

Strategies for rehabilitating mercury-contaminated mining lands for renewable energy and other self-sustaining re-use strategies.

Output 1. An onsite field testing plan for techniques that promise to be replicable to other similarly contaminated sites, based on technology evaluations and bench scale test work.

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March 2017

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Acknowledgements

This report is one of the outputs of the Colombia Prosperity Fund project on "*Strategies for rehabilitating mercury-contaminated mining lands for renewable energy and other self-sustaining re-use strategies*"

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The authors are grateful to all partners and collaborators for this project, and in particular the people of FCO Colombia, Ministry of Environment of Colombia, Ministry of mining of Colombia, local and regional environmental authorities of Colombia who supported the BOM case study development project and shared its findings with this project.

Key findings

- Widespread international consensus exists on the hazardous exposure values (and appropriate safe levels) for mercury and other metals in soils and other media.
- Low cost, plant-based agronomic techniques already used in many other countries can be adapted to reduce risks from mercury and other metal contaminated sites in Colombia
- Gentle Remediation Options, or GROs, are effective risk management methods involving either:
    - the use of plant, fungi, and/or bacteria-based methods,
    - soil amendments which can change contaminant speciation, leachability or bioavailability
    - the combination of plant, fungi, and/or bacteria-based methods with soil amendments.
- GROs can have significantly lower deployment costs than conventional remediation technologies, and can also contribute strongly to sustainable remediation strategies.
- In most contaminated soils and mine tailings, Hg does not accumulate in the above-ground biomass, but may volatilise through the plants leading to mercury emissions to the atmosphere. Therefore, the most effective plant-based approach to Hg remediation or management is through stabilising Hg in the soil with soil amendments and then establishing a vegetative cap of green cover or biomass, rather than extracting the metal.
- Soil or spoil amendments with biochar may be used in this approach to immobilise heavy metals (including Hg) and simultaneously act as soil conditioners, to reduce soil toxicity and enhance plant establishment and growth.
- Lab scale testing of soil samples from Colombia containing mercury (and other metals) treated with C-Cure products show considerable promise in reducing risks and restoring soil quality. Water soluble mercury was eliminated and large reductions of other metals occurred in the few sample sets available in this study.
- A plan for an 18-month field scale project to evaluate C-Cure products and associated gentle remediation techniques is presented to validate lab studies and assess the feasibility of a larger scale effort as well as evaluate cost effectiveness and related benefits for a wider range of sites in Colombia

Executive Summary

Colombia is endowed with abundant minerals, metals and fossil fuels. Increasing extraction of natural resources such as gold is driving economic growth, while at the same time causing pollution of soil and water, degradation of sensitive ecosystems, and increased risks to human health. Since 2000, the area covered by mining titles rose from 1 million ha to 8.5 million ha (about 8% of the land area). Artisanal mining accounts for 70% of the gold mined in Colombia, and provides a livelihood for about 200 000 poor people. (OECD, 2014). A recent study conducted by the Ministry for Environment and Sustainable Development found nearly 1843 locations potentially considered brownfields or contaminated sites for all economic sectors.

In response to this situation, the UK Prosperity Fund commissioned a project on strategies for rehabilitating mercury-contaminated mining lands (brownfields) for renewable energy and other self-sustaining re-uses. This document is one of several outputs from this project, specifically on approaches, feasibility, and a field implementation plan to rehabilitate land affected by soil mercury pollution in order to bring this land back into productive use, focusing on renewable energy opportunities and/or other services as most appropriate. This onsite field testing plan, which suggests techniques potentially replicable at other similarly contaminated sites, is based on the outcomes of a desk study and bench scale testing of the soil samples from the two sites selected in the project.

Section 2 of this document provides an overview of low input “gentle remediation" options for mercury and other metals based on the results of international research and best practices. Gentle Remediation Options, or GROs, are defined as risk management strategies/technologies that result in a net gain (or at least no gross reduction) in soil function as well as achieving risk management. GROs encompass many technologies, including the use of plant (phyto), fungi (myco-), and/or bacteria-based methods, with or without chemical additives or soil amendments. They can be applied to reduce contaminant transfer to local receptors by in-situ stabilization, or extraction, transformation, or degradation of contaminants.

A number of studies internationally have shown the potential of GROs to provide rapid risk management via pathway control, through containment and stabilization, coupled with a longer-term removal or immobilization/isolation of contaminants. As the treated soils remain unsealed, GROs are highly applicable to soft-end use for a site, e.g. for urban or community park-land, renewables deployment, biomass generation etc. Depending on the specific site situation GROs can have significantly lower deployment costs than conventional remediation technologies, and contribute to sustainable remediation strategies, by providing a broad range of wider economic, social and environmental benefits.

A special focus of this project was evaluating biochars as a soil amendment—given their special potential for mercury treatment. Biochars and activated carbons show good potential for Hg adsorption and stabilization. A partner in this project, C-Cure Solutions, has developed proprietary biochar products which could potentially be applied to mercury sites as discussed in Section 4.

Section 3 provides the background information related to two mining sites in Colombia from which samples were taken to evaluate the nature and extent of mercury (and other metal) contamination at typical contaminated sites. These samples were then subjected to bench scale testing of the innovative mercury stabilization product—biochars—mentioned above. This section frames the environmental context and risks associated with the two mining sites:

Segovia in the department of Antioquia and Tadó in Chocó. These municipalities were selected in concert with the Ministries of Mines and Environmental and Sustainable Development Ministry given their history of artisanal mining and associated mercury use. Samples were taken from areas where gold is being currently extracted or had been in the past (abandoned sites). Along with the guidance of the community leaders from the two areas, identification of specific sampling locations in Segovia was made in concert with staff from the municipal government, who are part of the "Agricultural, Mines and Environmental Direction", and in Tadó in a gold mining area abandoned about 8 years ago.

Section 4 describes the bench scale testing and analysis used to quantify mercury and other metal contaminants in the Colombian soil samples, and the different treatment regimens applied to the samples using biochars developed by project partner C-Cure Solutions. The success of the various treatment options are described in the context of internationally accepted standards for mercury (and other metals) for several exposure scenarios.

As background for assessing acceptable levels of metal concentrations in contaminated soil, this section outlines several International Environmental Quality Standards. These include Soil Guideline Values (SGV), Waste Acceptance Criteria (WAC) and the EU Water Framework Directive (WFD). SGV's are intended to assist professionals in assessing long-term risk to health from human exposure to chemical contamination in soil. WAC's ensure that potentially hazardous waste is safely disposed of so that it no longer poses a risk to humans and the environment. Unlike the Soil Guideline Values, WAC's assess the risks that contaminated materials pose to the environment and human receptors based on water leachable concentrations of contaminants. Finally, the EU WFD, 2000/60/EC was developed to protect surface waters from pollution. Each of these benchmark standards can be of value in evaluating the effectiveness of remediation approaches for metals.

The technologies licenced to C-Cure are designed to immobilise heavy metal pollutants by adsorbing them. Once adsorbed onto C-Cure products, pollutants are no longer leachable and don't interfere with biological processes (de-toxification). Depending on the soil conditions, adsorption of most heavy metals onto the C-Cure products is irreversible and stable. Furthermore, detoxification of soil leads to restoration of normal soil function and allows revegetation to take place.

The on-site samples taken in Colombia were assessed for total metal concentrations and leachable metal concentrations using standard procedures. Subsequently, samples that contained the highest concentrations of mercury were extracted using a sequential extraction procedure to determine if the mercury was (a) water soluble, (b) stomach acid soluble (c) bound to organic matter, (d) in an elementary form or (e) present as mercury sulphide. Each of these extractions can be related to significant exposure routes of mercury.

One (of 8) soil sample having both the highest total Hg concentration and highest leachable Hg concentration was used to test treatment with the C-Cure-CCA treatment product. Using an amendment rate of 5% (wet weight) resulted in all of the water soluble and human stomach acid soluble mercury being stabilised in the soil. For eight additional metals, amendment rates of the C-Cure product ranging from 2.3% to 8.4% were successful in reducing concentrations to values classified as inert according to UK WAC criteria.

Section 5 outlines a proposed 18-month plan for onsite field testing of remediation of metal contaminated sites to validate the technologies, understand cost, and consider implementation, business development, and other scale up issues. Preliminary results suggest that the C-Cure remediation technique is very effective at reducing leachable and bioavailable heavy metals and mercury in contaminated mine wastes. Further work would be required to test and demonstrate the technique at a commercially relevant scale. The plan would be composed of several stages beginning with a detailed mapping of contaminant levels on five legacy mine sites and on six fresh mine process wastes. Targeted sampling and analysis will then be conducted to ascertain the leachable and bioavailable of metal contaminants followed by a lab based optimisation of the required amendment rate of the C-Cure products. This information will be used alongside other site data to form a conceptual site model of potential exposure and risk to human, livestock and ecological receptors. This material will be presented and reviewed with site stakeholders to establish site 'success criteria' for the field scale remediation activity. The consensus proposal would be used to select trial areas, set up and monitor field plots, and demonstrate and evaluate the efficacy, cost effectiveness, benefits, and other aspects of remediating the metal contamination using these innovative approaches.

Key conclusions and recommendations

Gentle remediation options provide significant opportunities for mitigation of risks from mercury. Mercury's complicated speciation behaviour means that it is one of the more difficult toxic elements to treat, so some GROs such as phytoextraction, may not be appropriate. However, *in* situ immobilisation does show promise, in particular for the protection of water resources from leaching from soil. Initial test work using C-=CURE biochars has provided a preliminary proof of concept. However, this needs to be better validated by a programme of field site studies. It seems likely that i*n situ* immobilisation will be enhanced by revegetation as an adjunct to provide soil stability and maintenance of pH and redox conditions. Vegetation cover should also be designed with human exposure minimisation as well, for example the use of non-food crops such as for energy or fibre, or for other purposes such as habitat / amenity.

Providing stable risk mitigation will facilitate re-use of the affected land, and renewable energy production could be a major re-use opportunity, for example in conjunction with local supply and community enterprise projects. A series of initial renewable energy feasibility studies carried out have confirmed the potential for approaches such as solar (Photovoltaic) energy.

The recommendation of this report is that field deployment test work should be initiated as a matter of urgency, given the potential GRO has for mercury problem mitigation in Colombia.

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1. Introduction

1.1 Project overview

The UK Prosperity Fund project in Colombia on Strategies for rehabilitating mercury-contaminated mining lands for renewable energy and other self-sustaining re-use strategies, operated from mid-2016 until early 2017. Its intent was to facilitate change by providing a range of science based strategies to rehabilitate land affected by soil mercury pollution in disadvantaged areas in Colombia while bringing this land back into productive use, focusing on renewable energy opportunities and/or other services as most appropriate. The project supports the FCO goals of increasing regional stability, facilitating sustainable economic growth, harnessing innovation in particular for low carbon development, supporting OECD accession, and identifying possibilities for new community enterprise (EA 2010).

Colombia's two most vital assets – social and natural capital – are at chronic risk after a half-century of conflict. Gold mining using unsafe recovery techniques has resulted in severe health and environmental impacts, largely from mercury at perhaps more than 7,000 locations. This project considers both risk mitigation and community enterprise opportunities for rehabilitated land.

The UK is at the forefront of research and practical investment in sustainable remediation, community engagement in regeneration, and brownfields[1] re-use for renewables, improved amenities and leisure. This integrated approach offers positive health and environmental benefits and sustainable economic growth including commercial and community enterprise opportunities in Colombia, benefits to UK partners for future business and influence, and possibilities for climate change adaptation and resiliency.

The project adapted UK, EU and US EPA thinking on brownfields rehabilitation for renewable energy and other soft re-uses for these gold mining areas impacted by mercury contamination. It combined structural and policy level research with site specific investigations (at locations identified in concert with the Colombian Environmental and Mining Ministries) to suggest high level policy and overview direction, design and decision support guidance, and proposals for further development at one or more sites. It evaluated and adapted innovative low input strategies for land management, sustainable remediation and commercial or community enterprise development (particularly for renewable energy) for these areas blighted by artisanal gold mining, connecting the science and technical base for policy in Colombia to the international state of the art.

The focus on mercury links directly to Colombia's current concerns under the Minamata Convention which it joined in 2013. In addition to desk top feasibility studies relating to renewable energy production on mining lands, the project conducted lab scale testing of mercury immobilisation techniques on samples from two locations in Colombia: Segovia in Antioquia and Tadó in Chocó. These two areas have a history of artisanal gold mining with its

[1] In this context, a brownfield describes degraded or previously used land that is not being redeveloped, for example, a former waste disposal site or former urban area.

associated environmental (including mercury) contamination and social impacts, and were selected in consultation with the Colombian Ministries of Environment and Mining.

The project provided three principal public domain outputs:

1. <<report Tile>> [*A plan for onsite field testing of techniques that promise to be replicable to other similarly contaminated sites, based on technology evaluations and bench scale test work*.]
2. <<report Tile>> [*Guidance and strategies for re-use of contaminated mining land, by transferring state of the art knowledge and successful implementation approaches from the UK, EU and North America, and adapting them to the local situation in Colombia.*]
3. <<report Tile>> [*A policy brief for regional and national governments in Colombia. The brief outlines strategies for dealing with contaminated mining sites and address policy commitments contained in Law 1658 of 2013, Colombia's commitment to the UN Minamata Convention (i.e. The Unique Plan of Mercury), the 2015 Paris Climate agreement, and Colombian accession to the OECD*].

1.2 Scope of the Output 1 Report

The purpose of Output 1 was to develop the design of an onsite field testing plan for techniques that promise to be replicable to other similarly contaminated sites. This design is based on the outcomes of the desk study and bench scale testing of the soil samples from the two sites selected in the project.

2. Overview of low input “gentle remediation" options for mercury

2.1 Gentle remediation concept

Gentle Remediation Options, or GROs, are defined as risk management strategies/technologies that result in a net gain (or at least no gross reduction) in soil function as well as achieving risk management (Cundy, et al., 2013). GROs encompass many technologies, including the use of plant (phyto), fungi (myco-), and/or bacteria-based methods, with or without chemical additives or soil amendments, which can be applied to reduce contaminant transfer to local receptors by in-situ stabilization (using biological and/or chemical processes), or extraction, transformation, or degradation of contaminants. Gentle remediation options, specifically those using plants and their associated soil microbial systems, can be deployed to remove the labile (or bioavailable) pool of inorganic contaminants from a site (phytoextraction), remove or degrade organic contaminants (e.g., phytodegradation), protect water resources (e.g., rhizofiltration), or stabilize or immobilize contaminants in the subsurface (e.g., phytostabilisation, in-situ immobilization/ phytoexclusion). These approaches are summarised in Table 1. Of these, phyto-extraction is perhaps the most widely known, particularly for heavy metal contaminants. A number of studies internationally have shown the potential of GROs to provide rapid risk management via pathway control, through containment and stabilization, coupled with a longer-term removal or immobilization/isolation of contaminants, using an approach which can be tailored along contaminant linkages (Figure 1). Notably, as the treated soils remain unsealed, GROs are highly applicable to soft-end use for a site, e.g. for urban or community park-land, renewables deployment, biomass generation etc. (Cundy, et al., 2016). Depending on the specific site situation GROs can have significantly lower deployment costs than conventional remediation technologies, and can also contribute strongly to sustainable remediation strategies, by providing a broad range of wider economic, social and environmental benefits (e.g. biomass generation, leisure and recreation, carbon sequestration, water filtration and drainage management, restoration of plant, microbial, and animal communities, (Vangronsveld *et al.* 1995, 2009; Witters *et al* 2012; Cundy, *et al.,* 2013; Cundy, *et al.,* 2015). These potential benefits, and decision support tools aiding their identification and quantification, have been summarised in the outputs of the EU Greenland and HOMBRE projects (www.greenland-project.eu; www.zerobrownfields.eu), particularly the HOMBRE Brownfield Opportunity Matrix (BOM, discussed further in Output 2 Report[2]).

Table 1. Examples of Gentle Remediation Options used to remediate soils contaminated by either metal(loid)s or mixed contamination (from (Cundy, et al., 2016)).

GRO	Description
Phytoextraction	The removal of metal(loid)s or organics from soils by accumulating them in the harvestable biomass of plants. When aided by use of soil amendments (e.g. EDTA or other metal-mobilising agents), this is termed “aided phytoextraction”.

[2] Guidance and Strategies for Re-use of Land by Transferring State of the Art Knowledge. www.r3environmental.com.co/descargas

GRO	Description
Phytodegradation / phytotransformation	The use of plants (and associated microorganisms such as rhizosphere and endophytic bacteria) to uptake, store and degrade organic pollutants.
Rhizodegradation	The use of plant roots and rhizosphere microorganisms to degrade organic pollutants.
Rhizofiltration	The removal of metal(loid)s or organics from aqueous sources (including groundwater) by plant roots and associated microorganisms.
Phytostabilization	Reduction in the bioavailability of pollutants by immobilisation in root systems and/or living or dead biomass in the rhizosphere soil – creating a substrate which enables the growth of a vegetation cover. When aided by use of soil amendments, this is termed “aided phytostabilization”.
Phytovolatilization	Use of plants to remove pollutants from the growth matrix, transform them and disperse them (or their derived products) into the atmosphere.
In situ immobilization / phytoexclusion	Reduction in the bioavailability of pollutants by immobilizing or binding them to the soil matrix through the incorporation into the soil of organic or inorganic compounds, singly or in combination, to prevent the excessive uptake of essential elements and non-essential contaminants into the food chain. Phytoexclusion, the implementation of a stable vegetation cover using excluder plants which do not accumulate contaminants in the harvestable plant biomass, can be combined with *in situ* immobilization.

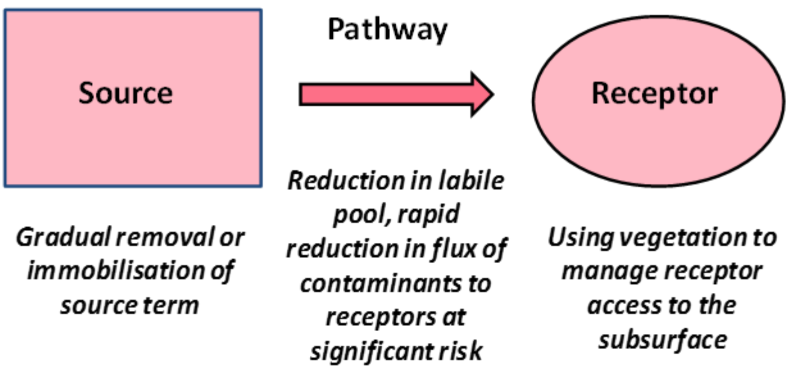


Figure 1. Example GRO-based risk management strategy, tailored along contaminant linkages (Cundy, et al., 2015).

2.2 Techniques of low input remediation

2.2.1 Phytotechnologies

In most contaminated soils and mine tailings, mercury (Hg) is not readily available for plant uptake (Moreno, *et al.* 2004). A range of studies on sites contaminated by artisanal mine workings have shown that Hg is present in oxygenated soils, sediments and tailings dominantly as elemental mercury (which may be bound to sulphur and Fe/Mn oxides in soils and sediments), or bound to organic matter (e.g. in sediments, (Pinedo-Hernandez, *et al*. 2014)), and has relatively low bioavailability. This effectively limits a direct phytoextraction approach, although a number of authors have examined the potential for induced Hg uptake in plants following addition of complexants (e.g. sulphur containing ligands which bind Hg and enhance its mobility and plant availability, in aided phytoextraction approaches, (Moreno, *et al.* 2004)) to contaminated soils. There are significant concerns however over Hg leaching and volatilization to air in this type of approach, and indeed over the subsequent use of Hg-containing biomass (for fuel, animal fodder etc.). (Kennen & Kirkwood, 2015) note in a recent review of phytotechnologies that Hg is considered a difficult to extract metal for plant uptake, and argue that the most effective plant-based approach to its remediation or management is through stabilising Hg on-site (via phytostabilisation or aided phytostabilisation, depending on site Hg concentrations) or by physically filtering Hg-containing particles from water. In the former approach, it may be necessary to stabilise the Hg and co-contaminants from mining activity in the soil prior to plant growth, due to soil phytoxicity. A range of soil amendments may be used for this purpose, including compost, biochars and activated carbons (discussed below), and organic-mineral mixtures.

2.2.2 Biochars and activated carbons

Biochars and activated carbons show good potential for Hg adsorption and stabilisation, given the strong association of Hg species with carbon and with other elements such as sulphur and iron which may be present in biochars or associated with active carbon surfaces. Hg immobilisation is controlled both by the form of the mercury (i.e. its speciation) and the characteristics of the biochar or activated carbon used, such as active surface area, surface chemistry, and pore size distribution. (Gomez-Eyles, et al., 2013) compared Hg sorption by a range of commercially-available and laboratory synthesised biochars and activated carbons and noted that while steam activated carbons were significantly more effective than biochars in sorption of Hg, both showed a similar (strong) adsorption performance for methyl Hg (MeHg). Notably, biochar can potentially be used in combination with phytoremediation in an aided phytostabilisation / soil improvement approach (mentioned above), where biochar is used to immobilise heavy metals (including Hg) and simultaneously acts as a soil conditioner to enhance plant establishment and growth (e.g. (Paz-Ferreiro *et al*, 2014)). This in turn prevents soil erosion and reworking, increases soil organic matter, and improves soil structure.

3. Description of Colombia Mining Sites and Samples Evaluated in Lab Studies

This Section briefly describes the two mining-related sites from which multiple samples were taken and laboratory analysis was conducted to determine the potential for treatment of mercury and other metal contamination (See Section 4). While this Section summarizes the background for site and sample selection in the context of the current and past mining activities as well as risks at these sites, Annex 2 provides a comprehensive profile of each site in terms of economic, social, environmental, ecological and other dimensions.

