Pollution of Rivers by Artisanal Mining Activities and Use of Bioremediation Techniques for Heavy Metal Reduction. Case Study: Ponce Enriquez-Ecuador

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Sustainable and Innovative Technique for Heavy Metal Reduction in Ecuadorian Mining Areas

Today's Topics:

- Ecuadorean Mining and Acid Mine Drainage Background
- Water Quality Survey in the Study Area
- Acid Mine Drainage Bioreactor Investigation
- Conclusions

Background

General Information about the project:

Objective:
Implementation of a sustainable remediation technique using industrial by-products such as sugarcane bagasse for the remediation of water contaminated with acid mine drainage in the Canton of Ponce Enriquez, Ecuador.

Funded by: Ecuadorian Government
Participating Institutions: ESPOL – CU
Mine Partner: SOMILOR
Duration: May 2015 - May 2018

Mining Activity in Ecuador

Mining in Ecuador is primarily Artisanal and Small-scale Gold Mining (ASGM). This type of mining is associated with severe environmental damages.

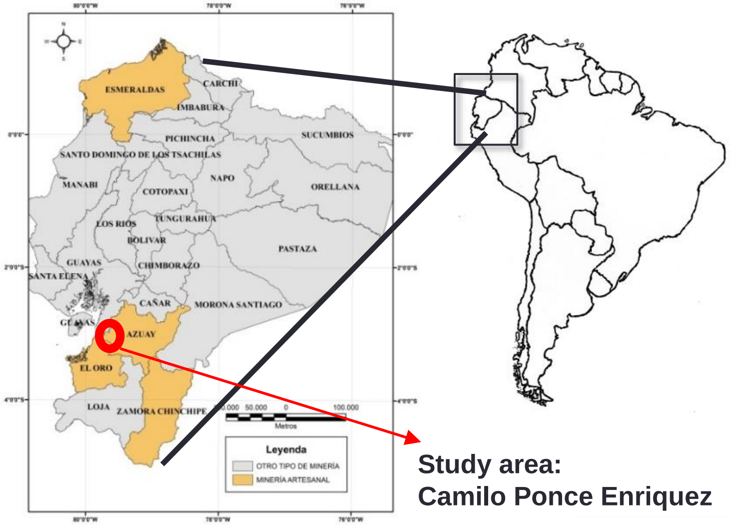
What does ASGM mean?

ASGM is the type of mining performed using rudimentary techniques and producing less than 300 tons/day. It is usually performed without technical or environmental surveillance.

Approximately 85% of the gold production in Ecuador comes from ASGM.

Ecuadorian ASGM is concentrated in four provinces: Esmeraldas, Azuay, El Oro and Zamora Chinchipe.

The study area of Ponce Enriquez is located in the province of Azuay.

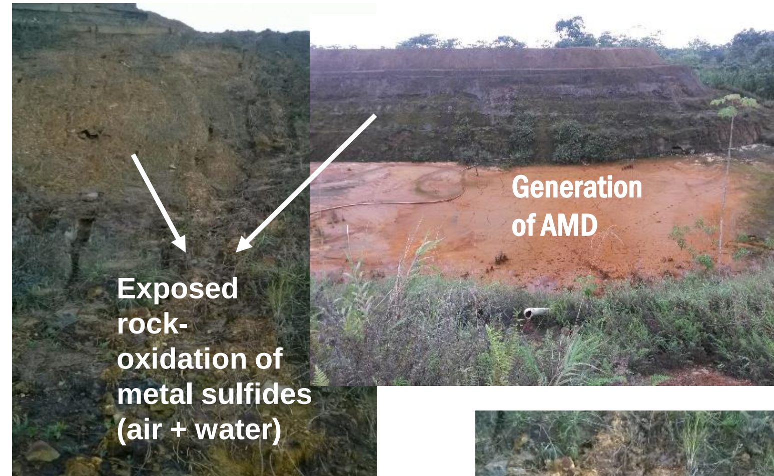


Study area:
Camilo Ponce Enriquez

Acid Mine Drainage (AMD)

In general, mining activities generate significant amounts of pollutants. One of the biggest challenges related to mining is how to remediate Acid Mine Drainage (AMD).

AMD is produced when sulfide minerals in rocks (e.g. pyrite **FeS_2**) are exposed to oxidizing conditions (O_2 + H_2O) after the process of metal extraction.

