SUSTAINABLE MINERAL RESOURCES IN THE PHILIPPINES (SMRP) PROGRAMME

The SMRP programme aims to **improve understanding of the impacts of past and future mining practices in the Philippines** and to **develop innovative approaches for mineral production** that minimise adverse effects on the environment and promote the health and well-being of communities.

This programme is funded by UK Research and Innovation - Natural Environment Research Council (UKRI-NERC) and the Department of Science and Technology – Philippine Council for Industry, Energy, and Emerging Technology Research and Development (DOST-PCIEERD).

RESEARCH THEMES

Developing novel technologies for the sustainable extraction and understanding of mineral deposition in the Philippines.

Understanding legacy (abandoned) mines and mine tailings including resource recovery, processing of untapped or unprocessed minerals, and appreciating the impacts of past practices and routes to ecosystem rehabilitation.

Understanding the fate, transport, and impact of associated contaminants through the environment.

SMRP PROJECTS

1. Philippine Mining at the National to Catchment Scale: from Legacy Impacts to Sustainable Futures (PAMANA)
2. Philippines Remediation of Mine Tailings (PROMT)
3. Sustainable Minerals Knowledge Exchange Fellowship

PAMANA

PHILIPPINE MINING AT THE NATIONAL TO CATCHMENT SCALE: FROM LEGACY IMPACTS TO SUSTAINABLE FUTURES

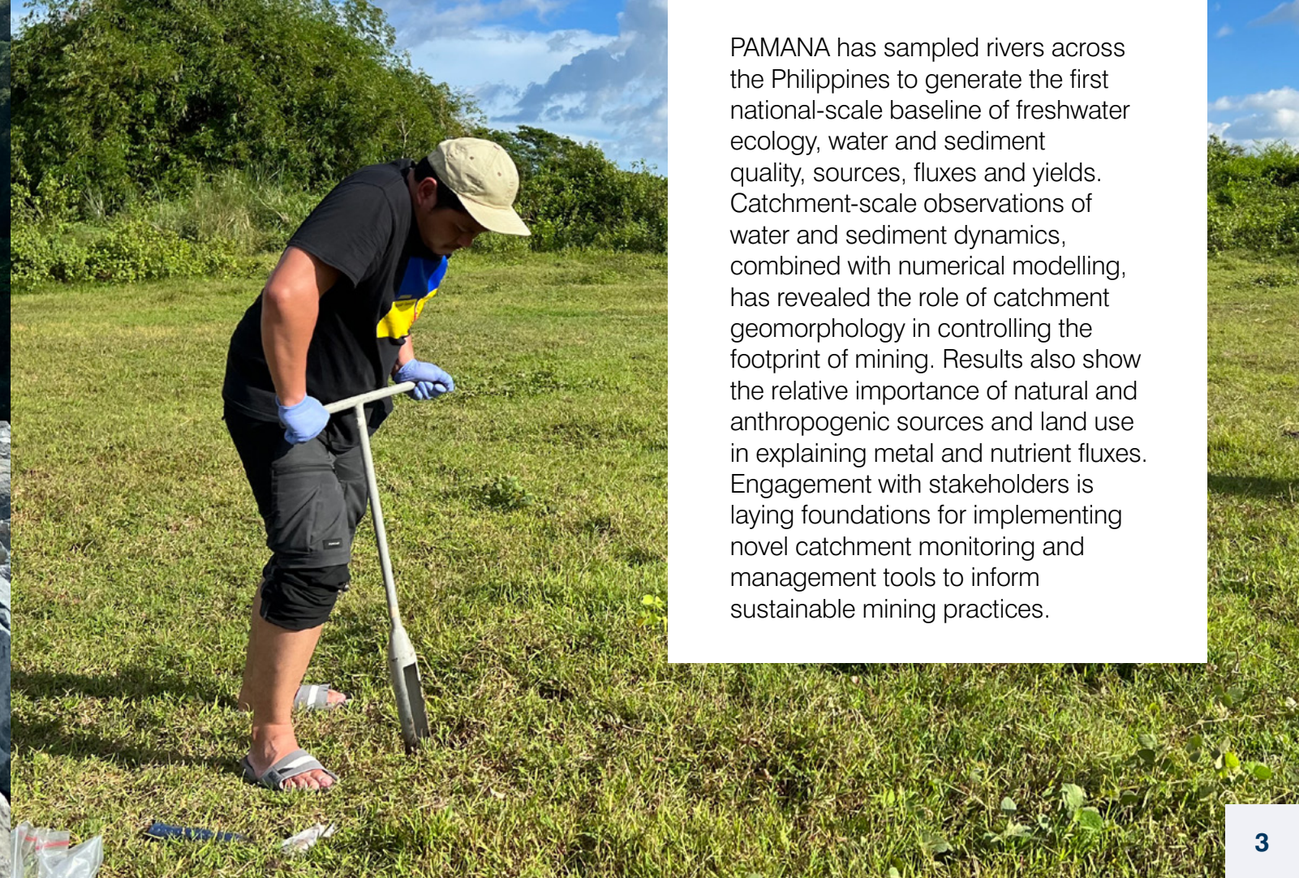
INTRODUCTION

Key environmental and social requirements for managing mining in the Philippines sustainably include:

1. effective baselining and monitoring of water and sediment quality
2. understanding of the sources, fate, transport, and impacts of mine waste
3. methods for remediating and managing active and legacy mining areas
4. catchment level management of mining areas
5. aligning regulatory requirements with on-the-ground conditions and achievable solutions to increase compliance in the artisanal and small-scale mining (ASM) sector

FRAMING THE PROBLEM

Wastes from contemporary and historical mining, whether from large, small, or even artisanal scales cannot be avoided. In the Philippines, mining activities take place in the context of frequent typhoons/storms with associated flooding and landslides, and considerable vulnerability to climate change impacts. Mining is also carried out in catchments where sediment and water quality may also be influenced by different land uses, inherent geological mineralisation, and natural source inputs (e.g., geothermal springs). The Philippines currently lacks national geochemical databases and standardised sampling procedures for determining background and baseline metal concentrations in water and soil, all of which are required to support environmental management. Managing mining in the Philippines sustainably thus requires assessment of landscape properties, collation of comprehensive data sets, and understanding of the source and fate of chemicals and sediments as they move through river systems.



EXECUTIVE SUMMARY

PAMANA has sampled rivers across the Philippines to generate the first national-scale baseline of freshwater ecology, water and sediment quality, sources, fluxes and yields. Catchment-scale observations of water and sediment dynamics, combined with numerical modelling, has revealed the role of catchment geomorphology in controlling the footprint of mining. Results also show the relative importance of natural and anthropogenic sources and land use in explaining metal and nutrient fluxes. Engagement with stakeholders is laying foundations for implementing novel catchment monitoring and management tools to inform sustainable mining practices.

RESEARCH APPROACH

Research has been undertaken at the national-scale, across ten catchments in Luzon and Mindanao, and also at the catchment-scale within the Agno catchment and its sub-catchments including the Itogon (also known as the Ambalanga) catchment. These catchments are variously mineralised, impacted by anthropogenic activities including large-scale mining, ASM and agriculture.

KEY RESEARCH OUTCOMES

The first nationwide baseline survey of water quality and ecological health of major Philippine rivers.

Novel bioavailability analysis reveals that thresholds for potentially harmful aqueous trace metals vary between Philippine rivers.

Unexpectedly, geothermal inputs rather than mining are responsible for the most elevated aqueous trace metal concentrations in the Itogon catchment. Many of these concentrations exceed Philippine water guideline values.

Numerical modelling shows geomorphology and connectivity control the footprint of mine waste sediment fluxes and deposition.

Impacts from ASM can be mediated by storing mine waste locally.

Bioremediation using indigenous microbial populations from tailings storage facilities increases plant height and stem diameter, which is comparable with or better than commercially available biofertilizers.

Insights from an Institutional Analysis and Development (IAD) Framework show the complexities of the Philippine mining industry (both large-scale and ASM) through the interactions between different actors, rules, and outcomes.

RESEARCH ACTIVITIES INCLUDED:

National-scale baselining. We monitored river hydrology, sediment and water quality, and freshwater ecology, at ten catchments distributed across Luzon and Mindanao islands. This enabled us to estimate metal and nutrient fluxes and yields from catchments to transitional and coastal waters, and establish river ecological health, to inform Philippine specific baselining.

Disentangling contributors to water and ecosystem quality. To assess the relative importance of different catchment geological settings and land use pressures (e.g. mining, agriculture, geothermal) on river health, we monitored water quality during wet and dry seasons for eight sub-catchments of the Agno catchment, and sampled sediment and water quality along the river network of the Itogon catchment.

Numerical modelling of mine-sourced sediment. An innovative nested numerical modelling approach was employed to quantify the effects of both large-scale and ASM activities on mine source sediment fluxes. We investigated a wide range of scenarios to assess the transport and accumulation of mine waste across different scales, highlighting potential avenues for policy changes to mediate the impact of mine waste.

Bioremediation experiments. Indigenous microbial populations of mycorrhizal fungi and nitrogen-fixing bacteria were isolated from Agno catchment mine tailings to assess their potential for bioremediation. The materials were propagated in the lab and then used to inoculate nursery stocks. Field trials are building up information on their effectiveness to support strategies for rehabilitating mined-out areas.

Stakeholder engagement. Key Informant Interviews and Focus Group Discussions with stakeholders included national, regional, and local government agencies, non-government organisations, large-scale and ASM industry, people's organisations, and the academe. Insights were synthesised using the Institutional Analysis and Development (IAD) Framework.

