

OPHELIA

Transdisciplinary project on the Santiago River, Mexico

SCIENTIFIC REPORT – CHEMICAL ANALYSIS OF METALS

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EXECUTIVE SUMMARY

SAMPLING AND ANALYSIS

12 samples (S01-S12) were collected on July 3-4, 2019 on Rio Santiago (6 spots between Cuitzeo and El Salto), Rio Zula (1 spot at Ocotlán), Casa Blanca (1 spot; water sewer), Las Pintas (1 spot; inlet of Lago Las Pintitas), Alameda (1 spot; outlet of wetland area), and Los Laureles (2 spots; outlet of municipal discharge). All samples were collected as raw (R) and filtered (F) and immediately acidified with analytical grade nitric acid for further chemical analyses. Non-acidified fractions of raw samples were also prepared for complementary biological analyses. Samples were analyzed at the University of Geneva for the chemical elements Chromium Cr, Cobalt Co, Nickel Ni, Copper Cu, Zinc Zn, Arsenic As, Selenium Se, Cadmium Cd, Mercury Hg, Thallium Tl, Lead Pb (indicators of anthropogenic/industrial contaminations), as well as for Manganese Mn, and Iron Fe (indicators of natural sources). Biological analyses will be described in a separate report.

RESULTS OF CHEMICAL ANALYSES

The sample from the lixivate of the municipal discharge contains several toxic elements at highly worrisome concentrations, far above the international guidelines of the World Health Organization (WHO) for drinking waters. All other samples contain Lead Pb (10-40 µg/L) above the WHO guidelines (Pb max. 10µg/L). Other toxic metals are at or below the WHO guidelines.

OTHER OBSERVATIONS

During the sampling period, water flow and level were much below usual observations according to local communities. At many places, a dense and thick layer of vegetation completely covered the waters, potentially indicating a heavy eutrophication with resulting anoxia, corroborated by persistent smells of sulfides and putrefaction. A dense and thick layer of artificial foam was observed wherever a waterfall was present, indicating contaminations by synthetic detergents. There is apparently no publicly available official cadaster of wastewater pipes allowing keeping track of the path of industrial and domestic waters.

The author has the feeling that the heritage of Rio Santiago for its local communities is sacrificed or at least minimized for the wealth and interests of the economic/industrial sphere active in the region.

RECOMMENDATIONS AND CONCLUSIONS

A detailed description of waters should include the on-site analysis (e.g. by local communities after training by UNIGE experts) of indicators of eutrophication and anoxia (nitrates, nitrites, ammonia, phosphates, dissolved dioxygen), as well as carbon contents (Total Organic Carbon TOC, Chemical Oxygen Demand COD, Biological Oxygen Demand BOD).

A detailed description of industrial organic contaminants (pesticides, pharmaceuticals, agrochemicals, solvents, etc.) is far beyond the scope of the present project and would require additional funding by neutral agencies and foundations. A sound understanding of the water paths from industrial and non-industrial areas can only be obtained with access to official cadasters of wastewater pipes. Finally, an open repository of all existing documentation (governmental, academic, other sources) of Rio Santiago and its tributaries should be created and given access to all actors –including local communities– involved in the understanding of the environmental situation in the area.

PRELIMINARY REMARKS

This scientific report is part of a large transdisciplinary project focused on the heritage of Rio Santiago and its tributaries for the local communities living along the riverside.

The project, OPHELIA, is aimed at intermingling dimensions of science (including citizen science), social science, and art, to better understand anthropogenic, natural and cultural evolutions of water and to raise awareness of populations on the fragile status of water as a fundamental resource for life and health.

The author of this scientific report declares no conflict of interest with any company or government or individual. The results presented in this report have been obtained by state-of-the-art scientific approaches, both for the sampling campaign on field, and for the analyses performed at the University of Geneva. The scientific part of the transdisciplinary project is self-financed by the Chimiscope, while the artistic part of the project is supported by a grant of the *Fondation Ernst & Lucie Schmidheiny* (Geneva), a neutral and independent foundation aimed at supporting the advancement of academic knowledge.

The University of Geneva is a public institution functioning with a transparent ethic on the production and dissemination of neutral and independent information. It is highly ranked and recognized worldwide (Shanghai Ranking, Times Higher Education Ranking, QS World University Ranking); it is located in a politically and economically neutral country, Switzerland, which gives it a sound reputation and level of confidence.