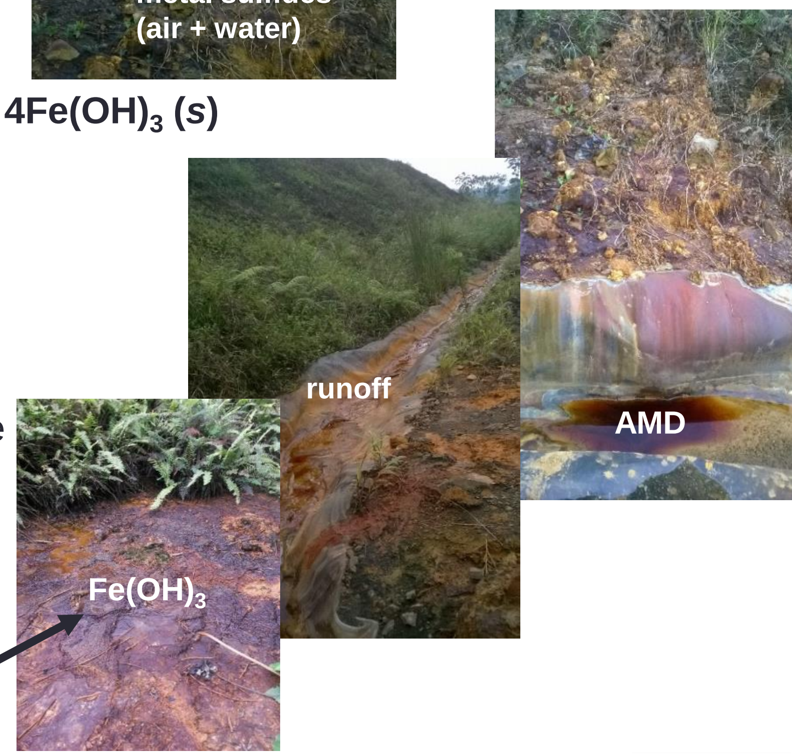


$$4FeS_2\,(s) + 15O_2 + 14H_2O \text{ ------> } 16H^+\,(aq) + 8SO_4^{2-}\,(aq) + 4Fe(OH)_3\,(s)$$

Why AMD is a problem:

The chemistry of AMD is perfectly suited to concentrate its damage on water ecosystems.

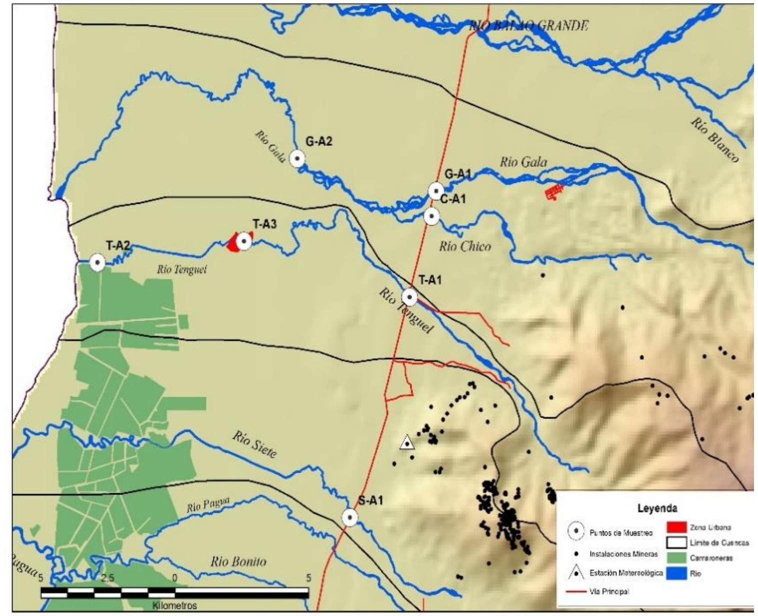
- First, the very low pH of mine runoff (< 3) holds aqueous Fe(II) and Fe(III) in solution, which facilitates the contamination of the water.
- Then, when the runoff meets a stream and becomes diluted, the slightly higher pH causes $Fe(OH)_3$ to precipitate.
- Even if the acid runoff cease, a layer of hydrous iron oxides remains on the soil making difficult for an ecosystem to flourish



Pollution of Ecuadorian rivers due to mining activities

The study area of Ponce Enriquez is irrigated by the rivers Tenguel, Siete, Gala, Chico and Grande which have been severely polluted by AMD derived from ASGM in the area.

Rivers are used in many ways by the local community, from irrigation of fields to recreational and domestic chores.



AMD (pH < 3) → discharged into runoffs

↓

Pollution of rivers

↓

Environmental Impacts

- Pollution of high value crops like cocoa, bananas
- Degradation of human health (consumption/ contact)
- Decrease of aquatic life in polluted streams

Hrubá and Betancourt (2012) revealed high concentrations of Cd, Pb and Hg in blood samples of local children and Cd in cocoa plantations in the area. Cocoa is our 3rd exportation product.