In summary, the controls on river health are catchment specific and include mineralisation, large-scale and ASM activities, land use, geothermal activity and catchment geomorphology. Catchment-scale observations, modelling and impact assessment are needed to understand the local characteristics that will enable more sustainable mining practices and facilitate decadal and century-timescale management.

CASE STUDIES

How can a river monitoring programme be designed to inform national environmental decision-making?

National environmental decision-making requires a detailed understanding of the state of the water environment. We undertook the first national survey of water quality and ecosystem health in ten Philippine rivers to highlight human pressures and to reveal the natural diversity of river ecosystems. We demonstrated a suite of novel monitoring tools (Diffusive Gradients in Thin-Films; Uncrewed Survey Vessels) that could form the foundation of a national Philippine river monitoring programme. We quantified how much trace metals and nutrients are transferred by rivers from the land to the sea. We discovered natural variability in bioavailable trace metals across the Philippines, which means that environmental quality standards for metals should be uniquely determined for each catchment.

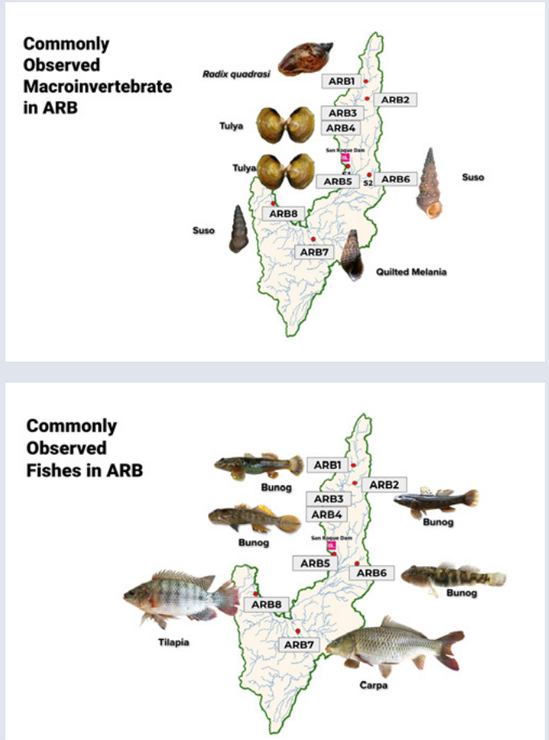
What is the impact of mining and other pressures on the Agno catchment's ecology?

The Agno River Basin (ARB) in the Philippines provides a unique case study of river ecological health in the region, emphasizing both the richness of biodiversity and the threats it faces. Despite the Philippines' rivers being globally recognized for their high biodiversity, pressures from human activity—such as intensive water management, agricultural practices, and resource extraction— are posing significant risks to these ecosystems.

Our study revealed low to moderate levels of fish and macroinvertebrate diversity, indicating that human activities in the catchment area are affecting the river's ecological health. The Upper Agno is still dominated by native species while Lower Agno is dominated by aquaculture fish such as Tilapia and Carpa. The limited diversity and shifts in fish and macroinvertebrate assemblages suggest that anthropogenic pressures are altering the ecosystem.

This research highlights the critical need for routine ecological assessments to monitor changes in biodiversity and detect the impacts of human activities. Such monitoring is crucial for preserving the ecological balance and biodiversity of rivers in the Philippines.

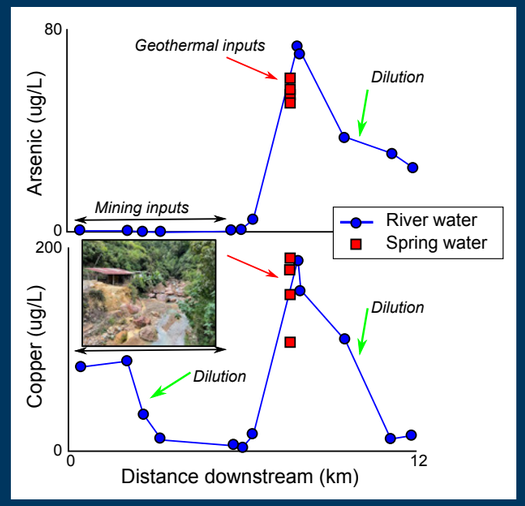
We recommend implementing a national river health monitoring programme that includes regular assessments of fish and macroinvertebrate diversity. This programme would help track ecological health trends, enabling conservation efforts to protect and enhance biodiversity in the ARB and other Philippine rivers.



