Remediation Australasia

CRCCARE

ISSUE 19/2018

Effects of pollutants on human health

Master of Environmental Risk Assessment and Remediation

Are you an environmental practitioner or consultant who is concerned about the risks (human and ecological) associated with environmental pollution and want to be involved in providing creative solutions to minimise those risks? The University of Newcastle's Master of Environmental Risk Assessment and Remediation can be the pathway to that position you've been dreaming of.

Overview

Providing you with specialised training in risk assessment and environmental remediation designed for the growing needs of the remediation industry both nationally and globally, this hands on practical and research-focused program will help prepare you for your dream job.

Using a balanced approach that includes both hands on and case studies, you'll examine the core concepts, principles and techniques underlying environmental risk assessment and remediation. You'll learn how to assess a contaminated site including following guidelines for contaminated site assessment (eg NEPM-ASC) and jurisdictional legislation regulating management of contaminated land; carry out desktop research for preliminary site investigation (PSI), develop conceptual site models, produce a sampling plan for a detailed site investigation using data quality objectives (DQOs) and evaluate contaminated site data to identify contaminant fate and pathways and assess the risk presented by the contaminant(s) detected on site and determine the need for further investigation or remediation.

On completion, you'll be able to provide full site assessment reports that exceed clients expectations, provide innovative solutions to remediation and/or risk assessment problems, and bring remediation projects to a successful conclusion.

Is it for you?

Environmental practitioners can have different backgrounds and their previous experience and knowledge often help shape the future direction of their careers. You may have a bachelor's degree in science or applied science (engineering) and now want to expand your skills and move into the growing field of environmental remediation. Or you may want to start a research career in the field of environmental chemistry, toxicology and technology.

Career opportunities

The University of Newcastle's Master of Environmental Risk Assessment and Remediation will prepare you for managing contaminated site(s) projects and developing remediation action plans for both private and public organisations. With a core focus on environmental risk assessment and remediation, you will have specialised and instrumental skills that will be highly valued by mining, property development and industrial sectors. Your capacity to work internationally will be supported by the University's own reputation in the field. Distance study may be possible; for more information contact ravi.naidu@newcastle.edu.au.

To register your interest in this program, visit gs.edu.au

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Remediation Australasia is an industry magazine published 3 times per year by the Cooperative Research Centre for Contamination Assessment and Remediation of the environment (CRC CARE) for the Australasian remediation industry.

Editor's Note

Welcome to *Remediation Australasia* no. 19, the second issue of our new, improved version of the magazine. In this issue, we explore the crucial topic of contaminants and human health.

We all know that toxic substances can, potentially, harm us. But, as every scientist knows, the road from correlation to causation is rocky, slippery and filled with potholes. If a contaminant is present in the environment, is it in a form that allows human exposure? If we are exposed, can the contaminant enter our bodies? If it enters our bodies, is it bioavailable? If it is bioavailable, will it do us damage? If so, how much and what sort of harm will it cause? And, further, what are the critical pathways of exposure – ingestion, transdermal, inhalation or another route?

Often, these questions and answers get lost in the confusion created when a contaminated site is identified, which brings the urgent need for methodical research. Amid the noise from concerned communities, risk-averse authorities, anxious businesses and populist politics, contamination experts are responsible for shining light on a problem that is growing at an alarming rate. Indeed, a recent World Health Organization report estimated that in 2012 almost 13 million people died as a result of living or working in an unhealthy environment. Air, water and soil pollution, and chemical contaminant exposure are among the leading factors.

Using research from leading environmental scientists, this issue examines how contaminants such as mercury, particulate matter and heavy metal(loid)s affect human health. We also look at reference doses for PFAS and how they are established. I am also proud to include the winning essay from the 2017 *Dr Roneal Naidu award for writing on chemical contamination and its effect on food quality and human health*. This award, open to Australian high school students, was presented to 15-year-old Edith Spiers at the CleanUp 2017 conference. I am sure you will be as impressed as I was with Edith's essay, and agree that the future of environmental science is in good hands.

Finally, I would like to flag CRC CARE's next event in our rapidly expanding CleanUp Conference series. I am excited to announce that the 1st Global CleanUp Congress will be in Coimbatore, India, from 21 to 25 October 2018. With more than 1000 delegates expected from across the world, the congress will offer presentations and discussions from global leaders in remediation science and practice. Abstract submission is open now. Visit the conference webpage for more information. I hope to see some of you there!

Professor Ravi Naidu
Managing Director and CEO, CRC CARE
Editor-in-chief, *Remediation Australasia*

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Cover photo

Studying the effects of contaminants on human fertility is one of the research areas featured in this issue of *Remediation Australasia*.

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reMEDIAtion

A quirky snapshot of recent contamination and remediation issues in the media.

Polluted water? Lead-soaking moss to the rescue

Phytoremediation – that is, plant-based remediation – is an attractive clean-up option. It is more sustainable and less costly than other methods such as chemical sedimentation, electro-deposition and ion-exchange adsorption. Now, researchers in Japan have dug up another botanical ally in the pollution battle. A species of moss, *Funaria hygrometrica*, often found at industrial sites, can survive a lot of local heavy metal contamination. But its ability to take up lead – up to 74% of its dry weight in less than a day – is what made researchers take a second look. The moss is a good candidate for removing lead from water, as it can grow in water without the need for a substrate such as soil or rocks. The researchers are working with a recycling company to test its real-world potential. The story was covered by science news websites such as *Inside Science*, and the work published in *PLOS One*.

David J

Mercury mayhem – how is the Arctic involved?

The Arctic is viewed as a pristine wilderness, relatively untouched by human activity. But underneath, it is contaminated by mercury, a problem commonly associated with industrialisation. How and why? Reported in *The Conversation*, researchers may have uncovered the secret after decades of monitoring. Tonnes of mercury are emitted into the air all over the world – coal-fired power plants and gold mining are the worst offenders. Gaseous elemental mercury remains in the atmosphere for a long time and can travel thousands of kilometres, including to the Arctic. Tundra plants absorb mercury from the atmosphere, and, when they die or lose their leaves, the mercury ends up in the soil. Runoff then washes mercury into the Arctic Ocean. Biomagnification results in mercury in the tissues of Arctic animals such as beluga whales, polar bears, eagles and fish. Some of these animals form part of the diet of Indigenous people, who have increased mercury levels as well. The bad news is that climate change could make it worse, with permafrost soils potentially warming and even more mercury being washed into the ocean. The good news is that the Minamata Convention on Mercury, which took effect in August 2017, should help mitigate mercury build-up. Ratified by 120 countries, the pact requires members to phase out or reduce mercury from several products and sources.

Not so fine: ultrafine particulate matter pollution linked to premature births

Scientists have long known about the human health risks associated with fine particulate matter (PM) air pollution. Governments around the world are now making recommendations for $PM_{2.5}$ and PM_{10} (2.5 and 10 microns, respectively) exposure limits. However, recent studies are suggesting that PM_1 (1 micron) and smaller are just as dangerous – something scientists have suspected all along. The *Sydney Morning Herald* reported that researchers based in China and Australia have linked preterm births to PM_1 exposure during pregnancy. Premature babies have long-term health effects as a result of their early entry to the world, including asthma, diabetes and a lower life expectancy. The study – published in *JAMA Paediatrics* – looked at Chinese pregnancies and births, but the risks are borderless. Coal-fired power stations are the largest source of PM_1 in Australia, and other work has shown that babies born near coal-fired power stations have a lower birth weight. Many countries only monitor larger PM sizes, but if this research can be replicated, it may become harder for governments to ignore the importance of monitoring ultrafine particles as well.