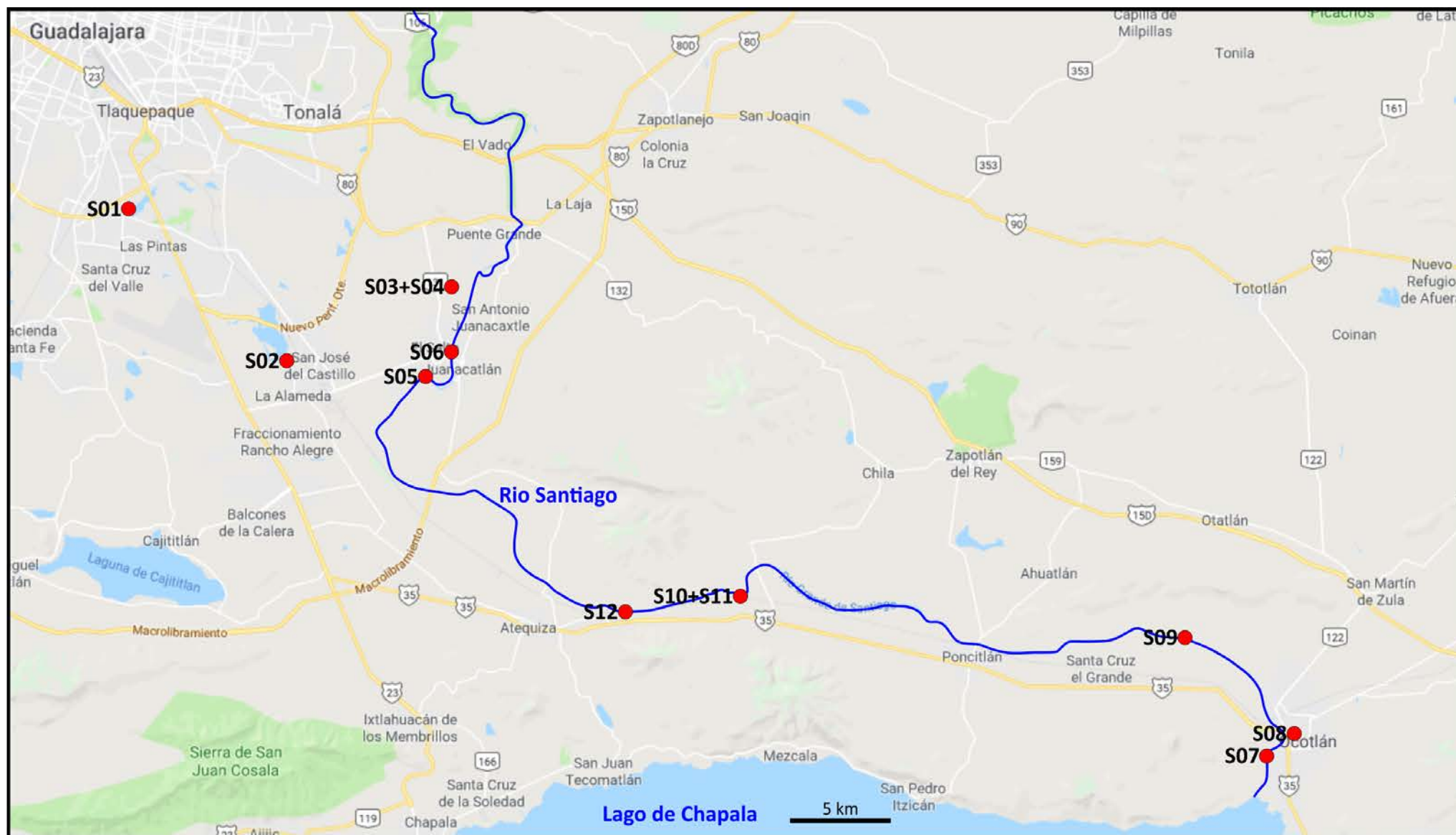
Within the frame of this project, the sampling campaign has been organized in July 2019 to collect fractions of waters from Rio Santiago and other sources of waters in the vicinity. Samples have been collected by the author with the help of inhabitants participating in the group “*Unidos por la vida. agua, tierra y aire limpio para nuestros pueblos*” from the local communities of El Salto, Juanacatlán, and Puente Grande y Tololotlán.

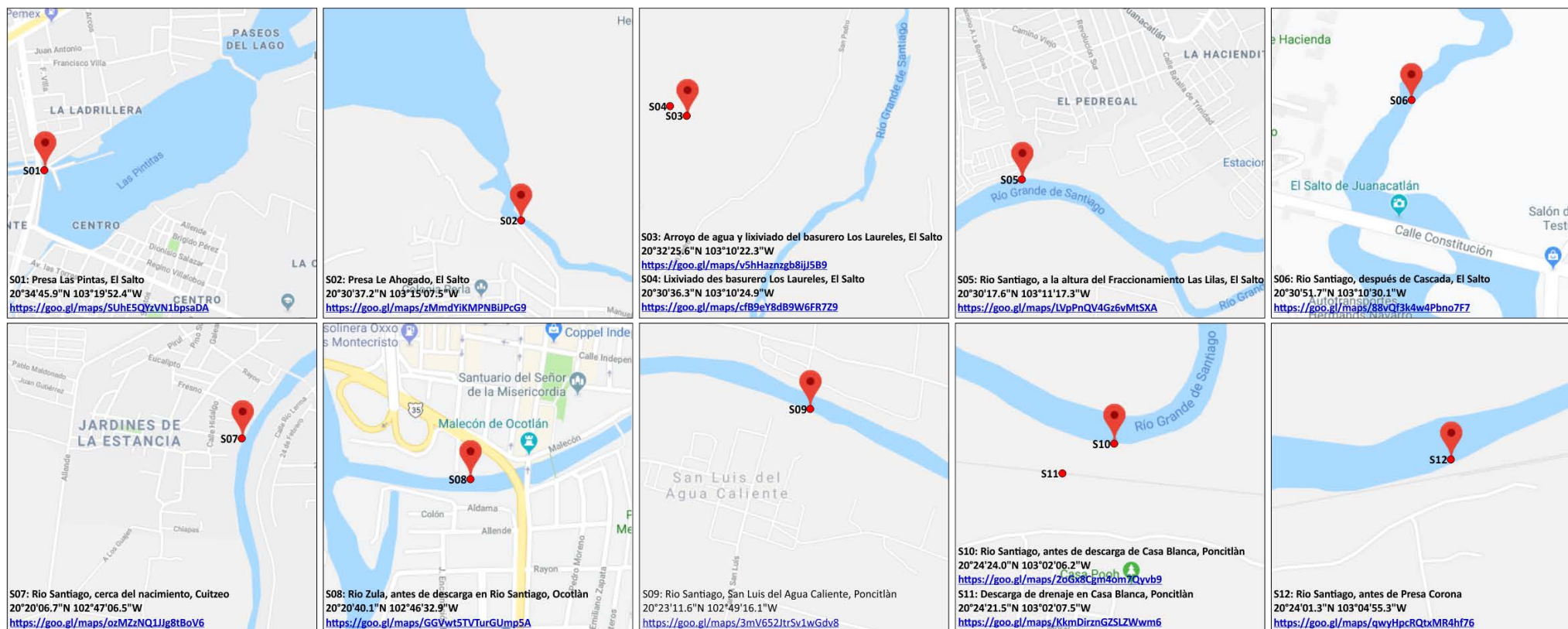
The aim of the scientific part of the transdisciplinary project OPHELIA is not at finding solutions (e.g. purification processes adapted to the local conditions) to potential problems of contamination of the waters along which the populations live, but to obtain a better insight on the chemical status of Rio Santiago and its tributaries. It was found, indeed, that independent scientific literature on Rio Santiago is scarce and that governmental data on the status of the river is not readily and publicly accessible, which makes the present scientific project perfectly justified.