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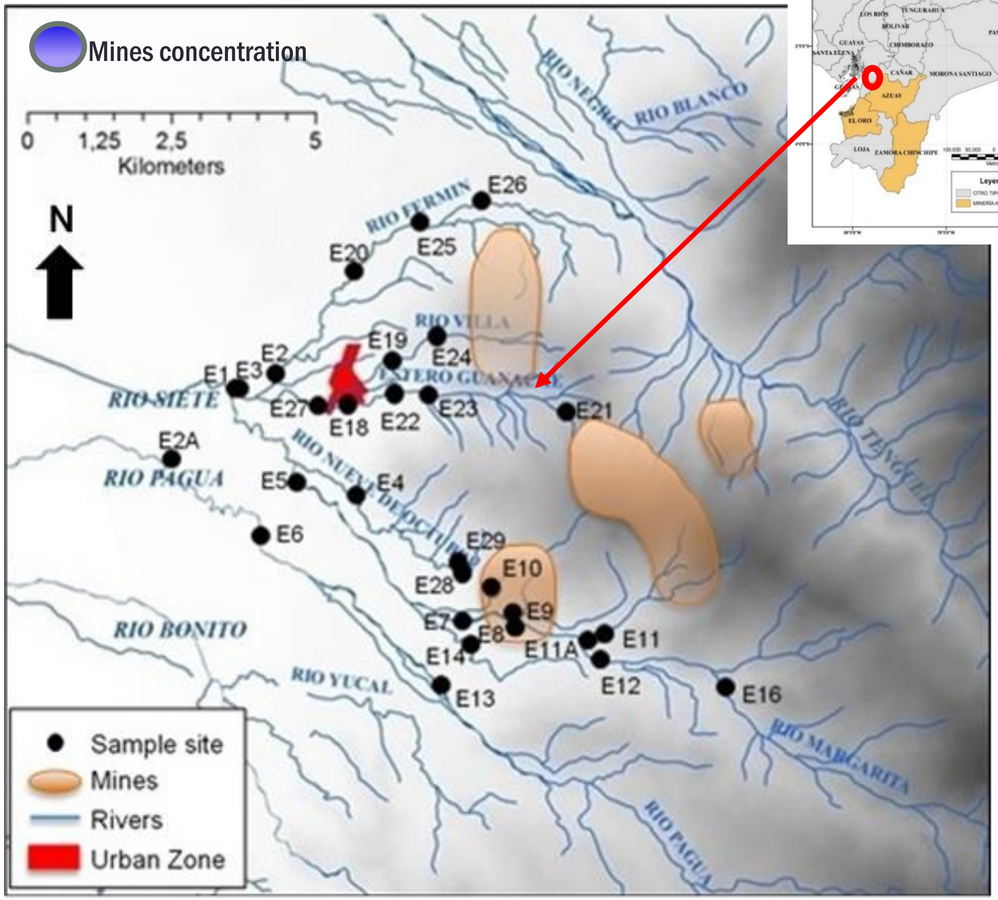
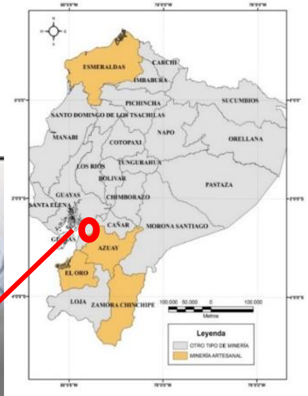
Study area water quality survey

The environmental characterization study of the area was performed as follows:

- Two field campaigns were executed during the dry (December 2015) and wet (February 2016) seasons.
- 29 sampling points were selected along the main rivers in the area.
- Water samples were taken in all sampling points to determine heavy metal (HM) concentrations.
- Samples of microorganisms
- Physico-chemical parameters such as Tº, DO, COD, pH, alkalinity, nitrate, ammonia were measured onsite.

Study area: Camilo Ponce Enriquez





Field Campaign – Dry Season (December 2015)

Participation of ESPOL students and Faculty in the field campaigns

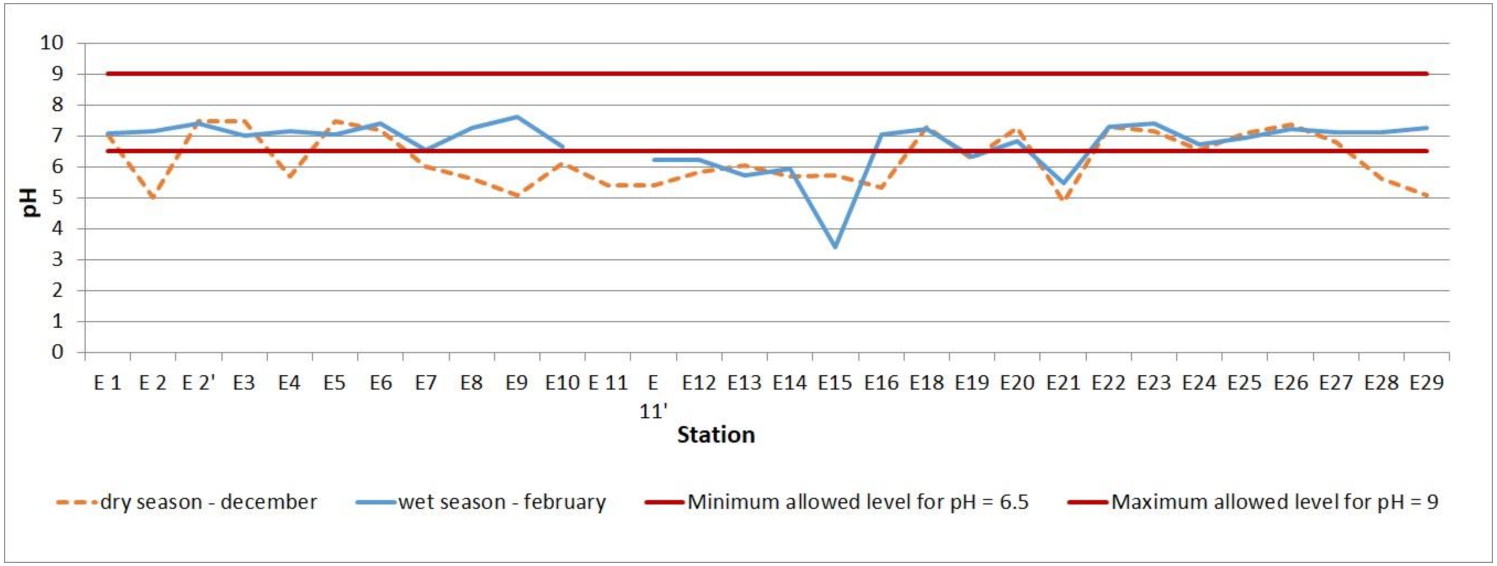
Field Campaign – Wet Season (February2016)