Phosphorus pollution reaching dangerous levels worldwide

Excess agricultural phosphorus from fertilisers gets washed into nearby water bodies, where the contaminant gets diluted to a nondangerous level. No worries, right? Wrong. Researchers have determined that more phosphorus is entering some waterways than what can be diluted – a problem in 38% of the world's freshwater basins (excluding Antarctica). This 38% is home to 90% of the world's population. The worst affected regions correlate with high population and intensive agricultural practice, such as the Aral Sea drainage basin in Central Asia, the Huang-He (Yellow) River in China, the Indus and Ganges rivers in India, and the Danube River in Europe. However, places such as Australia and northern Africa are also feeling the effects – although populations are lower here, so is freshwater availability. Excess phosphorus can lead to eutrophication, which in turn causes algal blooms, reductions in light and oxygen availability, and plant and fish death. Eutrophication also affects drinking water quality and recreational activities. The story was reported in *Science Daily*.

From the fringe

It wasn't me: when a clean-up notice for contamination can be set aside

Kate Mclean and Jessica Howe
CLAYTON UTZ

Landowners who receive a clean-up notice should review it for both liability and the remedial actions required.

Can a landowner be required to clean up legacy contamination? A recent decision of the Queensland Planning and Environment Court provides essential lessons to demonstrate why this may not always be the case.

What is a clean-up notice?

A clean-up notice is a written notice issued under the *Environmental Protection Act 1994* (Qld) for a contamination incident.

When can a clean-up notice be given and what can it do?

A clean-up notice may only be given to a person who is reasonably believed to be one of the following:

- an occupier of a place at or from which a contamination incident is happening (or happened)
- an individual or corporation who is causing or permitting (or caused or permitted) a contamination incident to happen
- an owner, individual or corporation in control of a contaminant involved in a contamination incident.

A clean-up notice must, among other things, state actions that the recipient must take and the time for each action to be taken.

It is an offence for a person not to comply with the notice unless the recipient has a reasonable excuse.

Hungtat v Chief Executive Department of Environment and Heritage Protection [2017] QPEC 62

The facts

Hungtat operated a golf course in a catchment affected by acid sulfate soils, which, due to historical disturbance, had contributed to leaching of contaminants into nearby waterways and canals.

In 2012, Hungtat received a clean-up notice for a contamination incident involving release of acidic soil products and iron rich water into nearby waterways and canals from premises owned by Hungtat located west of Surfers Paradise, Queensland.

Hungtat appealed the issuing of the Notice to the Planning and Environment Court; it argued that the company was:

- not a prescribed person for a clean-up notice
- not responsible for the contamination.

Factors relevant to the Planning and Environment Court setting aside the clean-up notice

Even though a contamination incident causing significant or material environmental harm had occurred, and the Planning and Environment Court accepted that Hungtat, as an occupier, met the statutory test for a person to whom a clean-up notice could be given, the Court ordered that the clean-up notice should not have been issued.

In this respect, the Court:

- was satisfied that Hungtat did not cause the contamination, which was both a legacy issue, and contributed to by a number of diffuse sources from elsewhere in the catchment. Activities undertaken by Hungtat had not caused or contributed to the contamination
- found that the remedial actions required by the regulator in the clean-up notice were inadequate to address the underlying historic acid sulfate issue, and unjustifiably disproportionate to the contribution of Hungtat to pre-existing contamination. The experts retained to provide a joint expert report to the Planning and Environment Court identified alternative works that would be more likely to address the historical acid sulfate issue
- found that this was not a case in which there was clear and compelling evidence on which the Court could be satisfied, on the balance of probabilities, that it was appropriate that the Notice be issued. This finding was supported by intra-departmental advice that had cautioned against the issuing of the Notice to Hungtat.

The effect of the decision

The case provides key lessons for regulators and recipients of clean-up notices:

- A regulator must:
  - be able to prove causation between the happening of an incident and the liability of an owner/occupier or polluter to clean up. This is extremely important where premises are affected by pre-existing contamination
  - ensure that the actions directed to be undertaken by a clean-up notice are both effective and proportionate to the liability of the recipient.
- A recipient of a clean-up notice should carefully review a clean-up notice with respect to both liability and the remedial actions required. For instance, remedial actions stated in a clean-up notice must be reasonable and proportionate to the source and extent of environmental harm caused by an incident. There are both internal review and appeal processes that may be considered by a recipient of a clean-up notice who believes that a clean-up notice has been wrongly issued.

This article was originally published on the Clayton Utz website on 9 November 2017. It is reprinted with permission.

Regulator roundup

This edition of Regulator Roundup includes information about the new National Environment Management Plan, the merging of two certification schemes, EPA Victoria's new chairperson and the NSW Government's recent commitment for contaminated land management funding.

PFAS National Environment Management Plan released

A National Environment Management Plan (NEMP) for per- and poly-fluoroalkyl substances (PFAS) was approved by Australian, state and territory environment ministers in February 2018. All state and territory environment protection authorities (EPAs) and the Australian Government developed the NEMP, under the leadership of EPA Victoria.

PFAS have multiple industrial uses, including as components in firefighting foams, nonstick cookware, food packaging, insecticides, and waterproof and fire-resistant fabrics. PFAS are very stable and can accumulate in the environment, and in the bodies of the people and animals exposed to them. Regulators in Australia and several other countries have been developing guidelines for the assessment and management of PFAS, because of the growing concerns about their effects on human health.

According to EPA Victoria, 'The PFAS NEMP provides governments with a consistent, practical, risk-based framework for the environmental regulation of PFAS-contaminated materials and sites'.

CRC CARE published interim guidance on the assessment, management and remediation of 2 PFAS (PFOS and PFOA) in 2017. It is planning to update its guidance to complement the recommendations in the NEMP.

The NEMP can be downloaded from the EPA Victoria website.

Contaminated site practitioner certification schemes merge

CRC CARE's Site Contamination Practitioners Australia (SCPA) and the Environment Institute of Australia and New Zealand's Certified Environmental Practitioners Scheme (CEnvP) have merged into an amended certification scheme for site contamination specialists. The CEnvP brand will host the unified scheme. SCPA members and CEnvP Contaminated Land Specialists have been transitioned to the new initiative, which will incorporate elements of both previous schemes. The NSW EPA has already recognised the new scheme.

For more information, visit the CEnvP website.

EPA Victoria Chair Ms Cheryl Batagol presents the Brian Robinson memorial lecture at CleanUp 2015, Melbourne

EPA Victoria chairperson appointed

Ms Cheryl Batagol has been appointed chair of the new EPA Victoria Governing Board, which is being reconstituted under the Victorian Government's EPA reform process.

Ms Batagol, who has been the EPA chair under its current governing structure since 2009, has more than 40 years' experience in the waste management, water and environment sectors. As EPA chair, she has had a close association with CRC CARE and was instrumental in bringing the CRC CARE CleanUp Conference to Melbourne in 2013, 2015 and 2017.

Ms Batagol's 2-year appointment will take effect from 1 July 2018 when the new Governing Board starts and the *Environment Protection Act 2017* comes into effect. In January, an interim advisory board was established to advise Ms Batagol about delivering agreed reforms as part of the government response to the Victorian Government's Independent Inquiry into the EPA.

New funding for NSW contaminated land management

In November 2017, the NSW Government announced that it will dedicate an additional $23.5 million to the NSW EPA for contaminated land management.

The government will implement 75 recommendations from 3 external reviews:

- Macquarie University Professor Mark Taylor's *Review of the New South Wales Environment Protection Authority's management of contaminated sites: final report*
- the *Lead Expert Working Group report on managing residual lead contamination in north Lake Macquarie*
- the Fell and Leeder *Review of the EPA's* Contaminated Land Management Act 1997 *procedural guide*.

