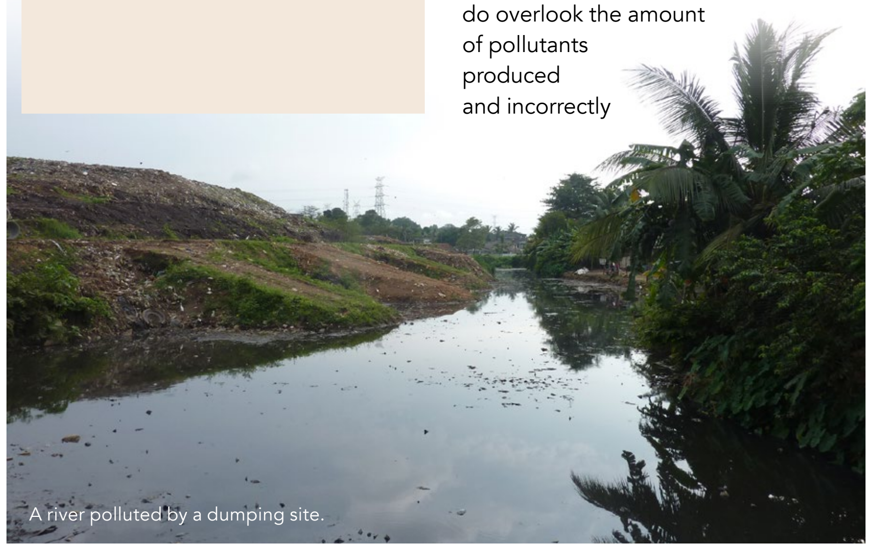
Soil and groundwater contamination

An old and new issue needs to be solved

Dr Ming Zhang is an innovation coordinator at Geological Survey of Japan, AIST. Alongside his research group, he is advocating the importance of using interdisciplinary tools for sustainable remediation of contaminated soil and groundwater. Their research has shown that cost-effective and environment-friendly technologies such as the use of microorganisms to degrade organic contaminants and the use of minerals to immobilise heavy metals can be the key to achieving sustainable remediation.

Industrialisation as we know it started in the 1700s and paved its way into our modern world without respite. What was a catalyst of our progress, economic advancement and globalisation came alongside a by-product: environmental pollution. Indeed, over the centuries, various industrial activities have spewed dust, toxic gases and chemicals into our environment, leaving a 'negative legacy' for future generations. We are familiar with global warming and its impact on our climate. Similarly, we are aware that fresh water is becoming a scarce resource, and with land being used for high-intensity agriculture and urbanisation, our soils are becoming endangered. Thus, we should not cast aside our glance from what is being polluted close to home: our soil and groundwater.

Nowadays, developing countries who have joined the globalisation race are going all-out to catch up with the developed regions. The players in this race keep changing; however, they do overlook the amount of pollutants produced and incorrectly disposed into the environment. This is contributing to the ever-rising levels of contaminants (heavy metals, organic compounds, and other toxic substances) present in the soil and groundwater. Meanwhile, developed countries are remediating their waste footprint from the decades afore by issuing regulations and defining standards on the concentration of toxic substances allowed to be present in the land and water.