Environmental Characterization
pH Measurements

One important parameter to determine water quality is pH, which is strongly related to the effects of mining activities in water ecosystems.

The pH measured at sampling sites shows the following results:

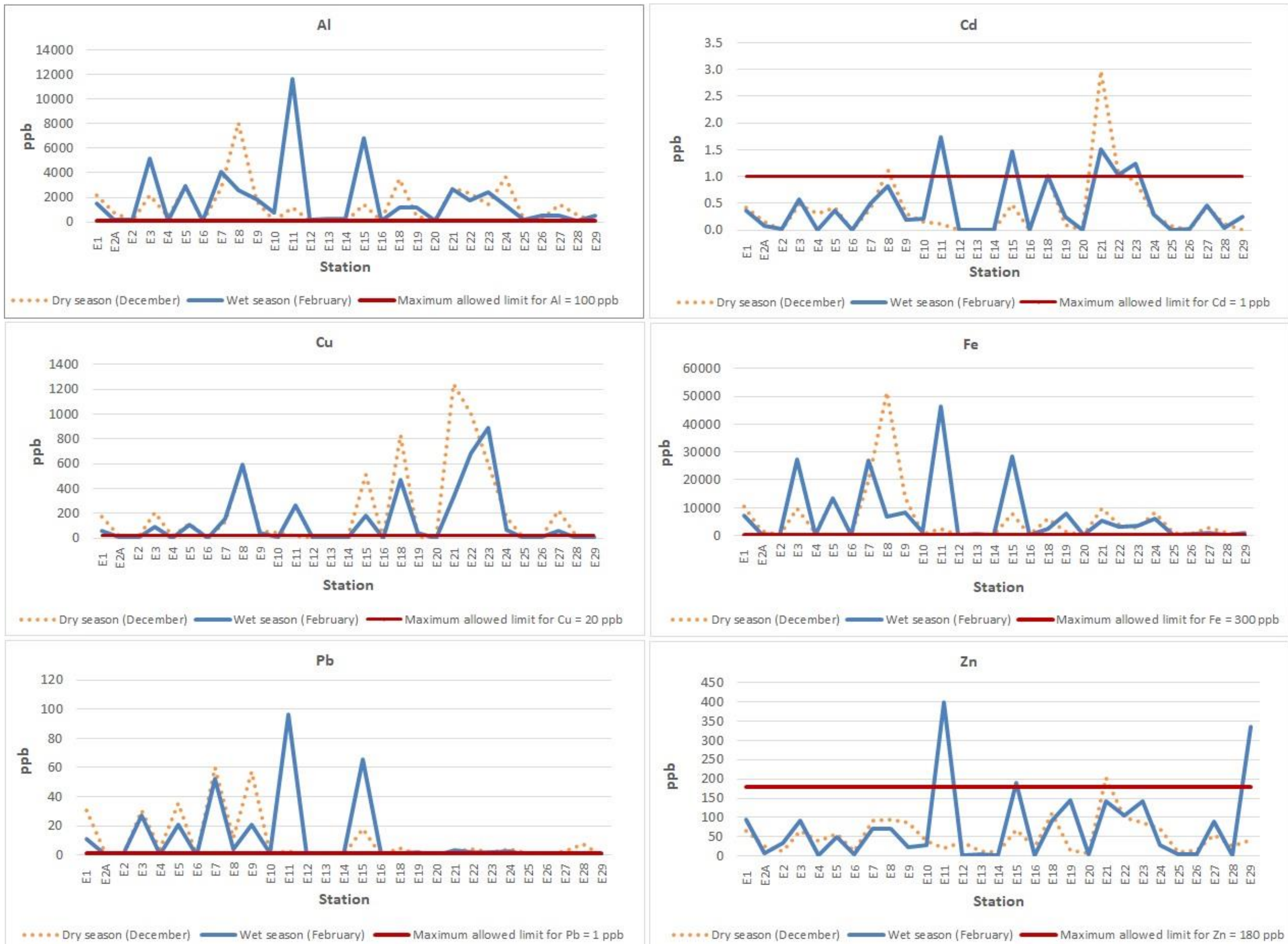
- Differences can be observed regarding pH measured during the dry and wet seasons.
- During the wet season, dilution seems to take place therefore pH increases
- Most of the sampled stations (dry season) due not fulfill the Ecuadorian environmental standards
- Acidic conditions (lower pH) can be observed on those stations (12, 13, 14, 15, 21) closer to the mines