The 75 recommendations will be adopted into 8 priority areas designed to improve the EPA's operations:

- clear the backlog of contaminated sites
- target illegal waste disposal with tougher regulations
- improve the capacity of planning authorities in contaminated land management
- improve public access to information
- review and strengthen the *Contaminated Land Management Act 1997*
- investigate options to improve the waste and environment levy
- establish a new independent expert technical and scientific panel, and an environmental sampling capability for emerging contaminants within the EPA
- improve management of large-scale emergency clean-up, and orphaned, abandoned or high-risk sites.

In January 2018, the NSW Department of Planning and Environment announced that it is reviewing the State Environmental Planning Policy (SEPP) for the remediation of land and the *Contaminated land planning guidelines* as part of its wider policy review program. A proposed Remediation of Land SEPP will:

- provide an updated and a clear statewide planning framework for land remediation
- require consent authorities to consider the potential for land to be contaminated when determining development applications
- clearly list the remediation works that require development consent
- introduce certification and operational requirements for remediation works that can be undertaken without development consent.

More information is available on the NSW Government website.

Roneal Naidu award winner

The cost of our errors is immediate

Edith Spiers (aged 15)
SALESIAN COLLEGE, SUNBURY, VICTORIA

At CleanUp 2017 in Melbourne last September, CRC CARE presented its High School Essay Competition. In this issue of *Remediation Australasia*, we're proud to reprint the winning essay from the 2017 *Dr Roneal Naidu award for writing on chemical contamination and its effect on food quality and human health*. The award honours Dr Naidu, who, as a medical doctor, acted on his passion for the environment to inspire others.

Globalisation has brought about a radical change in humanity's way of life, irreversibly altering our interconnectedness, communications, trade, industry and technology. It has even influenced the variety, cost and production of the food we eat. A global industry is difficult to regulate, posing challenges for the control of chemical contaminants. As our food travels further, grows faster and finds itself in more packaging than ever before, we are forced to consider the implications of industrialised agriculture, chemical discharge and pollution for the environment and our health.

The human preoccupation with distancing ourselves from nature and synthesising our own needs extends to our food. We not only create artificial environments and clothing for ourselves, but we have in the past century introduced potentially harmful chemicals in order to enhance crop production and processing. The humble carrot, bought in an Australian supermarket, may carry pesticide and fertiliser residues, chemicals involved in cleaning, processing and transport, and migratory compounds from its associated packaging. Chemical contamination has come to be the inevitable, and unless we sacrifice availability for complete freedom from contaminants, it cannot be avoided. The challenge now lies in understanding the risks posed by the introduction of foreign materials into food, in addition to minimising human and environmental exposure.

Contamination occurs not only in crops, but also in meat, poultry and fish. Veterinary treatment in livestock, such as vaccinations and added growth hormone, remain in the meat and can transfer adverse effects into those who consume it. Battery farming not only poses ethical questions, but risk to human health in regards to high levels of hormone and other chemicals present in feed. Levels of industrial pollutants, plastics and agricultural runoff are ever increasing in our oceans, harming marine life and those it nourishes. Supplying the world with one-third of its protein, particularly in developing nations, the ocean represents a major food resource. By leaching chemical contaminants and discarding plastics into it, we are not only endangering marine life but our own food security. If contamination is not reduced, safe seafood may become scarce.

The media has prompted a negative reaction against the use of pesticides, herbicides and synthetic fertilisers in crop farming among consumers, with many opting for organically grown produce. While chemical contamination remains a concerning issue, it should be noted that the world cannot sustain its current population using organic farming methods alone. While good in principle, it increases the disparity in quality of health between the rich and poor. Consumers should be focused on advocating for both alternatives and solutions to the problem of chemical contamination. The answer lies in increased awareness of ingredient origin and commercial responsibility for the use of chemicals.

Consumers carry the greatest power in advocating for change, but perhaps suffer the least direct consequences of chemical contamination. Consumption of toxins can be very harmful, but the greatest dangers exist for those involved in food processing and production. Particularly in developing countries, where herbicide and pesticide use are not well regulated and proper safety equipment is not widely available, workers and their families can suffer health consequences from inhalation and direct contact with chemicals. These health consequences can be extremely serious and, at sufficient levels, some toxins can cause organ failure and death.

The absorption of toxins by any means, be they organic or synthesised, can be extremely harmful. Some act as carcinogens, such as dioxins produced during the manufacture of chlorinated herbicides, while others, including mercury present in tuna, can cause brain damage. The effects of chemical exposure are particularly acute in children and adolescents, causing delayed development and growth problems. Exposure during pregnancy can result in severe birth defects, or death of the fetus.

The regulation of chemical toxins present in food is critical in preventing outbreaks of poisoning. With food being traded and exported at a greater rate than ever before, this becomes increasingly important, as cases can be far reaching and widely distributed. We cannot avoid the use of chemicals in agriculture outright, but we can minimise the risk by monitoring levels administered to crops. Problems arise when contamination occurs that cannot be regulated. Fertiliser runoff, heavy metal leakage, petroleum spillage and industrial waste chemicals contribute to the gradual toxification of our oceans. Such leakage occurs as a result of discharge of chemical waste into waterways, which eventually are released into the ocean. It is difficult to monitor or prevent this, and when contamination occurs as a result of nature, such as rainfall or wind, it is impossible to gauge the risk.

Like all of our depredations of the environment, chemical contamination will ultimately affect us. Yet the speed and the potency with which it does so are far more direct than other environmental concerns. When we compromise our own food quality, one of the many things which we depend on nature for, the cost of our errors is immediate. When we place profit above the health of our environment and the health of people, the issues created affect us directly, not just future generations. It seems that the preoccupation with the now, with the synthesised and the artificial, with output and efficiency, is all too deeply ingrained into the human psyche. The issue of chemical contamination is not merely a logistical or scientific problem, it extends to our morals, our philosophy. All too soon we must ask ourselves: is it right to value productivity over safety?

Essay topic: Chemical contamination and its effect on food quality and human health

Prize: $1000 and trip to CleanUp2017 dinner

Judging criteria: writing quality, interest, newsworthiness, and scientific accuracy

Special advertising article

AgriRem case study: bioremediation

Dean Hore
DIRECTOR OF AGRIREM

This case study looks at the remediation of a contaminated land site that was in the middle of a suburban area, 150 metres from the Noosa River. Gaffville Pty Ltd commissioned AgriRem Earth Care to remediate lots 3 and 4 RP122928, 14–16 Mary Street, Noosaville, Queensland.

Site background

AgriRem Earth Care was called into the Mary Street project after the project had been stalled by unforeseen developments. The Gaffville project aimed to have the site cleared from the Environmental Management Register for future developments, including residential.

The site was contaminated because it hosted a service station that stored liquid petroleum in underground tanks. The tanks became unstable over time and cracked, allowing the petroleum to seep into the surrounding soil.