3.1 Site Selection

UK based lab scale testing of mercury immobilisation (using metal-adsorbing biochars developed previously by C-Cure) was carried out on soil samples from sites in two Municipalities in Colombia: Segovia in the department of Antioquia and Tadó in Chocó. These municipalities were selected in concert with the Mines Ministry and the Environmental and Sustainable Development Ministry (MADS) given their history of artisanal mining and associated mercury use. In addition, personnel security for r3 Colombia staff was also an important factor in selecting areas to take soil samples.

Initial samples were taken from areas where gold is being currently extracted or had been in the past (abandoned sites). Along with the guidance of the community leaders from the two areas, identification of specific locations was made in Segovia in concert with staff from the municipal government, who are part of the “Agricultural, Mines and Environmental Direction”-DAMMA, and made in Tadó in a gold mining area abandoned about 8 years ago.

3.1.1 Description of Site 1: Segovia, Antioquia

Segovia is a municipality located in the department of Antioquia, located 227 km northeast of the department capital within the region known as the coffee zone; covering an area of 1,231 km^2 (Mayoralty of Segovia, 2008), or about 2% of the departmental territory (DNP, 2015). Figure 2 shows the location of Segovia in the Department of Antioquia and in Colombia.

Figure 2. Location of the Municipality of Segovia at national and departmental level. Source: Ecodes Ingeniería, 2016.

The three most important sectors in the economy of the municipality of Segovia are, the mining of metal ores, which accounts for 42.52% of the municipal per capita added value, services activity companies (10.22%), and trade (7%) (DNP, 2015). Gold mining is the most significant mining activity, as the city produces 39.4% of all gold mined at the regional level and 6.66% nationally (Mayoralty of Segovia - Antioquia, 2012). Segovia is a traditional mining town with an estimated production of more than 3000 kg of gold and over 1,700 kg of silver per year (DAMMA, 2008).

Figure 3. Main sector in the economy. Source: r3 Environmental Technology Colombia SAS, 2016.

The mining economy is largely dependent on artisanal mining and some more technological advances which have developed through history.

According to DAMMA, one hundred twenty-three thousand hectares are identified as suitable for mining exploitation; however, the development of this activity has been carried out in an unsustainable way due to the implementation of inappropriate techniques with a high impact on natural resources. In addition, of 150 gold underground mining sites, only 10 mining units are operating legally (DAMMA, 2008).

Threats and Risks

According to a report on public health risks made to the Planning Office of Segovia, nine risk factors for the local population have been identified: the first is the contamination of water sources by receiving wastewater (both domestic and commercial and industrial (mining beneficiation plants, car washes)) and solid waste, air pollution caused by gold processing, trash and firewood for cooking, and noise and smog from cars in urban areas. In addition, 80% of the sample population has levels of mercury above acceptable levels in urine samples, and the remaining 20% are people are contaminated with levels very close to the allowable limit (Mayoralty of Segovia, 2008).

3.1.2 Description Site 2: Tadó, Chocó

Tadó is located to the northeast of the department of Choco Colombia about 68 km from the provincial capital, Quibdó (Agualimpia Caicedo, 2012). Figure 4 shows the location of the town at the national and departmental levels.

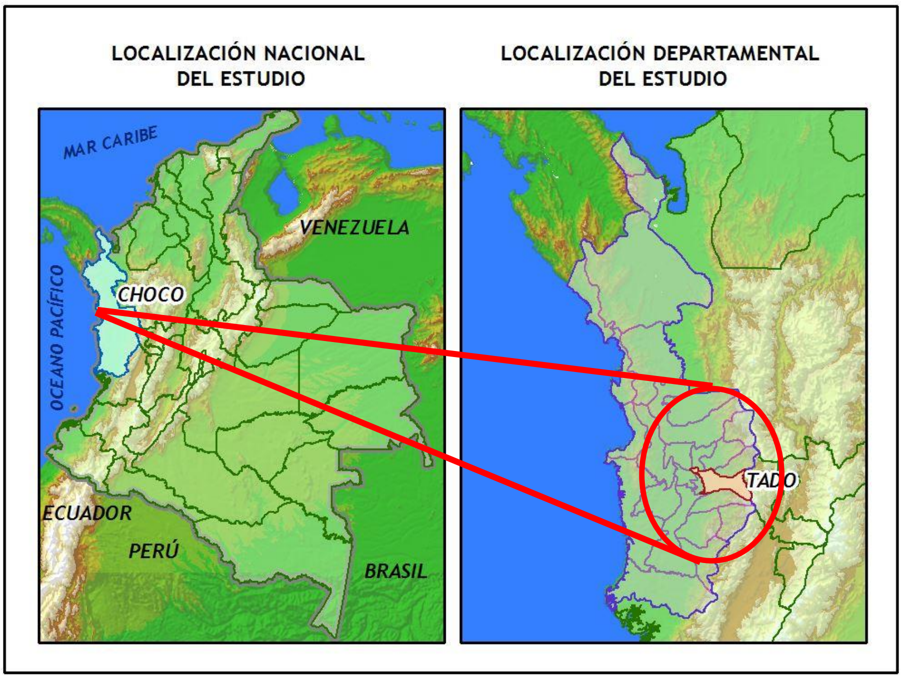


Figure 4. Location of San José de Tadó (Tadó). Source: R3 Environmental Technology Colombia SAS, 2016.

Context of Gold Mining in Tadó

Tadó has great gold mineral wealth given the alluvium located in the basin of the San Juan River and its tributaries, although it also produces minerals such as copper, coal, lead, zinc and oil (Palacios Perea, EOT Tadó, 2000). This resource is usually mined by artisanal methods, i.e. by proprietary technologies or “ethnotechnologies”, as “barequeo” or “mazamorreo” as shown in Figure 5. These involve moving only small volumes of gold-bearing gravels which facilitates the assimilation and natural resilience of the different environmental matrices affected. However, the rise in gold prices has led to the introduction of heavier, mechanical technologies that accompanied the arrival of medium and large businesses with associated greater environmental impacts.

According to data from the official mineral production in Colombia, provided by the Colombian Mining Information System (SIMCO), the municipality of Tadó has the sixth largest gold production in the department of Chocó: 751.73 Kg of gold per year (CODECHOCÓ, 2014). However, these data do not consider the artisanal gold mining; which is estimated to increase these values.

Figure 5. People around trying to extract gold in abandoned sites. Source: R3 Environmental Technology Colombia SAS, 2016.

Per the environmental authority of the Chocó Department reports, in 2010 each mining settlement consumed 30 Kg of mercury per year. It must be said that environmental authorities detected the presence of 70 illegal mechanic settlements with backhoes (GOMIAN, 2014). Additionally, it is estimated that the annual deforestation because of gold mining in the San Juan zone (in which Tadó is located) is close to 50.000 hectares (GOMIAN, 2014).

Threats and Risks

In Tadó, artisanal mining, also known as subsistence mining, is carried out illegally; in addition, more exploration and opencast mining medium farms have been developed (Palacios Perea, EOT Tadó, 2000). These activities have caused environmental crimes, forced displacement, killings, child labour, among other unlawful conduct (Palacios Murillo & Rengifo Arias, 2014).

In response to these risks, the respective entities in the local area have formulated the Management Plan and Environmental Management of Mining, with guidelines and regulations to reduce the impacts and illegality; to increase sustainability; to require back filling and land reclamation, to add farm registry. These changes are to aid the growth of royalties, formal employment and income for the people of Tadó (Agualimpia Caicedo, 2012). Still, the public has appeared unsatisfied, arguing that the management of formalization and legalization of mining ignores the remediation of past activities. They point out that "the basin of the Atrato River passes through a remarkable crisis in socio-environmental ", and demand lasting solutions to protect the rights of the population at high risk.

3.2 Sampling

3.2.1 Segovia, Antioquia

Taking into account previous information on gold mining and in consultation with local authorities, two sampling sites were selected: at the first, corresponding to a currently developed mine, three samples were taken; at the second site, a mine was chosen at which machinery was used to extract the metals. Annex 3 contains a detailed description of the context and locations for each of the six samples.

3.2.2 Tadó, Chocó

A gold mining area abandoned about 8 years ago, was the selected site for soil sampling. This site is located in the rural area of Tadó and covers an area of almost 1 Km^2.

Figure 6 shows the distribution of the samples. A total of six (6) samples were taken: four (4) of which are located in representative areas of the site and two (2) of them near the houses of the inhabitants of the area. A detailed description of each sample is found in Annex 2.

Figure 6. Distribution of samples points. Rural area of Tadó. Source: R3 Environmental Technology Colombia SAS, 2016.

4. Bench Scale Assessment of C-Cure Carbons for the Treatment of Mercury Impacted Soils

4.1 The C-Cure Technology

The technologies licenced to C-Cure are designed to accelerate the degradation of organic pollutants via bio-remediation or to immobilise pollutants, including heavy metals by adsorbing them. Once adsorbed onto C-Cure products, pollutants are no longer leachable and don't interfere with biological processes (de-toxification). In the case of heavy metals, the C-Cure treatment does not reduce the total concentration of heavy metals, but instead, makes those metals non-bio-available and non-leachable. This means that application of the C-Cure products to contaminated soil ensures that pollutant – receptor pathways are broken, so that pollutants no longer leach into ground and surface waters, and are no longer taken up by plants or cause eco-toxicity. Depending on the soil conditions, adsorption of most heavy metals onto the C-Cure products is irreversible and stable, but even if soil conditions could lead to desorption (such as low soil pH) the pore structure of the products ensures that the conditions within the product is buffered from external soil conditions. Under unfavourable conditions it was shown that metal desorption from charcoal particles that were 2 mm in diameter was 2000 times slower than metal desorption from lime.

Furthermore, detoxification of soil leads to restoration of normal soil function and allows revegetation to take place. Both adsorption of metals and subsequent ecological restoration ensure sustainable land regeneration of contaminated soil.

4.2 Aims

The aims of this part of the project were as follows:

- Assess the concentrations of leachable mercury and other metals in soil samples taken from two mine site locations in Segovia.
- Assess the total concentrations of mercury and other metals in soil samples taken from the same two locations in Segovia
- Determine in which chemical form (leachable, organic bound, methyl mercury, elementary or sulphur bound) the mercury was present within the most contaminated soil sample for mercury.
- Test the ability of C-Cure products to reduce the risk of leachable and stomach acid extractable mercury in the most mercury contaminated soil sample.
- Test the ability of C-Cure products to reduce leachability of heavy metals other than mercury.

4.3 Environmental Quality Standards for Mercury and other Heavy Metals

To assess the risks associated with contaminated soil there are a number of International Environmental Quality Standards (EQS) in use that use a variety of criteria to determine if the levels of heavy metals found in soil pose an acceptable risk to humans and the environment.

These include Soil Guideline Values (SGV), Waste Acceptance Criteria (WAC) and EU Water Framework Directive (WFD).

Soil Guideline Values (SGV) and supporting technical guidance notes are intended to assist professionals in the assessment of long-term risk to health from human exposure to chemical contamination in soil (EA, 2009). There are different SGVs according to land-use (residential, allotments, commercial) because people are exposed to land differently and this affects who and how people may be exposed to soil contamination. SGV are 'trigger values' for screening-out low risk areas of land contamination. They give an indication of representative average levels of chemicals in soil below which the long-term health risks are likely to be minimal. Exceeding an SGV does not mean that remediation is always necessary, but should trigger further investigations and a further evaluation of the risk a given contaminant might pose. SGV values are expressed as total concentration per kg soil [mg/kg] and, therefore, don't take into account the mobility or bio-availability of a given element. Mobility of heavy metals (and therefore the risk they pose to human health) is largely dependent on environmental factors, including soil type and soil pH.

The Waste Acceptance Criteria (WAC) (EA, 2010) were introduced in the UK to ensure that potentially hazardous waste is safely disposed of so that it no longer poses a risk to humans and the environment. Unlike the Soil Guideline Values, which base risk on 'total metal concentrations' combined with land use or soil pH, Waste Acceptance Criteria assess the risks that contaminated materials pose to the environment and human receptors on water leachable concentrations of contaminants and their inherent toxicity. The WAC have been set as maximum limit values which must not be exceeded to allow characterisation of a specific waste stream into three different hazard classes. The different WAC classes are: 'Inert non-hazardous waste', 'Stable, non-reactive hazardous waste' and 'Hazardous waste'. Waste that falls into each class requires different levels of containment and management; waste classified as hazardous waste requires the most stringent measures and monitoring, while waste that is classified as 'inert' requires minimal containment, management and monitoring.

The EU Water Framework Directive, 2000/60/EC (EU WFD) is the most significant legal instrument in the water field that has been developed by the EU to protect surface waters from pollution. The key objectives of the WFD are general protection of the aquatic ecology, specific protection of unique and valuable habitats, protection of drinking water resources, and protection of bathing water.

4.4 Samples and Sample Analysis

Six samples were taken from each of two different sites in Segovia with a history of gold mining (as seen in the Annex 3). The first set of 6 samples were taken from an area where active mining was taking place. These samples were labelled S1 to S6. The second set of samples were taken from Tadó in Chocó, a site where mining had ceased. These samples were labelled T1 to T6.

Each of the samples was assessed for total metal concentrations and leachable metal concentrations using standard procedures. Subsequently samples that contained the highest concentrations of mercury were extracted using a sequential extraction procedure to determine if the mercury was (a) water soluble, (b) stomach acid soluble (c) bound to organic matter, (d) in an elementary form or (e) present as mercury sulphide.

4.5 Mercury Contamination

All samples taken from Segovia where soil was being processed for gold recovery (Samples S1-S6) showed elevated concentrations of mercury, with levels in samples S1, S2, S5 and S6 being more than 10mg Hg/kg soil, S3 being 60mg Hg/kg soil and S4 being 360mg Hg/kg soil. According to the Soil Guideline Values (SGV), soils that contains >26 mg Hg/kg soil would be deemed unsuitable for any form of land use unless the pollutant linkages and associated risks were assessed further, while soil that contains >10mg Hg/kg soil should not be used for building houses on unless the pollutant linkages and associated risks were assessed further. All of the Segovia (S1 to S6) samples would exceed the SGV for residential land use, warranting further investigation of potential pollutant linkages.

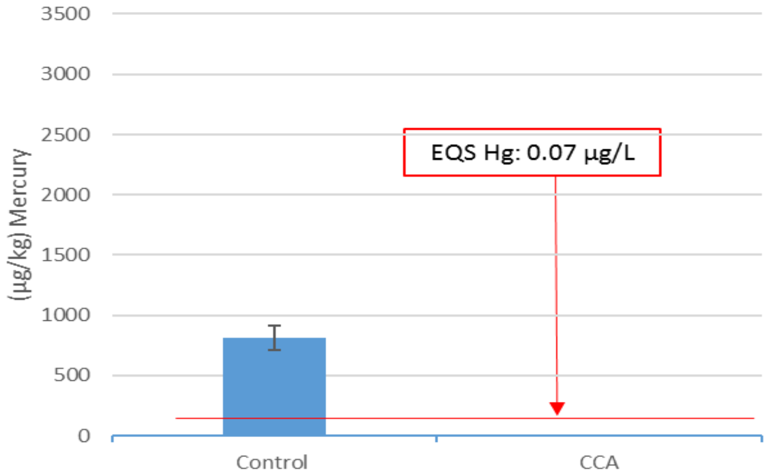
In contrast the total concentrations of mercury in the samples taken from Tadó (Samples T1-T6) where between 0.16 and 1.6mg/kg. These values are well below the Soil Guideline Values (SGV) for residential (SGV < 10mg/kg) allotment and commercial (SGV < 26mg/kg) land use. Only samples T1, T3 and T4 had concentrations of mercury that were above the SGV value for agricultural land use (SGV < 1mg/kg) (Figure 28 in the Annex 3). Similarly, none of the samples taken from Tadó were contaminated with significant amounts of other heavy metals (Table 8 in Annex 3).

From the total amount of mercury found in the different samples, < 0.1% was water soluble. In sample 4S this amounted to 0.38mg/kg mercury, which would classify this material as hazardous according to WAC regulations. Samples 1T, 5T and 6T also exceeded WAC for inert waste.

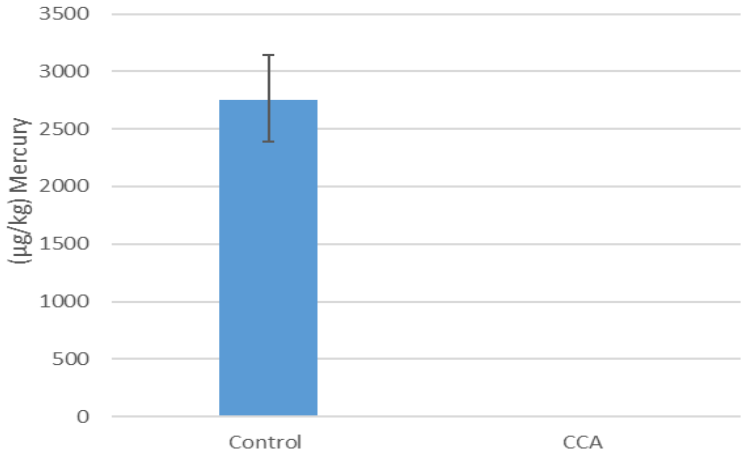
4.6 Treatment of Mercury Contamination using C-Cure Products

Because soil sample 4S had both the highest total Hg concentration (361 mg/kg) and highest leachable Hg concentration (383 µg/kg) it was used to test treatment with C-Cure-CCA treatment product.

Sequential analyses showed that sample S4 contained no organic-matter bound mercury or methyl mercury, but did contain 812 µg/kg of water soluble and 2755 µg/kg of human stomach acid soluble mercury (Figure 7). Treatment with the C-Cure-CCA product at an amendment rate of 5% (w/w) resulted in all of the water soluble and human stomach acid soluble mercury being stabilised in the soil (Figure 7). In the CCA treated soil most (72%) of the mercury was found to be extractable with 10M HNO3, which represents elemental mercury. In the non-treated soil the percentage 10M HNO_3 extractable mercury was 51%



a) Water Soluble Mercury



b) Human Stomach Acid Soluble Mercury

Figure 7. Amounts of water soluble (a) and human stomach acid soluble (b), in soil taken from sampling site S4 in the control sample and samples treated with 5% (w/w) C-Cure product (CCA). N=2.

A further test aimed at quantifying the minimum amount of C-Cure product that was needed to bind all the water soluble and stomach acid soluble mercury showed that an amendment rate of 0.5% (w/w) reduced the concentration of water soluble mercury by 80%, while a 1% amendment rate resulted in the complete elimination of water soluble mercury (Figure 8).

To remove all stomach acid soluble mercury an amendment rate of 5% was needed while an amendment rate of 3% (w/w) eliminated 95% of all the stomach acid soluble mercury from the soil (Figure 9).

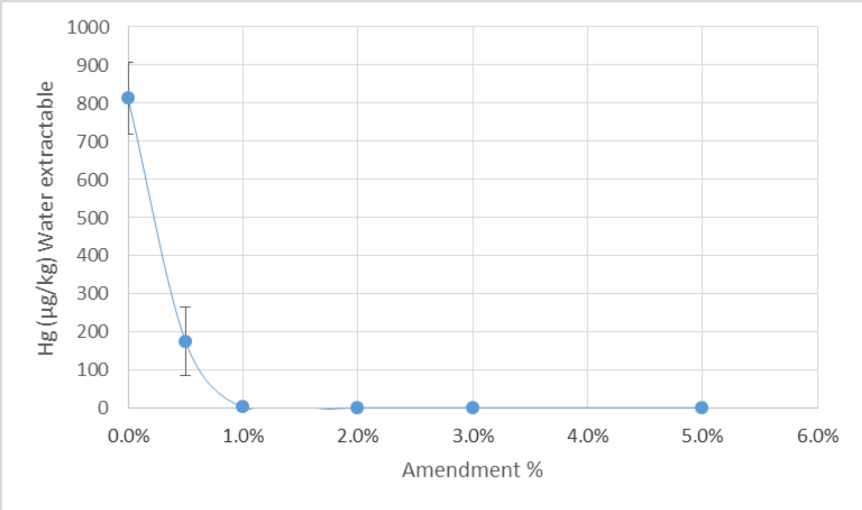


Figure 8. Concentrations (µg/kg) of water soluble mercury, in soil taken from sampling site S4 amended with increasing amounts (0, 0.5, 1, 2, 3, and 5% w/w) C-Cure product (CCA). N=2.

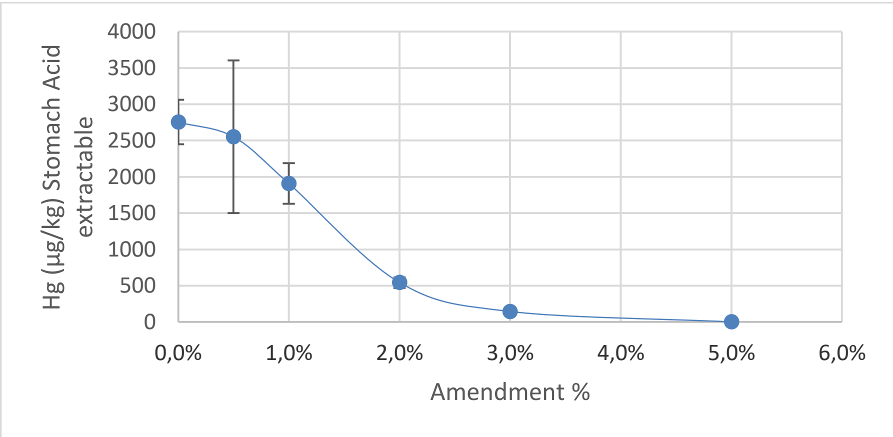


Figure 9. Concentrations (µg/kg) of stomach acid soluble mercury, in soil taken from sampling site S4 amended with increasing amounts (0, 0.5, 1, 2, 3, and 5% w/w) C-Cure product (CCA). N=2.