The primary objective of the sampling campaign was thus to gain insight into the contents of metals in the collected waters, and to put focus on potential issues related to toxic metals, which would require further in-depth studies. Additionally, the microbiological status of the samples has been surveyed and will be the subject of a separate report.

A more complete survey, including the analysis of nutrients and indicators of eutrophication (phosphates, nitrates, nitrites, ammonia, dissolved dioxygen, sulfides) as well as the analysis of the carbon content (Total Organic Carbon, Chemical Oxygen Demand, Biological Oxygen Demand) and eventually the organic contaminants (synthetic detergents, pesticides and agrochemicals, organic solvents, pharmaceutical drugs), performed over a long period of time (at least one complete year) at repeated intervals, would be compulsory to provide a complete chemical status of the waters. Such a complete survey would require the contribution of the local communities for the collection of samples and for the direct on-field analysis of simple chemical parameters.

SAMPLING SPOTS





SAMPLING AND SAMPLE PRETREATMENT

Raw samples were collected with a 5 L bucket (pre-rinsed with the water of interest) in 15 mL Falcon tubes (sterilized, metal-free). Filtered samples were obtained by syringe filtration (50 mL sterilized, metal-free syringes; pre-rinsed with the water of interest) equipped with 0.2 μ m hydrophilic cellulose acetate membranes (Sartorius model XXX, 25 mm; pre-rinsed with 10 mL of the water of interest before collecting the filtrate).

Immediate acidification of raw and filtered samples was obtained by micropipetting (Socorex with single-use PP tips) 1.0 mL of analytical grade HNO_3 70 % to 14.0 mL samples ($[\text{HNO}_3]_{\text{final}} = 4.7$ %). Tightly sealed (Parafilm) samples were kept at room temperature and shipped on July 5, 2019, by express mail to the University of Geneva (2-day delivery), where they were stored at 4 °C until they were analyzed by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES; Thermo Fisher iCAP 6000).

Raw non-acidified samples (2 mL; Eppendorf tubes, pre-rinsed with the water of interest and fully filled without air gap) were processed immediately after arrival at the University of Geneva; their treatment and microbial analysis is described in a separate report.

GUIDELINES ON HEAVY METALS IN WATERS

The table below lists several guidelines, rules and recommendations for the maximum concentrations of heavy metals in waters of different origins. Concentrations are given in micrograms per liter [µg/L].

Source	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
1-WHO	50	–	70	2'000	–	10	40	3	6	–	10	–	–
2-CH	5 ^a 2 ^c	–	10 ^a 5 ^b	5 ^a 2 ^b	20 ^a 5 ^b	–	–	0.2 ^a 0.05 ^b	0.03 ^a 0.01 ^b	–	10 ^a 1 ^b	–	–
3-CH	2'000 ^a 100 ^c	500	2'000	500	2'000	100	–	100	–	–	500	–	–
4-CAN	50	–	–	2'000	5'000	10	50	5	1	–	5	120	300
5-USA	570 ^{a,1} 74 ^{b,1} 16 ^{a,2} 11 ^{b,2}	–	470 ^a 52 ^b	–	120 ^a 120 ^b	340 ^a 150 ^b	–	1.8 ^a 0.72 ^b	1.4 ^a 0.77 ^b	–	82 ^a 3.2 ^b	–	1000 ^b

Sources of data:

- Guidelines for drinking-water quality: fourth edition incorporating the first addendum. World Health Organization. 2017. 631pp. ISBN 978-92-4-154995-0. Maximum concentrations in drinking waters.
https://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/
- Ordonnance 814.201 sur la protection des eaux (OEaux; 28.10.1998, état 01.06.2018). Government of Switzerland. 76pp. Maximum concentrations in surface waters. (a) Total concentrations allowed; (b) Dissolved concentrations allowed. (c) Cr(III) + Cr(VI).
<https://www.admin.ch/opc/fr/classified-compilation/19983281/index.html>
- Ordonnance 814.201 sur la protection des eaux (OEaux; 28.10.1998, état 01.06.2018). Government of Switzerland. 76pp. Maximum concentrations in industrial waters discharged in sewage pipes directed to wastewater treatment plants.
<https://www.admin.ch/opc/fr/classified-compilation/19983281/index.html>
- Drinking water quality guidelines - Chemical and physical parameters of Government of Canada. Internet page. Maximum concentrations in drinking waters.
<https://www.canada.ca/en/services/health/publications/healthy-living.html#a2.2>
- National recommended water quality criteria – Aquatic life criteria table. Government of the United States of America. Maximum concentrations in freshwaters. (a) Maximum episodic/acute concentration; (b) Maximum continuous/chronic concentration; (1) Cr(III); (2) Cr(VI).
<https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table>