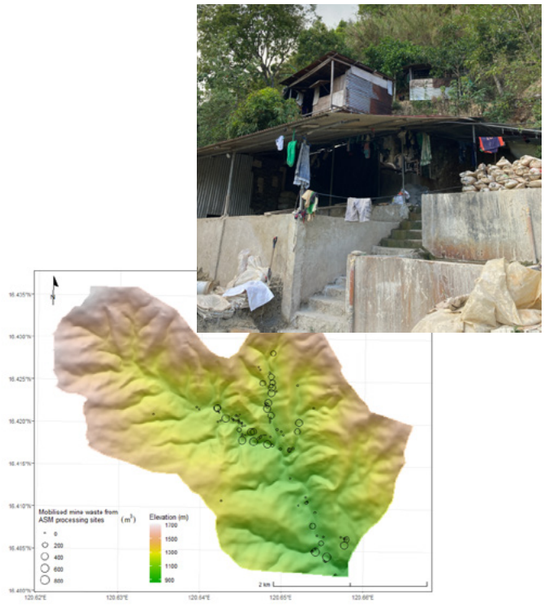
Commonly observed macroinvertebrates and fish at the monitoring sites in the Agno River Basin.

Is mining responsible for all metal contamination of waters in affected catchments? The case of the Itogon catchment, Philippines.

Globally, mining activities can cause metal contamination of waters in host catchments through direct discharge of effluents and wastes and through chemical interactions between waters and deposit mine wastes. Thus, it is often hypothesized that mining is the main cause of elevated metal concentrations in such catchments. This hypothesis was tested in the Itogon (also known as the Ambalanga) catchment, by sampling waters downstream of large- and small-scale mining and processing operations, and in sites that were apparently unaffected by mining. Analysis of the data suggests that the major sources of most metals were geothermal springs rather than mining inputs. Geothermal springs accounted for elevated filtered aqueous concentrations of arsenic, copper, vanadium, lithium, boron, vanadium and cadmium, whereas mining inputs accounted for elevated filtered aqueous concentrations of copper, zinc, vanadium and cadmium. Geothermal-related copper and vanadium river water concentrations were equal to, or greater than, mining-related concentrations of these elements. This study highlights the necessity to consider all possible natural and anthropogenic (including mining) sources of metals when designing research programmes and, if required, remediation and management strategies for contamination.



Filtered concentrations of arsenic and copper in the South Itogon (also known as the Ambalanga) River waters and springs. Elevated arsenic concentrations are likely due to inputs from geothermal springs, whereas elevated copper concentrations arise from both mining and geothermal spring inputs.



Contribution of processed sediment from different ASM processing sites across the catchment that drains into the Antamok open pit mine during a 10-year period. Inset photograph shows one such ASM processing site.

How do artisan mines contribute to mine waste in rivers?

Artisan small-scale mining (ASM) is widespread in mineralised catchments. However, the environmental impacts of mine waste from ASM are poorly understood because mined ore is processed at many smaller sites instead of a centralised facility. This distributed processing setup makes managing any waste from mining harder to manage and regulate. Often, waste from processing that may contain contaminants from extraction is pushed into local rivers for disposal. This potentially contaminated sediment product is often transported by surface runoff and through rivers during high river flows. Some of the product is then likely to become trapped in floodplain deposits. We used the river catchment that flows into the now abandoned Antamok open pit mine as an exemplar to numerically model the fate of solid mine waste produced by local ASM processing facilities. Results show that when solid mine waste is deposited close to rivers (for this catchment, within 60 m) it is mobilised during rainfall events and may become a diffused source of pollution, which is difficult to manage. Conversely, solid mine waste stored further away from streams is not mobilised, making its future management possible. These findings are important for guiding provision for the storage and management of ASM tailings.

This research and knowledge exchange activity was funded by UK Research and Innovation - Natural Environment Research Council (UKRI-NERC) and Department of Science and Technology - Philippine Council for Industry, Energy and Emerging Technology Research and Development (DOST-PCIEERD) – Grant NE/W006871/1.

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RECOMMENDATIONS

Building on the success of this project, we recommend a number of next steps. If implemented, these recommendations could ultimately improve the environment and lives of Philippine citizens.

- **Environmental management of mining-impacted catchments should consider: (i) 100-1000 year timescales, including land use and climate change impacts, (ii) sediment as a contaminant, and (iii) all possible trace metal sources, in addition to those that are mining related.**

Rationale: Modelling and field studies indicate that the effects of mining will persist for decades to hundreds of years after mining has ceased. This may be in increased sediment loads rendering sediment as a contaminant, and elevated metal loads in water and sediment. Magnitudes of sediment delivery and movement are highly contingent on flooding events that will be increasingly governed by climate change as well as land use.

- **Establish a national-scale river health monitoring programme.**

Rationale: Environmental management decision-making depends upon an understanding of the state of the environment. River ecosystem health responds to wider environmental pressures within a catchment. Our national-scale monitoring has demonstrated the techniques that can be used to quantify water quality and ecology. These could form the foundation of a national-scale river monitoring programme to provide baselines to inform decision-making.