Water quality

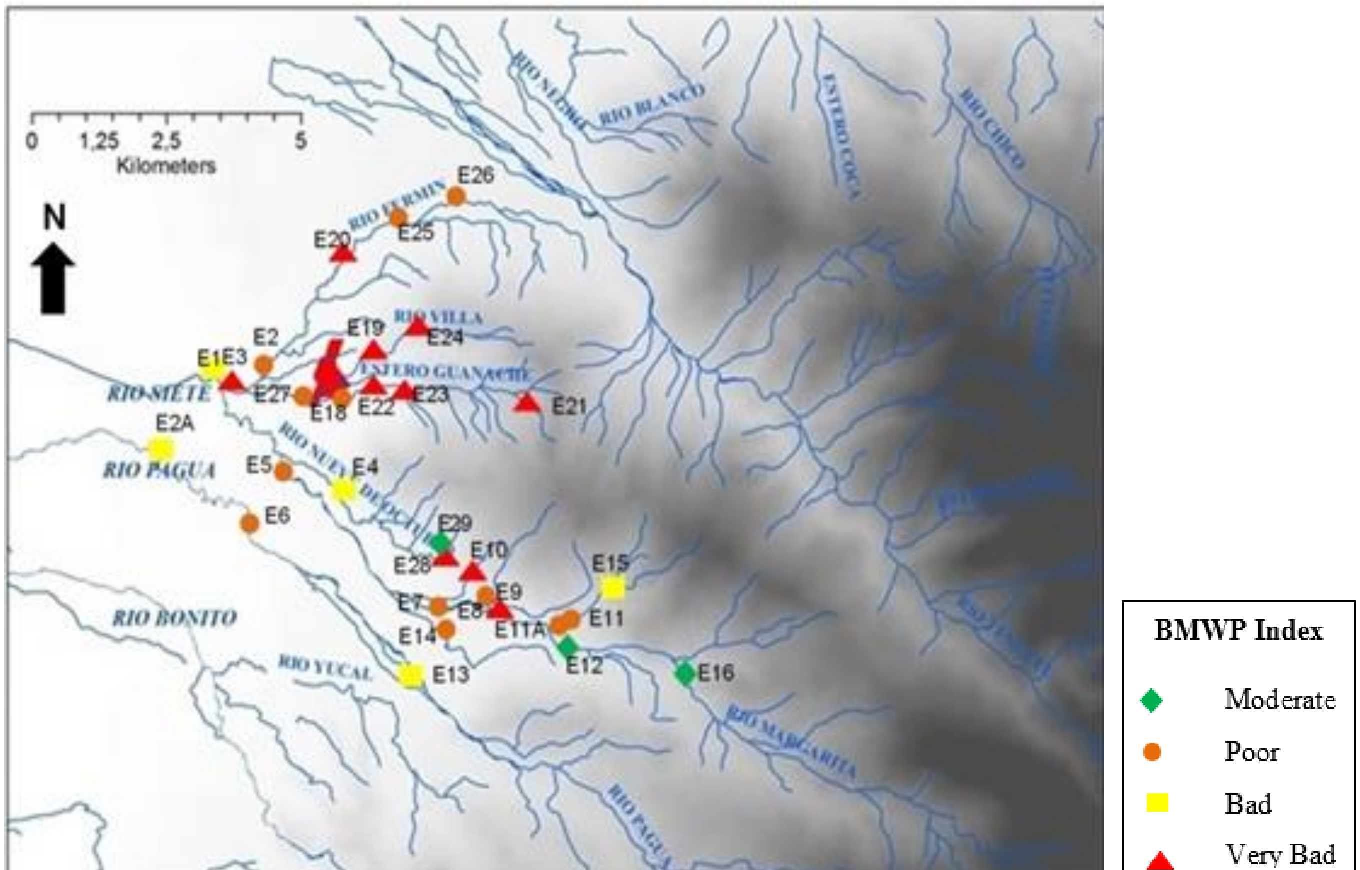
Heavy metal concentration on sampling sites

Almost all sampled stations exceed the Ecuadorian environmental standards for allowed heavy metals concentrations in fresh water



Study area water quality survey

The BMWP index was applied to determine water quality as part of this study. Based on the microorganisms found in the water and sediment samples collected in the 29 sampling sites was possible to determine that the average water quality at the sampled rivers is “Bad”.