SAMPLING SPOT S01

Las Pintas, inlet of Lago Las Pintitas; 20°34'45.9"N 103°19'52.4"W; <https://goo.gl/maps/SUhE5QYzVN1bpsaDA>



RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [$\mu\text{g/L}$])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S01 RAW	2.5 ± 0.5	2.3 ± 0.9	4.4 ± 0.5	9.7 ± 0.5	contam.	<LOD	1.1 ± 0.2	1.1 ± 0.2	<LOD	<LOD	23.4 ± 4.3	440.1 ± 1.5	1886.1 ± 5.7
S01 FILTRATE	<LOD	1.2 ± 0.4	2.2 ± 1.0	4.3 ± 0.3	contam.	<LOD	<LOD	<LOD	<LOD	<LOD	18.6 ± 5.1	359.3 ± 3.5	92.1 ± 1.2

REMARKS

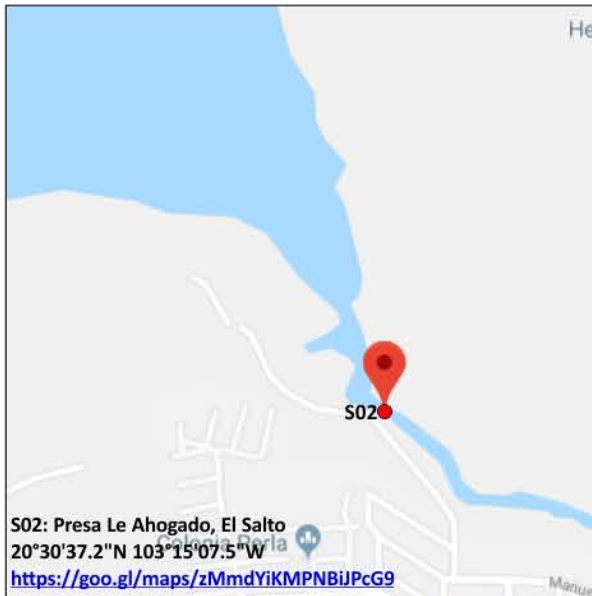
At the time of sample collection, a large and dense layer of synthetic detergents covered the water surface, just downstream of a 1m-high waterfall.

Except lead (Pb), which exceeds the maximum allowed WHO limits, the other toxic metals are at low levels. Zinc (Zn) cannot be discussed, as the raw (R) and filtered (F) samples have unfortunately been externally contaminated by an unknown source of this element.

A solid sample, taken from a large pile of sediments extracted from the waterbed and stored along the side of the river (ca. 100 m long and 2 m high), was collected for complementary qualitative analyses by X-Ray Fluorescence Spectroscopy (XRF; Thermo Niton XL3t Gold+; results provided in a separate report).

SAMPLING SPOT S02

Alameda, outlet of wetland area; 20°30'37.2"N 103°15'07.5"W; <https://goo.gl/maps/zMmdYiKMPNBiJPcG9>



RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [µg/L])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S02 RAW	3.3 ±0.2	0.8 ±0.2	8.3 ±0.8	3.8 ±0.6	contam.	<LOD	<LOD	<LOD	<LOD	<LOD	9.7 ±3.7	263.9 ±1.1	347.6 ±2.2
S02 FILTRATE	1.7 ±0.3	<LOD	6.6 ±0.8	<LOD	contam.	<LOD	<LOD	<LOD	<LOD	<LOD	contam.	240.9 ±2.0	68.9 ±0.9

REMARKS

At the time of sampling, a large and dense layer of synthetic detergents covered the water surface, just downstream of a 1m-high waterfall. Lead (Pb) exceeds the maximum allowed WHO limits, while the other toxic metals are at low levels. Zinc (Zn) cannot be discussed, as the raw (R) and filtered (F) samples have unfortunately been externally contaminated by an unknown source of this element.

Several portions of the waters show high signs of strong anoxia, with strong smell of sulfides.

The waters from the outlet pipe of a wastewater treatment plant located upstream in the vicinity (ca. 500 m) were not sampled; sampling and analysis of these waters would give important information on the treatment efficiency of the plant.

SAMPLING SPOT S03

Los Laureles, outlet of municipal discharge; 20°32'25.6"N 103°10'22.3"W; <https://goo.gl/maps/v5hHaznrgb8ijJ5B9>



RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [µg/L])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S03 RAW	11.6 ±0.4	6.5 ±0.8	13.3 ±1.1	7.9 ±1.3	426.3 ±70.9	<LOD	2.4 ±1.1	<LOD	<LOD	<LOD	26.0 ±7.5	637.4 ±4.1	1199.6 ±12.6
S03 FILTRATE	9.5 ±0.4	5.0 ±0.4	11.6 ±0.9	3.4 ±0.3	356.1 ±17.5	<LOD	<LOD	<LOD	<LOD	<LOD	16.1 ±2.8	540.7 ±4.6	242.1 ±3.5

REMARKS

At the time of sampling, the water flow was very low, with minor traces of synthetic detergents; it has not been possible to identify the path of the waters from the huge (ca. 80 ha) nearby domestic discharge to the sampling spot.

Lead (Pb) exceeds the maximum allowed WHO limits but is in the range of the previous samples, while the other toxic metals are at low levels.