Regarding the situation the project was in when he deemed it necessary to contact AgriRem Earth Care, Tony Blackmore said:

> *During the excavation of the specific locations it became apparent that both building and road obstructions were going to prevent the full excavation as required. On the day of excavation, it became apparent that the level of excavation required, ridding the site of the contaminants reached a point of impossibility. The undermining of the building was occurring in pursuit of the fuel contaminant. A situation of absolute disappointment grew with the fact that we were not going to be able to achieve the desired outcome, to this stage we had exhausted substantial funds and we were ready to surrender to the obvious and backfill the sites in surrender.*

Tony was advised to contact AgriRem Earth Care. After an onsite meeting with Dean Hore and Chris Allman, Tony said:

> *This [meeting] was a game changer for the process and the ultimate outcome moving forward. Both Chris and Dean were able to assess the situation and recommended the use of 'AgriRem A100' as a treatment of both the excavated areas and the stockpile. I can honestly say that up to that meeting, I had given up and was ready to simply fill in the holes, and surrender to the fact I was never going to achieve the desired results.*

Site assessment and results

Duke Environmental performed a contamination assessment, and remediation and validation assessment, in line with the *Draft guidelines for the assessment and management of contaminated land in Queensland 1998* (EPA 1998) and the National Protection (Assessment of Site Contamination) Measure 1999 (NEPM 1999), in 2 stages.

Stage 1: Before AgriRem® A100 treatment

Duke Environmental's assessment report describes the following for the stage 1 contamination assessment, and remediation and validation assessment:

> *Samples of soil and groundwater, collected by Duke Environmental on 29 February 2012, were sent to Australian Laboratory Services (ALS) for analysis of a variety of contaminants including eight (8) metals (arsenic, cadmium, chromium, copper, lead, nickel, zinc, mercury), total petroleum hydrocarbons (TPHs), total recoverable hydrocarbons (TRHs), benzene, toluene, ethyl benzene, meta- and paraxylene and orthoxylene (BTEX), and polynuclear aromatic hydrocarbons (PAHs). These tests showed that the levels exceeded EPA 1998 and NEPM 1999 EIL [ecological investigation level] requirements accordingly.*

Stage 1 test findings for the soil and groundwater samples taken on 29 February 2012 before AgriRem® A100 treatment are shown in Table 1.

Table 1 Stage 1 contamination assessment results, soil and groundwater samples, 29 February 2012

Sample	Total petroleum hydrocarbons	Total recoverable hydrocarbons	Naphthalene
Soil (mg/kg)	5 410	5 300	3
Groundwater (mg/L)	12 200	260	167

Stage 2: After AgriRem® A100 treatment

The Duke Environmental report describes the results of the stage 2 contamination assessment, and remediation and validation assessment:

> *As a result of the bioremediation process performed by AgriRem Earth Care on 22nd August 2012, validation sampling was undertaken by Duke Environmental on 20 September 2012 and sent to ALS for analysis of eight (8) metals, TPH, BTEX and PAH.*
>
> *Laboratory results for soil and groundwater samples indicated that material did not exceed EPA or NEPM 1999 HILs [health investigation levels] for a residential 'A' setting. The sample material did not exceed EPA EILS or NEPM EILs.*
>
> *The results of groundwater testing indicated levels of PAH and TPH/TRH had declined. A further round of groundwater testing was undertaken from GW1 on 15 October 2012, which indicated a continued downward trend in levels of TRH contamination, with PAH levels and the TRH (>C10-C40 fraction (sum)) below laboratory limits of reporting. The levels of TRH contamination for C6-C10 fraction in the groundwater fell below the CRC CARE health-based screening levels (HSL) for low-density residential.*
>
> *Based on the results of the bioremediation process and subsequent analysis the site has been removed from the EMR and been declared suitable for any use, including low-density residential 'A'.*

The results from stage 1 and stage 2 soil and groundwater samples are shown in Tables 2 and 3.

Table 2 Comparison of soil samples from stage 1 (29 February 2012) and stage 2 (20 September 2012) testing

Contaminant	Stage 1 (mg/kg)	Stage 2 (mg/kg)	Reduction (%)
Total petroleum hydrocarbons	5410	50	99
Total recoverable hydrocarbons	5300	50	99
Naphthalene	3	1	67

Table 3 Comparison of groundwater samples from stage 1 (29 February 2012) and stage 2 (15 October 2012) testing

Contaminant	Stage 1 (mg/L)	Stage 2 (mg/L)	Reduction (%)
Total petroleum hydrocarbons	12 200	<100	99.00
Total recoverable hydrocarbons	260	0.5	99.99
Naphthalene	167	16	90.00

Summary

Tony Blackmore summarises the results of the AgriRem Earth Care treatment of the site and the impact of the results for him and Gaffville Pty Ltd:

> *The application of the product [AgriRem® A100] to the ground chased the fuel through the groundwater and the surrounding area, saved any further excavation expenses. The treatment was also applied to the stockpile. Subsequent testing 4 weeks later revealed a massive decline in the previous readings, and resulted in the site being totally cleared from the [EMR] register.*
>
> *Without the application of AgriRem® A100 this result could not have been achieved. The fact that this organic material was able to clean up the site was a miracle to myself at a very vulnerable time. The boys from AgriRem Earth Care achieved something I had given up on, and consequently I have no hesitation endorsing their process to anyone going through the harrowing experience of contaminated land.*

AgriRem Earth Care
Bioremediation Regeneration

www.agriremearthcare.com.au

Male infertility: how environmental pollutants may be affecting sperm quality

SVA Chamila Samarasinghe, Kannan Krishnan, Ravi Naidu, John Aitken and Megh Mallavarapu
UNIVERSITY OF NEWCASTLE, NEW SOUTH WALES, AUSTRALIA

The global population is 7.2 billion and growing. Around the world, nearly 250 babies are born every minute. This equates to 131.4 million births per year. Despite this global 'baby boom', the total fertility rate (TFR) – the number of babies born per woman – has declined by about half over the past 5 decades.

Infertility could be contributing to the drop in TFR. Approximately 15% of couples are infertile, and male infertility contributes to half of the cases. Semen quality has been declining over the past decades, consistent with the drop in TFR. In 1940, the sperm concentration was 100 million counts/millilitre, which dropped to 60 million counts/millilitre in 1990.[1] The percentage of motile sperm also declined by about 0.6% per year from 1973 to 1992.[2]

Male infertility can be influenced by several factors, including genetic, occupational and lifestyle, and environmental. This article focuses on the environmental factors.

The research in this article is part of CRC CARE's Cleaning Up research program, which develops technologies and strategies for in situ contaminated site remediation.

How are we exposed to environmental pollutants?

Nearly all the commercial products in our everyday life contain different toxic chemicals, which can enter the air, soil and groundwater. Humans can be exposed to these chemicals by either using them or being exposed to them through the environment, and during all life stages – as adults, children and even during pregnancy (in utero).

After exposure, some pollutants may end up in the circulatory system, which can carry chemicals to distal organs and cross physiological barriers of the body (such as the blood–brain barrier and the blood–testis barrier), and accumulate in organs. Toxicant accumulation in the male reproductive organs could risk the normal function of male germ cells – spermatozoa.

How can environmental pollutants disrupt normal cellular functioning?

The following environmental pollutants are considered to be reproductive toxicants:

- polychlorinated bisphenyls
- perfluorinated alkyl substances
- parabens
- phthalate esters
- heavy metals – lead, cadmium, arsenic and uranium
- polycyclic aromatic hydrocarbons
- nanoparticles
- pesticides.

Environmental pollutants can negatively affect the male reproductive function by generating reactive oxygen species (ROS) and causing oxidative stress. ROS and oxidative stress both damage cells. The pollutants may also disrupt the anti-oxidative capacity of organisms. Anti-oxidative enzymes protect cells from the harmful effects of oxidative stress. In human sperm, oxidative stress and disruption of anti-oxidative enzymes may lead to poor sperm motility, low sperm count and sperm DNA damage, all of which compromise fertility.

Men are exposed to these environmental pollutants every day, which may result in declining sperm quality. Some of these toxicants have been detected in blood, urine and semen. Several studies have shown increased levels of these chemicals in infertile men compared with fertile groups, suggesting that these toxicants play a role in infertility.