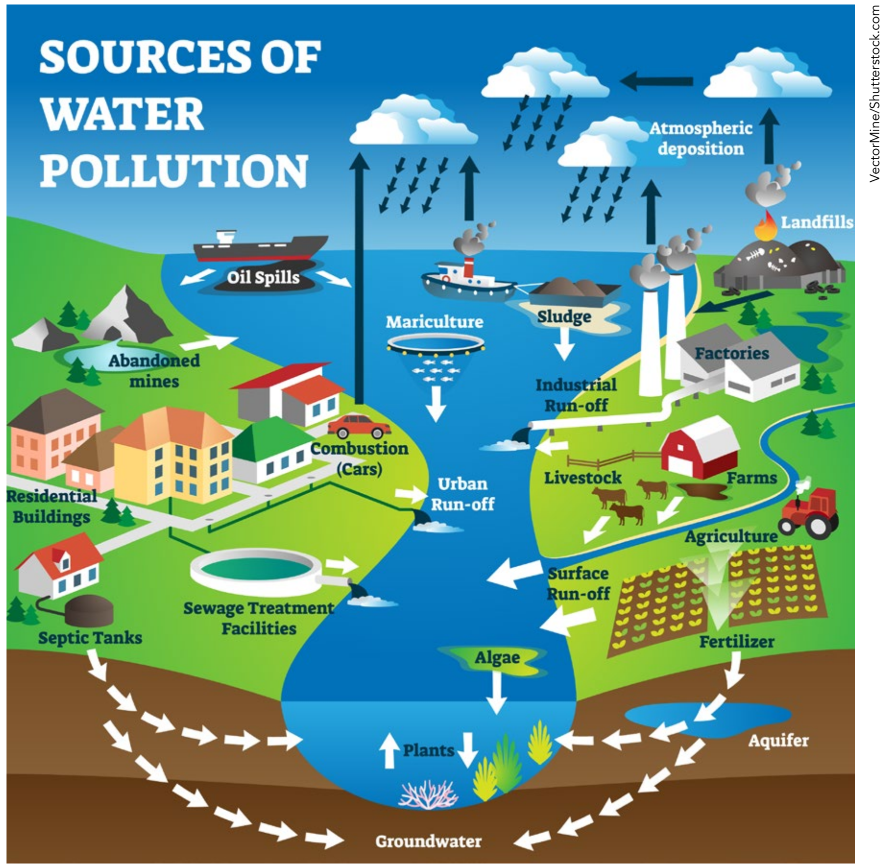
A river polluted by a dumping site.

POLLUTANTS: DOMESTIC AND INDUSTRIAL

Soil and groundwater contamination is closely interlinked with human society because of its direct impact on population health and socioeconomic activities. Toxic contaminants can enter the human body through the food chain, the water we drink and the air we breathe. Close to home, we have landfill sites, or open dumping sites as the worst case, where toxic substances from organic waste, batteries, electronics, plastics, etc. leach into the soil and, over time, accumulate and find their way into the freshwater streams. Similarly, chemical fertilisers and pesticides in agriculture, dyes in the textiles industry, additives and oils in the cosmetics industry, heavy metals, minerals and radioactive waste from the energy and transport industry, antibiotics used in healthcare, and food-producing animals have been leaving a long-lasting mark in the environment.

So, how do these substances once spilled into the soil reach the groundwater? Take an open dumping as an example. The spilled contaminants get absorbed into the land and when it rains, these compounds are flushed away by the rainwater, which buries it deeper into the ground or sweeps it away to join larger pools of water. In agriculture, fertilisers and pesticides get continuously washed away during irrigation and enter drinking water resources of the populations nearby, eventually making them ill. It is important to bear in mind that not everything that is dumped/spilled into the soil is washed away. Like a stain, it remains within the land, accumulates and keeps discharging into the water.

At an industrial scale, polluting substances (dyes, chemicals, heavy metals, volatile organic compounds (VOCs), etc.) were discharged into the environment due to delay in regulation and/or incidental accidents. Legislative requirements defining the permissible levels of pollutants are outlined by each government. However, in some countries these are more stringent than in others, meaning that although on one side we are diminishing the contamination, on the other, the amounts disposed are not balancing out. In countries where waste management is not strictly regulated, the concentration of contaminants disposed into the environment is so high that populations living alongside contaminated soils and groundwater have been bearing the consequences with their health. You may still think that these small amounts are nothing compared to the size of the water bodies, but over time these chemicals, like each grain of sand in the desert, build up and become an enormous heap of pollution, if the toxic substance is not naturally biodegradable and the toxicity or elevated toxicity is sustained.



Pollution pathways: landfills, industry, agriculture and more contaminate the soil and groundwater.