4.7 Heavy Metal Contamination

The most contaminated sample with respect to levels of leachable heavy metals was sample 3S. Leachability of cadmium, lead and zinc in this sample exceeded the EU Waste Acceptance Criteria (WAC) for hazardous waste, meaning that the soil at sampling site S3 would be too toxic to be put in a specially designed hazardous waste site. The next most contaminated sample was S2, which would be classified as hazardous waste based on the levels of leachable Zn. Sample S5 had concentrations of cadmium that were above the WAC Inert concentration. Most samples were contaminated sufficiently to cause water pollution if the soil was to enter a river or lake.

Soil sample S3 had some of the highest concentrations of leachable aluminium (41 mg/kg), cadmium (32 mg/kg), iron (1.66 mg/kg), lead (109 mg/kg) and zinc (898.7 mg/kg) concentrations of all the samples tested (Table 2). In fact, the leachable concentrations of cadmium, lead and zinc would make this soil too toxic to be landfilled in a specially designed hazardous landfill site.

4.8 Treatment of Heavy Metal Contamination using C-Cure Products

Sample S3 was therefore used to test C-Cure's standard heavy metal treatment product (C-Cure-TTLX).

The soil was treated using different amendment rates of approx. 2.3% wet weight (w/w), 4.4% (w/w), 6.7% (w/w) and 8.9% (w/w) on a soil dry-weight basis. These concentrations are equivalent to amendment rates of 2.5, 5.0, 7.5 and 10% (w/w) on a wet-weight basis [as supplied]. Table 2 shows the percentage reduction for each of nine metals when treated with the indicated percentages of C-Cure product.

Table 2. Percentage reductions in leachable metal concentrations after treatment with different amounts of C-Cure metal adsorbent product.

Metal	C-Cure Product Application Rate [% w/w]			
	2.3	**4.4**	**6.7**	**8.9**
Aluminium (Al)	97.8	100.0	100.0	100.0
Arsenic (As)	99.4	98.3	98.0	98.0
Cadmium (Cd)	0.0	84.6	94.7	95.9
Chromium (Cr)	98.0	98.1	98.1	98.5
Copper (Cu)	94.7	99.2	98.8	98.9
Iron (Fe)	100.0	100.0	100.0	100.0
Nickel (Ni)	4.7	86.5	94.2	91.4
Lead (Pb)	19.6	97.1	97.8	98.7
Zinc (Zn)	9.6	93.5	97.7	96.9

The following is a detailed discussion of the concentrations of the nine metals resulting from the treatment with various amendment levels of C-Cure product. As shown in Table 3, depending on the metal, different amendment levels of the C-Cure product were successful in reducing concentrations of a majority of the metals to be classified as inert according to UK WAC criteria.

Water leachable concentrations of aluminium went from 947 mg/kg in the untreated soil to less than 0.01 mg/kg in soil that was amended with >4.4% C-Cure product, a reduction of 99.999% (Table 2). This meant that the treated samples would comply with the most stringent EQS (Table 3).

Leachable nickel was reduced by 94% using the C-Cure treatment. Leachable concentrations went from 2.1mg Ni/kg soil to 0.12 mg Ni/kg soil with an amendment rate of 6.7% C-Cure product (Table 2). This value would classify the material as 'inert' according to the UK WAC (Table 3).

The concentration of leachable copper went from more than 14mg/kg to 0.114mg/kg with an amendment rate of 4.4%, a reduction of 99.2%. This decrease brought the soil to below the WAC for inert waste. Increasing the amendment rate above 4.4% did not result in significant further reductions of leachable copper (Table 2).

The concentration of leachable iron went from more than 1500mg/kg soil in the non-treated control to 0.1mg/kg in soil amended with an amendment rate of 2.3% or more; a reduction of 99.99% (Table 2). This concentration was well below the concentration of leachable iron that would be acceptable for classification as inert waste according to the WAC (Table 3).

The concentration of leachable lead went from more than 26 mg/kg in the non-treated control to 0.34 mg/kg in soil amended with 8.9% C-Cure product; a reduction of 98.7%. A similar reduction in leachable lead was achieved with half the amendment rate (Table 2). The non-treated soil would be classified as hazardous according to WAC. However, after treatment the remaining concentration of leachable lead in the C-Cure treated soil would allow the soil to be classified as inert waste according to the WAC criteria (Table 3).

The concentration of leachable zinc went from more than 2000mg/kg in the non-treated control to around 50 mg/kg in soil amended with >6.7% C-Cure product. Whereas the remaining leachable Zn is still regarded as hazardous, the soils hazard class was reduced from 'above hazardous' to 'Stable Non-Reactive Hazardous waste' (Table 3).

The concentration of leachable cadmium went from 85.8 mg/kg to 3.5 mg/kg with an amendment of 8.9% TTLX, a reduction of 96% (Table 2). This reduction was sufficient to reduce the hazard class of the soil from 9x over the hazardous waste class, to well within the hazardous waste category according to WAC (Table 3).

The concentration of leachable chromium went from more than 2 mg/kg to 0.114mg/kg with an amendment rate of 4.4%, a reduction of 99.2%. This meant that the hazard classification of this soil went from 'non-reactive hazardous waste' to 'inert' (Table 3).

The non-treated S3 sample contained 2000µg leachable arsenic per kg soil. A 2.5% amendment rate with C-Cure product resulted in the almost complete removal of leachable arsenic (Table 2). Adding more C-Cure-TTLX product resulted in a gradual small rise in as leachability from 12µg/kg at an amendment rate of 2.3% (w/w) to 42µg/kg at an amendment rate of 10% (w/w). This meant that the treated sample could be classified as 'inert' according to WAC. Also, the low levels of leachable arsenic in the treated sample meant that this sample would not cause water pollution according to WFD criteria.

Table 3. Summary of metal concentrations in treated and non-treated samples and hazard classification before and after treatment with different amounts of C-Cure metal adsorbent product. Unless specified differently hazard classifications are based on WAC where green shading represents 'inert waste' yellow shading represents 'Stable Non-Reactive Hazardous Waste', amber shading represents 'hazardous waste' and red represents waste that is too toxic for acceptance in a hazardous landfill site.

Element	Amendment Rate (% w/w)				
	0 (control)	2.3%	4.4%	6.7%	8.9%
Al*[µg/kg]	946733	20487	90	333	0
As [µg/kg]	2092	12	36	42	41
Cd [µg/kg]	85785	86663	13225	4534	3513
Cr [µg/kg]	2167	44	41	40	32
Cu[µg/kg]	14043	738	114	175	148
Fe* [µg/kg]	1519008	668	92	105	121
Ni [µg/kg]	2076	1978	281	121	179
Pb [µg/kg]	26607	21392	767	584	338
Zn [µg/kg]	2092372	1891961	136821	48919	64837

EQS based on EU Water Framework guidelines

5. Proposed Plan for On-site Testing of Gentle Remediation and Renewables in Colombia

A range of potential gentle remediation options are of potential use, including both phytoremediation and *in situ* stabilisation approaches. Renewable energy options include biomass, wind and photovoltaics. This section proposes two testing plans as case studies: the use of modified chars produced by C-CURE as a GRO case study, and next steps for photovoltaic deployment as a renewables case study.

5.1 On site testing of modified (bio)chars

5.1.1 Project Duration

Estimated as 18 months

5.1.2 Objectives and Introduction

Preliminary results suggest that the C-Cure remediation technique is very effective at reducing leachable and bioavailable heavy metals and mercury in contaminated mine wastes. However, work to date was based on laboratory assessment on a very limited number of samples. Further work would be required to test and demonstrate the technique at a commercially relevant scale. This proposed project plan would begin with a detailed mapping of total contaminant levels on five legacy mine sites and on six fresh mine process wastes. Targeted sampling and analysis will then be conducted to ascertain the leachability and bioavailability of contaminants followed by a lab based optimisation of amendment rate of the C-Cure products. This information will be used alongside other site data to form a conceptual site model of potential exposure and risk to human, livestock and ecological receptors. This material will be presented and reviewed with site stakeholders to establish site 'success criteria' for the remediation activity. The resulting proposal will be used to select trial areas to set up and monitor field plots demonstrating the efficacy of the technique.

5.1.3 Project Outputs

The project will provide the following outputs:

1. A map of five sites showing total heavy metal levels based on the field survey data
2. A site report against Project Success Criteria providing costed specification for deployment at full-scale for the selected sites used in the field trial
3. Case studies for the trial sites detailing the approach, demonstrating the effectiveness of the technique, and the wider benefits to the local people and environmental quality.
4. A market viability and local benefits assessment for widespread use of the technique in Colombia.
5. Deployment plans for the technique including business partnerships, training needs, logistical planning, production needs, and employment opportunities.

Work Package 1: Site Investigation of Legacy Mine Waste Deposits

1.1 Conduct on-site survey of total heavy metal levels using Field Portable(FP) XRF on five sites suspected of requiring remediation. Samples will be taken based on a grid sampling [minimum 30 samples] and on potential point sources [e.g. distinct features such as fine tailings deposits]. Bulked samples will be analysed from the surface to 50 cm depth. Pit sampling will be conducted at 3 to 4 locations to ascertain the total depth of material deposits. The stoniness and texture of the material will be quantified via observation at each sampling location.

1.2 Document and map location of site features/potential contaminant sources [e.g. watercourses, waste tips, process waters], potential receptors [e.g. houses, workers, livestock, crops, waters, ecological], and pathways [e.g. wind erosion, water erosion, leaching, plant uptake, volatilisation] by which contaminants could travel directly or indirectly from sources to receptors.

1.3 Develop a map overlay of total contaminant levels and stoniness/texture based on 1.1.

1.4 Identify potential pollutant linkages within a Conceptual Site Model based upon 1.1 to 1.3.

1.5 Identify seven potential 2 by 2 m target areas for remediation and pilot trials to provide a range of contamination types and levels based on 1.1 to 1.4. Conduct targeted soil sampling of materials for specific suspected contaminated areas, and analyse fine fraction (<2mm) samples for leachable metals and stomach extractable mercury. A minimum of 6 sampling point will be used per 2 by 2 m plot.

Work Package 2: Assessment of 'Fresh' Mine Waste

2.1 Analyse six fresh mine process wastes using FPXRF.

2.2 Conduct laboratory analyses of selected four fresh mine process wastes [based on results of 2.1] to determine leachable levels of heavy metals and stomach acid extractable mercury.

Work Package 3: Setting Site Success Criteria through Stakeholder Engagement

3.1 Present and review site investigation data and identify Contaminants of Concern (CoCs), pollutant linkages and pollutant pathways.

3.2 Utilise the results from Work Package 1 to select five trial areas and three fresh wastes to represent a broad spread of material types and properties.

3.3 Agree upon Project Success Criteria with the client, site owner, regulator and/or wider stakeholders: This should include:

a. Target concentrations in treated or receptor media [e.g. concentrations of leachable soil contaminants; reductions in concentrations of specific metal species; reductions in human ingestion potential; reductions in soil erodibility through re-vegetation]
b. Re-vegetation success [e.g. ground coverage attained; plant or biomass growth; contaminant concentrations in plant tissues]
c. An appraisal of social, economic and environmental benefits. At minimum, this should include benefits to the local people and local economy or, 'Local Content'. This should include employment opportunities of remediation and monitoring activities, reductions in contaminant exposure, environmental health improvements, benefits to the wider economy and secondary benefits such as facilitating more people leaving poverty and being able to access education. Environmental health improvements should consider ecological and human impacts, and be delineated by demographic groups of the local population. The

results of this exercise should be transferrable and scalable to a widespread deployment of the technology [See Work Package 6].

Work Package 4: Laboratory Optimisation and Preparation for Field Demonstration

4.1 Assess optimal C-Cure amendment type and application rate using laboratory studies for delineated areas on legacy wastes and fresh mine process wastes of contaminant type, levels and leaching behaviour.
4.2 Select five 2 x 2 m site areas [plots] for demonstration and fence to prevent damage from grazing animals. At least one of the plots should be constructed of fresh mine process waste.
4.3 Assess plant suitability for establishment based on the soil nutrient regime, texture, water holding capacity, pH, EC, rooting depth etc.
4.4 Address shortfalls in plant nutrient requirements or water holding capacity of the soil by selection of appropriate co-amendment [e.g. compost materials, mineral fertiliser]. Application rates of fertilising materials should be based on target plant species and should account for the presence of local features e.g. watercourses, drainage ditches, drinking water supplies.
4.5 Assess site accessibility for plant and machinery.
4.6 Specify appropriate mixing method.

Work Package 5. Field Trial Establishment

1.1 Cultivate soil in the Plots. Cultivation depth should be determined by target rooting depth of the vegetation to be established plus 20cm.
1.2 Amend C-Cure products and additional fertiliser materials to target treatment depth for the selected vegetation. Optimal application rates should have been predetermined in laboratory testing [Work Package 3].
1.3 Seed plots.

Work Package 6. Monitoring and Evaluation

Typically, samples of soil and water [where water is being monitored] should be taken at a minimum of three intervals [start, middle, end] and vegetation [mid trial, end of trial]. Samples should be replicated or at minimum made up of bulked samples. The trial will be run for one complete growing season.

6.1 Monitor leachable concentrations of CoCs and/or speciation of metals in soil material samples from the five trial plots. Samples will be taken from outside the plot areas as controls.
6.2 Monitor vegetation establishment, growth [height and/or biomass], ground coverage, and uptake of CoCs into the above-ground biomass.
6.3 Monitor or model changes in pollutant linkages based on field measurements and sample analyses.

Work Package 7. Results Reporting and Dissemination

7.1 Report against Project Success Criteria and provide costed specification for deployment at full-scale.

7.2 Develop case studies for the trial sites detailing the approach, demonstrating the effectiveness of the technique, and the wider benefits to the local people and environmental quality.
7.3 Conduct a market viability and local benefits assessment for widespread use of the technique in Colombia.
7.4 Develop deployment plans for the technique including business partnerships, training needs, logistical planning, production needs, and employment opportunities.

5.1.4 Cost Estimates of Proposed On-Site Testing Programme:

Work Package	Timing	Cost (£k GBP)
WP 1: Site Investigation of Legacy Mine Waste Sites	Months 1 to 3	45
WP 2: Assessment of 'Fresh' Mine Waste	Months 1 to 3	5
WP 3: Setting Site Success Criteria through Stakeholder Engagement	Month 1, 3, 6, 9, 12, 15, 18	19
WP 4: Laboratory Optimisation and Preparation for Field Demonstration	Months 4 to 6	42
WP 5: Field Trial Establishment	Month 7	45
WP 6: Monitoring and Evaluation	Month 8 to 16	60
WP 7: Results Reporting and Dissemination	Months 6, 12, 18	32
	Total	£248k

A more detailed breakdown of activities, timings, costs and deliverables can be made available upon request.

5.2 Renewable energy deployment planning

After the treatment and recovery of the soil decreasing the risk by contamination, generating a reuse of the site is quite important. One possibility is for the generation of renewable energy.

Key steps in renewable energy deployment planning are as follows.

1. Carry out an evaluation of the land to see the feasibility that serves the purpose. The US EPA has developed a tool call "RE-Powering's Electronic Decision Tree" to help in determining this feasibility of a site for development a renewable energy project, taking into account its use in contaminated or degraded sites. The decision tree tool is intended to engage non-experts in renewable energy to screen potentially contaminated or underutilized sites or landfills for whether they are good candidates for solar PV or wind projects.

One of the sites considered in this project (Segovia) was evaluated using the US EPA tool and the initial finding was that the site “Satisfied Criteria on General Site Characteristics, Redevelopment Considerations and Load Assessment and Financial.”

2. Estimate the general cost of the project under the local conditions. In reference to the same site we developed an exercise with local suppliers, taking into account the current costs in the country and the benefits that could be granted by the new law in Colombia to estimate the general costs for a pilot project in a site of 2000 m^2.

6. Concluding Remarks and Recommendations

Gentle remediation options provide significant opportunities for mitigation of risks from mercury. Mercury's complicated speciation behaviour means that it is one of the more difficult toxic elements to treat, so some GROs such as phytoextraction, may not be appropriate. However, *in* situ immobilisation does show promise, in particular for the protection of water resources from leaching from soil. Initial test work using C-=CURE biochars has provided a preliminary proof of concept. However, this needs to be better validated by a programme of field site studies. It seems likely that i*n situ* immobilisation will be enhanced by revegetation as an adjunct to provide soil stability and maintenance of pH and redox conditions. Vegetation cover should also be designed with human exposure minimisation as well, for example the use of non-food crops such as for energy or fibre, or for other purposes such as habitat / amenity.

Providing stable risk mitigation will facilitate re-use of the affected land, and renewable energy production could be a major re-use opportunity, for example in conjunction with local supply and community enterprise projects. A series of initial renewable energy feasibility studies carried out have confirmed the potential for approaches such as solar (Photovoltaic) energy.

While the remediation approaches outlined in this document holds promise for environmental improvement at many different sites affected by mining in Colombia, it is also necessary for the Colombian government to strengthen oversight over illegal mining and unauthorized processes in order to implement this strategy on a larger scale Although mercury is one of the most relevant environmental problems, this project revealed very high concentrations of other heavy metals that also cause problems for those exposed. These metals include nickel, cadmium, lead and chromium. Thus, it is important for environmental authorities in Colombia to raise awareness within the mining industry of problems from exposure to not only mercury, but also other metals and to establish monitoring systems in areas with suspected contamination.

The use of biochar as a low impact remediation technique was very effective in the immobilizing mercury as well as a number of the metals analysed. It is important to continue this project on a larger scale (as proposed in the document) in order to validate the results of laboratory testing under field conditions and provide understanding for implementation issues such as scale up, economics, and others. In addition, a second detailed field analysis and pilot could be undertaken at a former mining site for a renewable energy project to showcase the link between mining site restoration and further sustainable use.

Additional resources

This report is supported both by supplementary information in the annexes and by references signposted from this guidance. Additional information is also downloadable from http://www.r3environmental.com.co/es/descargas.html, including a Spanish language version of the opportunity guidance described herein and the other publicly available outputs of this project:

- Output 2: Strategies for rehabilitating mercury- contaminated mining lands for renewable energy and other self-sustaining re-use strategies [*Guidance and strategies for re-use of land by transferring state of the art knowledge and successful* *implementation from the UK, EU and North America, and adapting it to the local situation as circumstances dictate*]

- Output 3: A policy brief for regional and national governments in Colombia. [*A policy brief for regional and national governments in Colombia. The brief will address Law 1658 of 2013, Colombia's commitment to the UN Minamata Convention (i.e. The Unique Plan of Mercury), the 2015 Paris Climate agreement, and Colombian accession to the OECD*]

Next steps

The recommendation of this report is that field deployment test work should be initiated as a matter of urgency, given the potential GRO has for mercury problem mitigation in Colombia.

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Annex 1: Detailed Description of Colombia Mining Sites and Related Samples Evaluated in Laboratory Studies

UK based lab scale testing of mercury immobilisation (using metal-adsorbing biochars developed previously by C-Cure) was carried out on soil samples from sites in two Municipalities in Colombia: Segovia in the department of Antioquia and Tadó in Chocó, agreed in advance with the Mines Ministry and the Environmental and Sustainable Development Ministry (MADS) given their history of artisanal mining and associated mercury use. In addition; security for r3 Colombia staff was also an important item taken into account in selecting areas to take soil samples.

Description Site 1: Segovia, Antioquia

Segovia is a municipality located in the department of Antioquia, 227 km northeast of the department capital within the region known as the coffee zone; covering an area of 1,231 km2 according to the Development Plan of the municipality (Mayoralty of Segovia, 2008), i.e. 2% of the departmental territory (DNP, 2015).

Geographically, its coordinates are North Latitude 7 ° 04'28 "and 74 ° 41'56" longitude West; It covers altitudes between 500 to 1000 meters above sea level (m.a.s.l.), with an average altitude in its main town of 650 m.a.s.l (Mayoralty of Segovia - Antioquia, 2012). Figure 10 shows the location of Segovia in the Department of Antioquia and in Colombia.

Figure 10. Location of the Municipality of Segovia at national and departmental level. Source: Ecodes Ingeniería, 2016.

The land route that connects the city of Segovia is the backbone of the northeast, which has lately received infrastructural investments, resulting in noticeable improvement in mobility conditions, with an approximate travel time of 5 hours from Medellin. This shuttle is mainly covered by companies as Transporte Segovia and Flota Nordeste, providing load and passenger services, especially for the Segovia-Medellin route and vice versa; and locally, in order to communicate between the municipal main town and the villages, the service is provided by companies like Transporte Segovia and the Cooperative of Conveyors (Mayoralty of Segovia - Antioquia, 2012). Rural areas lack roads in good conditions, which has affected the conditions of development and investment (Mayoralty of Segovia, 2008).

Figure 11. Tertiary access road between urban and rural areas. Source: r3 Environmental Technology Colombia SAS, 2016.

Air access was via Otú airport in the neighbouring municipality Remedios, but the frequency of flights and their costs has meant that this way of mobility to the municipality has been discontinued. Finally, the municipality does not have a navigable waterway.

Economy and Productivity

The three most important sectors in the economy of the municipality of Segovia are the mining of metal ores, which accounts for 42.52% of the municipal per capita added value, services activity companies (10.22%) and trade (7%); among others (18.9 %) like electricity, building construction, land transport, hotels, restaurants and bars, health and social services, public administration and defense (DNP, 2015). Thus, the Segovian productivity is mostly based on the gold mining, since the city produces 39.4% of all gold mined at the regional level and 6.66% nationally (Mayoralty of Segovia - Antioquia, 2012).

Figure 12. Main sector in the economy. Source: r3 Environmental Technology Colombia SAS, 2016

Among other economic activities in Segovia, cattle raising, concentrated in few farms with low productivity due to the difficulty of producing healthy grazing, logging, whose production is processed in other cities; and small-scale agriculture, mainly for self-sustaining of people that practice it, are locally important. Although the municipality has land for agricultural activities, production is insufficient even for domestic consumption (Mayoralty of Segovia, 2008).