- **Develop ecologically relevant environmental quality standards for trace metals in rivers using DGT.**

Rationale: Universal environmental quality standards for trace metals in Philippine rivers may misrepresent ecosystem risk. This is because the biologically available fraction of metals is usually lower than the filtered fraction typically used to evaluate risk, and there is also considerable variability in bioavailability between catchments. Environmental quality standards for trace metals in rivers should be unique to each catchment and based on the bioavailability of metal solutes.

- **Establish a national-scale soil geochemical database for the Philippines.**

Rationale: There are currently no baseline standards for element concentrations in mineralized soils in the Philippines. The Philippines' tropical climate combined with its island-arc geology developed a varied distribution of background metal concentrations and soil characteristics, and therefore, a national-scale soil geochemical database needs to be developed.

- **Localise landscape-based designs for the containment of artisanal small-scale tailings.**

Rationale: A difficulty for the ASM sector is its inability to comply with the requirements of the law to establish and operate communal tailings storage facilities. Tailings impoundments need to be designed for ASM that consider the local geophysical, topographical, geomorphological and climatic conditions to enable compliance and environmental security.

- **Manage mining areas at the catchment level.**

Rationale: Catchments function as interconnected ecological units, where upstream activities such as mining impact downstream water quality and biodiversity. Managing mining areas at catchment levels allows for more comprehensive understanding into social and environmental impacts, helping identify critical areas for policy interventions and management decisions.

- **Improve support to increase compliance in the artisanal and small-scale mining sector.**

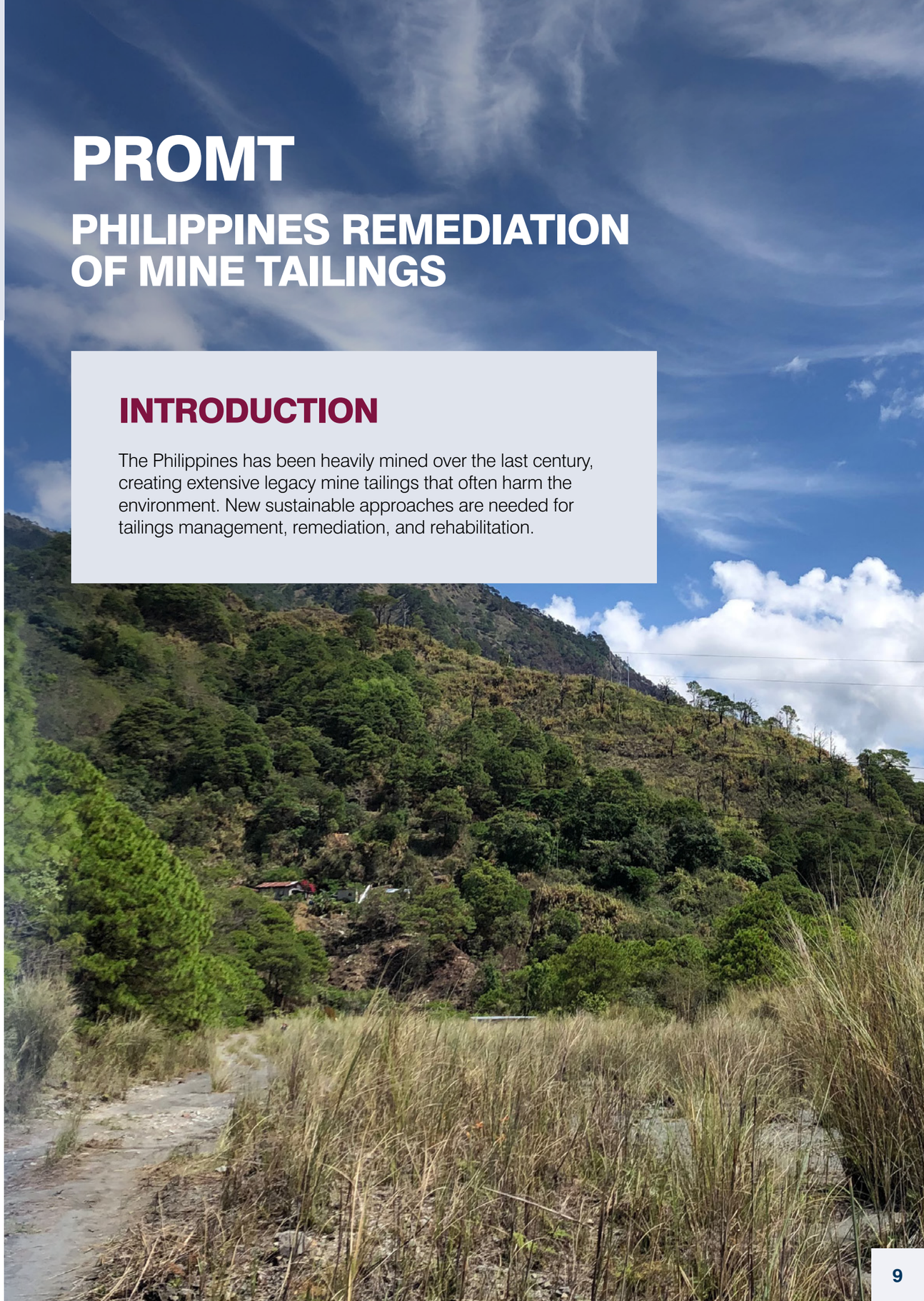
Rationale: Artisanal and small-scale mining (ASM) are relatively unregulated industries, and this has resulted in longstanding issues of non-compliance with taxes, and environmental, health, and safety violations. Formalisation of ASM operations through simplified regulations would improve environmental accountability and socio-economic equity by ensuring tax compliance, fair wages, and better environmental standards.