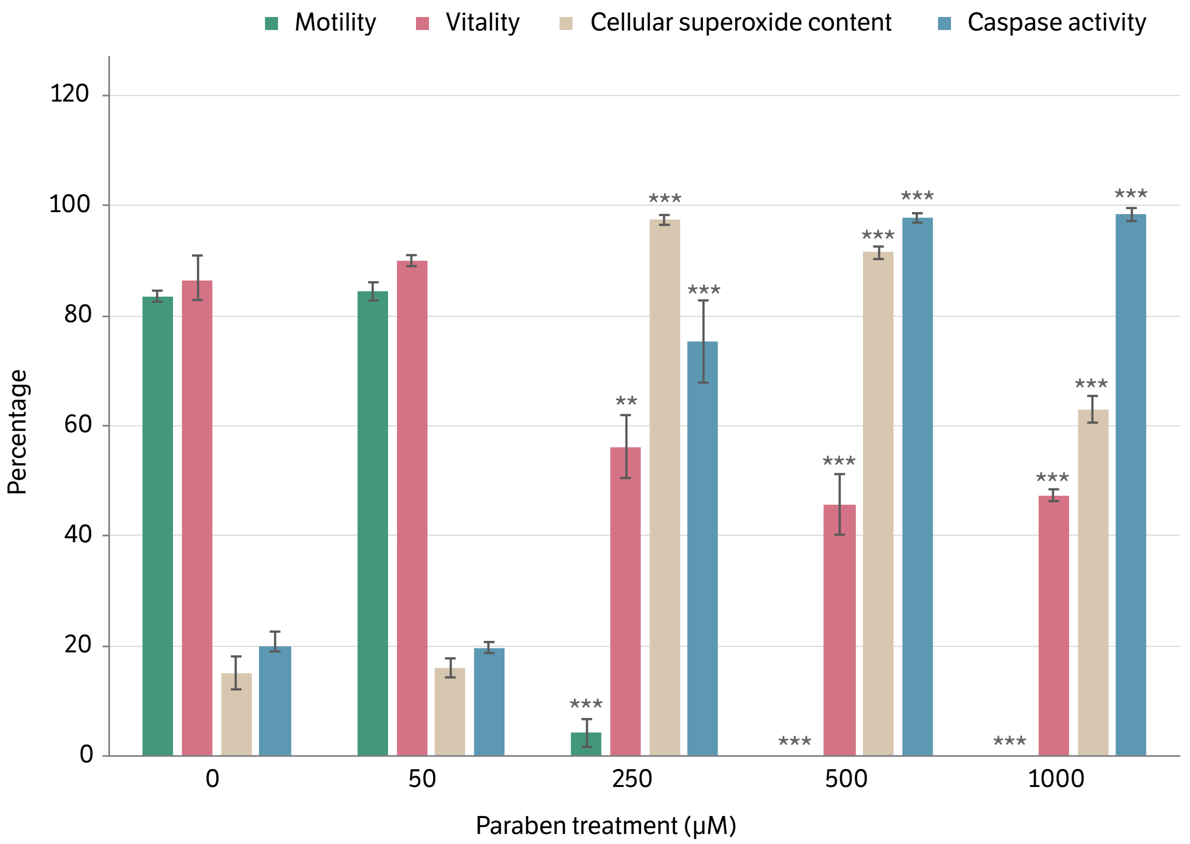
What do we know so far?

Animal models have provided evidence that some environmental pollutants can compromise production and maturation of spermatozoa (spermatogenesis), and impair sperm function. Although there are clear correlations with certain pollutants, there is not enough information available to correlate exposure to some of the emerging environmental toxicants with male fertility. To properly understand the environmental causes of infertility, we need to broaden our knowledge of how some toxicants affect semen quality.

Parabens as possible culprits

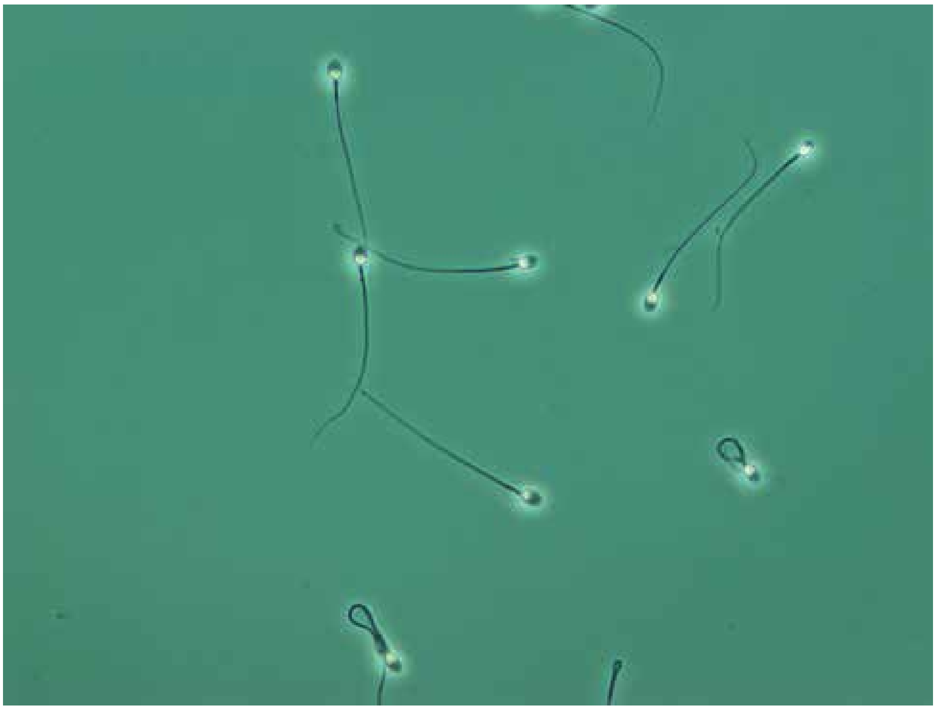
Parabens are alkyl esters of *p*-hydroxy benzoic acids, and are widely used in cosmetics, pharmaceuticals and foods. The most commonly used parabens are methyl, ethyl, propyl and butyl esters, and are mixed in consumer products as preservatives (together, these parbens have antimicrobial properties). Therefore, people are likely to be exposed to several parabens from the same source at the same time. Parabens act as endocrine disruptors and disturb sperm function in laboratory mice.

Our group recently showed that a mixture of parabens was acutely toxic to human sperm. We exposed human sperm to a paraben solution containing equimolar concentrations of methyl, ethyl, propyl and butyl parabens for 24 hours. Sperm motility and vitality started to drop at a total of 1 mM paraben concentration (that is, 250 μM of each paraben). Cellular superoxide anion (cytosolic ROS) percentage and caspase activity were used as oxidative stress markers. Both markers were increased, meaning ROS was induced in a dose-dependent manner (Figure 1).



$^{**}P < 0.01$; $^{***}P < 0.001$
Notes: Treatment concentration shown in the graph indicates the concentration of each paraben in the equimolar mixture. Motility, vitality, cellular superoxide content and caspase activity are markers of sperm function and oxidative stress.

Figure 1 Impact of incubation for 24 hours with equimolar paraben mixture on motility, vitality, cellular superoxide content and caspase activity of human spermatozoa



Human sperm under a microsope

What do the results mean?

This study reveals that human sperm function is negatively affected by an acute exposure to a 1 mM mixture of parabens. However, the general population is unlikely to be exposed to a such high concentrations of parabens through the environment. It is possible that chronic exposure to low levels would result in long-term negative effects. Also, multiple toxic chemicals in the environment may be harmful on their own or in combination with each other.