Threats and Risks

According to a report on public health diagnosis made to the Planning Office of Segovia, nine risk factors for the local population have been identified: the first is the contamination of water sources by receiving wastewater (both domestic and commercial and industrial (mining benefication plants, car washes)) and solid waste, air pollution caused by gold processing, trash and firewood for cooking, and noise and smog from cars in urban areas. Wastewater is also discharged into the ground and there also wastes from other sources (Mayoralty of Segovia, 2008). A significant environmental risk focuses on logging, mainly of native trees like Abarco, Sapan, Coco Cabuyo, Perillo, among others (Mayoralty of Segovia - Antioquia, 2012), which leads to deterioration of the virgin tropical forest and generates ecological risks.

Figure 13. Pool with cyanide or mercury leachate waters. Source: r3 Environmental Technology Colombia SAS, 2016

Another risk factor for human health results from disease-carrying mosquitoes. The proliferation of these is mainly due to water storage for use and consumption in homes because of the discontinuous nature of the local (piped) water service. Likewise, labour and ergonomic hazards risks, sexual health risks due to the extent of prostitution, consumption of alcohol and psychoactive substances, mental health risks due to domestic violence, physical aggression, violence by armed groups and displacement were identified, mainly in people involved in the mining activity (Mayoralty of Segovia, 2008).

Finally, there are the risks of natural origin, such as landslides mainly in the districts of the periphery, windstorms, hurricane winds, torrential rains and flooding in the slums (Mayoralty of Segovia, 2008). Within this category, also reported recently by the Institute of Hydrology, Meteorology and Environmental Studies – IDEAM, are mulched fires with high recurrence in forest areas, crops and pastures (UNGRD, 2016).

In general, and based on information on degrees of threat, it is identified that 50% of the neighbourhoods in the urban area are classified as high risk by natural phenomena and 100% presents a risk by anthropogenic phenomena (Mayoralty of Segovia, 2008).

Social Aspects

Demographics

The municipal territory hosts a total of 40,174 people according to the report by the National Administrative Department of Statistics - DANE to the DNP in 2015, of which 31,934 are located in the municipal capital (79.49% of the total) and 8,240 in the rest of the municipal area (20.51%); giving a population density of 32.24 people per km2 (DNP, 2015). Demographics are characterized by a very even representation of men and women, this being 49.9% and 50.1% respectively (DANE, 2005).

As shown in Figure 14 and according to the DANE report in 2015, the potentially active population, comprising the age range between 15 and 59 years is 62.1% and 37.9% inactive (DNP, 2015), corresponding to the population outside the range mentioned above. In the same way, there is evidence of a pyramid effect of migration in both sexes, male mortality and high birth-rates. It is noteworthy that 43.1% of the population characterized in the 2005 census were not born in urban areas, but migrated to these, and more than 90% have resided more than 5-year period (DANE, 2005).

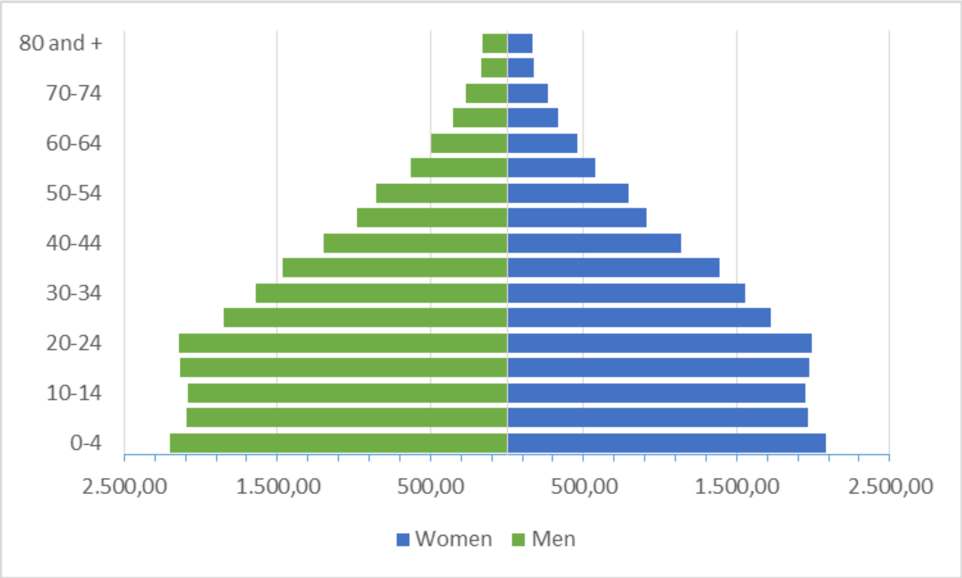


Figure 14. Population pyramid by age and sex. Source: (DNP, 2015).

On the other hand, Segovia houses 406 people who self-identify as indigenous, 6,666 as blacks, mulattos and Afro-Colombians and 6 raizales. Additionally, an indigenous reserve is recorded in the municipality (DNP, 2015). The ethnic population is 7,078 people, representing 17.62% of the population in 2015, and has decreased compared to the 19.6% that was reported by DANE in the census conducted in 2005.

Life Quality

The UBN (Unmet Basic Needs) index determines, based on simple indicators (such as inadequate housing, critically overcrowded conditions, inadequate services, high economic dependency truancy or illiteracy), the amount of basic needs of the population that are not covered (DANE, 2016). In 2005, the population reflected in the census index is 41.37% (DNP, 2015), meaning that 41.37% of the households in the municipality of Segovia, are in poor condition with high unmet basic needs (from those described previously), which is 3.33 times the index obtained in the population of Medellín (capital of the department of Antioquia), and also corresponds to 1.8 times the UBN of the department. But it is characteristic for the subregion in which it is located (subregion of the Northeast with 42.23% of UBN in the total of its population) (Government of Antioquia, 2013).

Another index to demonstrate quality of life in a population is the IPM (Multidimensional Poverty Index), which reflects the degree of deprivation of people in a set of dimensions; it allows determination of the nature of deprivation in selected dimensions (educational, children and youth, work, health, home services and housing conditions) and the intensity of it (Mateus, 2012). In this regard, an improvement in IPM has taken place, which was recorded as 44.3 in 2005 and within 9 years had decreased to 19.5; however, this calculation is performed using the 2005 census results with a weighted average of the population of each subsequent year (DNP, 2015).

Armed Conflict

One of the most recognized events of violence in Segovia occurred in 1998, executed by one of the blocks of the National Liberal Army - ELN; It consisted of the attack on the bridge crossing the river Pocuné Machuca, leaving terrible consequences. The main reason for disputes is the section of oil pipeline from Ecopetrol (Colombian Oil Company) passing through the village of Fraguas (Mayoralty of Segovia - Antioquia, 2012).

The actions taken in the region, along with investments conducted by state public institutions and companies such as Ocensa and Frontino Gold Mines, has enabled a lifting of the image of the municipality and most importantly: improved security and economic development. However, lately it has become clear that illegal mining (one of the main activities) has developed links with armed groups. This was reported by the magazine Semana in one of its reports, which also mentions, according to a study of the Ideas Foundation for Peace, "in more than half of the municipalities producing gold, there is presence of criminal gangs" and emphasizes that police have captured several members of these bands in the middle of mining (Semana - Nation, 2013). This has hindered the security issue, added to disputes over entrance to private property for gold mining.

Drinking Water and Basic Sanitation Aspects

As part of the system of public services, urban, Townships and Villages have aqueducts for water supply, taken from the upper basin of the popales and Manila creek, also from Puerto Calavera, La Po, The Aporriado and Marmajón. In addition, the aqueducts have a purification treatment plant in the area of Campo Alegre.

Water supply networks cover 65% of the population (DANE, 2005), but are frequently interrupted so the community stores water in tanks, thus diminishing its quality. The remaining population (35%) collects water for consumption from pits or streams. Due to the discontinuity and coverage mentioned, the aqueduct actually provides water to around 30% of the population (Mayoralty of Segovia, 2008).

The sewerage service coverage is 46.2% in the 2005 census (DANE, 2005), but in 2007 the Municipal Development Plan mentioned much less coverage: 20% in the municipal capital. The network combines wastewater and storm run-off in old concrete pipes which have caused leaks in the basements of some houses (Mayoralty of Segovia, 2008). In rural areas, most households discharge sewage into streams such as El Tigrito, El Matadero and La Paz.

On the other hand, for the disposal of solid waste, estimated at an average of 20.66 tons / day generation, the urban area of Segovia has a landfill. The service provider went from the municipality to the company “Segovia Aseo”, reaching 93.5% coverage to homes in the urban area, limited by difficult access and some very narrow roads in poor condition. In rural areas, the only waste collection service is provided to the township Fraguas, which still does not have a landfill for disposal (Mayoralty of Segovia, 2008).

Compared to other home services, the Ministry of Mines reported in the second quarter of 2015 to the DNP that only 21.8% of homes have coverage for Natural Gas, but 95.4% have electricity for 2014; and the Ministry of Information and Communication Technologies registers only 6.8% with internet access (DNP, 2015).

Abiotic Aspects

Topography

The topography of the municipality of Segovia is characterized by being undulating with some steep slopes and features high forestry potential. As mentioned above, the altitudes can vary from 200 m.a.s.l. in its lower part, to 800 m.a.s.l at its highest points. According to the Municipal Administration of Segovia of the Department of Agriculture, Mines and Environment (DAMMA), two general soil types are present: quartz-clay soils, with acid pH between 5 and 6, and which are hydrophobic and high in iron; and low-nitrogen soils with thin topsoil (10 to 20 cm) (DAMMA, 2008).


Figure 15. Landscape of Segovia, Antioquia. Source: r3 Environmental Technology Colombia SAS,2016

Climate

The region where the municipality is located is characterized by a humid tropical warm climate, with annual rainfall between 2000 and 4000 mm and relative humidity of 84% (Mayoralty of Segovia, 2008). The average temperature in the Segovian territory is between 24 and 32 °C (DAMMA, 2008).

Hydrology

The extensive drainage network of the municipality flows mainly from south to north, and is composed of three areas:

Chart 1. Surface drainage network in the municipality of Segovia. Adapted from: (Mayoralty of Segovia, 2008)

East	Rivers Tigüi, Tamar and the creeks Amará, Champán and Chicamoque.
Centre	Rivers Bagre, Pocuné, Cuturú, El pescado, Capitán and Doña Teresa. This last mentioned, on its way by the urban area, is known as “La cianurada” and flows into the river Bagre.
West	River Mata

Among other sources of water for Segovia, the principal and urban aqueduct that feeds from the Pocuné river and Popales creek; additionally, there are small streams that, in their transit through the urban perimeter, are recipients of urban wastewater, these are: the Tigrito Quebrada and La Paz; the tributaries of the first is La Argelia, Caracol, Caño May 13, El Tejar; and the second: El Guamo, La Chumeca and La Reina (Mayoralty of Segovia, 2008).

It is worth mentioning that the Municipality has detected until 2008, 89 gold benefication plants pouring their waste cyanide to the aforementioned water sources (Mayoralty of Segovia, 2008). In fact, the DAMMA estimates a flow rate of 500 L/s of water contaminated by particulates, high pH, load minerals and organic compounds (DAMMA, 2008).

Biotic Aspects

The municipality of Segovia is one of the last bastions left that are part of the Northeast Forest at Antioquia, which is a habitat of great variety and quantity of native species of fauna and flora; this makes it a highly-valued forestry potential area for trade in raw materials with cities like Medellin, Bogota, Bucaramanga, Pereira, Barrancabermeja, among others; however, nowadays the importance of this ecosystem has not been taken into account. (Mayoralty of Segovia - Antioquia, 2012). In addition, the municipality has part of its land inside the Magdalena Forest Reserve, which has not been characterized and studied. Therefore, the municipality's development plan includes this as part of its objectives in the short-term projects.

Flora

Among the relevant species in the forest ecosystem of the municipality, are the Amargo, Abarco, Acite María, Arenillo, Coco Cabullo, Tamarindo, Guamo Rosado, Cargamanto Masábalo, Ceiba, Tolúa, Caguí (Mayoralty of Segovia - Antioquia, 2012)

Fauna

The descriptions about this aspect at the municipal documents such as the municipal development plan and the basic land use plan, refer to the wealth of forests and water resources, hosting a range of resident and transient animals, among which are the Tapir, the Hornless Deer, Anteater Bear, Ocelot, Wild Dog, Sloth Bear, Otter, Armadillo, Chigüiro, Ñeque, Guagua, Mapana Coral, Huntress, Stifle, Iguana, Morrocoy, Tortoise, Poisonous Frog, Gavilan, Aguija, Owl, Guacharaca, Hummingbird, Macaw, Parrot Red Front, Parrot Yellow Front, Carpenter, Turpial, Backpacking and Titi monkey (Mayoralty of Segovia, 2008). Those same documents also acknowledge that there are human factors that are strongly impact these species and the environment in general.

Context of Gold Mining in Segovia

Segovia is a traditional mining town with an estimated production, according to official reports, of more than 3000 kg of gold and over 1,700 kg of silver per year (DAMMA, 2008). Because of this and official statistics, these reports state that the basis of the economy of this town is the handmade and slightly technified extraction of gold; an activity which has been being developed throughout history, since the discovery of Tierradentro (as the municipality was called then); Through the first excursions to the jungle, what at the time was known as the "gold rush", bringing the arrival of slaves during the colonial period. These milestones triggered a subsequent massive mining development with exponential population growth (Mayoralty of Segovia - Antioquia, 2012).

Figure 16. Underground mine and bennefication plant involved in the gold mining process in Segovia, Antioquia. Source: r3 Environmental Technology Colombia SAS, 2016.

The mining began in a very artisanal way like barequeo or mazamorreo, but began to evolve in a slightly more technical manner, using heavy machinery and more invasive technologies; Thus, proportionally they have increased the harmful effects exerted on natural resources. Additionally, the number of sites where the mineral is exploited have been increasing so a mining sites census is lacking and is needed.

According to the diagnosis made by the DAMMA of Segovia, one hundred twenty-three thousand hectares are identified as suitable for mining exploitation, however the development of this activity has been carried out in an unsustainable way due to the implementation of inappropriate techniques with high impact on natural resources. In addition, this body mentions that in 2008, from 150 gold underground mining sites only 10 mining units are formalized (DAMMA, 2008). In contrast, regarding to the views of residents and people dedicated to the subject in the municipality, there is a monopolization of mining in Segovia, where the Colombia Gold mining company is the only one with a mining title.

The issues that the Municipality of Segovia identifies in the mining sector are primarily the presence and extent of urban mining especially in neighbourhoods like Alto de los Patios, The Hueso and The Paraíso, the invasion by informal mining on to mining titles, low diversification of the economy that, as mentioned is focused almost exclusively on mining, resulting in lack of jobs, development and productivity; also, lack of support is presented by technical and legal entities to formalize mining as well as absence of added value in the productive chain of gold due to inadequate training in jewellery and nonexistence of jewellery companies, in addition to reduced investment in technology and equipment (Mayoralty of Segovia, 2008).

Still, the issue of regulation regarding policies and actions by municipal order is limited considering that mining activity is already regulated by higher levels such as the Mining Code and subsequent decrees, with departmental and national regulatory authorities; one of the actions implemented, which so far has yielded results was the creation of a Mining Environmental Unit of the municipality, with the aim to support, promote and regulate the miners benefication plants for small and medium scale mining by the environmental authorities and mining promotion (Municipal Mayoralty of Segovia, 2002 - 2011). In addition to inadequate technical support to informal mining, however, it also lacks investment, as previously mentioned.

Finally, according to the public health diagnosis report, 80% of the sample population has levels of mercury in urine above acceptable limits, indicating intoxication; making it a public health problem. The remaining 20% people are contaminated at levels very close to exceeding the allowable limit (Mayoralty of Segovia, 2008).

Sampling Strategy Site 1

The sampling strategy proposed is based on the following selection criteria, which are aligned with the objectives of the study: sites where mining activities have been carried out in the past or are currently underway, sites where artisanal mining activities are carried out, that the owner of the property or the surrounding community is interested in recovering the site and/or that the community is currently being affected by the previous or current use of the site. The Site selection was held in conjunction with representatives from the municipal government, who belong to the “Dirección de Agricultura, Minas y Medio Ambiente” - DAMMA.

Taking into account previous information, two sites to visit for sampling were located: the first, corresponding to a currently exploited mine, where three samples were taken; and the second site a mine where people extracted the mineral with machinery on site. Figure 17 shows the distribution of the total of 6 sampling points.

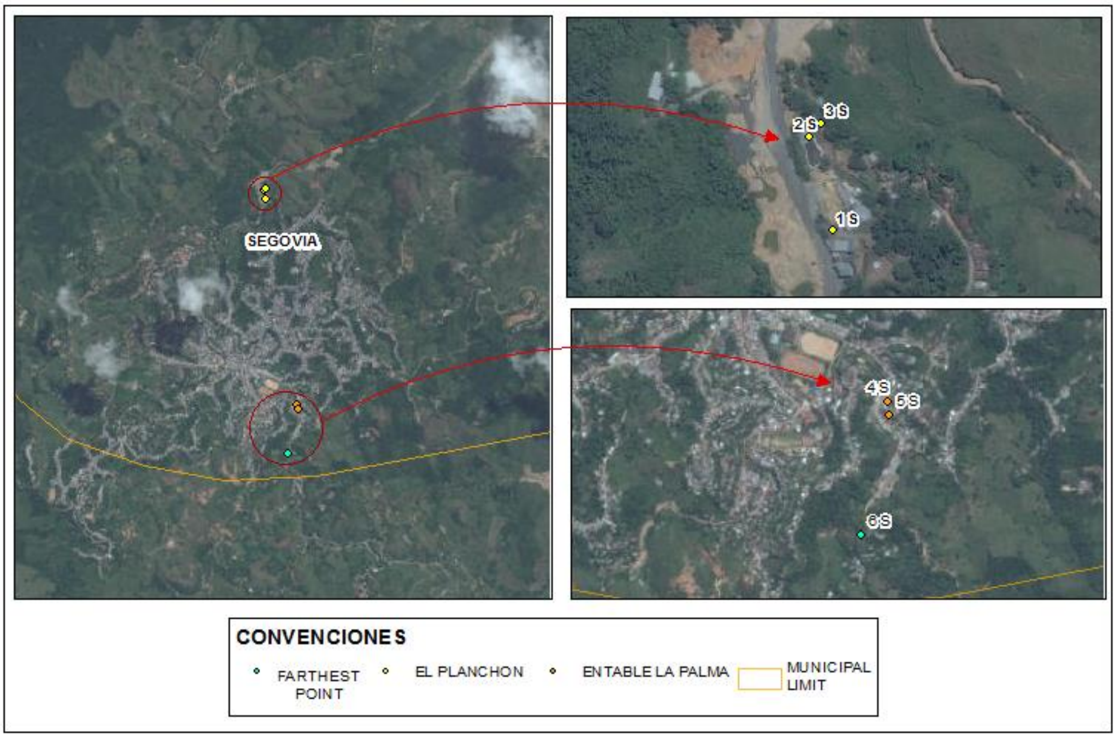
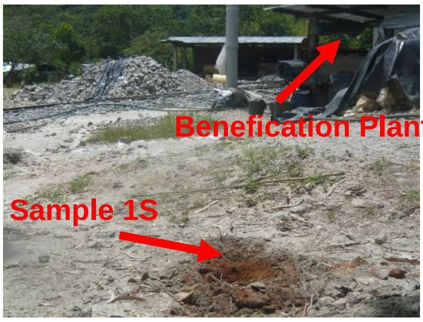


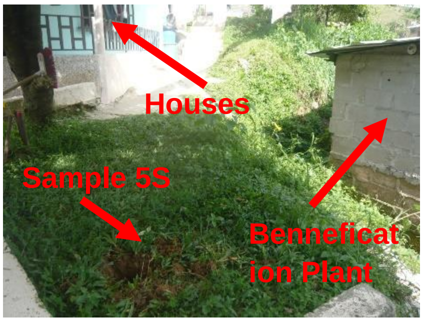
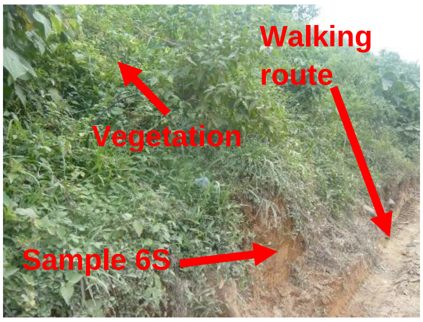
Figure 17. Distribution of sampling points at the urban area of Segovia, Antioquia. Source: Ecodes Ingeniería S.A.S, 2016.

Sample Details

Detailed information about each sampling point is presented at the following chart (view Chart 2), indicating the sample code, its georeference, description and photographic record which highlights key factors.

Chart 2. Detailed information from sampling points taken at the Segovia municipality, Antioquia. Source: R3 Environmental Technology Colombia S.A.S, 2016.

Code	Georeferentiation		Description	Photographic Record
	N	E		
1 S	7,09117	-74,7019	This sample was taken in dry soil with no vegetation cover. It is located near to the benefication plant where gold obtained from the El Planchón mine processed.	
2 S	7,09185	-74,7021	The second sample in Segovia was taken in dry soil with no vegetation cover, close to a creek, downstream of the gold processing plant El Planchón. Though not visible in the photo, a pool where cyanide and mercury-bearing water is contained is also present near to the sample point.	
3 S	7,09195	-74,7020	The last sample taken in El Planchón is sample 3S, crossing the creek downstream of the processing plant, very close to the neighbouring town houses.	
4 S	7,07552	-74,6996	Inside the processing plant La Palma, a pile of soil emerging as a by-product of the plant is stored. On top of this stack, the dry solid sample was taken.	

Code	Georeferentiation		Description	Photographic Record
	N	E		
5 S	7,07515	-74,6995	Segovia's fourth sample was taken in the back of the gold processing plant La Palma, which adjoins at the same time with settlers' houses. It was dry soil under planted vegetation and near to trees.	
6 S	7,07183	-74,7003	The last sample taken in Segovia (6S) corresponds to a remote spot entering the rural area of the municipality, on the rise of a mountain by a small walkway. It is dry soil under natural vegetation.	