SAMPLING SPOT S04

Los Laureles, raw lixivate of municipal discharge; 20°30'36.3"N 103°10'24.9"W; <https://goo.gl/maps/cfB9eY8dB9W6FR7Z9>



RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [µg/L])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S04 RAW	416.3 ±3.6	268.4 ±2.0	446.6 ±3.9	261.1 ±1.5	559.6 ±23.2	12.7 ±5.4	11.2 ±3.2	1.1 ±0.1	3.8 ±2.0	<LOD	36.8 ±4.3	1180.4 ±7.8	2141.5 ±16.5
S04 FILTRATE	408.5 ±3.3	264.0 ±2.3	433.9 ±4.5	240.8 ±2.9	485.2 ±22.6	13.5 ±1.5	10.5 ±1.4	<LOD	3.1 ±1.3	<LOD	31.0 ±3.5	1075.1 ±7.9	1581.3 ±17.4

REMARKS

The pure lixivate escaping from the domestic discharge is dark (almost black), oily, and heavily smells organic chemicals; it quickly clogs the filtration membrane, indicating that the sample may contain huge amounts of organic matter.

Chromium (Cr), Cobalt (Co), Nickel (Ni), Arsenic (As), Mercury (Hg), and Lead (Pb) are present at high or very high concentrations; some of these toxic elements exceed the maximum allowed WHO limits. The presence of these toxic metals can be an indication that the municipal discharge does not merely contain domestic wastes, but could also host important amounts of toxic chemical wastes from industrial origins; according to the local communities, it is extremely difficult, if not risky, to have access to the facilities located inside the perimeter of the discharge.

SAMPLING SPOT S05

Rio Santiago, El Salto, upstream of waterfall; 20°30'17.6"N 103°11'17.3"W; <https://goo.gl/maps/LVpPnQV4Gz6vMtSXA>



RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [$\mu\text{g/L}$])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S05 RAW	19.0 ± 0.4	4.2 ± 0.2	37.2 ± 1.0	50.2 ± 1.2	704.1 ± 3.8	6.0 ± 1.2	<LOD	1.1 ± 0.1	<LOD	<LOD	31.8 ± 3.9	486.2 ± 1.9	2030.4 ± 13.8
S05 FILTRATE	1.5 ± 0.2	<LOD	7.2 ± 0.6	<LOD	383.3 ± 7.0	<LOD	<LOD	<LOD	<LOD	<LOD	17.1 ± 5.1	258.2 ± 1.5	50.2 ± 1.2

REMARKS

The sampled area was so densely covered by a heavy and thick layer of vegetation, showing evidences of a strong eutrophication, that the flow of the river is not visible.

Lead (Pb) exceeds the maximum allowed WHO limits but is in the range of the previous samples, while the other toxic metals are at low levels.

SAMPLING SPOT S06

Rio Santiago, El Salto, downstream of waterfall; 20°30'51.7"N 103°10'30.1"W; <https://goo.gl/maps/88vQf3k4w4Pbno7F7>



RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [µg/L])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S06 RAW	32.8 ±0.4	5.5 ±0.4	50.6 ±0.5	87.8 ±1.3	1044.5 ±14.4	9.3 ±3.7	3.1 ±1.8	1.3 ±0.1	<LOD	<LOD	41.5 ±1.9	382.1 ±3.1	2270.8 ±8.3
S06 FILTRATE	1.3 ±0.4	3.3 ±0.6	7.1 ±0.5	<LOD	357.6 ±6.0	<LOD	contam. (>RAW)	<LOD	<LOD	<LOD	19.3 ±2.0	249.7 ±2.3	78.0 ±0.9

REMARKS

At the time of sampling, and according to local communities, the water flow was very low, but it exhibited the characteristic presence of synthetic detergents (although less abundant and thinner than usually at the waterfall).

Lead (Pb) exceeds the maximum allowed WHO limits and is found at higher concentrations than in the sample collected upstream the waterfall (S5).

The other toxic metals are at low levels, but Chromium (Cr), Nickel (Ni), Copper (Cu), Arsenic (As), and iron (Fe) are found in raw samples (R) at higher concentrations than in the sample collected upstream the waterfall (S5); this can be explained by resuspension of the waterbed's sediments below the waterfall (although in low regime), which remobilizes the metals potentially trapped in the waterbed.

SAMPLING SPOT S07

Rio Santiago, Cuitzeo; 20°20'06.7"N 102°47'06.5"W; <https://goo.gl/maps/ozMZzNQ1JJg8tBoV6>



RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [$\mu\text{g/L}$])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S07 RAW	2.5 ± 0.3	3.3 ± 0.6	6.5 ± 0.6	5.7 ± 0.4	398.5 ± 33.2	<LOD	3.4 ± 1.2	<LOD	<LOD	<LOD	19.9 ± 5.4	553.5 ± 4.0	1838.3 ± 17.0
S07 FILTRATE	<LOD	1.0 ± 0.3	3.8 ± 0.7	<LOD	351.7 ± 9.9	<LOD	2.0 ± 1.7	<LOD	<LOD	<LOD	20.4 ± 2.8	464.6 ± 1.4	123.0 ± 2.1

REMARKS

At the time of sampling, the water was heavily covered by a dense and thick layer of vegetation, and it was not possible to see the water flow; the smell was characteristic of anoxic situations (sulfide-like), which corroborates the apparently strong eutrophication of this portion of the river.

Lead (Pb) exceeds the maximum allowed WHO limits but is in the range of the previous samples, while the other toxic metals are at low levels.

SAMPLING SPOT S08

Rio Zula, upstream of junction with Rio Santiago, Ocotlán; 20°20'40.1"N 102°46'32.9"W; <https://goo.gl/maps/GGVwt5TVTurGUmp5A>



No picture available for this sampling spot.

RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [µg/L])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S08 RAW	1.0 ±0.2	1.5 ±0.6	4.7 ±0.7	2.2 ±0.4	535.1 ±9.4	<LOD	1.8 ±1.2	<LOD	<LOD	<LOD	23.0 ±4.0	346.9 ±1.8	320.6 ±3.0
S08 FILTRATE	<LOD	1.0 ±0.4	3.9 ±0.7	<LOD	376.9 ±6.4	<LOD	<LOD	<LOD	<LOD	<LOD	17.9 ±6.3	318.0 ±1.6	87.9 ±1.5

REMARKS

At the time of sampling, the water flow was fairly low; there were no signs of strong eutrophication or anoxia.

Lead (Pb) exceeds the maximum allowed WHO limits but is in the range of the previous samples, while the other toxic metals are at low levels. The concentrations of elements found in Rio Zula indicate that this river is not a contamination source of metals for Rio Santiago.

SAMPLING SPOT S09

Rio Santiago, San Luis del Agua Caliente, Poncitlán; 20°23'11.6"N 102°49'16.1"W; <https://goo.gl/maps/3mV652JtrSv1wGdv8>



No picture available for this sampling spot.

RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [$\mu\text{g/L}$])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S09 RAW	1.1 ± 0.3	1.1 ± 0.4	4.5 ± 0.5	<LOD	444.5 ± 14.8	<LOD	<LOD	<LOD	<LOD	<LOD	18.1 ± 5.0	204.94 ± 1.3	427.1 ± 2.8
S09 FILTRATE	<LOD	<LOD	4.1 ± 0.6	<LOD	403.6 ± 25.5	<LOD	<LOD	<LOD	<LOD	<LOD	19.5 ± 3.8	191.1 ± 1.6	86.9 ± 2.5

REMARKS

At the time of sampling, the water was heavily covered by a dense and thick layer of vegetation, and it was not possible to see the water flow; the smell was characteristic of anoxic situations (sulfide-like), which corroborates the strong eutrophication of this portion of the river.

Lead (Pb) exceeds the maximum allowed WHO limits but is in the range of the previous samples, while the other toxic metals are at low levels.

SAMPLING SPOT S10

Rio Santiago, Casa Blanca, Poncitlán; 20°24'24.0"N 103°02'06.2"W; <https://goo.gl/maps/2oGx8Cgm4om7Qyvb9>



No picture available for this sampling spot.

RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [µg/L])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S10 RAW	10.2 ±0.5	7.7 ±0.8	10.6 ±0.7	12.5 ±0.3	428.4 ±13.2	10.1 ±3.8	<LOD	<LOD	<LOD	<LOD	31.5 ±2.8	451.2 ±3.2	7178.5 ±62.8
S10 FILTRATE	<LOD	<LOD	1.9 ±0.6	<LOD	60.4 ±12.9	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	331.5 ±1.6	135.2 ±2.8

REMARKS

At the time of sampling, the water was heavily covered by a dense and thick layer of vegetation, and it was not possible to see the water flow; the smell was characteristic of anoxic situations (sulfide-like), which corroborates the strong eutrophication of this portion of the river.

Lead (Pb) exceeds the maximum allowed WHO limits but is in the range of the previous samples, while the other toxic metals are at low levels. Iron in the raw sample is found at a surprisingly high concentration, which may eventually indicate that the sample has been partly contaminated by sediments during collection of the water.

SAMPLING SPOT S11

Casa Blanca, Poncitlán, drainage pipe to Rio Santiago; 20°24'21.5"N 103°02'07.5"W; <https://goo.gl/maps/KkmDirznGZSLZWwm6>



RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [$\mu\text{g/L}$])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S11 RAW	2.7 ± 0.3	<LOD	5.8 ± 0.7	7.0 ± 0.6	543.1 ± 5.0	<LOD	<LOD	<LOD	<LOD	<LOD	22.1 ± 4.5	96.3 ± 2.4	341.3 ± 2.3
S11 FILTRATE	2.1 ± 0.2	<LOD	6.1 ± 0.4	3.8 ± 0.3	contam. (>RAW)	<LOD	<LOD	<LOD	<LOD	<LOD	26.8 ± 5.1	74.2 ± 0.3	116.5 ± 3.7

REMARKS

At the time of sampling, the water flow out of the water pipe was very low.

Lead (Pb) exceeds the maximum allowed WHO limits but is in the range of the previous samples, while the other toxic metals are at low levels. The presence of lead in domestic wastewaters produced in this community may indicate that at least a certain proportion of the waters used in the village may originate from Rio Santiago.

SAMPLING SPOT S12

Rio Santiago, nearby Presa Corona; 20°24'01.3"N 103°04'55.3"W; <https://goo.gl/maps/qwyHpcRQtXMR4hf76>



No picture available for this sampling spot.

RESULTS OF CHEMICAL ANALYSES (Concentrations given in micrograms per liter [µg/L])

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S12 RAW	<LOD	<LOD	3.2 ±0.2	<LOD	404.3 ±10.1	3.4 ±1.8	2.8 ±2.2	<LOD	<LOD	<LOD	15.3 ±4.7	240.2 ±1.3	206.0 ±1.7
S12 FILTRATE	<LOD	<LOD	2.6 ±1.4	<LOD	395.9 ±9.8	4.0 ±2.9	<LOD	<LOD	<LOD	<LOD	15.5 ±2.9	229.0 ±2.2	46.8 ±1.2

REMARKS

This portion of Rio Santiago was visually the least affected by eutrophication problems, with water flowing freely.