Studying the potential risk of environmental pollutants on sperm quality is important for public health, because these toxicants are so common in the environment. Expanding our knowledge about the effects of toxicants will help to:[3]

- initiate and amend regulatory requirements (eg listing substances that affect semen quality)
- establish and identify likely exposure places, which would
  - make it easier for pregnant women to avoid environmental exposures during pregnancy
  - identify and prioritise remediation technologies for high-risk environments
- manage the harmful effects (eg guidance for couples about anti-oxidant therapies).

More epidemiological and reproductive toxicity studies are needed, to assess risk and start public health initiatives.

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Reference doses for PFAS: moving from animal to epidemiological studies

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Our exposure to per- and poly-fluoroalkyl substances (PFAS) is a major health concern due to their widespread occurrence and adverse health effects. Mounting evidence indicates that PFAS pollution, even at low levels, affects human development and reproductive functioning.

During the past decade, reference doses (RFDs) for PFAS have become more conservative (Table 1). On 25 May 2016, the United States (US) EPA released RfDs for perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) of 20 ng/kg/day. Compared with the draft values (77 ng/kg/day for PFOS and 189 ng/kg/day for PFOA) suggested in 2009, the new RfDs were sharply reduced by a factor of 2 for PFOS and 8 for PFOA. Currently, most RfDs are based on animal rather than human evidence. Thus, two factors are crucial when deriving human RfDs:

- the point of departure (PoD) (includes the procedure for estimating human equivalent dose from animal PoD)
- quantifying uncertainty factors (UFs).

Selecting the points of departure

In particular, the animal PoDs that were adopted ranged from 0.00051–0.03300 mg/kg/day to 0.0053–0.3000 mg/kg/day for PFOS and PFOA, respectively, since various agencies selected different toxicity studies to base their PoDs on.

The US EPA used 11 candidate studies to base their recent RfDs on. Of these 11 studies:

- 1 study and 4 others focused on the PFOS hepatic effects and PFOS developmental effects, respectively
- 1, 4 and 1 studies reported on the hepatic toxicity, developmental toxicity and immunotoxicity for PFOA, respectively.

This indicates that the RfD/PoD selection was heavily weighted for developmental effects. Candidate studies are largely selected based on the availability of toxicokinetic (TK) data rather than the toxicity study itself, and evidence is suggesting that using different critical endpoints may result in lower RfDs. The rationale of the current selection strategy should be redesigned, by incorporating the merits of toxicity studies (such as toxicological endpoints, duration and species). Meanwhile, some scientists noted that the parameters used in the adopted TK model to quantify UFs are not biologically plausible, and it did not consider gestation and lactation exposures.

PFOS and PFOA in firefighting foams have contaminated numerous sites in Australia and other countries

Quantifying the uncertainty factors

Although the consensus has been to apply a default UF of 10 for intraspecies and 3 for inter-toxicodynamics, quantifying the inter-toxicokinetics difference and exposure duration difference has been more variable, and is based on evolving TK models. For example, using the first-order model as the TK model, the US EPA has determined an inter-toxicokinetics difference of 13 from monkeys to humans. The Danish EPA also used the method to designate a PFOS inter-toxicokinetics difference of 41 from rats to humans.

Recently, with the development of compartment models, an approach termed human-equivalent dose (HED) was used to integrate the inter-toxicokinetics difference and exposure duration difference. Using the HED approach, the Danish EPA estimated the total of inter-toxicokinetics difference and exposure duration difference for PFOA to be 133.

Epidemiological studies to guide reference doses

In 2016, the German Human Biomonitoring I (HBM I) values of PFOA and PFOS in human serum were published by the German Federal Environment Agency (UBA). The safety thresholds have been set at 5 ng/mL for PFOS and 2 ng/mL for PFOA. These HBM I values are based on epidemiological studies. The HBM Commission concluded that exposure to PFOA and PFOS was adversely associated with:

- fertility and pregnancy
- newborn birth weight
- lipid metabolism
- immunity after vaccination
- hormonal development
- thyroid metabolism
- onset of menopause.

In addition, the HBM Commission suggested that these effects were 'well proven' and 'relevant'. Until now, only these 2 guidelines were extrapolated based on human evidence, whereas all other RfDs were obtained by using animal studies.

The 5 ng PFOS/mL and 2 ng PFOA/mL in human serum are equivalent to RfDs of 0.4 ng PFOS/kg/day and 0.28 ng PFOA/kg/day. Compared with the US EPA–derived RfDs of 20 ng PFOS/kg/day and 20 ng PFOA/kg/day, the two HBM I values are approximately 50–70 times lower. Such a huge difference in RfDs indicates there may be an overestimation bias when using the animal data, which brings into question our choice of the data source for RfD determination.

Animal studies have helped researchers determine reference doses for PFAS

Limitations of using human data to derive reference doses

An advantage of using human data is that the quantification of interspecies UF is avoided, as is the issue of relevance between human and animal response. However, using human data to extrapolate the health advisories is controversial, since the arguments on a consistent causality between PFOS/PFOA exposure and adverse effects in humans are ongoing.

Some adverse effects observed in humans (eg immunotoxicity) are consistent with those seen in animals, whereas some effects, such as the neurobehavioural developmental effects (possibly mediated via disturbance of thyroid hormone functions) are not. Most findings based on human data come from cross-sectional studies, which are limited in their ability to establish cause. Some other studies are also limited by sample size and reliance on mortality data. Thus, data from human studies are still not strong enough to be used as the primary basis for risk assessment.

Reviewing data from different studies may overcome some of the inherent uncertainties in using human studies. For example, a systematic review illustrated evidence for the correlation between PFOA exposure and increased serum cholesterol and uric acid, and decreased fetal growth. Another example is a systematic review of 33 human studies, recently undertaken by the National Toxicology Program (NTP). The NTP concluded that a moderate level of evidence supports the idea that PFOS/PFOA suppress the antibody response.

Considering the advantages of using human data to determine RfDs, CRC CARE is attempting to use advanced statistical techniques to analyse data. For example, data from the US-based National Health and Nutrition Examination Survey provide an avenue to clarify the association between PFAS exposure and adverse effects. Such efforts will narrow the uncertainties in RfD determination and underpin knowledge on PFAS toxicity.

Table 1 Development of proposed reference doses for PFOS and PFOA

Chemical	Organisation	Species, duration	Endpoint	Tolerable daily intake or reference dose (ng/kg/day)	PoD (mg/kg/day)	UF			
						UF_1	UF_2	UF_3	UF_4
PFOS	UK COT	Cynomolgus monkeys, 26 weeks	Decreased serum t3 levels	300	NOAEL, 0.03	10	10	na	na
PFOS	EFSA	Cynomolgus monkeys, 26 weeks	Decreased serum t3 levels	150	NOAEL, 0.03	10	10	2	na
PFOS	US EPA	Cynomolgus monkeys, 26 weeks	Decreased serum t3 levels	77[a]	NOAEL, 0.03	39[b]	10	na	na
PFOS	Danish EPA	Rats, 104 weeks	Liver hypertrophy	30[a]	$BMDL_{10}$, 0.033	123[c]	10	na	na
PFOS	US EPA	Rats, 12 weeks	Pup body weight	20[a]	HED, 0.00051	3	10	na	na
PFOA	UK COT	Male rats, 13 weeks	Hepatic effects	3000	$BMDL_{10}$, 0.3	10	10	na	na
PFOA	EFSA	Male rats, 13 weeks	Hepatic effects	1500	$BMDL_{10}$, 0.3	10	10	2	na
PFOA	US EPA	Mice, 17 days	Hepatic effects	189[a]	$BMDL_{10}$, 0.46	243[d]	10	na	na
PFOA	Danish EPA	Male rats, 13 weeks	Hepatic effects	100	HED, 0.003	3	10	na	na
PFOA	US EPA	Mice, 17 days	Decreased pup ossification, accelerated male puberty	20	HED, 0.0053	3	10	na	10[e]