Description Site 2: Tadó, Choco

Tadó was founded on March 19th 1740 (Palacios Murillo & Rengifo Arias, 2014) and is located to the northeast of the department of Choco Colombia at 68 Km from the provincial capital, Quibdó (Agualimpia Caicedo, 2012). Its geographical coordinates are 76°73'10" latitude and 5°16'10" longitude, and it is at about 75 meters above sea level (average altitude). Figure 18 shows the location of the town at the national and departmental levels.

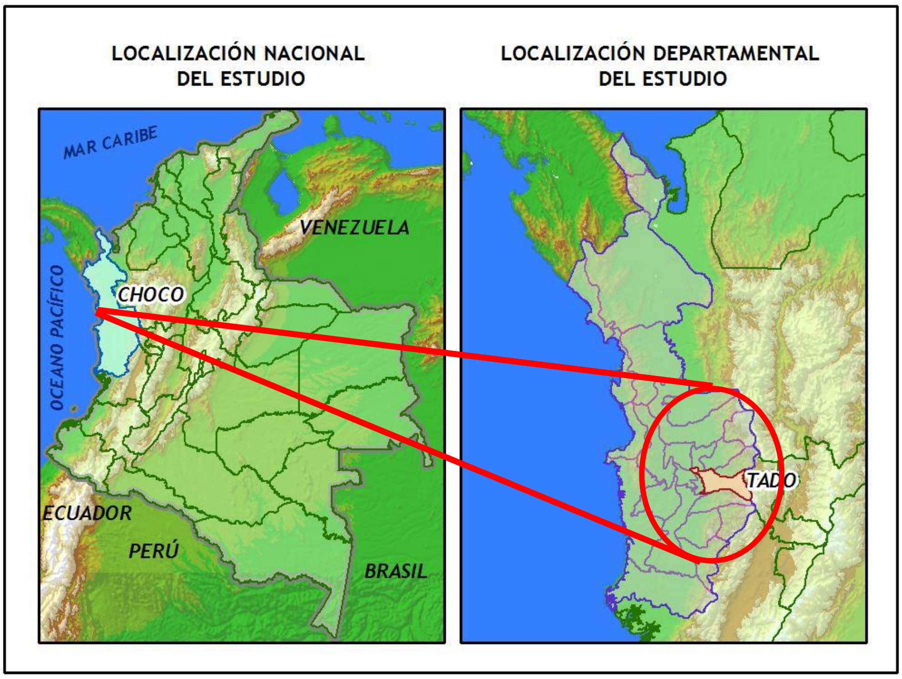


Figure 18. Location of San José de Tadó (Tadó). Source: R3 Environmental Technology Colombia SAS, 2016.

The urban area of Tadó is composed of 13 neighbourhoods and the rural area of the municipality is comprised of 11 districts and 12 villages in collective territories of settlement black community represented in councils, administered by ASOCASAN (Agualimpia Caicedo, 2012).

The Central Pacific road is the main land route that connects with Tadó (Figure 19). Additionally, at the regional level, there are three main roadways: Road Playa de Oro - Carmelo that connects Tadó with Bagadó, road Tapon - Campo Alegre communicating with the Rio Iró and the road Via Pueblo Viejo – Manungará (Palacios Murillo & Rengifo Arias, 2014).

Figure 19. Principal road access to Tadó. Source: R3 Environmental Technology Colombia SAS, 2016.

Air access to Tadó is not possible, since it has not airport; but the closest is the city of Quibdó. Finally, by river, the main navigable route is the river San Juan, followed by Mungarrá, Chato and Tadocito (Agualimpia Caicedo, 2012).

Economy and Productivity

Agricultural production and mining are the two pillars of the economy in the town of Tadó. Within the first activity, predominantly fruit crops such as banana, peach palm, borojó, pineapple, cassava, banana, among others are cultivated (Agualimpia Caicedo, 2012). On the other hand, trade is the most common activity in which the inhabitants of Tadó are engaged; in fact, according to National Department of Statistics (DANE), 60.7% of establishments are engaged in trade; while 10.3% are in industry, services 26.6% and 2.3% are engaged in other activities (DANE, 2005).

The main generators of formal employment for the people of the area are the state entities, the hospital and other health firms. However, an unemployment rate of 42%, 24% of informal employment in mining activities and a recurrence of 6% under 15 related to others work activities (Agualimpia Caicedo, 2012) are noted.

Figure 20. Commercial area of Tadó. Source: R3 Environmental Technology Colombia SAS, 2016.

Threats and Risks

Natural threats by geological origin, orographic distribution and climate regime have been identified in Tadó. Among these risks, landslides due to geological composition, intensity and rainfall, a steep slopes regime, areas without vegetation cover and mining according to Scheme Land Management (EOT) are included; the latter is one of the strongest foundations of the town's economy and the lack of protection embankments.

Earthquakes are another natural threat at the national level because of Colombia's location on three major tectonic plates (Nazca, South America and the Caribbean); especially the western part of the country is considered to have high seismicity, which is therefore relevant for the municipality threat (Palacios Perea, 2000).

Finally, floods are identified in the EOT of Tadó as a phenomenon of periodic occurrence at the departmental level, mainly due to the climate regime and an increase in intensity, duration and frequency of rainfall; adding that the rivers San Juan (Figure 6) and Atrato are considered heavy in the portion of descent and foothills of the mountains; however, in this regard, the location of Tadó favours the reduction of the occurrence of this phenomenon, except the San Pedro (Palacios Perea, 2000).

Figure 21. San Juan River. Tadó. Source: R3 Environmental Technology Colombia SAS, 2016.

Other risks and threats identified are those of anthropogenic origin, such as deforestation, fire stations because fuel service suppliers in residential areas and increased sediment load in streams (Palacios Perea, 2000)

Social Aspects

Demographics

According to DANE´s Census conducted in 2005, of the total population of Tadó 48.3% are men and 51.7% are women as evidenced in Figure 22. 64.03% of people live in urban areas, while 35.97% populate rural areas (Agualimpia Caicedo, 2012). Also in Figure 22 a high birth rate and migration of population greater than 24 years is evident.

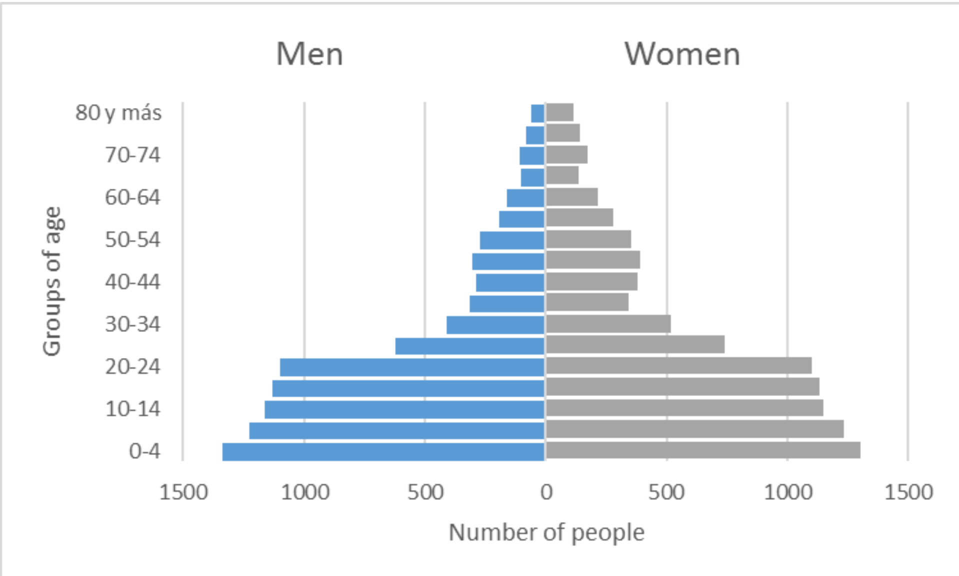


Figure 22. Distribution of the population of Tadó. Source: (DANE, 2005)

Figure 22 shows the data collected and reported by the DANE (DNP, 2016). The total population in this report is 18,906 people, representing 3.8% of the total departmental population, in which a close one to one relationship between men and women is presented.

As an additional feature, the population of the municipality can be distributed three ethnic groups: 8.34% indigenous population, 70.8% blacks, mulattos or Afro-Colombians and 20,86% native islander population (DNP, 2016). Finally, the ANSPE (National Agency for

Overcoming Extreme Poverty) in 2015 reported to the National Planning Department a total of 3,768 people linked to the program of the government RED UNIDOS, taking this as an indicator of families in extreme poverty and / or displacement.

Lifestyle

The Unsatisfied Basic Needs Index (NBI) determines the amount of basic needs of the population that are not covered in an area. This index is based on simple indicators such as inadequate housing, critical overcrowding, inadequate services, high economic dependency truancy or illiteracy (DNP, 2016). Following this definition, statistics for this indicator is high, with 89.30% in urban areas and 82.43% for the rural sector, and with an average NBI of 86.86% in the municipality in June 2011 (Agualimpia Caicedo, 2012), reflecting the lack of investment policies aimed improving quality of life of its inhabitants.

Armed conflict

The geographical location of Tadó plays an important role for economic development of Choco; for this reason, actions of groups outside the law, in their efforts to control this territory have led to intimidation in communities of the municipality, such as clashes including targeted killings of community leaders and members of the population and forced displacement of communities in the 90´s. Today that problem has been reduced considerably and Tadó is now considered a safe area (Agualimpia Caicedo, 2012).

Drinking Water and Basic Sanitation

According to DANE (2005), the population of Tadó has no natural gas service, 13.1% of the inhabitants have a sewer service, management of wastewater through sewage is present for 16.2% housing and telephony is a service that only 20.9% of the population has access to. 81.2% of households have access to Electric Power (Agualimpia Caicedo, 2012), being the largest service coverage for the census year.

The municipal EOT identified as a problem the lack of drinking water and sewerage in the houses of the people, with 90% of people in the rural sector not having basic sanitation; and pollution caused by solid and liquid waste, since the solid waste generated by the population (approximately 10 tonnes in 2000) is disposal in inappropriate places and water sources (Palacios Perea, 2000).

Abiotic Aspects

Topography

Tadó is slightly hilly, with mountainous valleys and planes (Agualimpia Caicedo, 2012) with two forms of topography, one is the alluvial plains of the Atrato river with slopes less than 3%, formed from sedimentary material, low fertility and poor drainage surface. The other form is the hills, consisting of units of landscape from slightly to strongly with slopes of 25%, located in the rain belt mainly developed from sediment, surface materials, low evolution, well drained and very low fertility. Finally, Tadó is geologically located in the basin of the Atrato and San Juan rivers, both located on the western slope of the western mountain range (Palacios Perea, 2000).

Figure 23. Landscape of Tadó. Source: R3 Environmental Technology Colombia SAS, 2016.

Climate

The climate of Tadó is warm humid to tropical, characterised by very small annual fluctuations in temperature and daily temperature ranging between 26 °C and 29 °C, with an average of 28 °C. It has also a high rainfall ranging between 6800-7600 mm per year (Palacios Perea, 2000). It presents two winter periods: the first between April and June and the second between September and November, forming a bimodal climatic pattern for the area. Other meteorological features that contribute to the climate of Tadó are presented in Chart 3.

Chart 3. Meteorological factors characteristic of the climate in Tadó, Choco. Source: Adapted from (Palacios Murillo & Rengifo Arias, 2014)

Meteorological Parameter	Range	
	From	To
Win speed (predominantly eastbound)	9 Km/h	28 Km/h
Sunshine	0,7 h/day	9 h/day
Relative Humid	90%	95%

Hydrology

The hydrological system of Tadó consists of two large basins: The San Juan River and the Atrato River. The first extends 180 km on its main part, with an 80 Km basin width in the west of the western range; a further 12 small rivers form tributaries to the San Juan river such as Tadocito, Mungarrá, Guarato, Chato, among others; these tributaries have high flow and high gradients, increasing the flow of the San Juan River which forms the major drainage system of the Pacific slope, with flow of 2721 m^3/s (Palacios Perea, 2000).

The mainstream of the second basin (Atrato River) is one of the major rivers of Colombia, with an area of 24710 Km, which collects water from several streams, among which are Hábita, Riogrande, El Toro, Girardot, and Playa del Carmen in the area of Tadó (Palacios Perea, 2000).

Biotics Aspects

The rainforest of the Pacific is known as one of the most biodiverse ecosystems (Agualimpia Caicedo, 2012), however, human intervention on forests in the area and the pressure that is exerted and exercised for several years only allows the use of these areas for development of secondary forests; also, several endemic species that would be part of this ecosystem, are seriously threatened due to the rapid destruction of their habitats (Palacios Perea, 2000).

Flora

Tadó has abundant and varied vegetation, including timber species are as Guasca, Carbonero, Rubber, Chanu, Laurel and Trúntago (Palacios Murillo & Rengifo Arias, 2014). Additionally, abundance occurs in species such as Mora, Anime, Chachajo, Canime, Chanu, Algarrobo, Otobo, Volador, Botejo, Carra, Mojao, Oil Mary, Jigua and many palms (Palacios Perea, 2000).

Generally, the forests of old alluvium and colluvium with varying degrees of dissection (Agualimpia Caicedo, 2012). Among the vegetation of the municipality we can find forests with trends in species heterogeneity and variation in size and height, hill forests with strong reliefs and heterogeneous forests (Palacios Perea, 2000).

Fauna

The department of Chocó is known for its vast wealth of wildlife and great forests serve as their habitat; the vast majority are endemic species. The Chart 4 shows known.

Chart 4. Known species in Tadó. Source: Adapted from (Palacios Perea, EOT Tadó, 2000)

Type	Known Species
Mammals	Tiger or Jaguar, Ocelot, Wildcat, Chucha, Bear "ponytail", Anteater and Danta.
Amphibian	Stifle and turtles; also among the trades are warty Chocoan, Equis tail Chucha, Equis, Chocoan and a variety of corals.
Fishes	Zabaleta, Chad, Nicuro, Mojarras and Barbudos.

Especially with regard to the fish diversity, 63 endemic freshwater species exist in Choco, a total of 186; among which 15 are in high threat (Research institute of biological resources Alexander Von Humboldt,Institute of Natural Sciences of the National University of Colombia, University of Manizales, WWF Colombia, 2013). According to the municipal EOT, mercury pollution from illegal mining activity is a major area of concern for aquaculture species (Palacios Perea, 2000).

Context of Gold Mining in Tadó

Tadó has a great gold mineral wealth given their alluvium located in the basin of the San Juan River and its tributaries, although it is also representatively extracted minerals such as copper, coal, lead, zinc and oil (Palacios Perea, 2000). The way this resource is exploited in the area is usually by artisanal ways, i.e. by proprietary technologies or “ethnotechnologies”, as “barequeo” or “mazamorreo” (Figure 24), moving small volumes of gold-bearing gravels, which could facilitate the assimilation and natural resilience of the different environmental matrices affected; unlike the heavy and new technologies that were coming to the department through mine development and the arrival of medium and large businesses machinery. In addition to the pressure exerted by the productive and extractive advantages of technologies, joins the rise in gold prices over the last decade, it has put new pressure intensified the extractive activity of this mineral, implementing the use of mercury for amalgamation and decreased losses (Medina Mosquera, Ayala Mosquera, & Perea, 2011).

Figure 24. People around trying to extract gold in abandoned sites. Source: R3 Environmental Technology Colombia SAS, 2016.

Under the definition of illegal Mining, which contains any work of exploration, extraction or collection of minerals of national or private property without mining title or authorization of the owner to grant him such rights, artisanal mining included as a part of this term due to the conditions in which it is performed. In Tadó, it is recognized artisanal mining, also known as subsistence, as registered; of it illegally, they have been developed most exploration and opencast medium farms (Palacios Perea, 2000). These activities have caused environmental crimes, forced displacement, killings, child labour, among other unlawful conduct (Palacios Murillo & Rengifo Arias, 2014).

In this regard, the respective entities in the local area have committed, by formulating the Management Plan and Environmental Management of Mining, formalities and regulations to reduce the impacts and illegality of mining; and increase sustainability, and responsibility for site amelioration and land reclamation, increase mine registration and with this, the growth of the royalties, formal employment and income for the people of Tadó (Agualimpia Caicedo, 2012). Still, the population has appeared unsatisfied, arguing that the management of formalization and legalization of mining ignores the recognition and remediation of previous mining consequences, highlighting that "the basin of the Atrato River passes through a remarkable crisis in socio-environmental ", demanding lasting solutions to protect the rights of the population at high risk(Tutela for violation of Articles 1, 2, 7, 11, 13, 44, 49, 366 of the Constitution of Colombia, and the violation of the fundamental rights to life, health, water, rights the food and territory., 2015).

Sampling Strategy Site 2

The sampling strategy was made taking into account the selection of an abandoned gold mining area about 8 years ago. This site is located in the rural area of Tadó and covers an area of almost 1 Km^2.

Figure 25 shows the distribution of the sample collection points. A total of six (6) samples were taken, four (4) of which are located in representative areas of the site and two (2) near the houses of the inhabitants of the area.

Figure 25. Distribution of sample collection points. Rural area of Tadó. Source: R3 Environmental Technology Colombia SAS, 2016.

Sample Details

The Chart 5 shows a detailed description of each sampled point.

Chart 5. Details information sampled points. Source: R3 Environmental Technology Colombia SAS, 2016.

Code Sample	Georeferentiation		Description	Photo
	N	E		
1T	5,2226	-76,6526	This sample was taken in dry soil with little vegetation and near water reservoirs (small lakes) used for the extraction of gold.	
2T	5,2219	-76,6525	This sample was taken on dry soil in an area where new vegetation of native species is observed after the abandonment of the mina eight years ago.	

Code Sample	Georeferentiation		Description	Photo
	N	E		
3T	5,2212	-76,6516	This sample was taken in dry soil with little vegetation and no special specifications.	
4T	5,2198	-76,6508	This sample was taken on dry soil in an area where a reforestation program with the species "Acacia magnum" was made 5 years ago in the area.	
5T	5,2239	-76,6462	This sample was taken on dry soil at the boundary between the abandoned mining area and some houses of the rural area of Tadó.	
6T	5,2218	-76,6431	This sample was taken on dry soil at the boundary between the abandoned mining area and some gardens of the houses on the rural area of Tadó.	

Annex 2: Details of leaching tests and results

Aims

The aims of this part of the project were as follows:

- Assess the concentrations of leachable mercury and other metals in soil samples taken from two mine site locations in Segovia.
- Assess the total concentrations of mercury and other metals in soil samples taken from the same two locations in Segovia
- Determine which chemical form (leachable, organic bound, methyl mercury, elementary or sulphur bound) the mercury was in within the most contaminated soil sample for mercury.
- Test the ability of C-Cure products to reduce the risk of leachable and stomach acid extractable mercury in the most mercury contaminated soil sample.
- Test the ability of C-Cure products to reduce leachability of heavy metals other than mercury.

Mercury toxicity

Mercury toxicity is related to three factors: (1) the inherent toxicity of mercury once it has been taken up into an organism (2) the ease by which a specific form of mercury can be taken up into an organism and (3) the exposure of that organism to a specific form of mercury.

The inherent toxicity of mercury is well understood. Neurological and behavioural disorders may be observed after inhalation, ingestion or dermal exposure of different mercury compounds. The inhalation of mercury vapour can produce harmful effects on the nervous, digestive and immune systems, lungs and kidneys, and may be fatal. Once mercury is taken up, the principal target organs for the toxic effects of mercury are the central nervous system (CNS), the brain and the kidneys. Symptoms of mercury toxicity include tremors, insomnia, memory loss, neuromuscular effects, headaches and cognitive and motor dysfunction. The inorganic salts of mercury are corrosive to the skin, eyes and gastrointestinal tract, and may induce kidney toxicity if ingested. Long-term and repeated occupational exposure to concentrations of 20 µg m^{-3} produced mild effects on the CNS and provided the basis for the tolerable concentration in air of 0.2 µg m^{-3}. Single or repeated oral ingestion of inorganic mercury compounds has been linked to kidney toxicity in reported human cases. Similarly, in rats, repeated oral administration of mercuric chloride for six months resulted in kidney damage with a no-observed adverse effect level (NOAEL) of 0.16 mg kg^{-1} body weight day^{-1}. The brain is the key target for the toxic effects of ingested methylmercury. Epidemiological studies indicate that developmental neurotoxicity may occur at maternal doses in the order of 1 µg kg^{-1} body weight day^{-1} (UNEP, 2002).

Similarly, the ease with which a specific form of mercury can be taken up into an organism and the pathways by which this occurs are well understood. For example, elemental mercury is volatile and well absorbed following inhalation, whereas absorption of elementary mercury following oral ingestion is extremely limited (UNEP, 2002).

Exposure to mercury once it has been deposited in the environment is complicated. People may be exposed to mercury in any of its forms under different circumstances. However, exposure mainly occurs through consumption of fish and shellfish contaminated with methylmercury and through worker inhalation of elemental mercury vapours during industrial processes (UNEP, 2002).

Behaviour of Mercury in the Environment

During artisanal gold mining, metallic mercury is mixed with gold bearing sediments and soils, where it forms an amalgam with gold particles that are present in the soil. The gold mercury amalgam is then separated from the soil using gravity. Because mercury has a lower boiling point than gold, the mercury can be boiled away leaving pure gold behind. As a result of this activity, artisanal and small scale gold mining creates the largest input of mercury into the environment with estimated annual emissions ranging from 800 to 1000 tonnes (Hinton *et al*., 2002). This (elementary) mercury is then deposited in the environment where it can be transformed into more toxic forms, such as inorganic mercury (Hg(II)). Inorganic mercury can be transformed by bacteria into methylmercury. Methylmercury easily bio-accumulates in fish and shellfish. If these organisms are then eaten by predatory fish, mercury bio-magnifies up the food chain (Díez, 2009; Wang *et al*., 2013).