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Finding a Sustainable Technique for AMD Remediation

We have two main challenges in our research project:

1. Remediation of mining effluents (AMD) in water ecosystems
2. Identification of an affordable and sustainable remedial mechanism

Possible Solutions

- Conventional abiotic AMD treatment systems using lime and related chemicals

  Not sustainable due to the constant addition of lime and the generation of secondary wastes

- Bioremediation using Sulfate Reducing Bacteria (SRB).

  Has the potential to be sustainable, efficient and affordable

  Sustainability can be achieved by:

  - Identifying local supplies of SRB
  - Considering reuse of industrial by-products

Industrial By-Product Reuse for Sustainable Metals Sequestration

Use of by-products for:

1. Bacteria Source:

Local SRB can be easily obtained from WWTP or anaerobic digestors

2. Food (carbon) Source:

Sugarcane bagasse

What is sugarcane bagasse:

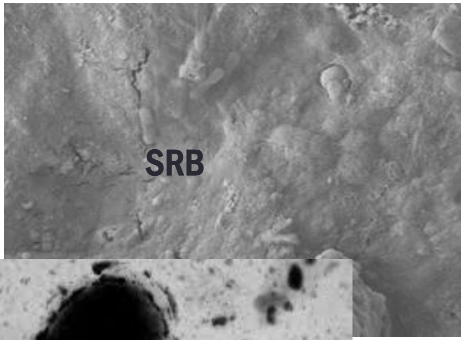
Fibrous matter that remains after sugar extraction

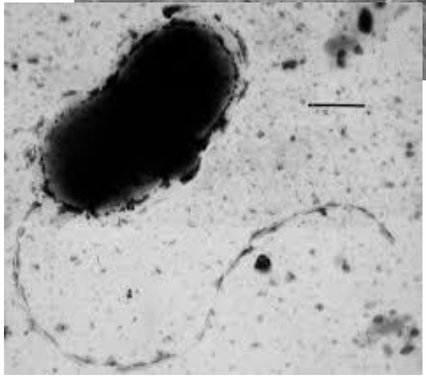
Why sugarcane bagasse:

- Long term source of organic carbon
- Supports biological (bacterial) activity
- Fibrous and porous structure like hay (matrix-trap HM)
- Abundant in Ecuador
- Found near mining areas
- Low cost agricultural residue

Bioremediation
Basic Precipitation Mechanism

SRB get their energy by oxidizing organic compounds (e.g. sugarcane bagasse) while reducing sulfate (SO_4^{2-}) to hydrogen sulfide. (H_2S). These organisms "breathe" sulfate rather than oxygen by anaerobic respiration.





Basic Precipitation Mechanism:

- SRB produce sulfide during their bacterial activity (breathing, feeding).
- Sulfides combine with the heavy metals (AMD) which are in a very soluble state
- Heavy metals are transformed into metal sulfides which are now insoluble
- Precipitation of metal sulfides take place and pollutants can be removed

$$S^{2-} + M^{2+} \longrightarrow MS \downarrow$$

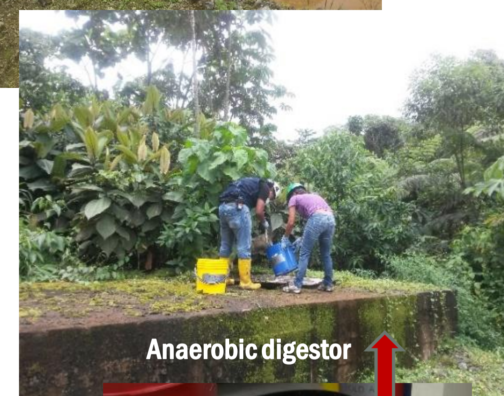
S^{2-}	+	M^{2+}	→	$MS \downarrow$
Sulfide		heavy metal (soluble-liquid) highly polluting		metal sulfide (insoluble-solid) can be removed

What is the great advantage of metal sulfides:

In general "metal sulfides" are remarkably insoluble over a relatively large pH range and many are stable in acid. They are also rapid to form, but slow to dissolve

In this "state" metal sulfides can easily be trapped in the structure of sugarcane bagasse and be removed

Sources of Materials for Bioreactors AMD-Bagasse-SRB



- AMD was collected from a local mine (SOMILOR)
- The bagasse was collected from a local sugar mill (Ingenio San Carlos)

Sugar mill San Carlos

- Wastewater from the anaerobic digestor of a local mine was used as a source of bacteria.