$BMDL_{10}$ = 95% lower confidence limit of benchmark dose at benchmark response of 10%; EFSA = European Food Safety Authority; HED = human equivalent dose; na = not applicable; NOAEL = no observed adverse effect level; PFOA = perfluorooctanoic acid; PFOS = perfluorooctane sulfonate; PoD = point of departure; UF = uncertainty factor; UF_1 = interspecies uncertainty factor; UF_2 = intraspecies uncertainty factor; UF_3 = uncertainty factor to account for studies with less than lifetime exposure; UF_4 = other uncertainty factor; UK COT = United Kingdom Committee on Toxicity

a Calculated as PoDs/UF_1/UF_2/UF_3/UF_4

b 3 (toxicodynamics differences) × 13 (toxicokinetics differences)

c 3 (toxicodynamics differences) × 41 (toxicokinetics differences)

d 3 (toxicodynamics differences) × 81 (toxicokinetics differences)

e Lowest observed adverse effect level to NOAEL UF

Securing safer seafood: the health effects of mercury in fish

Dr Andina Faragher, Carrie DeHaan
BIOTEXT

Environmental mercury that is absorbed in the diet can have serious effects on human health, including neurological and reproductive effects. The Pearl River Delta in south China has transformed from an agricultural centre to a manufacturing centre during the past few decades. It is now a hot spot for persistent toxic substances, including mercury, with implications for the health of the region's residents.

What are the sources of mercury in the environment?

A major source of environmental mercury is coal combustion in coal-fired power plants. Mercury released into the atmosphere by combustion is deposited on land and water surfaces. Asia produces more than 50% of global emissions of mercury.[1] China is the largest emitter in the world (followed by South Africa and India), producing most of its mercury emissions through nonferrous metal smelting, coal combustion and cement production.[2,3]

Mercury is mainly in the form of elemental mercury in the atmosphere and inorganic mercury (Hg^{2+}) in water. Under anaerobic conditions, sulfide reduction bacteria in aquatic environments can convert inorganic mercury to organic mercury (methylmercury).

Alexander Meins

How does mercury enter the human food chain?

Methylmercury is readily absorbed by living organisms, including aquatic species and humans, and efficiently binds to fatty tissues.

Mercury and other persistent toxic substances accumulate in animal tissues (bioaccumulation). Mercury is found at higher concentrations in carnivores at higher trophic levels along the food chain, known as biomagnification. It can be detected in the human body through tissue and hair analyses.

What effects does mercury have on environmental and human health?

Methylmercury and other organo-metallic compounds, such as those of tin and lead, share some characteristics of the persistent organic pollutants listed on the control list of the Stockholm Convention: they are persistent, toxic, bioaccumulative and able to travel long distances through different media.

In mercury-contaminated wetland areas, elevated mercury levels in predatory fish have affected the reproductive success of fish-eating predators such as osprey, eagles, herons, kingfishers and songbirds.[4] Adverse effects of mercury exposure on reptiles and mammals have also been reported.[5]

In humans, mercury is a neurotoxin: it affects the central nervous system, leading to neurological defects such as vision impairment, loss of coordination, muscle weakness and, in extreme cases, insanity, paralysis, coma and death. The developing fetus, especially during the first trimester of pregnancy, is particularly vulnerable. Fetal exposure to mercury, which can occur through placental transfer (during pregnancy) and lactation, can cause impairments in cognitive ability, attention span, memory and motor skills.

Acute or long-term exposure to mercury associated with consumption of contaminated fish has well-established adverse human health effects. The link between consumption of large predatory fish and mercury levels in human tissues has led to health authorities, including Food Standards Australia New Zealand and the United States Food and Drug Administration, recommending that the following groups should limit their consumption of fish such as tuna, swordfish and shark:

- women who are pregnant
- women who plan to become pregnant
- young children.

Case study: the Pearl River Delta of China

The Pearl River Delta in south China has been a centre for agriculture and aquaculture for centuries. In the dyke–pond system, fish and shrimp are reared in ponds adjacent to the sea, often in polyculture – that is, mixtures of freshwater fish species such as grass carp, mud carp, tilapia and grey mullet. Wastes such as digested pig manure and grass clippings are used as the major energy inputs.

During the past 30 years, the Pearl River Delta has become the most developed and industrialised region in China, and is now the world's centre for manufacture of electronic equipment, textiles and pharmaceuticals. These activities have led to discharge of a wide range of toxins into the delta. Several studies have identified the Pearl River Delta as a hot spot for a number of persistent toxic substances, including mercury.[6]

Numerous pathways contribute to the mercury contamination of the region. Industrial ash, which is contaminated with heavy metals and persistent organic pollutants, is used as fertiliser, leading to contamination of crops. Increased coal combustion to generate electricity, often from power stations that lack emissions controls, results in increased mercury emissions, which enter the food chain when they are deposited onto soil and water from the air. The 'trash fish' (small fish with no commercial value) that are used as fish feed, and feed pellets containing fishmeal are often contaminated with mercury and other toxins, leading to contamination of the cultured fish.

Fortunately, the relatively short period of cultivation of most freshwater fish in fish ponds means that bioaccumulation of mercury in the food chain is not a major problem. However, levels of mercury in hair samples from residents of the area are correlated with the daily intake of mercury via fish consumption.

What can we do to minimise the risks?

Some success has been achieved in controlling mercury emissions. In the United States and Canada, stricter regulatory controls over emissions, including from coal-fired power plants, have led to reductions in mercury levels in fish. There is evidence that as levels of inorganic mercury decrease in the atmosphere, so does methylmercury accumulation in aquatic biota. Newly deposited mercury also appears to be methylated more efficiently than existing mercury in aquatic systems. This means that rapid reductions in mercury emissions – to minimise further deposition of mercury – should result in rapid benefits to human and wildlife health.

In China, efforts have been made to reduce mercury emissions from coal-fired power plants through improvements in energy efficiency and pre-combustion control measures.

The Global Mercury Partnership has started negotiations on a legally binding instrument to control global mercury pollution. In January 2016, 140 countries signed the Minamata Convention on Mercury, which aims to protect human health and the environment from human activities leading to release of mercury and its compounds.

At the global scale, reduction of mercury contamination will require sustained national and international commitments for decades to centuries. An effective strategy for reducing mercury exposure requires an examination of the complete life cycle of mercury, including regional sources and fates of mercury, and dietary exposure of coastal communities. In China, there appears to be an urgent need to establish a regional list of toxic chemicals for more efficient control, focusing on chemicals – such as mercury – commonly found in local food items.

This article is based on Ming-Hung Wong (2017). Chemical pollution and seafood safety, with a focus on mercury: the case of Pearl River Delta, South China. ***Environmental Technology & Innovation*** **7:63–76.**

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'Guardians of the gut galaxy': how gut microbes modulate the bioaccessibility of ingested heavy metal(loid)s

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The bioavailability and toxicity of contaminants such as heavy metal(loid)s is underpinned by their bioaccessibility. Some heavy metal(loid)s are ingested accidentally, such as arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb). Therefore, gut microbes may play an important role in the absorption of nutrients and heavy metals in the human intestine through their effect on bioaccessibility.