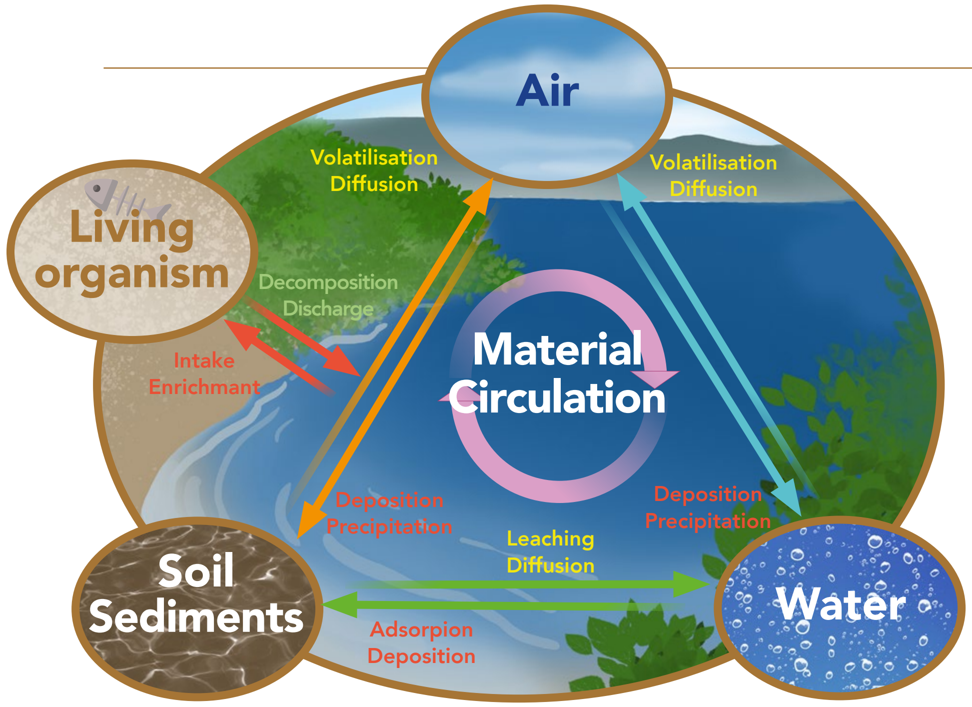
> ***Collaboration between science and engineering is necessary if we want to find viable and sustainable remediation methods. A good example of this is the use of microorganisms for bioremediation. Another one can be immobilisation using minerals.***

CONTAMINANT CHARACTERISATION AND REMEDIATION

Waste from different places has different contaminants, and various soil types (sandy, silty, peaty, chalky, loamy and clay) make the problem of soil and groundwater contamination even more complicated. Once contaminants pollute the soil it is quite hard to remove them, as these get absorbed into the soil and in some cases change their chemical forms. This adds to the difficulty in characterising and estimating the level of each contaminant present for subsequent clean-up. In light of this, researchers have developed technologies of contaminant characterisation via analytical chemistry tools and spectrometry techniques. Following that, the right type of remediation treatment is chosen. In some cases, only one pollutant may need to be removed, for example lead, asbestos, petroleum or radioactive isotopes, while in other cases a mixture of pollutants may need to be handled simultaneously, thus various sequential removal processes are used during clean-up.

AN INTERDISCIPLINARY APPROACH

Contaminant remediation methods include flushing soil contaminants with water and subsequent water treatment, chemical solvents to leach the contaminants out, incineration to destroy the contaminant and so on. These methods, though successful, have the added implication of using hard and environmental harmful substances that need to be disposed accordingly. Therefore, more sustainable remediation methods have been investigated – such as the



Interactions among air, water and soil pollutions due to material circulation.

use of microorganisms to break down the contaminants or adding naturally available materials to the soils to adsorb and immobilise the contaminants to prevent them from spreading.

Dr Ming Zhang and his group at Geological Survey of Japan, AIST, pursue sustainable solutions to remove various types of pollutants from contaminated soil and groundwater. They maintain that collaborations between science and engineering is necessary if we want to find viable and sustainable remediation methods. A good example of this is the use of microorganisms for bioremediation. The right candidate, in this case the one that can 'consume' the contaminant, needs to be identified: be it archaea, bacteria, microalgae or yeast, or a consortium of those (a group of symbiotic microorganisms). As demonstrated by Dr Zhang, bacterial consortia have been shown to degrade dichloromethane, benzene and toluene simultaneously, below their detection limits through aerobic biodegradation. In more complicated conditions that include the three contaminants as well as four other contaminants – perchloroethylene, trichloroethylene, *cis*-1,2-dichloroethene and vinyl chloride – integrated anaerobic-aerobic biodegradation is a promising approach to facilitate biodegradation. Bioremediation microorganisms are also used to increase the biomass of waste material, later used for the production of nutraceuticals (nutritional supplements) and biofertilisers, hitting two-birds with one stone. However, the process relies on 'living beings' and can be slow and hard to replicate since microorganisms are highly affected by their surroundings. Thus, careful management of the environmental conditions is required.