PROMT

PHILIPPINES REMEDIATION OF MINE TAILINGS

INTRODUCTION

The Philippines has been heavily mined over the last century, creating extensive legacy mine tailings that often harm the environment. New sustainable approaches are needed for tailings management, remediation, and rehabilitation.



FRAMING THE PROBLEM

Tailings are the finely ground waste product which is left over after the valuable minerals or metals from mined ore have been extracted. They present a variety of challenges: they can cause acid mine drainage, release toxic metals affecting people and ecosystems, are slow to revegetate, and can be prone to catastrophic failure. On the other hand, if they can be successfully revegetated, they can be returned to productive land use. In addition, they may be significant resources of unrecovered valuable metals. Remining and reprocessing to recover metals and decontaminate is possible, but disadvantages include the danger of weakening the tailings storage facility, handling costs, the possibility of contaminant release, and that the tailings may already be vegetated. One alternative solution is to leach the tailings in place by moving a liquid solvent through them to extract remaining metals – a process called "*in situ* leaching". However, this has not yet been sustainably achieved for tailings because of underlying science and technology gaps. The PROMT project has aimed to fill these gaps to make *in situ* leaching a workable possibility.

EXECUTIVE SUMMARY

This project developed new approaches for tailings remediation that will pave the way towards reducing community and environmental impacts, and long-term liabilities and risks from legacy sites, whilst improving mining companies' social license to operate, and providing revenue sources by recovering additional metals and land re-use.

KEY RESEARCH FINDINGS

Simple, cheap, readily available, environmentally friendly solvents such as organic acids can be very effective at leaching copper from tailings.

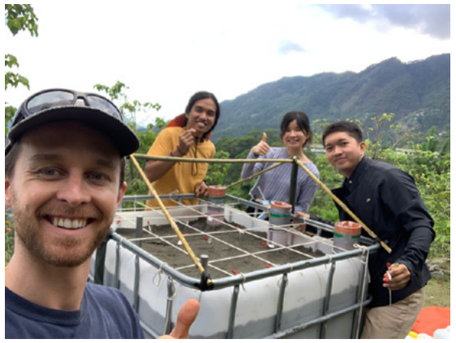
Continuous geoelectrical monitoring was proved to show not only changes in tailings saturation with rainfall and seasons, but also solvent movement and reaction.

The first-ever field demonstration of solvent leaching in an electrical field showed potential for enhancing leaching and capturing dissolved metals.

Tailings have naturally developed a specialised ecosystem, including metal-tolerant plants and a diverse microbial community. Plants and microbes are tolerant to some possible solvents, and some solvents may even promote growth.

The local community is optimistic about the restoration potential for the tailings, and engagement has enabled concerns to be addressed early on.

As a result of the progress made in this project, we recommend proceeding to the next testing phase by scaling up to an *in situ* pilot demonstration within a limited volume of tailings.



RESEARCH APPROACH

We think that to successfully carry out *in situ* leaching of tailings economically and safely requires four key components:

- An effective, safe, and cheap solvent.
- Reasonable rates of liquid flow, which can be monitored and ideally controlled, and the solvent and leached metals can be recovered.
- Impacts on the ecosystem, including microbiota, flora, and sustainable land use pathways, should be positive or at least neutral.
- The necessary social licence to operate must be obtained with all stakeholders, especially locally.

This transdisciplinary project brings together geologists, metallurgists, chemists, geophysicists, environmental scientists, plant and soil scientists, microbiologists, and social scientists to develop the science and technology towards achieving *in situ* leaching of tailings. The research has focused on leaching copper, which is both a contaminant and a valuable metal, from the historical tailings of the Philex Mining Corporation Padcal Mine, Benguet Province, but our aim is that the approach is generic and can be translated to other settings with suitable adaptions.

RESEARCH ACTIVITIES INCLUDED:

Instrumented field laboratories. We constructed eight instrumented “mesocosms” containing ~1 m^3 of tailings that are located outdoors in the natural environment. These enabled us to carry out more realistic experiments at a much larger scale than is possible in the laboratory.