Lead (Pb) exceeds the maximum allowed WHO limits but is in the range of the previous samples, while the other toxic metals are at low levels.

GLOBAL VIEW OF RESULTS ON RIO SANTIAGO

From Cuitzeo, prior to junction with Rio Zula, to El Salto, downstream of waterfall

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S07 Raw	2.5	3.3	6.5	5.7	398.5	<LOD	3.4	<LOD	<LOD	<LOD	19.9	553.5	1838.3
S07 Filt.	<LOD	1.0	3.8	<LOD	351.7	<LOD	2.0	<LOD	<LOD	<LOD	20.4	464.6	123.0
S09 Raw	1.1	1.1	4.5	<LOD	444.5	<LOD	<LOD	<LOD	<LOD	<LOD	18.1	204.94	427.1
S09 Filt.	<LOD	<LOD	4.1	<LOD	403.6	<LOD	<LOD	<LOD	<LOD	<LOD	19.5	191.1	86.9
S10 Raw	10.2	7.7	10.6	12.5	428.4	10.1	<LOD	<LOD	<LOD	<LOD	31.5	451.2	7178.5
S10 Filt.	<LOD	<LOD	1.9	<LOD	60.4	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	331.5	135.2
S12 Raw	<LOD	<LOD	3.2	<LOD	404.3	3.4	2.8	<LOD	<LOD	<LOD	15.3	240.2	206.0
S12 Filt.	<LOD	<LOD	2.6	<LOD	395.9	4.0	<LOD	<LOD	<LOD	<LOD	15.5	229.0	46.8
S05 Raw	19.0	4.2	37.2	50.2	704.1	6.0	<LOD	1.1	<LOD	<LOD	31.8	486.2	2030.4
S05 Filt.	1.5	<LOD	7.2	<LOD	383.3	<LOD	<LOD	<LOD	<LOD	<LOD	17.1	258.2	50.2
S06 Raw	32.8	5.5	50.6	87.8	1044.5	9.3	3.1	1.3	<LOD	<LOD	41.5	382.1	2270.8
S06 Filt.	1.3	3.3	7.1	<LOD	357.6	<LOD	contam.	<LOD	<LOD	<LOD	19.3	249.7	78.0

DISCUSSION

The toxic metal lead (Pb) in raw samples of Rio Santiago ranges between ca. 15 µg/L and ca. 40 µg/L, systematically above the WHO guidelines for drinking waters (<10 µg/L). This represents a potential threat to living species, including populations and livestock, and to cultivated soils if they are irrigated with untreated waters. In most filtered samples, the concentration of lead is similar or close to raw samples, indicating that lead is mostly present in dissolved, readily bioavailable forms; this could be ascertained by further speciation analyses of lead.

The other toxic metals chromium (Cr), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), cadmium (Cd), mercury (Hg), thallium (Tl), are neither a threat for the environment, nor for the humans as far as they remain at or below the actual levels.

The elements manganese (Mn) and iron (Fe), which are indicators of soil leaching, are at high concentrations with respect to regulations for drinking waters, but they are not problematic as far as waters are treated (coagulation/filtration) prior to use for domestic purposes.

The concentration increase of most elements at sampling spots S10 and S05, although below WHO guidelines, indicates a potential external input (industrial?) of metal-loaded waters into Rio Santiago. For these spots, the filtered fractions remain at very low levels, indicating these elements are mostly present in particulate forms, which can readily fall down to the sediments when the water flow is low, but which can be remobilized whenever a waterfall is encountered (e.g. El Salto); this could be ascertained by further analyses of river sediments.

As particulate forms of iron and manganese are strong absorbents of heavy metals, an important risk of remobilization of heavy metals exists whenever the river waters are under strong eutrophication/anoxia, which is apparently the case where the river is densely covered with vegetation; this can only be ascertained with additional analyses of indicators of anoxia (nutriments, dissolved dioxygen, ammonia, etc.).

The spatial and temporal distribution of elements in Rio Santiago (i.e. highlighting if waters are systematically loaded with lead) could only be ascertained with repeated sampling campaigns (day/night; day of the week; season; high/low water regime).

GLOBAL VIEW OF RESULTS IN THE VICINITY OF RIO SANTIAGO

Rio Zula (S08), Casa Blanca (S11), Las Pintas (S01), Alameda (S02), Los Laureles (S03 + S04)

Sample	Cr	Co	Ni	Cu	Zn	As	Se	Cd	Hg	Tl	Pb	Mn	Fe
S08 Raw	1.0	1.5	4.7	2.2	535.1	<LOD	1.8	<LOD	<LOD	<LOD	23.0	346.9	320.6
S08 Filt.	<LOD	1.0	3.9	<LOD	376.9	<LOD	<LOD	<LOD	<LOD	<LOD	17.9	318.0	87.9
S11 Raw	2.7	<LOD	5.8	7.0	543.1	<LOD	<LOD	<LOD	<LOD	<LOD	22.1	96.3	341.3
S11 Filt.	2.1	<LOD	6.1	3.8	contam.	<LOD	<LOD	<LOD	<LOD	<LOD	26.8	74.2	116.5
S01 Raw	2.5	2.3	4.4	9.7	contam.	<LOD	1.1	1.1	<LOD	<LOD	23.4	440.1	1886.1
S01 Filt.	<LOD	1.2	2.2	4.3	contam.	<LOD	<LOD	<LOD	<LOD	<LOD	18.6	359.3	92.1
S02 Raw	3.3	0.8	8.3	3.8	contam.	<LOD	<LOD	<LOD	<LOD	<LOD	9.7	263.9	347.6
S02 Filt.	1.7	<LOD	6.6	<LOD	contam.	<LOD	<LOD	<LOD	<LOD	<LOD	contam.	240.9	68.9
S03 Raw	11.6	6.5	13.3	7.9	426.3	<LOD	2.4	<LOD	<LOD	<LOD	26.0	637.4	1199.6
S03 Filtr.	9.5	5.0	11.6	3.4	356.1	<LOD	<LOD	<LOD	<LOD	<LOD	16.1	540.7	242.1
S04 Raw	416.3	268.4	446.6	261.1	559.6	12.7	11.2	1.1	3.8	<LOD	36.8	1180.4	2141.5
S04 Filt.	408.5	264.0	433.9	240.8	485.2	13.5	10.5	<LOD	3.1	<LOD	31.0	1075.1	1581.3

