, hydrocarbons and detergents. Up to 5.5 mg/L DO there is a slight impairment of aquatic life, that turns moderate up to 5.0, and severe up to 4.5 (CWT, 2004). DO in Arroyo Matute became harmful to aquatic life during the dry season in the Cartagena urban area and showed a tendency to decrease with the distance from the source. This is possibly due to eutrophication and oxidizable organic matter by the dumping of waste and may have caused recent fish kills (Figure 1). In the rainy season, DO was high in all stations, likely because of the turbulence of the stream and the surface stirring with rain.

The **total solids** concentration indicates the amount of suspended solids that may seep up through a membrane of 2.0 microns pores. **Suspended solids** can be separated by mechanical means such as filtration or centrifugation. High solids content prevents penetration of light, reduces dissolved oxygen and limits the development of aquatic life. Terrain features, a mass of limestone coral (Berna & Orjuela, 1992), justify the high solids content. Suspended solids increased towards the river mouth because more solids from the bottom and banks are expected to be removed and more solids are received from runoff.

Oils and fats tend to float over the waters and hinder the dissolution of oxygen. The concentration of oils and fats exceeded the MPL; this would be associated with activities like washing motor vehicles near the stream banks and nearby petrol stations. **Phosphates** are essential nutrients to living organisms. They enter natural waters from the runoff of soils, and agricultural, industrial and domestic effluents. Phosphates produce eutrophication, which reduces dissolved oxygen threatening aquatic animals. Phosphates decreased, as expected, towards the river mouth and positively correlated with the eutrophication in stations D and E, where MPL were exceeded.

Nitrites in water could be the result of incomplete nitrification of ammonia. Except for two values, nitrite concentrations in Matute did not exceed the MPL and increased away from the source; this suggests anthropogenic pollution, such as high use of fertilizers and anaerobic conditions. High concentrations of **nitrates** in the rainy season were potentially due to this season's large amounts of atmospheric nitrogen oxidized into N₂O₅, which forms nitric acid, carried down by rain, forming nitrates (Fisher *et al.* 2007). Because station A

Table 1. Physicochemical parameters in mg/L and field data measured in situ (weather, air and water temperature, pH and conductivity), in the waters of Arroyo Matute.

Station	Season	A	B	C	D	E	MPL
Alkalinity	R	299	255	519	366	241	100 ^a
	D	292	247	223	436	229	
Hardness	R	292	219	286	280	321	160 ^a
	D	266	226	235	238	303	
Chloride	R	24.1	26.8	51.4	85.4	196	250 ^a
	D	19.3	21.3	28.7	46.6	177	
BOD ₅	R	1.92	0.16	2.02	5.44	2.03	6 ²
	D	1.09	2.92	3.90	4.42	1.52	
COD	R	3.6	3.3	8.4	20	32	10 ^a
	D	16	36	20	52	40	
Dissolved oxygen	R	6.40	7.68	7.52	7.36	5.12	>5 ^b
	D	5.28	7.52	8.01	7.68	2.88	
Total Solids	R	558	600	598	674	840	>500 ^a
	D	420	421	740	952	959	
Suspended solids	R	238	350	312	360	444	-
	D	24.3	148	382	454	348	
Oils and fats	R	0.978	1.13	1.53	1.54	1.53	Absent**
	D	2.05	3.39	0.74	1.84	2.35	
Phosphates	R	0.005	0.007	0.043	0.255	0.316	0.2
	D	0.019	0.019	0.009	0.293	0.264	
Nitrites (as NO ₂ ⁻)	R	0.002	0.009	0.015	0.086	0.135	0.1
	D	0.002	0.007	0.019	0.444	0.048	
Nitrates	R	8.46	7.71	4.17	1.55	1.38	10
	D	3.53	1.67	0.10	0.00	0.01	
Sulfates	R	6.04	7.37	36.6	55.2	67.4	400
	D	12.5	17.3	28.6	39.3	50.8	
Ammonium (as NH ₄ ⁺)	R	0.01	0.02	0.03	1.79	1.37	1.0
	D	0.02	0.12	0.03	1.85	1.46	
Time*	R	11:40	12:33	13:15	13:45	14:45	-
	D	11:55	12:40	13:01	13:30	14:05	
Weather ¹	R	Cloud	Cloud	Cloud	Sun	Sun	-
	D	Cloud	Cloud	Cloud	Cloud	Sun	
Air temperature, °C	R	30.6	29.1	26.8	28.9	33.4	-
	D	27.3	27.7	28.4	27.6	30.3	
Water temperature, °C	R	27.6	27.8	29.7	29.5	31.1	-
	D	27.2	27.1	25.8	27.4	26.8	
pH	R	7.3	7.9	7.9	7.8	7.7	6.5–9.0 ^c
	D	6.6	6.9	7.2	7.3	7.1	
Conductivity ² , µS/cm	R	332	409	141	895	1038	50–1000 ^c
	D	526	537	586	751	1736	
Other	R	NO	T	T,St	T,G	T,E,SO,G	-
	D	NO	T	T,St	T,G	T,E,SO,G	