However, the toxicity and bio-availability of mercury is also dependent on its interactions within the soil or sediment matrix. For example, if the soil or sediment contains organic matter and sulphur containing ligands, mercury might bind to these materials forming complexes that are less mobile and therefore less toxic (Hintelman *et al*., 1995). Sorption to soils, sediments, and humic materials is an important mechanism for the removal of Hg from solution. Sorption is pH dependent and increases as pH increases. Mercury may also be removed from solution by co-precipitation with sulphides. Under anaerobic conditions, both organic and inorganic forms of Hg may be converted to alkylated forms by microbial activity, such as by sulphur reducing bacteria. Elemental mercury may also be formed under anaerobic conditions by demethylation of methyl mercury, or by reduction of Hg(II). Acidic conditions ($pH < 4$) also favour the formation of methyl mercury, whereas higher pH values favour precipitation of HgS, which is insoluble. In contrast, if the soil is acidic, this might solubilise mercury allowing it to be taken up by organisms. Figure 26 represents a diagram of the different ways in which mercury can exist in the environment and a simplified illustration of their associated risks.

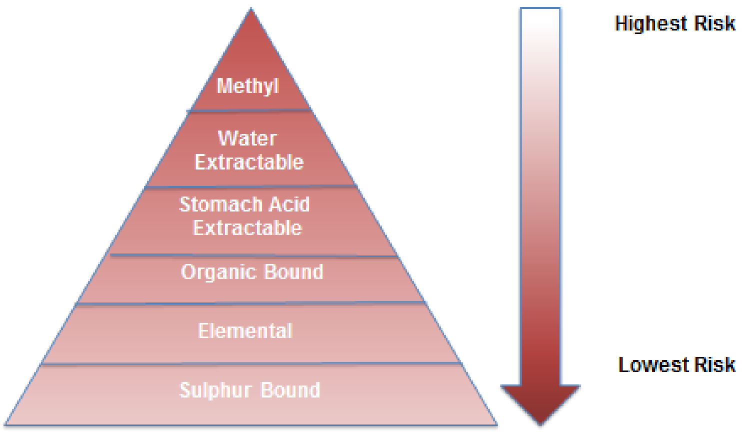


Figure 26. Forms by which mercury may be present in the environment and their associated risk to humans and wild life

The phytoavailability and toxicity of mercury in soil–plant systems depends on its form in, and sorption to, soil with simple salts and elemental mercury causing the greatest hazard because of the potential to generate toxic vapours. Plants differ in their ability to take up mercury and can develop a tolerance to high concentrations on contaminated sites, with corresponding elevated concentrations in edible parts compared with natural soils (Kabata- Pendias and Mukherjee, 2007).

Several studies have reported the accumulation of mercury in plant roots, although translocation within the plant to other parts including shoots and seeds will also occur (Hussein *et al*., 2007; Kabata-Pendias and Mukherjee, 2007).

Environmental Quality Standards for Mercury and other Heavy Metals

To assess the risks associated with contaminated soil there are a number of International Environmental Quality Standards (EQS) in use that use a variety of criteria to determine if the levels of heavy metals found in soil pose an acceptable risk to humans and the environment

Soil Guideline Values

Soil Guideline Values (SGV) and supporting technical guidance notes are intended to assist professionals in the assessment of long-term risk to health from human exposure to chemical contamination in soil (EA, 2009).

There are different SGVs according to land-use (residential, allotments, commercial) because people use land differently and this affects who and how people may be exposed to soil contamination.

SGV are 'trigger values' for screening-out low risk areas of land contamination. They give an indication of representative average levels of chemicals in soil below which the long-term health risks are likely to be minimal. Exceeding an SGV does not mean that remediation is always necessary, but should trigger further investigations and a further evaluation of the risk a given contaminant might pose. SGV values are expressed as total concentration per kg soil [mg/kg] and therefore don’t take into account the mobility or bio-availability of a given element. Mobility of heavy metals (and therefore the risk they pose to human health) is largely dependent on environmental factors, including soil type and soil pH.

Table 4. UK Soil Guideline values for 7 different heavy metals. Please note that SGV values are based on CLEA 2009 (Contaminated Land Exposure Assessment) values, which are updated technical documents issued by the Environmental agency. They replace CLEA2002 and ICRCL (Inter Departmental Committee for the Redevelopment of Contaminated Land) values for the assessment of the human health risk from land contamination. For lead (Pb) and chromium (Cr) no updates were issued in 2009 so the guidelines shown are from CLEA 2002.

Heavy Metal	Land Use	CLEA Soil Soil Guideline Value [mg/kg]
Arsenic (As)	Residential	32
	Allotment	43
	Commercial	640
Cadmium (Cd)	Residential	10
	Allotment	1.8
	Commercial	230

Heavy Metal	Land Use	CLEA Soil Soil Guideline Value [mg/kg]
Chromium (Cr)	Residential	130
	Allotment	200
	Commercial	5000
Mercury (Hg)	Residential	10
	Allotment	26
	Commercial	26
Nickel (Ni)	Residential	130
	Allotment	230
	Commercial	1800
Selenium (Se)	Residential	350
	Allotment	120
	Commercial	1300
Lead (Pb)	Residential	450
	Allotment	450
	Commercial	750

SGV values are only available for a few contaminants including Arsenic, Cadmium, Chromium, Mercury, Nickel and Lead (Table 4).

The Sewage Sludge Directive (EC Directive 86/278/EEC)

The Sewage Sludge Directive (EC Directive 86/278/EEC) was set up to encourage the use of sewage sludge in agriculture and to regulate its use in such a way as to prevent harmful effects of pollutants on soil, vegetation, animals and man. As such the directive provides environmental guideline values on metal concentrations in agricultural soils that are deemed acceptable after application of sewage sludge. Acceptable, meaning that those concentrations are supposed to have no negative effect on human health as a result of consuming produce grown on 'contaminated' land. Unlike the Soil Guideline Values (Table 4), the Sewage Sludge Directive takes into account soil pH for some heavy metals (nickel, copper and zinc) acknowledging that these heavy metals are in general more mobile at lower pH, and therefore pose a greater risk in acidic soils. As with the Soil Guideline Values, the Sewage Sludge Directive values are expressed as total metal concentrations (Table 5).

Table 5. EC Directive 86/278/EEC maximum concentrations of heavy metals in agricultural soils that differ in acidity and after sewage sludge application

Element	Soil pH			
	5.0 – 5.4	**5.5 – 5.9**	**6.0 – 7.0**	**> 7.1**
Arsenic [mg/kg]	50	50	50	50
Cadmium [mg/kg]	3	3	3	3
Chromium [mg/kg]	400	400	400	400

Element	Soil pH			
	5.0 – 5.4	5.5 – 5.9	6.0 – 7.0	> 7.1
Mercury [mg/kg]	1	1	1	1
Nickel [mg/kg]	50	60	75	110
Selenium [mg/kg]	3	3	3	3
Lead [mg/kg]	300	300	300	300
Copper [mg/kg]	80	100	135	200
Zinc [mg/kg]	200	250	300	450

Waste Acceptance Criteria (WAC)

The Waste Acceptance Criteria (EA, 2010) were introduced in the UK to ensure that potentially hazardous waste is safely disposed of so that it no longer poses a risk to humans and the environment. Unlike the Soil Guideline Values and the Sewage Sludge Directive, which base risk on 'total metal concentrations' combined with land use or soil pH, Waste Acceptance Criteria assess the risks that contaminated materials pose to the environment and human receptors on water leachable concentrations of contaminants and their inherent toxicity. Water leachable concentrations of contaminants are not necessarily correlated to 'total concentrations' of contaminants in the waste, but are dependent on metal speciation and the ability of the different pollutants to bind to the soil / waste matrix. The WAC have been set as maximum limit values which must not be exceeded to allow characterisation of a specific waste stream into three different hazard classes. The different WAC classes are: 'Inert non-hazardous waste', 'Stable, non-reactive hazardous waste' and 'Hazardous waste'. Waste that falls into each class requires different levels of containment and management; waste classified as hazardous waste requires the most stringent measures and monitoring, while waste that is classified as 'inert' requires minimal containment, management and monitoring.

WAC for the different waste categories are presented in Table 6. WAC is based on a 1:10 liquid:solid (L/S 10) water extraction method (BS EN 12457) which provides an assessment of leachable concentrations of metals and other contaminants.

Table 6. UK Waste Acceptance Criteria (WAC) for maximum contaminant concentrations within solid waste based on results of water-based leaching tests (mg/kg) derived from a liquid to solid (L/S = 10) extraction.

		A	B	C
Component	**Symbol**	**Inert Waste [mg/kg]**	**Granular/Stable, non-reactive hazardous [Waste mg/kg]**	**Hazardous Waste [mg/kg]**
Arsenic	As	0.5	2	25
Barium	Ba	20	100	300
Cadmium	Cd	0.04	1	5

		A	B	C
Component	Symbol	Inert Waste [mg/kg]	Granular/Stable, non-reactive hazardous [Waste mg/kg]	Hazardous Waste [mg/kg]
Total Chromium	Cr_{total}	0.5	10	70
Copper	Cu	2	50	100
Mercury	Hg	0.01	0.2	2
Molybdenum	Mo	0.5	10	30
Nickel	Ni	0.4	10	40
Lead	Pb	0.5	10	50
Antimony	Sb	0.06	0.7	5
Selenium	Se	0.1	0.5	7
Zinc	Zn	4	50	200
Dissolved Organic Carbon (DOC)	DOC	500	800	1000

The EU Water Framework Directive

The EU Water Framework Directive, 2000/60/EC (EU WFD) is the most significant legal instrument in the water field that has been developed by the EU to protect surface waters from pollution. The key objectives of the WFD are general protection of the aquatic ecology, specific protection of unique and valuable habitats, protection of drinking water resources, and protection of bathing water. The central requirement of the WFD is that the environment be protected to a high level in its entirety. For this reason, a general requirement for ecological protection, and a general minimum chemical standard of water quality, are introduced to cover all surface waters. Good ecological status is defined in terms of the quality of the biological community, the hydrological characteristics and the chemical characteristics of a water body. Good chemical status requires that the concentration of potentially toxic elements are below a set maximum concentration (Table 6). This concentration is for some elements, such as copper and zinc, dependent on water hardness (Table 6). Even if one element is above the maximum allowable concentration, this means that the water quality of that water body fails the EU WFD guidelines.

Table 7. Water framework Directive EQS of heavy metals in surface waters. Numbers represent Annual Average concentrations unless denoted as MAC, which represent Maximum Annual Concentration of a particular metal.

Metal	Water Hardness [mg $CaCO_3$/l]			
	0-50	**50-100**	**100-250**	**>250**
Al [µg/l]	100	100	100	100
As [µg/l]	50	50	50	50
Cd [µg/l]	0.25	0.25	0.25	0.25

Metal	Water Hardness [mg $CaCO_3$/l]			
	0-50	50-100	100-250	>250
Cd_{MAC} [µg/l]	1.5	1.5	1.5	1.5
Co [µg/l]	3	3	3	3
Cr(III) [µg/l]	4.7	4.7	4.7	4.7
Cr(VI) [µg/l]	3.4	3.4	3.4	3.4
Cu [µg/l]	1	6	10	28
Fe [µg/l]	1000	1000	1000	1000
Mercury (Hg)	0.7	0.7	0.7	0.7
Mn [µg/l]	30	30	30	30
Mn_{MAC} [µg/l]	300	300	300	300
Pb [µg/l]	7.2	7.2	7.2	7.2
Ni [µg/l]	20	20	20	20
Zn [µg/l]	8	50	75	125

Assessment of Mercury and other Heavy Metals in the Soil Samples

Sampling and Sample Storage

Segovia is a traditional mining town with an estimated production >3000 kg of gold and >1,700 kg of silver per year (DAMMA, 2008). Six samples were taken from each of two different sites in Segovia with a history of gold mining (Figure 27). The first set of 6 samples were taken from an area where active mining was taking place. These samples were labelled S1 to S6. The second set of samples were taken from Tadó in Choco, a site where mining had seized. These samples were labelled T1 to T6.

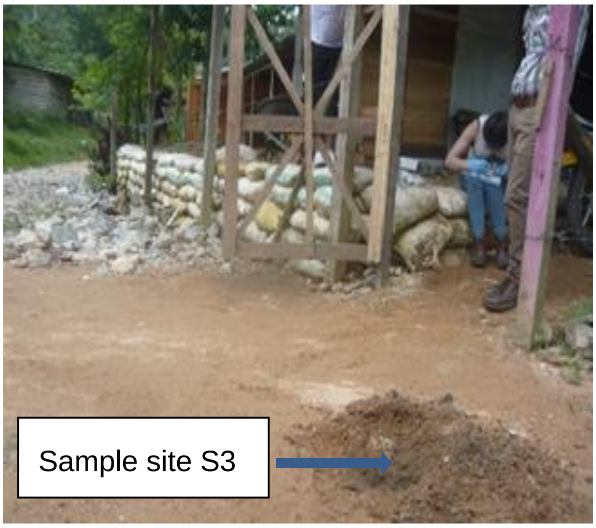


Figure 27. Example of sample site (S3) at El Planchón. Sample S3 was taken downstream from the gold processing plant, very close to the neighbouring town houses.

Once taken, each sample was placed in two plastic bags that were stored in a cool-box. Samples were sent to the UK for analysis and tests, where they were held in a cold storage at <4°C before being processed.

Extraction and Analysis of Total Metals

To quantify the total concentrations of heavy metals in the soil samples, each soil sample was first air dried for 10 days at 20ºC in a desiccator. Low temperatures were used to prevent loss of mercury as a result of evaporation. Once dried, each sample was finely ground in a pestle and mortar until the sample became a fine, homogeneous powder. 1.5 grams of each dried and ground soil sample was placed in 14ml *Aqua Regia* (10.5ml of concentrated HCl and 3.5 ml of concentrated HNO_3). The soil was then digested in a microwave oven (Anton Paar Multiwave 3000) at 180ºC for 20 min. The extract was then made to 50 ml with ultrapure deionised water before being analysed with an ICP-OES dual view analyser (Thermo iCap 6500).

Extraction of Water Leachable Metals

Analysis of water extractable Hg content was carried out by firstly determining the moisture content of the wet soil samples by desiccating 50g of each soil sample. The moisture content of the soil was then calculated from the mass loss of the sample after drying. The wet soil samples were then used for water extraction by adding 2 ± 1 g of soil from the different sites that were sampled (1S-6S and 1T-6T) to a 30 ml Sterilin vial to which 20 ± 1 ml deionised water was added. The soil suspensions were shaken on a rotary shaker for 24 hours before being filtered through a 0.45µm nylon filter, into a clean, 30 ml Sterilin vial. The filtered samples were acidified to stabilise extracted mercury by adding 100 µl of 50% concentrated HNO3 to 10ml of each water extract. The extract was then made to 50 ml before being analysed with an ICP-OES dual view analyser (Thermo iCap 6500).

Methyl Mercury extraction

Analysis of Methyl Hg concentration in sample 4S was carried out via HPLC-AFS. The soil samples were firstly dried at < 37°C and ground prior to analysis. The soil was then extracted using an ethanol/hydrochloric acid mixture and ultrasonic assisted extraction.

Sequential extraction to determine mercury speciation

A sequential extraction of soil sample 4S was carried out using methods outlined by Liu *et al*., (2006) and Bloom *et al.,* (2003).

Water extractable mercury:

To measure the water extractable Hg, 1 ± 0.1 g of the desiccated/ground 4S soil sample was placed into a 50ml centrifuge tube. To the soil, 10ml of deionised water was added. The obtained soil suspension was then shaken on a rotary shaker for 24 hours before being centrifuged at 3000 rpm for 30 minutes. The supernatant, containing the water extractable mercury, was decanted into a 30 ml Sterilin vial. The residual precipitate was rinsed with another 10 ml of deionised water and inverted by hand several times before being centrifuged again at 3000 rpm for 30 mins. The supernatant was decanted into the 30 ml Sterilin vial containing the first extractant. The solution was then being filtered through a 0.45 µm nylon filter to remove any particulates.

Stomach acid extractable mercury:

To measure human stomach acid extractable Hg, the residue in the centrifuge tubes from the water extractions was extracted with 10 ml of a 0.1M Acetic acid + 0.01M Hydrochloric acid solution. The extraction process was repeated as before by shaking, centrifuging, rinsing and decanting as outlined.

Extraction of mercury bound to soil organic matter:

To measure the mercury that is bound to organic matter in the soil, the residue in the centrifuge tubes from the human stomach acid extractions was extracted with 10 ml of a 1M KOH solution. The extraction process was carried out as described for the 'water extractable mercury'.

Extraction of elementary mercury:

To measure elementary Hg (Hg^0), the residue in the centrifuge tubes from the organic bound Hg extractions was extracted with 10 ml of a 12M HNO_3 solution. The extraction process was repeated as before. However, 10 ml of deionised water was instead used for the rinse step, and a 0.45 µm glass fibre filter was used to remove the residual turbidity.

Extraction of mercury sulphide:

To quantify the amount of mercury sulphide in the sample, the residue in the centrifuge tubes left after extraction of the elemental Hg was treated with *aqua regia* (10ml conc. HCl and 3ml of conc. HNO3). The *aqua regia* was pipetted directly into the centrifuge tubes. The extraction of mercury held in the residue was carried over a 24-hour period by gently agitating the suspension and leaving it to stand with the lid loosely capped to prevent build-up of gasses within the tube. After 24h, the extractions were diluted to 40 ml using RO water and then filtered through a 0.45 µm glass fibre filter to remove particulate matter.

Results

Total Concentrations of Mercury and other Heavy Metals in Samples taken from Segovia and Tadó

All samples taken from the area where soil was being processed for gold recovery (Samples S1-S6) showed elevated concentrations of mercury, with levels in samples S1, S2, S5 and S6 being more than 10mg Hg/kg soil, S3 being 60mg Hg/kg soil and S4 being 360mg Hg/kg soil (Figure 28). According to the Soil Guideline Values (SGV), soils that contains >26 mg Hg/kg soil is deemed unsuitable for any form of land use, while soil that contains >10mg Hg/kg soil should not be used for building houses on. All of the S samples would therefore fail the SGV for residential land use (Figure 28).

In contrast the total concentrations of mercury in the samples taken from Tadó (Samples T1-T6) where between 0.16 and 1.6mg/kg (Figure 28). These values are well below the Soil Guideline Values (SGV) for residential (SGV < 10mg/kg) allotment and commercial (SGV < 26mg/kg) land use. Only samples T1, T3 and T4 had concentrations of mercury that were above the SGV value for agricultural land use (SGV < 1mg/kg) (Figure 28). Similarly, none of the samples taken from Tadó were contaminated with significant amounts of other heavy metals (Table 8).

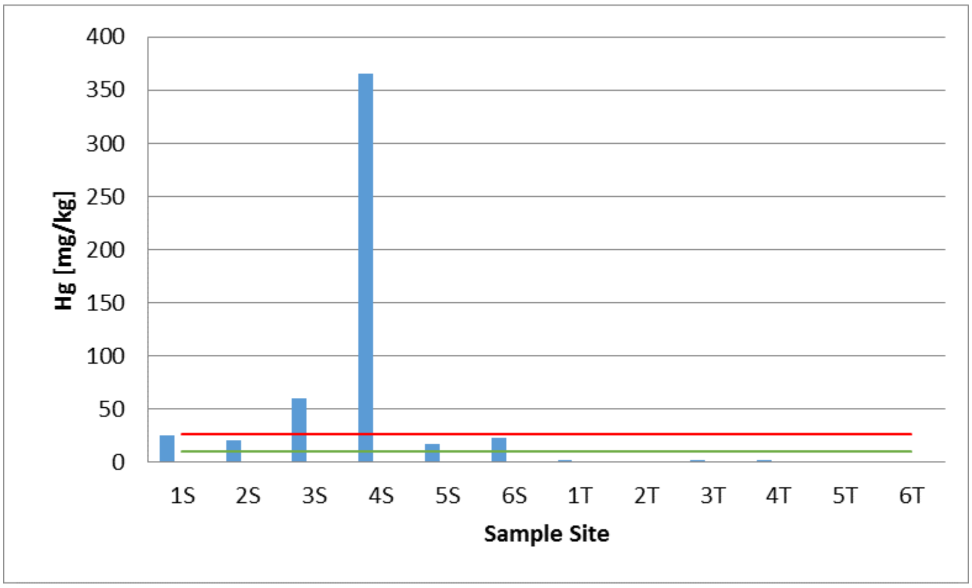


Figure 28. Total concentrations of mercury (mg Hg/kg) in samples taken from an active mining area (Samples S1-S6) and an abandoned mining area (Samples T1-T6). Red line represents SGV for Commercial and Allotment Land Use, Amber Line represents SGV for Residential Land Use.

In contrast, samples S1, S2, S3, S4 and S5 were also contaminated with high concentrations of cadmium, chromium, lead, zinc and arsenic. These concentrations were above the SGV 'trigger values' (Table 8). Notably sample S3 and S4 contained cadmium levels that were >9 times greater than the maximum SGV for commercial use and SGV values that were 4-5 times the commercial land use SGV for lead (Table 8).