DISCUSSION

The toxic metal lead (Pb) in raw samples of the 6 different spots collected around Rio Santiago ranges between *ca.* 10 µg/L and *ca.* 40 µg/L, above the WHO guidelines for drinking waters (<10 µg/L). As for the Rio Santiago samples, this represents a potential threat to living species and cultivated soils. In most filtered samples, the concentration of lead is also similar or close to raw samples (*i.e.* lead is mostly present in dissolved, readily bioavailable forms).

Rio Zula (sampling spot S8) is not a source of contaminations for Rio Santiago, as their respective levels of metals are roughly in the same orders of magnitude.

The lixivate (raw and filtered fractions) of the domestic discharge at Los Laureles (S4) contains worrisome and very high concentrations of the toxic metals chromium (Cr), cobalt (Co), nickel (Ni), lead (Pb), and to a lesser extent arsenic (As), which indicate that this discharge does not merely contain domestic wastes but also important amounts of toxic industrial wastes, representing a high threat for the surrounding populations. As a matter of facts, the high amounts of toxic metals found in the lixivate imply that the discharge is either not protected with a technical barrier to contain spills and leakages of toxic species, or that the technical barrier is not functioning properly.

Eventually, the outlet of the discharge at Los Laureles (S3) appears to be much less contaminated than the direct lixivate; without further studies on the behavior of the lixivate, it is impossible at this level to determine if the toxic metals present in the lixivate are caught up in the surrounding soils (thus representing a real threat for crops cultivated around), or if they are simply diluted with other water sources.

For the other sampling spots (S11, S1, S2), the toxic metals (except lead, see above) are at low levels, which represent no threat.

The situation for the elements manganese (Mn) and iron (Fe) is quite similar to the one found in Rio Santiago, and the same considerations and conclusions apply.

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Although providing merely a very short spatial and temporal window on the metal status of Rio Santiago and related water sources, this preliminary study shows that most toxic metals analyzed are not of environmental and health concerns.

The situation is different for Lead (Pb), which systematically exhibits non-negligible concentrations in the raw samples (R) and in most filtered samples (S). The concentrations are systematically above the standards of the World Health Organization for drinking waters.

It must of course be underlined that standards for drinking waters cannot be directly applied to freshwaters, as the latter are not meant at being used directly for domestic usage without undergoing preliminary treatments.

This emerges, for example, from the recommendations of the Government of the United States in its “*National recommended water quality criteria – Aquatic life criteria table*”: the maximum concentration of lead in natural waters, in a critical situation (high threshold which must not be exceeded upon episodic acute contamination) is fixed at 82 [µg/L], much above the concentrations found in all raw samples of this study, BUT the maximum concentration of this toxic element in freshwaters under permanent regime of continuous and chronic contamination must not exceed 3.2 [µg/L], much below the concentrations found in all raw and filtered (except one, S10) samples of this study. If it were to happen that the present study is representative of a continuous situation, then all water samples would have to be considered as permanently contaminated by Lead (Pb). As a matter of facts, chronic Lead (Pb) exposure leads to severe intoxication

The surprisingly higher concentrations of several toxic metals (although below the WHO guidelines for drinking water, except Lead) at sampling spots S10 (Casa Blanca, Poncitlán) and S5 (El Salto, upstream of waterfall) is an indicator of potential external water inputs by (industrial?) contaminated sources. This observation cannot be confirmed as far as no official cadaster of wastewater pipes in the region is available.

The observation that waters sampled just after the high waterfall at El Salto (S06) contains more metals than just before the waterfall (S05) is a clue that the waterbed of Rio Santiago traps toxic metals, which are remobilized from the sediment to the water. This is an indicator that metals are most probably transported in the river under a continuous regime.

The metals found in the lixivate of the discharge are a strong indicator that this discharge is not exclusively dedicated to domestic wastes, but also hosts industrial wastes containing important concentrations of toxic metals.

An important point to mention is that the author of this scientific report has met several citizens from the local communities during the sampling campaign; most citizens were aware of one bibliographic source or another dealing with the waters in the region, but no one was able to provide a compiled set of official data (governmental reports, scientific papers, medical reports, journalist's essays, etc.). It is thus very difficult to obtain complete and relevant data and information on the situation, and the author recommends that an independent group (e.g. local community, non-governmental association) create a serious repository of all available data, to be accessed by all parties.

As a concluding remark, the present report does not provide a spatially and temporally sustainable set of results; it gives a neutral and independent view on the concentrations of some metals of concern in the region. Many more chemical parameters, determined over a longer period of time, would be required to provide a complete view of the situation in the region with respect to metal contamination, eutrophication, organic contamination, and the relative contributions of domestic, agricultural, and industrial usages of water.

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