The reference station is A. ^a (Minsalud, 2016). ^b (WHO, 2008). ^c (WHO, 2008). R: rainy season; D: dry season. MPL: maximum permissible level or recommended levels for drinking water. PL: permissible levels. Cloud: cloudy; Sun: sunny. ¹ at the sampling time. ² multiplied by 0.01; T: turbidity; E: eutrophication; SO: strong bad odor; NO: no odor; G: garbage. St: Stagnant waters. * Time when measuring field parameters (weather, temperature, pH and conductivity). ** Decreto 1594-1984, Colombia, fat/oil films must be absent for recreational use.

is a protected area rich in flora and fauna, it shows a relatively high amount of nitrates.

Sulfate ion concentration in natural waters can reach 30 to 50mg/L if soils do not contain a significant proportion of sulfate minerals. Sulfate can lead to problems in agriculture and gastrointestinal problems in animals (Burgess *et al.* 2010). Sulfate concentrations in Matute were below the MPL and increased in both seasons towards the river mouth indicating the stream deterioration for allegedly human activities. **Ammonium** (NH_4^+) also had the same trend. In both seasons, ammonium concentrations in stations D and E were high, possibly due to organic matter contamination by the inadequate sewerage in the area.

Salinity, conductivity, turbidity, temperature, and pH were determined in situ, and served as a criterion for determining water quality. International standards indicate that natural waters pH should be 7.0-8.5; for most aquatic species, the favorable pH is 6.0-7.2 (WHO, 2008; CWT, 2004). pH values in the dry season were adequate for aquatic species. The high pH values in the rainy season in all stations, inadequate for aquatic species, may have been produced by antropogenic factors because the buffering power of water assimilates natural pH changes. These high pH values may be due to dissolution of carbonates/bicarbonates by the washing of the coral limestone soil. In addition, high temperatures in the rainy season decrease the solubility of CO_2 in water, and this increases pH.

High **temperatures** in natural waters impair reproduction of aquatic organisms (Miller *et al.* 2015). The temperature of natural water should be lower than that of air and this was found in all stations, except in C and D in the rainy season, indicating no thermal pollution. **Conductivity** evaluates the total amount of minerals in water; conductivity variations may come from spills or contaminated waters. Conductivity correlates with temperature, pH, alkalinity, hardness, total solids, total dissolved solids, COD, and chloride in waters; it has been suggested that water quality can be checked by controlling conductivity (Patil *et al.* 2012). Despite the lack of standards and the effects of the surrounding environment on conductivity, 50-800 $\mu\text{S}/\text{cm}$ in tap water and 100-2000 $\mu\text{S}/\text{cm}$ in fresh water streams can be expected (Fondriest Environmental Inc., 2016). In both seasons, conductivity increased when approaching the mouth of Matute, with a value at station E in the dry season that makes it unsuitable for many uses, including irrigation; in general, the conductivity was also high in the dry season, as expected, due to the concentration of minerals. Finally, the degradation of Matute was evident in stations D and E as indicated by turbidity, eutrophication, bad smell, garbage and water stagnation (Figure 1).

The physicochemical characterization of the waters of Arroyo Matute showed that, until 2000, the creek was in good condition as a natural water source up to the middle part of the river. The waters could be used for irrigation or other activities although some parameters exceeded the MPL for drinking water. Significant differences were found between the seasons for nitrates, ammonium, alkalinity, hardness, chloride and COD. The incidence of waste dumping and general deterioration of water was evident in stations D and E in the urban area of Cartagena.

Conflicts of interest: The manuscript was prepared and reviewed with the participation of all authors, who declare that there is no conflict of interest that compromise the validity of results. This study was funded with authors' own resources.

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