Experimental Set up of the Bioreactors

Seven reactors were installed in the lab: Two identical AMD+SRB+bagasse reactors and four control reactors containing some of the materials in the two main reactors. Additionally, a reactor with a biosurfactant (another remediation technique) was set up for comparison.

Reactors 1 and 2

Reactor 3

Reactor 4

Reactor 5

Reactor 6

Reactor 7

Reactor # 1 (yellow)	AMD + seeded bagasse with SRB
Reactor # 2 (blue)	AMD + seeded bagasse with SRB
Reactor # 3 (blue)	AMD
Reactor # 4 (yellow)	AMD + Dry Bagasse (not seeded)
Reactor # 5 (red)	AMD + SRB (wastewater)
Reactor # 6 (red)	AMD + biosurfactant product
Reactor # 7	AMD + seeded bagasse with known bacteria (*Bacillus subtilis*)

Measurements were performed on the reactors on a weekly basis:

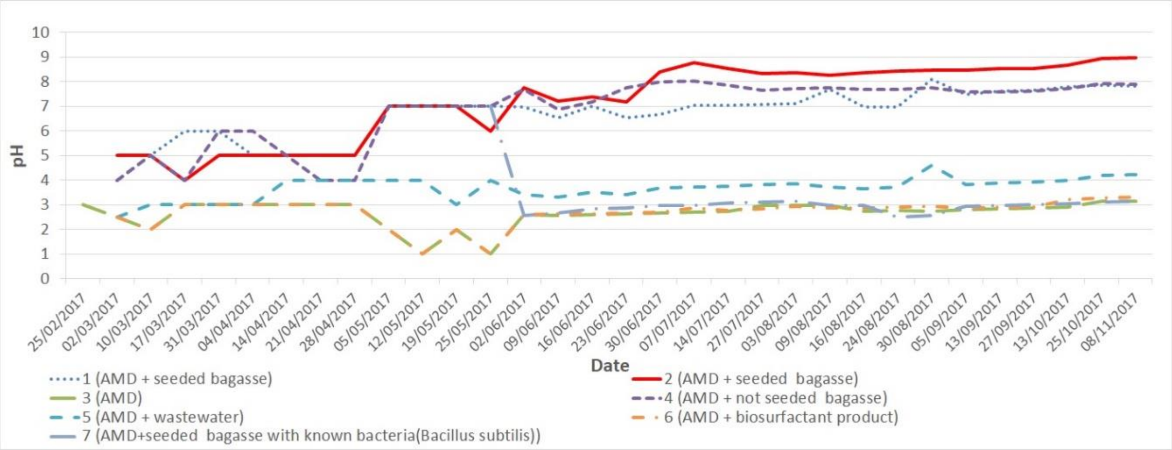
- Sulfide — to determine SRB activity
- pH — to check if alkalinity is generated
- Water samples — to determine heavy metals concentrations

Biorereactor Results
pH and sulfide

After seven months of continuous measuring, made it possible to determine a trend on the reactors' behaviors.

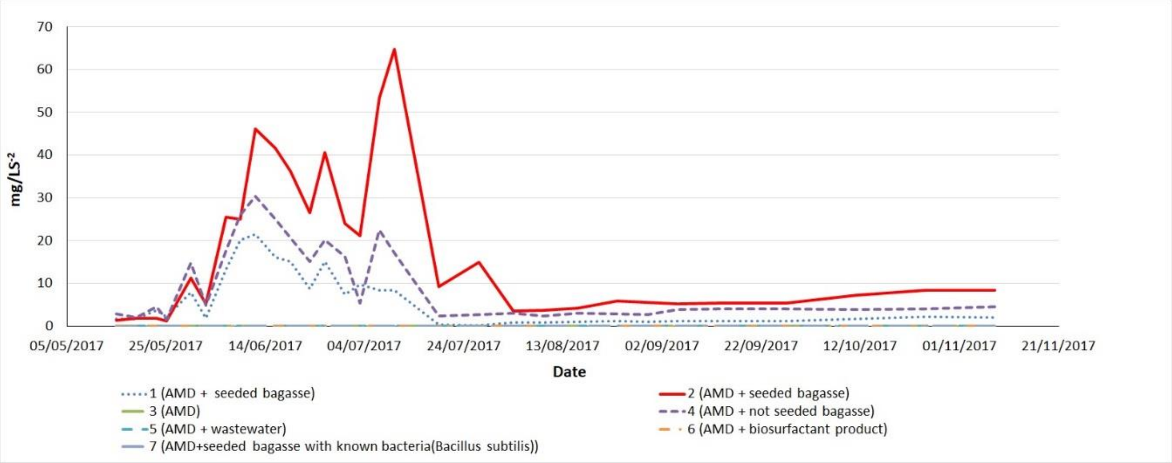
pH measurements:

- pH increased from 3 to above 7 in reactors 1, 2 and 4 (with bagasse), changing from acidic to alkaline conditions, critical for remediation of AMD polluted waters.