Solvent design. We developed a workflow for geometallurgical assessment of tailings and for design of a suitable solvent. A wide variety of novel solvents were tested, not just for the efficiency of copper leaching but also for cost, availability, and their effects on plants and microbes in the ecosystem.

Monitoring and control technologies. Geoelectrical techniques were employed to continuously monitor tailings in the laboratory, in the mesocosm experiments, and in a volume of ~250,000 m^3 within the Padcal tailings storage facility. We tested using a low voltage electrical field (“electrokinetics”) to promote movement of solvent and copper towards an electrode for capture.

Understanding tailings ecosystems. We surveyed the existing ecosystem on the Philex tailings and surrounding area, examining the microbiology, flora, and invertebrates. Experiments were conducted to assess the effects of leftover solvents on plants and microbes.

Stakeholder Engagement. Throughout the project, a range of stakeholders were not only informed about developments but were consulted on their needs and aspirations. Narrative techniques such as the ecosystems services framework and participatory mapping were used.

In summary, developing sustainable tailings reprocessing and remediation by *in situ* leaching requires a transdisciplinary approach that combines a wide range of studies of tailings. Read a full overview paper by Jenkin et al. here https://doi.org/10.36487/ACG_repo/2415_0.03

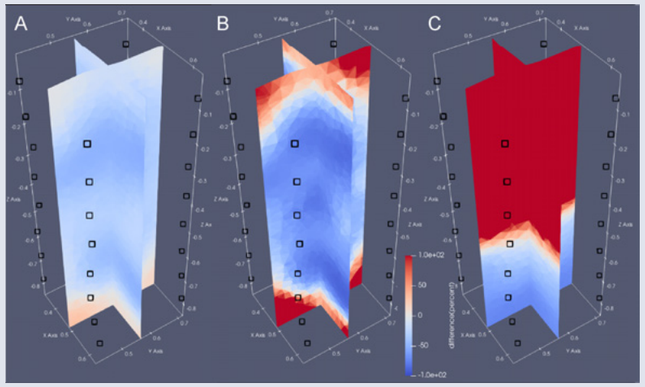
CASE STUDIES

Copper leaching

Testing of Padcal Mine tailings with a range of solvents showed that organic acids such as malic and citric acid are most effective at leaching copper. These acids are common additives in soft drinks, foodstuffs, soaps and cosmetics. Acid concentrations lower than occur naturally in lemon juice are effective, making these solvents easily accepted by the public, as seen in our community meetings. Furthermore, they are available in large quantities and are relatively cheap because of their common usage. Because tailings vary in composition and mineralogy, other solvents may be needed elsewhere. Our tailings characterisation and solvent design workflow can help find environmentally friendly solvents suitable for other settings.

Monitoring solvent movement and reaction

The electrical resistivity of tailings is sensitive to minerals present, moisture content, and pore water composition. Repeated measurement across electrode arrays has allowed us to carry out Electrical Resistivity Tomography (ERT), which shows the variations in moisture content and pore water composition with space and time. From this, we have demonstrated seasonal changes in saturation with depth in the tailings facility as well as more rapid changes due to rainfall events near surface in the mesocosms. Importantly, we have shown that we can “see” solvent moving through the mesocosm and even changes in solvent composition as it leaches metals. These results mean that we could use ERT to visualise what is happening during *in situ* leaching within a volume of tailings and help control the process.

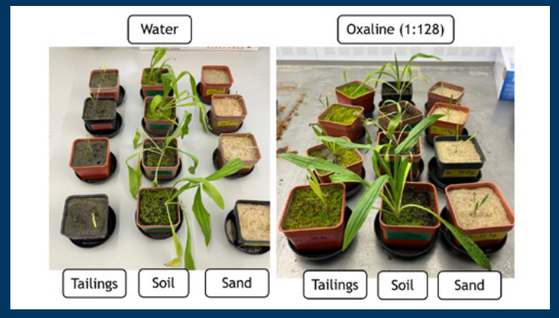


A time series of geophysical measurements, showing change in electrical conductivity in a mesocosm experiment fully saturated with solvent, where blue colouring indicates a decrease in resistivity, and red colouring indicates an increase.

Solvent effects on plants and microbes

Experiments were carried out to assess how the native microbial community responds to treatment with organic acid solvents. Initial results suggest that the solvent will be degraded slowly. Therefore, microbes can help clear up leftover acid after leaching.

Experiments with plants show that, depending on the solvent composition, concentration and length of exposure, effects can be both positive due to nutrient release from the tailings or negative due to phytotoxicity. By choosing the right conditions, it should be possible to carry out leaching and leave residual amounts of solvent that are beneficial to plant growth.