Table 8. Total Concentrations (mg/kg) of Heavy Metals (except Hg) in Samples taken from an active mining area (Samples S1-S6) and an abandoned mining area (Samples T1-T6) in Segovia. EQS are based on UK Soil Guideline Values;

	Metal Concentration [mg/kg]											
Sample	**Fe**	**Al**	**Mn**	**Cd**	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Sn**	**Zn**	**As**
S1	30,809	44,544	329	2	7	14	65	4	164	1	118	86
S2	31,537	17,511	103	3	3	24	54	2	416	1	93	239
S3	29,447	37,107	103	94	5	22	78	5	3,103	2	2,640	216
S4	45,180	1,310	157	98	5	60	29	7	4,431	1	3,128	375
S5	22,306	42,695	125	4	3	17	39	6	203	1	207	19
S6	41,768	54,424	977	0	29	34	27	22	143	1	47	8
T1	16,627	19,931	145	0	4	38	22	13	3	0	34	2
T2	11,245	21,343	112	0	3	37	21	11	2	0	30	2
T3	12,829	22,229	120	0	7	42	24	13	2	0	36	3
T4	2,171	31,942	20	0	5	28	16	16	6	1	18	0
T5	17,290	18,266	169	0	8	36	30	20	4	1	54	2
T6	8,721	13,679	88	0	3	28	16	11	2	0	27	1
SGV Residential	**n/a**	**n/a**	**n/a**	**10**	**n/a**	**130**	**n/a**	**130**	**450**	**n/a**	**n/a**	**32**
SGV Allotment	**n/a**	**n/a**	**n/a**	**1.8**	**n/a**	**200**	**n/a**	**230**	**450**	**n/a**	**n/a**	**32**
SGV Commercial	**n/a**	**n/a**	**n/a**	**1.8**	**n/a**	**5000**	**n/a**	**1,800**	**750**	**n/a**	**n/a**	**640**

Leachable Concentrations of Mercury and other Heavy Metals in Samples taken from Segovia and Tadó

From the total amount of mercury found in the different samples < 0.1% was water soluble. In sample 4S this amounted to 0.38mg/kg mercury, which would classify this material as hazardous according to WAC regulation (Figure 29). Samples 1T, 5T and 6T also failed WAC for inert waste (Figure 29). If material from S4 would wash into the river, 1 kg material could contaminate as much as 500 litre water to concentrations that would be above the Water Framework Directive allowable concentration.

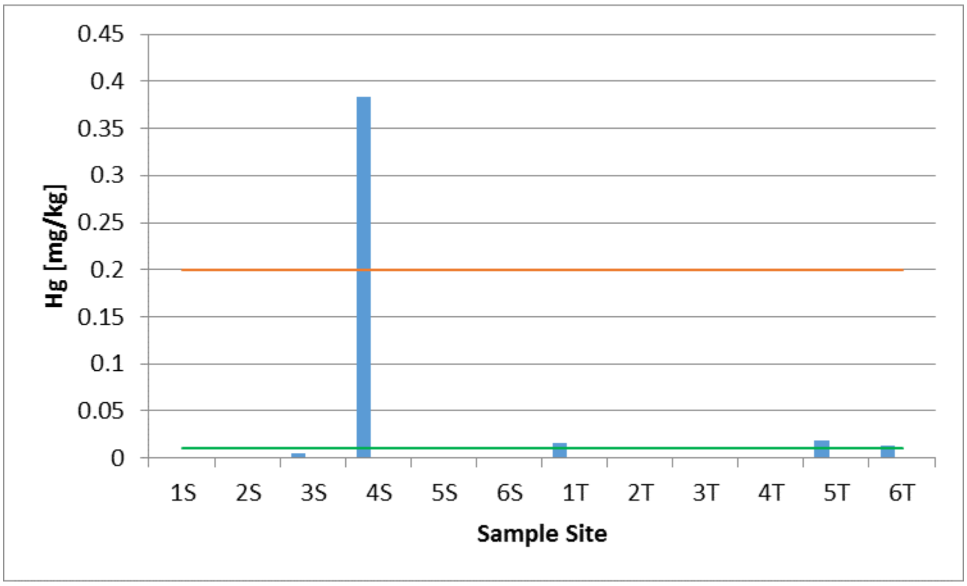


Figure 29. Water leachable concentrations of mercury (mg Hg/kg) in samples taken from an active mining area (Samples S1-S6) and an abandoned mining area (Samples T1-T6). Green line represents leachable mercury concentrations below which the soil would be classified as 'inert waste'; the amber line represents the concentration above which the soil would be classified as 'hazardous'

The most contaminated sample with respect to levels of leachable heavy metals was sample 3S (Table 9). Leachability of cadmium, lead and zinc in this sample exceeded WAC (Waste acceptance Criteria) for hazardous waste, meaning that the soil at sampling site S3 was too toxic to be put in a specially designed hazardous waste site. The next most contaminated sample was S2, which would be classified as hazardous waste based on the levels of leachable Zn (Table 9). Sample S5 had concentrations of cadmium that were above the WAC Inert (Table 9). Most Samples were contaminated sufficiently to cause water pollution if the soil was to enter a river or lake (Table 9).

Table 9. Leachable Concentrations (μg/kg) of Heavy Metals (except Hg) in samples taken from an active mining area (Samples S1-S6) and an abandoned mining area (Samples T1-T6) in Segovia

	Metal Concentration [μg/kg]											
Sample	**Fe**	**Al**	**Mn**	**Cd**	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Sn**	**Zn**	**As**
S1	43	113	36	6	3	6	9	18	0	2	232	1
S2	19,852	108,266	3,314	450	153	156	1,496	139	175	22	16,837	82
S3	1,658	41,008	10,268	32,097	1,382	22	299	1,448	109,307	41	898,740	76
S4	62	312	286	1	1	14	17	33	13	0	68	0
S5	33	155	81	50	3	0	68	53	33	19	1,679	9
S6	0	167	235	2	8	0	15	25	20	0	287	0
T1	27	817	101	0	34	4	110	146	7	18	388	7
T2	265	967	134	4	91	7	242	464	16	0	1,011	0
T3	0	96	69	0	24	0	30	97	0	0	169	0

						Metal Concentration [µg/kg]						
Sample	**Fe**	**Al**	**Mn**	**Cd**	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Sn**	**Zn**	**As**
T4	342	13,766	195	2	140	3	54	381	280	0	419	0
T5	70	789	5	0	0	1	21	32	6	19	163	0
T6	110	3322	106	3	159	5	212	390	1	0	1,054	0
Inert WAC	**N/A**	**N/A**	**N/A**	**40**	**N/A**	**500**	**2000**	**400**	**500**	**N/A**	**4000**	**500**
Stable WAC	**N/A**	**N/A**	**N/A**	**1000**	**N/A**	**10,000**	**50,000**	**10,000**	**10,000**	**N/A**	**50,000**	**2000**
Hazardous WAC	**N/A**	**N/A**	**N/A**	**5000**	**N/A**	**70,000**	**100,0000**	**40,000**	**50,000**	**N/A**	**200,000**	**25,000**
WFD	**1000**	**100**	**300**	**0.25**	**3**	**4.7**	**28**	**20**	**7.2**	**N/A**	**8**	**50**

WFD based on EU annual average surface water standards; WAC Inert represents concentrations of leachable metals below which the waste is classified as Inert; WAC Stable represents concentrations of leachable metals below which the waste is classified as Stable, non-reactive hazardous waste (yellow shading). WAC Hazardous represents concentrations of leachable metals below which the waste is classified as hazardous (orange shading); above this value the waste is too toxic to be landfilled (red shading). Blue shading represents cases where 1 kg of soil would contaminate 1 litre of water above concentrations that are deemed unacceptable for surface waters.

Methods used for Treatment of Metal Contamination

Background to C-Cure Products (info@ccuresolutions.com)

The technologies licenced to C-Cure are designed to accelerate the degradation of organic pollutants via bio-remediation or to immobilise pollutants, including heavy metals by adsorbing them. Once adsorbed onto C-Cure products, pollutants are no longer leachable and don't interfere with biological processes (de-toxification). It has to be noted that in the case of heavy metals, the C-Cure treatment does not reduce the total concentration of heavy metals, but instead, makes those metals non-bio-available and non-leachable. This means that application of the C-Cure products to contaminated soil ensures that pollutant – receptor pathways are broken, so that pollutants no longer leach into ground and surface waters, are no longer taken up by plants or cause eco-toxicity. Depending on the soil conditions, adsorption of most heavy metals onto the C-Cure products is irreversible and stable, but even if soil conditions could lead to desorption (such as low soil pH) the pore structure of the products ensures that the conditions within the product is buffered from external soil conditions. Under unfavourable conditions it was shown that metal desorption from charcoal particles that were 2 mm in diameter was 2000 times slower than metal desorption from lime.

Furthermore, detoxification of soil leads to restoration of normal soil function and allows revegetation to take place. Both adsorption of metals and subsequent ecological restoration ensure sustainable land regeneration of contaminated soil.

Treatment of Mercury contamination

Soil sample 4S had both the highest total Hg concentration (361 mg/kg) and highest leachable Hg concentration (383 µg/kg).

Therefore, soil sample 4S was used to test treatment with C-Cure-CCA treatment product.

Treatment of the soil was carried out using wet, unground soil, and the treatment was applied as outlined in Table 10. The soil was mixed thoroughly with the amendment in a crucible and a known amount of deionised water was added to the sample to create a sample with a moisture content of 25%. The treated soil was then incubated for 3 days at 4ºC.

Table 10. Treatment of soil sample 4S

Treatments	Dry Soil (g)	Amendment	Amendment [g]	Moisture added [ml]
CCA	11.666	5%	0.500	0.985

The treated soil was then sequentially extracted using the methods outlined in above noting that 1.3 g of treated soil was used initially to account for the moisture content of the sample.

Treatment of methyl mercury contamination

Soil sample 4S was used to test treatment methods of methyl mercury within the sample. 10g of wet soil was amended with 4 different products.

Ten g of wet soil was treated with each product using a 5% amendment rate. The soil was mixed thoroughly with the amendment and a little water was added. The treated soil was then incubated for 24 hours before analysis was carried out as outlined in the methods section above.

However, since there was no methyl mercury in the sample, the effectiveness of these treatments to adsorb methyl mercury could not be assessed.

Treatment of Al, Cd, Fe, Pb and Zn contamination

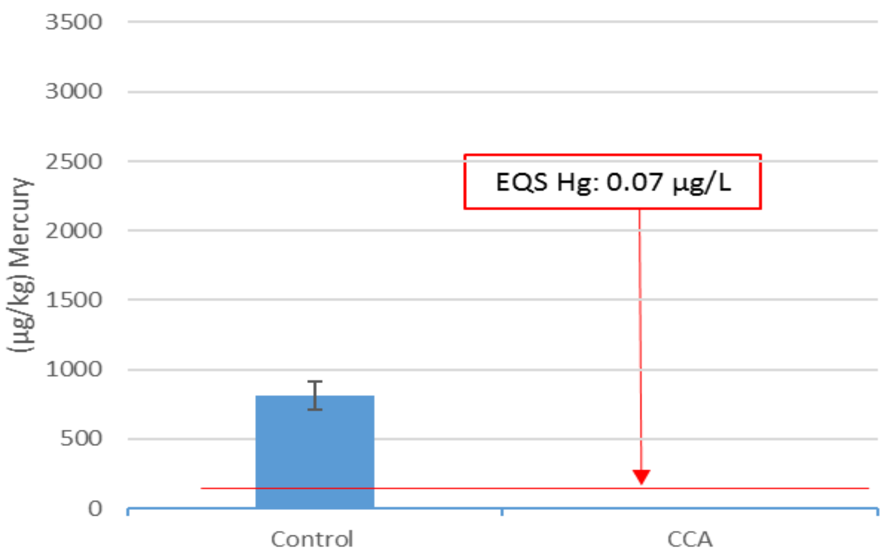
Soil sample S3 had some of the highest concentrations of leachable aluminium (41 mg/kg), cadmium (32 mg/kg), iron (1.66 mg/kg), lead (109 mg/kg) and zinc (898.7 mg/kg) concentrations of all the samples tested (Table 9). In fact, the leachable concentrations of cadmium, lead and zinc would make this soil too toxic to be landfilled in a specially designed hazardous landfill site. Sample S3 was therefore used to test C-Cure's standard heavy metal treatment product (C-Cure-TTLX).

The soil was treated using different amendment rates of approx. 2.3% (w/w), 4.4% (w/w), 6.7% (w/w) and 8.9% (w/w) on a soil dry-weight basis. These concentrations are equivalent to amendment rates of 2.5, 5.0, 7.5 and 10% (w/w) on a wet-weight basis.

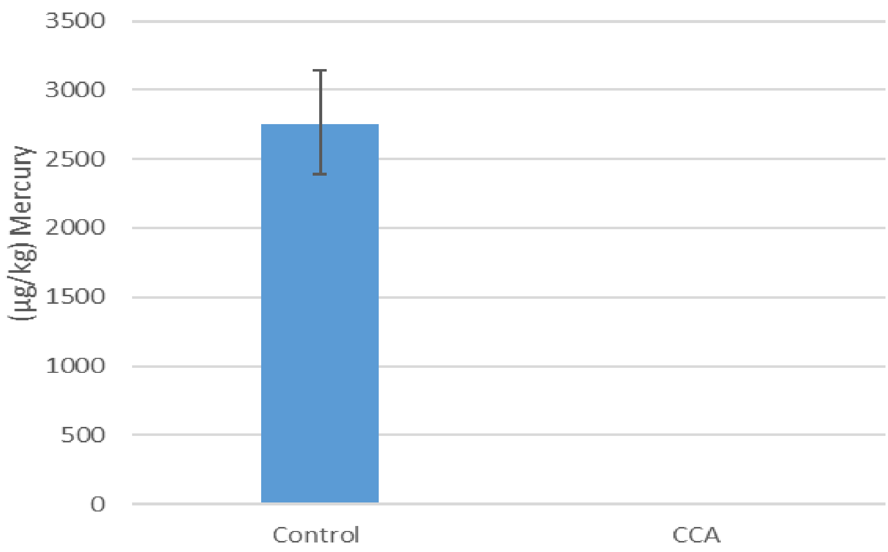
The treated soil was then extracted using the method outlined above, using 2.5g ± 0.1g of soil to account for the moisture content of the treated soil.

Results for C-Cure Treatment of Metal Contamination

Sample S4 contained no organic-matter bound mercury, nor did it contain methyl mercury. The non-treated S4 soil contained 812 µg/kg water soluble and 2755 µg/kg human stomach acid soluble mercury (Figure 30). Treatment with the C-Cure-CCA product at an amendment rate of 5% (w/w) resulted in all of the water soluble and human stomach acid soluble mercury being eliminated from the soil (Figure 30). Instead, in the CCA treated soil most (72%) of the mercury was found to be extractable with 10M HNO3, which represents elemental mercury. In the non-treated soil the percentage 10M HNO3 extractable mercury was 51%.



c) Water Soluble Mercury



d) Human Stomach Acid Soluble Mercury

Figure 30: Amounts of water soluble (a) and human stomach acid soluble (b), in soil taken from sampling site S4 in the control sample and samples treated with 5% (w/w) C-Cure product (CCA). N=2.

A further test aimed at quantifying the minimum amount of C-Cure product that was needed to bind all the water soluble and stomach acid soluble mercury showed that an amendment rate of 0.5% (w/w) reduced the concentration of water soluble mercury by 80%, while a 1% amendment rate resulted in the complete elimination of water soluble mercury (Figure 31).

To remove all stomach acid soluble mercury an amendment rate of 5% was needed while an amendment rate of 3% (w/w) eliminated 95% of all the stomach acid soluble mercury from the soil (Figure 32).

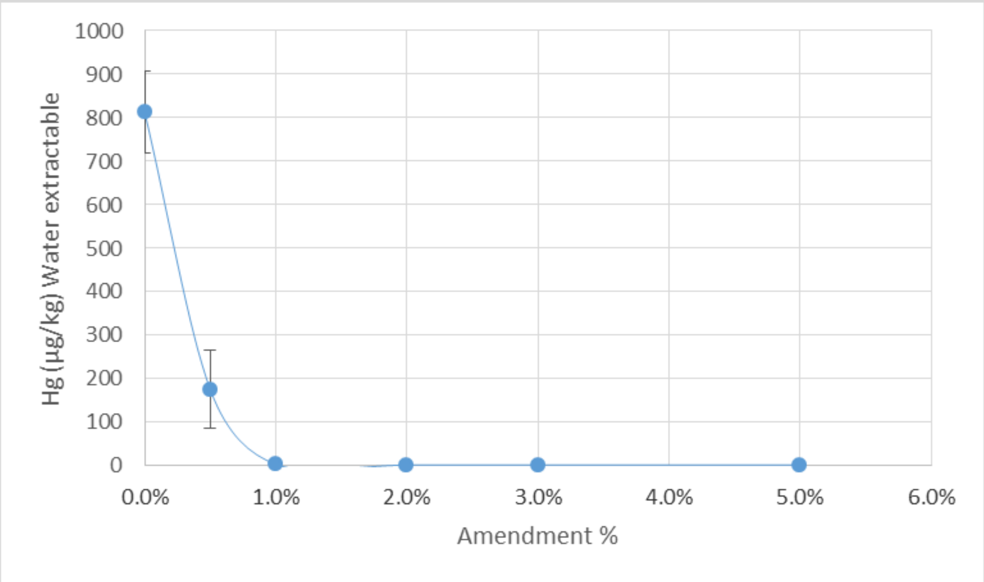


Figure 31. Concentrations (µg/kg) of water soluble mercury, in soil taken from sampling site S4 amended with increasing amounts (0, 0.5, 1, 2, 3, and 5% w/w) C-Cure product (CCA). N=2.

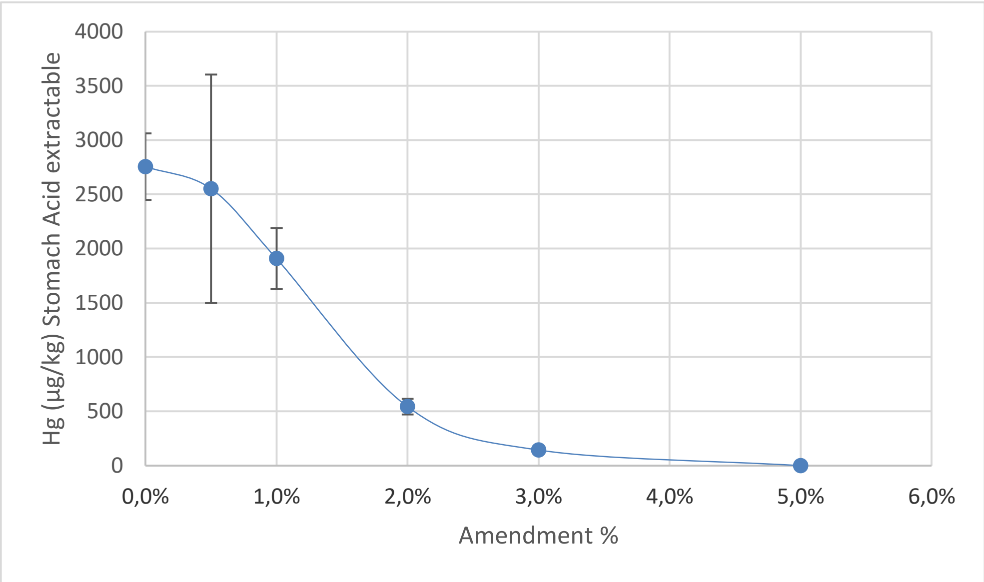


Figure 32. Concentrations (µg/kg) of stomach acid soluble mercury, in soil taken from sampling site S4 amended with increasing amounts (0, 0.5, 1, 2, 3, and 5% w/w) C-Cure product (CCA). N=2.

Treatment of Heavy Metal Contamination

Aluminium

Water leachable concentrations of aluminium went from 947 mg/kg in the untreated soil to less than 0.01 mg/kg in soil that was amended with 2.3% C-Cure product, a reduction of 99.999% (Figure 33). This meant that the treated samples would comply with the most stringent EQS.

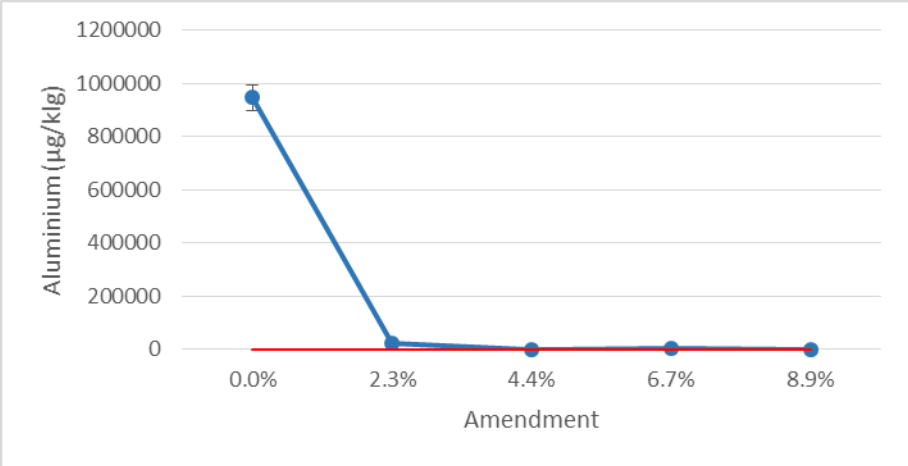


Figure 33. Concentrations of leachable aluminium (µg/kg) in soil taken from site S3 before and after treatment with either 2.3, 4.4, 6.7 or 8.9% (w/w) C-Cure metal adsorbing product (C-Cure-TTLX). N=2. Red line represents the annual average EQS for EU surface waters.

Nickel

Leachable nickel was reduced by 94% using the C-Cure treatment. Leachable concentrations went from 2.1mg Ni/kg soil to 0.12 mg Ni/kg soil with an amendment rate of 7.5% C-Cure product (Figure 34). This value would classify the material as 'inert' according to the UK WAC.