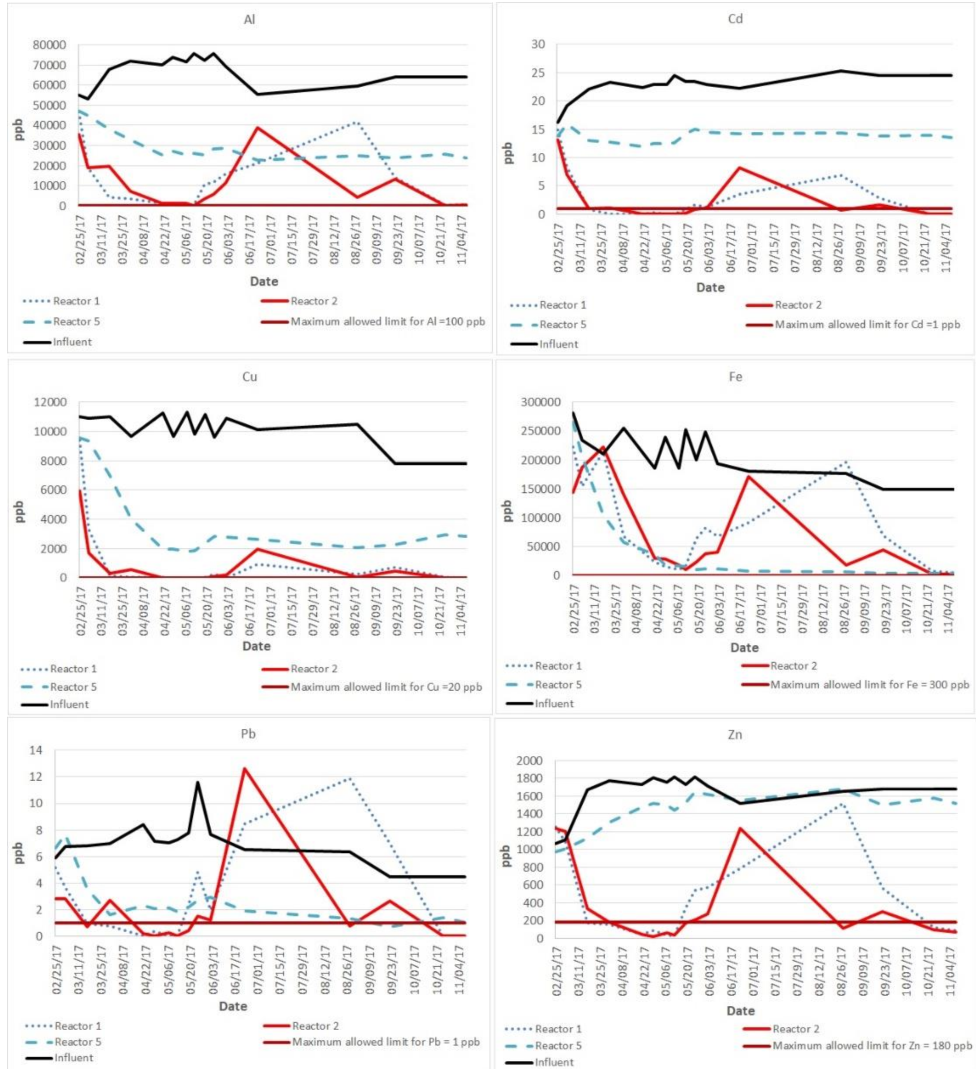
Sulfide (S^{-2}) measurements:

- Sulfide production (reactors 1, 2 and 4) indicates bacterial activity, good for heavy metal precipitation.



Bioreactor Results
Heavy Metal Remediation

- Reactors 1, 2 (bagasse+SRB) and 5 (SRB) achieved a considerable reduction in Al, Cu, Cd, Fe, Pb and Zn concentrations.
- Reactors 1 and 2 were most effective at heavy metal reduction. Reactor 5 did not have a long-lasting effect due to lack of food (bagasse) for sustaining bacterial activity.
- Initial HM concentrations in all reactors (influent) exceeded the Ecuadorian environmental limits allowed for HM concentration in fresh water.
- In most of the cases these concentrations were considerable decreased almost to fulfill the local environmental standards.



The remaining reactors were not effective at HM reduction

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Conclusions

- Water quality in the rivers located in the study area is not good.
  Heavy metal concentrations in the study area are higher than Ecuadorian environmental limits.

- Bagasse+SRB produced the most significant heavy metal reduction in pilot-scale AMD reactors, lowering heavy metal concentrations to Ecuadorian limits.

- The use of **Sulfate Reducing Bacteria** in combination with **sugarcane bagasse**, which are both affordable and sustainable industrial byproducts, has been shown to be an **effective technique** in the **remediation** of **Acid Mine Drainage**.

Future steps

- Implementation of the selected remediation technique at a larger scale by local mines.

- Possible sale of used bagasse for extraction of heavy metals to be used commercially. Residual mining muds are already sold for such purposes.

Acknowledgements

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Thanks