Like a snap trap, the bearing materials are able to capture the contaminant and keep hold of it until exposed to the right conditions to release it.

In a similar line of thought, Dr Zhang and his group are working to identify minerals that would immobilise contaminants. The team looked at the chemical properties of these minerals that rendered them distinct in capturing specific compounds. This is a very useful technique for decontaminating the ecosystem from heavy metals, such as arsenic, lead, and cadmium, which are prevalent in landfill sites as well as industrial and agricultural wastes. Immobilising materials, such as naturally available materials and biochar, act like snap-traps by capturing the contaminant within their matrix and locking it into place. In this way, the researchers are able to contain the contaminant and separate it from the uncontaminated source. Once collected, the immobilising material will only release the contaminant when exposed to the right conditions and be re-used again.

LEGISLATION AND RISK COMMUNICATION

Archiving sustainable remediation is not an easy task, as environmental problems are very complicated, and integration of the knowledge across different fields is necessary and important. At a legislative level, the number of toxic substances designated by national laws with regards to soil and groundwater contamination differs from country to country. For example, in Europe, the designated hazardous substances are categorised into heavy metals, aromatic hydrocarbons, organochlorine compounds, polycyclic aromatic hydrocarbon and mineral oils. In Japan, however, designated hazardous substances are only divided into three categories which refer to VOCs, heavy metals, and agrichemicals and PCB, respectively, and there is no regulation for mineral oils by law. Thus, what is deemed as a high-alert contaminant in one country is not in another. The regulations focus mainly on the designated hazardous substances, which account for the smaller portion of environmental contamination. However, the larger and less hazardous chemicals are loosely regulated. This, in due time, contributes to environmental contamination. Risk communication is paramount; educating the public to work towards preventing the release of these substances into the environment and using bio-based remediation techniques would lessen the burden capital costs while protecting both the ecosystem and human health. Within their research, Dr Zhang and his group look at nature for solutions and incorporate them into engineering practices.

Behind the Research

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Research Objectives

Dr Zhang studies the characterisation, remediation and management of contaminated soil and groundwater, joining efforts in science and engineering.

Detail

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Bio

Ming Zhang is an innovation coordinator at Geological Survey of Japan, AIST. He has an extensive knowledge of multiple disciplines, including geo-environmental sciences. Prior to his current position, he was in charge of the R&D on soil and groundwater contamination at the same national institute for nearly a decade.

Funding

- National Institute of Advanced Industrial Science and Technology (AIST)
- The Environmental Restoration and Conservation Agency of Japan

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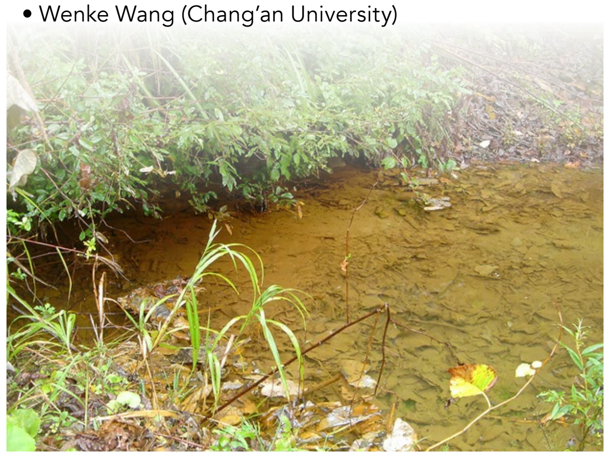

Leaching of acid water and toxic metals from an abandoned mine.

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Personal Response

Do you think bioremediation can be used as a clean-up finishing step?

" Bioremediation is typically applicable to the sites where concentration of contaminants is low and the area is huge which cannot be effectively remediated with other technologies. With a well-designed strategy, bioremediation can be successfully used for cleaning up multiple contaminants.

What are the challenges in up-scaling mineral immobilisation?

The stability of an immobilisation basically depends on redox and pH conditions. How to sustain the long-term stability condition and the function of land use are the major challenges. "