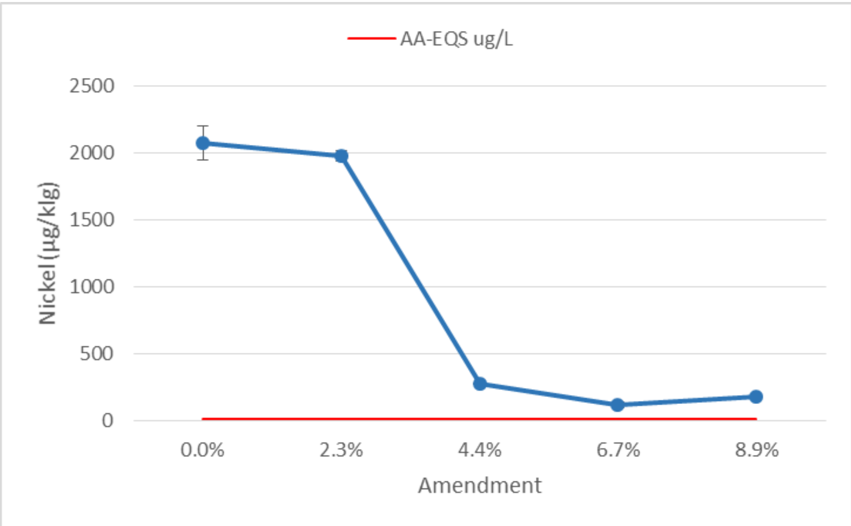


Figure 34. Concentrations of leachable nickel (µg/kg) in soil taken from site S3 before and after treatment with either 2.3, 4.4, 6.7 or 8.9% (w/w) C-Cure metal adsorbing product (TTLX). N=2. Red line represents the annual average EQS for EU surface waters.

Copper

The concentration of leachable copper went from more than 14mg/kg to 0.114mg/kg with an amendment rate of 4.4%, a reduction of 99.2%. This decrease brought the soil to below the WAC for inert waste. Increasing the amendment rate above 4.4% did not result in further reductions of leachable copper (Figure 35).

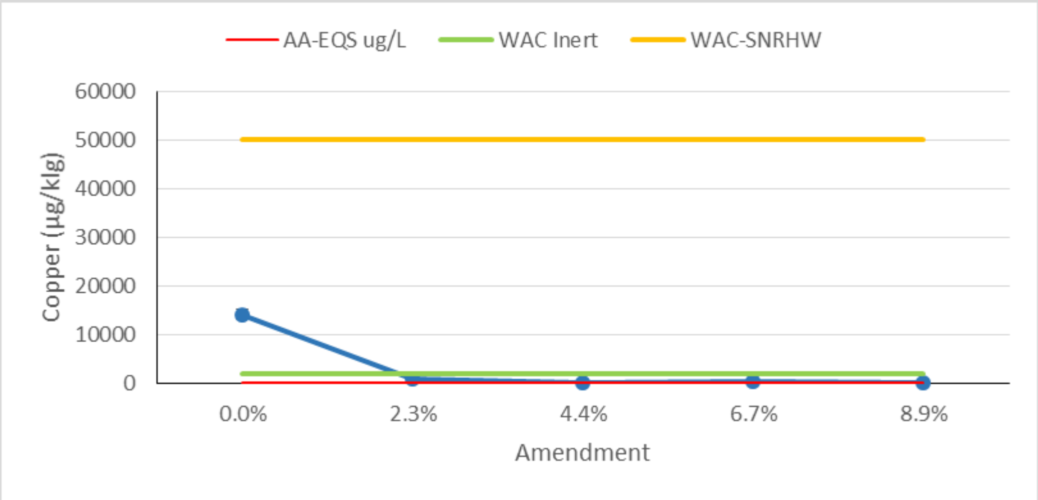


Figure 35. Concentrations of leachable copper (µg/kg) in soil taken from site S3 before and after treatment with either 2.3, 4.4, 6.7 or 8.9% (w/w) C-Cure metal adsorbing product (TTLX). N=2. Thin red line represents annual average EQS for EU surface waters; light green line is the Waste Acceptance concentration for inert waste and purple line is the Waste Acceptance concentration for Stable Non-Reactive Hazardous Waste.

Iron

The concentration of leachable iron went from more than 1500mg/kg soil in the non-treated control to 0.1mg/kg in soil amended with an amendment rate of 2.3% or more; a reduction of 99.99% (Figure 36). This concentration was well below the concentration of leachable iron that would be acceptable for classification as inert waste according to the WAC.

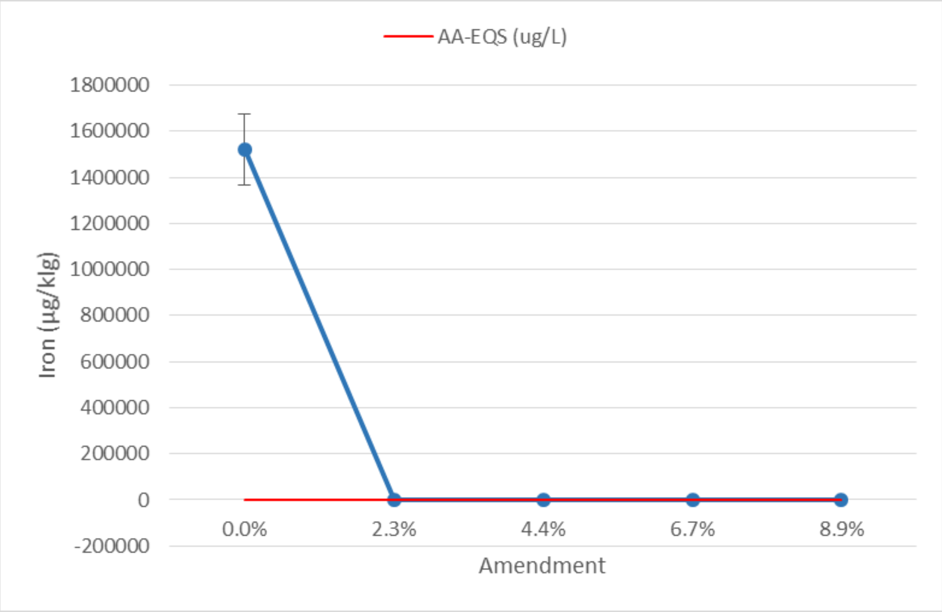


Figure 36. Concentrations of leachable iron (µg/kg) in soil taken from site S3 before and after treatment with either 2.3, 4.4, 6.7 or 8.9% (w/w) C-Cure metal adsorbing product (TTLX). N=2. Red line represents annual average EQS for EU surface waters.

Lead

The concentration of leachable lead went from more than 26 mg/kg in the non-treated control to 0.34 mg/kg in soil amended with 8.9% C-Cure product; a reduction of 98.7%. a similar reduction in leachable lead was achieved with half the amendment rate (Figure 37). The non-treated soil would be classified as hazardous according to WAC. However, after treatment the remaining concentration of leachable lead in the C-Cure treated soil would allow the soil to be classified as inert waste according to the WAC criteria (Figure 37)

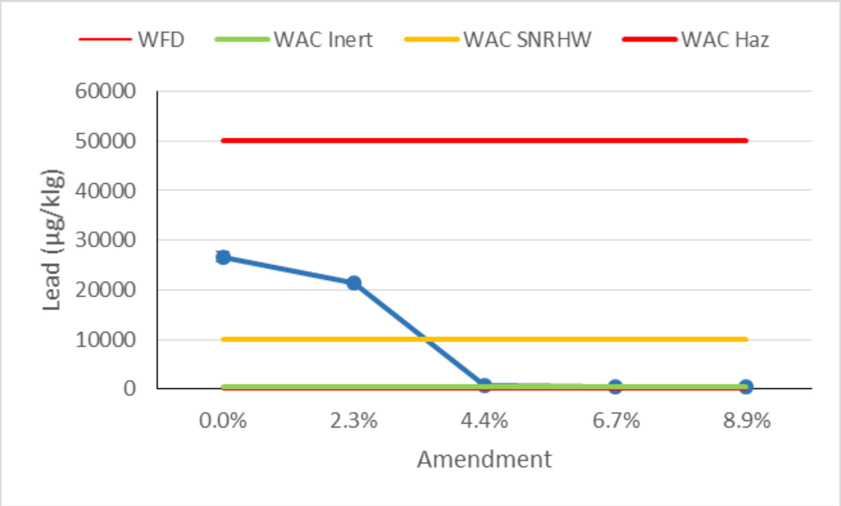


Figure 37. Concentrations of leachable lead (µg/kg) in soil taken from site S3 before and after treatment with either 2.3, 4.4, 6.7 or 8.9% (w/w) C-Cure metal adsorbing product (TTLX). N=2. Thin red line represents annual average EQS for EU surface waters; light green line is the Waste Acceptance concentration for inert waste and purple line is the Waste Acceptance concentration for Stable Non-Reactive Hazardous Waste and thick red line represents Waste Acceptance concentration for Hazardous Waste.

Tin

The concentration of leachable tin went from more than 57 µg/kg in the non-treated control to non-detectable concentrations in soil amended with 2.3% (w/w) or more C-Cure product. (Figure 38).

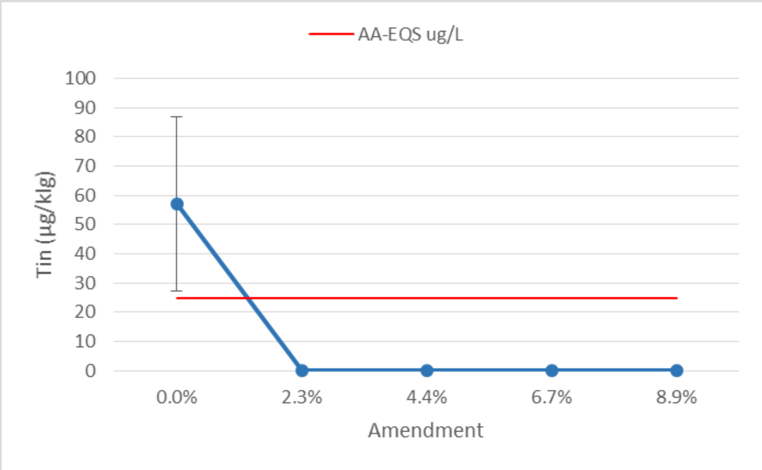


Figure 38. Concentrations of leachable tin (µg/kg) in soil taken from site S3 before and after treatment with either 2.3, 4.4, 6.7 or 8.9% (w/w) C-Cure metal adsorbing product (TTLX). N=2. Red line represents annual average EQS for EU surface waters.

Zinc

The concentration of leachable zinc went from more than 2000mg/kg in the non-treated control to around 50 mg/kg in soil amended with >6.7% C-Cure product (Figure 39). Whereas the remaining leachable Zn is still regarded as hazardous, the soils hazard class was reduced from 'above hazardous' to 'Stable Non-Reactive Hazardous waste' (Figure 39)

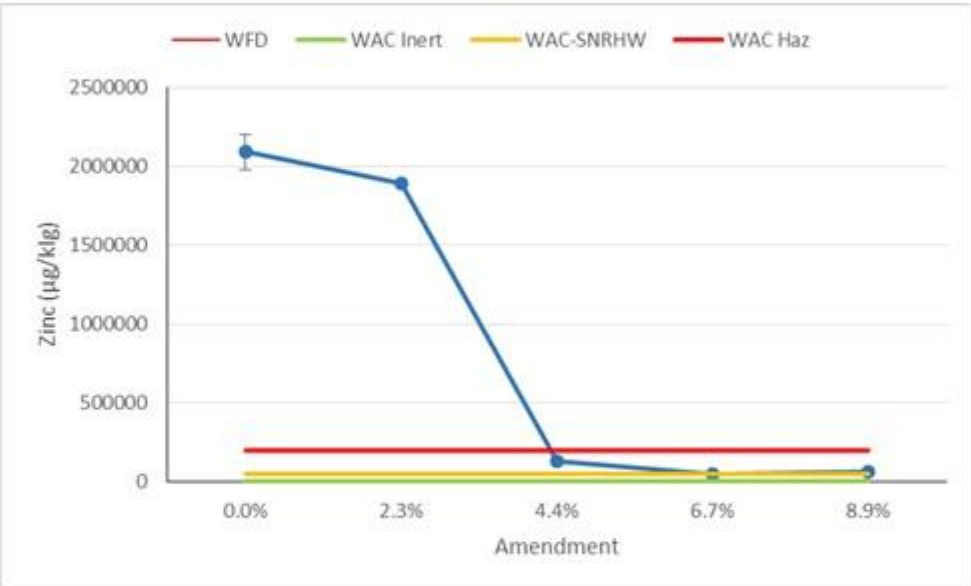


Figure 39. Concentrations of leachable zinc (µg/kg) in soil taken from site S3 before and after treatment with either 2.3, 4.4, 6.7 or 8.9% (w/w) C-Cure metal adsorbing product (TTLX). N=2. Thin red line represents annual average EQS for EU surface waters; light green line is the Waste Acceptance concentration for inert waste and

amber line is the Waste Acceptance concentration for Stable Non-Reactive Hazardous Waste and thick red line represents Waste Acceptance concentration for Hazardous Waste.

Cadmium

The concentration of leachable cadmium went from 85.8 mg/kg to 3.5 mg/kg with an amendment of 8.9% TTLX, a reduction of 96%. This reduction was sufficient to reduce the hazard class of the soil from 9x over the hazardous waste class, to well within the hazardous waste category according to WAC (Figure 40)

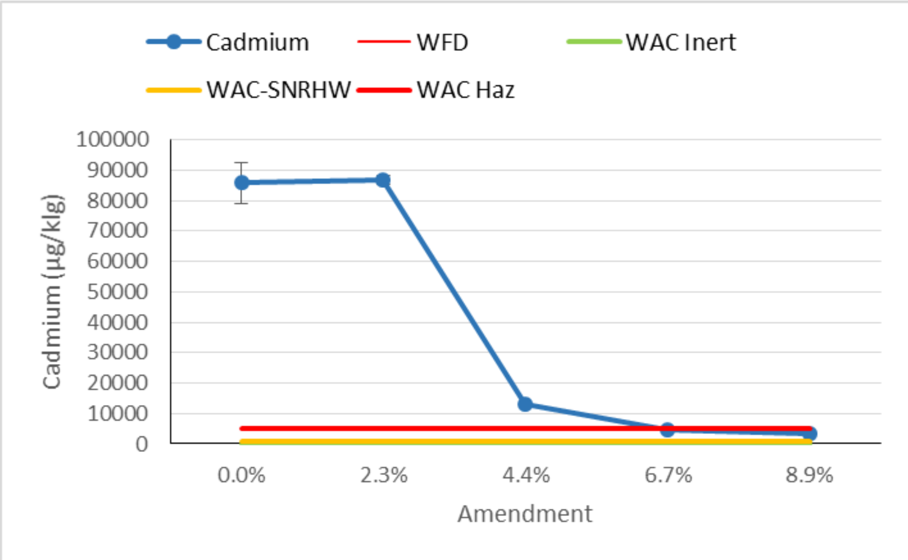


Figure 40. Concentrations of leachable cadmium (µg/kg) in soil taken from site S3 before and after treatment with either 2.3, 4.4, 6.7 or 8.9% (w/w) C-Cure metal adsorbing product (TTLX). N=2. Thin red line represents annual average EQS for EU surface waters; light green line is the Waste Acceptance concentration for inert waste and grey line is the Waste Acceptance concentration for Stable Non-Reactive Hazardous Waste and thick red line represents Waste Acceptance concentration for Hazardous Waste.

Chromium

The concentration of leachable chromium went from more than 2 mg/kg to 0.114mg/kg with an amendment rate of 4.4%, a reduction of 99.2%. Increasing the amendment rate above 2.3% did not result in further reductions of leachable chromium (Figure 41). This meant that the hazard classification of this soil went from 'non-reactive hazardous waste' to 'inert' (Figure 41)

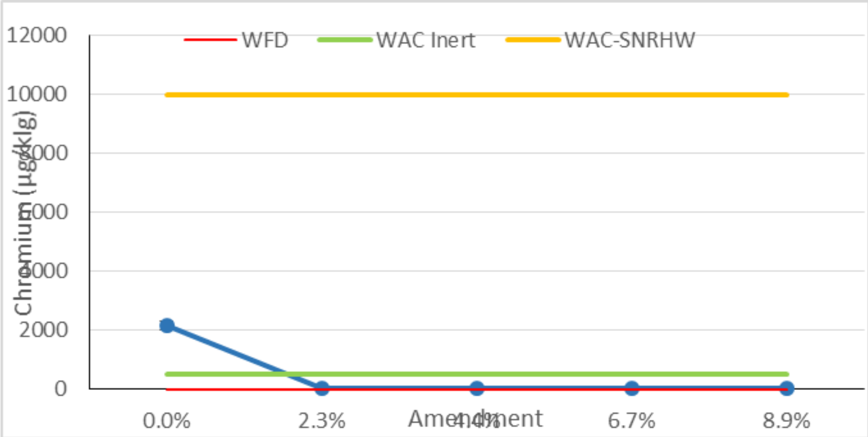


Figure 41. Concentrations of leachable chromium (µg/kg) in soil taken from site S3 before and after treatment with either 2.3, 4.4, 6.7 or 8.9% (w/w) C-Cure metal adsorbing product (TTLX). N=2. Thin red line represents annual average EQS for EU surface waters; light green line is the Waste Acceptance concentration for inert waste and purple line is the Waste Acceptance concentration for Stable Non-Reactive Hazardous Waste.

Arsenic

The non-treated S3 sample contained 2000µg leachable arsenic per kg soil. A 2.5% amendment rate with C-Cure product resulted in the almost complete removal of leachable arsenic (Figure 42). Adding more C-Cure-TTLX product resulted in a gradual small rise in as leachability from 12µg/kg at an amendment rate of 2.3% (w/w) to 42µg/kg at an amendment rate of 10% (w/w). This meant that the treated sample could be classified as 'inert' according to WAC. Also, the low levels of leachable arsenic in the treated sample meant that this sample would not cause water pollution according to WFD criteria (Figure 42).

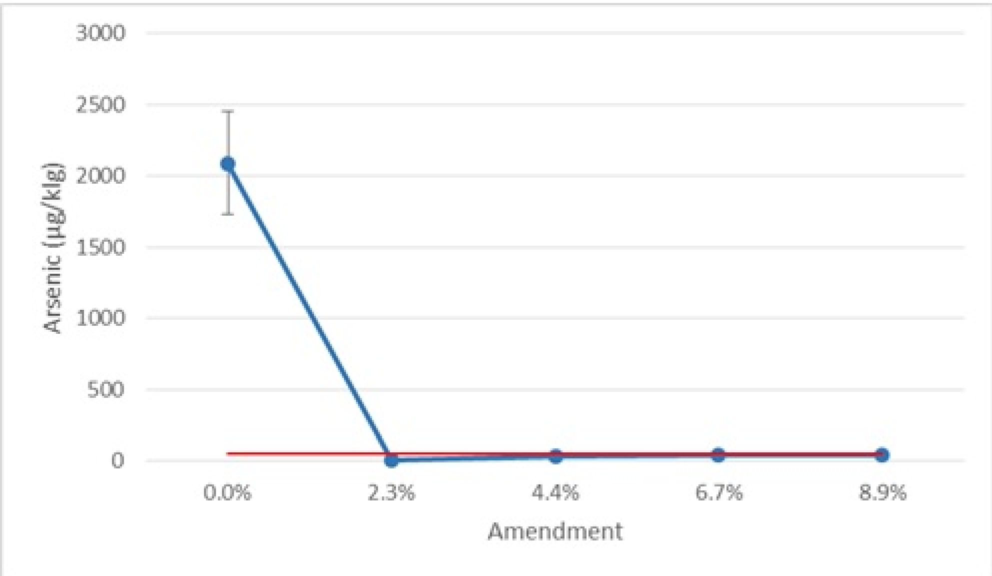


Figure 42. Concentrations of leachable arsenic (µg/kg) in soil taken from site S3 before and after treatment with either 2.3, 4.4, 6.7 or 8.9% (w/w) C-Cure metal adsorbing product (TTLX). N=2. Red line represents annual average EQS for EU surface waters.

Summary

- From the 12 samples received for analysis, only one (Sample S4) contained significant amounts (0.38mg/kg soil) of leachable mercury.
- Sample S4 had the largest amount of total mercury (350mg/kg), followed by sample S3 which contained 60mg/kg mercury.

- Sequential extraction of Sample S4 revealed that 1% of the total amount of mercury in this sample was water extractable, an additional 2% was extractable with stomach acids, an additional 51% was extractable with 10M Nitric acid and the rest (46%) became extractable with *Aqua Regia*.
- None of the mercury in sample S4 was bound to organic matter
- There was no methyl mercury in sample S4
- Treatment with C-Cure product CCA, resulted in the complete elimination of water soluble; and stomach acid soluble mercury.
- Sample S3 contained highly hazardous levels of water leachable cadmium, lead and Zn, while other heavy metals such as copper, tin, chromium, aluminium, iron and arsenic were elevated.
- Treatment with C-Cure's metal adsorbent product (CCLX) resulted in large reductions (90 to 100%) in all leachable metal concentrations.
- Treatment with C-Cure metal adsorbent product reduced the hazard class of the material significantly (Table 11).

Table 11. Summary of metal concentrations in treated and non-treated samples and hazard classification before and after treatment with different amounts of C-Cure metal adsorbent product. Unless specified differently hazard classifications are based on WAC where green shading represents 'inert waste' yellow shading represents 'Stable Non-Reactive Hazardous Waste', amber shading represents 'hazardous waste' and red represents waste that is too toxic for acceptance in a hazardous landfill site.

Element	**Amendment Rate (% w/w)**				
	0 (control)	**2.3%**	**4.4%**	**6.7%**	**8.9%**
Al*[µg/kg]	946733	20487	90	333	0
As [µg/kg]	2092	12	36	42	41
Cd [µg/kg]	85785	86663	13225	4534	3513
Cr [µg/kg]	2167	44	41	40	32
Cu[µg/kg]	14043	738	114	175	148
Fe* [µg/kg]	1519008	668	92	105	121
Ni [µg/kg]	2076	1978	281	121	179
Pb [µg/kg]	26607	21392	767	584	338
Zn [µg/kg]	2092372	1891961	136821	48919	64837

EQS based on EU Water Framework guidelines