Obtaining the social licence

There are many examples of new initiatives in mining not progressing because of poor stakeholder relations, especially with local communities. We ensured that local stakeholders were not only kept in touch with developments through the project but were collaboratively consulted on their needs and aspirations for new developments using the ecosystems services framework as a method for engagement. Participatory mapping was also used to understand the importance of different local features and amenities to the local population. Stakeholders raised questions about issues such as groundwater integrity, enabling the research team to address those concerns early on. Overall, participants were optimistic about restoration potential.

This research and knowledge exchange was funded by UK Research and Innovation - Natural Environment Research Council (UKRI-NERC) and Department of Science and Technology – Philippine Council for Industry, Energy and Emerging Technology Research and Development (DOST-PCIEERD) – Grants NE/W000385/1, NE/W006820/1, NE/W006839/1, NE/W006847/1.

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RECOMMENDATIONS

Building on the success of this project, we recommend several next steps towards developing *in situ* leaching of tailings in the Philippines and adoption of the technology and approaches. If implemented, these recommendations could ultimately improve the environment and lives of Philippine citizens through new sustainable approaches for tailings management, remediation, and rehabilitation.

- **Carry out a programme of exploration of other historical tailings in the Philippines to characterise their mineralogy, metal contents, and environments, and assess metal-rich ones for their suitability for leaching in different solvents.**

Rationale: Other tailings may be even higher metal grade and more economically viable for reprocessing than our study site at Padcal. Assessment of what is available in tailings for reprocessing provides an inventory of an important national resource.

- **Develop geoelectrical technology for continuous monitoring of water saturation in legacy tailings storage facilities.**

Rationale: This technique can provide reliable continuous monitoring of water saturation, which is a key indicator of dam failure. It may be combined with other geophysical and surveying techniques to provide early warning of issues at sites considered at risk.

- **Determine the tolerance and potential benefit to native biota of solvent leached tailings in controlled and field conditions, along with their long-term effect on ecosystem development.**

Rationale: The opportunity for successful ecosystem reconstruction on tailings needs assessment in the field to ensure successful post-mining land uses can be paired with the novel technologies we employ.

- **Ensure that our experience from community engagement can be more widely adopted for mining-related issues.**

Rationale: Techniques such as ecosystem services assessment and participatory mapping have been shown to be successful in engaging with communities and involving them in decision making.

- **Consider the legal and regulatory environment concerning tailings reprocessing and ensure that it is amenable to development while safeguarding and benefitting local communities.**

Rationale: Uncertainties remain regarding ownership and liabilities during and after reprocessing, and who will benefit. A clear legal and regulatory framework is essential for large-scale development.

- **Proceed to a scaled-up test of *in situ* leaching and metal recovery within a restricted volume of tailings.**

Rationale: Although our results are promising, they are insufficient to provide confidence in the commercial roll-out of the technology. Test work within a volume of tailings would enable development of the process engineering and provide techno-economic data that would provide confidence for commercial adoption.

SUSTAINABLE MINERALS KNOWLEDGE EXCHANGE FELLOWSHIP

The SMRP Knowledge Exchange Fellows collaborate across the PAMANA and PROMT teams to:

- Facilitate stakeholder collaboration and information sharing
- Lead policy and industry engagement efforts
- Enhance the visibility and legacy of the programme's outputs for relevant audiences

An initial output is a review of environmental challenges and research opportunities for sustainable mining in the Philippines by Domingo et al. To access the article, scan the QR code or visit https://doi.org/10.1016/j.jclepro.2024.143114

The KE Fellows developed a programme-level Theory of Change, serving as a strategic blueprint that outlines key activities, enabling factors, and desired outcomes to illustrate the ideal impact scenario for the SMRP programme. This framework aims to unify efforts toward the programme's goals and extend its impact beyond the completion of PAMANA and PROMT.

This research and knowledge exchange was funded by UK Research and Innovation – Natural Environment Research Council (UKRI-NERC) – Grants NE/X001784/1, NE/X001814/1

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Natural Environment Research Council

Republic of the Philippines
DEPARTMENT OF SCIENCE AND TECHNOLOGY
PHILIPPINE COUNCIL FOR INDUSTRY, ENERGY AND EMERGING TECHNOLOGY RESEARCH AND DEVELOPMENT

PAMANA Philippine Mining at the National to Catchment Scale: from Legacy Impacts to Sustainable Futures

Chamber of Mines of the Philippines

Environment Agency

USGS science for a changing world

University of Glasgow

LIVERPOOL JOHN MOORES UNIVERSITY

UNIVERSITY OF EXETER

UNIVERSITY of HULL

Brunel University London

PROMT Philippines Remediation of Mine Tailings

University of the Philippines Diliman

University of the Philippines LOS BAÑOS

UNIVERSITY OF EXETER

University of Reading

UNIVERSITY OF LEICESTER

BGS British Geological Survey

Domingo, J.P.T. et al., 2024. Sustainable Mineral Resources in the Philippines (SMRP) Programme. University of Glasgow https://doi.org/10.36399/gla.pubs.346694