Sources of heavy metal(loid) contamination

Heavy metal(loid) contamination of terrestrial and aquatic environments is mainly a result of human activities – metal mining and smelting, and irresponsible disposal of agricultural and industrial waste are all problematic. Humans encounter the heavy metal(loid) contaminants through water, soil, food and air.

As, Cd, Pb and Hg are some of the most common toxic metal(loid)s that humans ingest accidentally. For example, young children unintentionally ingest Pb-contaminated soil and dust. Pb is also a therapeutic compound in traditional Indian Ayurvedic medicine, used for treating diabetes, diarrhoea and skin diseases. In Bangladesh, deep watertables containing As have contaminated well water and rice (through irrigation), thus creating a pathway for accidental ingestion.

Bioaccessibility of heavy metal(loid)s

The amount of metal(loid) that is absorbed into the blood and systemic circulation (that is, the bioavailable fraction) may vary depending on the:

- nature and solubility of the metal(loid) source – that is, its bioaccessibility
- physicochemical properties of the ingested material.

Bioaccessible metal(loid) concentrations are more important for health and environmental risk assessment than total metal(loid) contents. Therefore, bioaccessibility studies are needed to determine human intake of heavy metal(loid)s from various sources, to accurately assess risk and establish maximum threshold levels for metal(loid)s.

Role of gut microbes

The human microbiome comprises bacteria and other microorganisms that live on and within a human. Most of our 3.8×10^{13} bacteria reside in our gastrointestinal tract, making up the gut microbiome, which:

- provides immune system training and modulation
- digests and ferments energy substrates
- is a source of vitamins and vitamin production
- helps with the structural integrity of the gastrointestinal tract.

These bacteria are essential to normal physiological human functioning. When the gut microbiome is disturbed, it can lead to poor health, including intra- and extra-gastrointestinal disorders.

Ingested contaminants go through the digestive tract, where they will interact with the gut microbes before passing through the intestinal cell wall into systemic circulation. These gut microbes therefore also play an important role in the transformation, bioavailability and, hence, metabolism of heavy metal(loid)s.

Testing the relationship between gut microbes and lead bioaccessibility

Most studies have examined bioaccessibility of heavy metal(loid)s in the absence of gut microbes. In this study, we examined the effect of three gut microbes – *Lactobacillus acidophilus*, *L. rhamnosus* and *Escherichia coli* – from various locations in the gut, on the bioaccessibility of soil-ingested Pb. Bioaccessibility was examined using both Pb-spiked and Pb-contaminated field soil samples from shooting ranges. Pb acetate was used as the reference material (3 samples in total). Bioaccessible Pb was estimated using the in vitro gastrointestinal method, which involves a 2-step sequential extraction: a gastric solution extraction and then an intestinal solution extraction. Both steps were done with and without gut microbes.

The gastric solution extracted more Pb than the intestinal solution for all 3 samples with and without gut bacteria. In the gastric phase (pH 1.5), the solubility of Pb acetate was approximately 100%. When the in vitro solution was modified to the intestinal phase (pH 5.8), Pb acetate solubility decreased to 65%. pH is often one of the main factors that control the solubility of metals, including Pb, in aqueous solutions. In the 3 samples, the absolute Pb bioaccessibility was 45.3–68.7% after gastric phase dissolution. When the solution was modified to reflect intestinal phase conditions, a similar decrease in soluble Pb was seen for the contaminated soils as for Pb acetate. Correspondingly, absolute Pb bioaccessibility decreased to 1.2–11.7%. As Pb dissolution is influenced by parameters such as Pb mineralogy, the source of Pb contamination is likely to significantly influence Pb bioaccessibility.

The difference in Pb bioaccessibility between gastric and intestinal phases can be attributed to the reduced solubility of Pb at pH 5.8. After transitioning from the gastric to the intestinal phase, a significant proportion of solubilised Pb is readsorbed onto soil particles or precipitated at the neutral intestinal phase pH, thereby reducing the bioaccessibility in the intestinal phase. The 2 soil samples showed different bioaccessibility because of the Pb mineral formed in the soil, and the length of interaction between Pb and soil particles.

In our study, gastric and intestinal Pb bioaccessibility decreased in the presence of bacteria, and the effect was more pronounced for gastric bioaccessibility. This may lead to a decrease in Pb bioavailability.

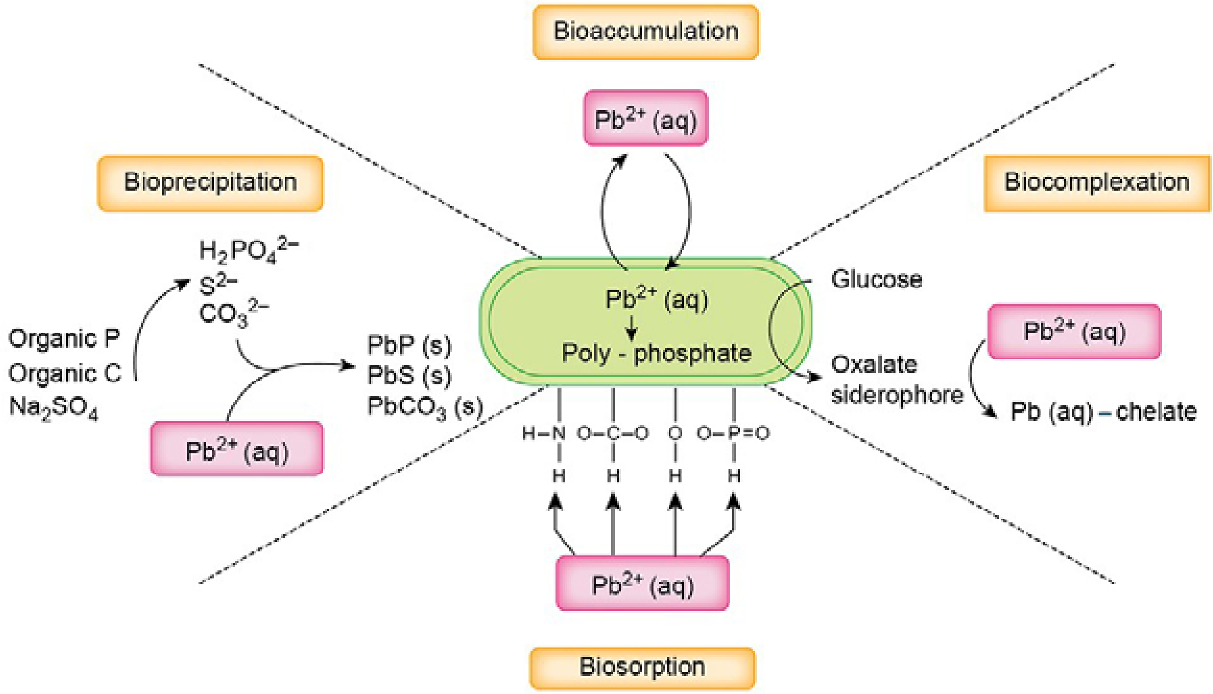
How microbes could modulate lead bioaccessibility

There are several possibilities for how microbes could modulate Pb bioaccessibility. Gut microbes may reduce the bioaccessibility of Pb by immobilising the Pb through adsorption, complexation and precipitation reactions (Figure 1). The microbial cell wall is a natural barrier for metals, including Pb^{2+}. Many microorganisms make extracellular polymeric substances (ESPs) that bind toxic metal cations, thereby protecting metal-sensitive and essential cellular components (Figure 1). The composition of ESPs is very complex, but includes proteins, humic acids, polysaccharides and nucleic acids, which chelate metals with different specificity and affinity. *Bacillus firmus*, *Pseudomonas* spp., cyanobacteria, *Halomonas* spp. and *Paenibacillus jamilae* are all reported to have ESPs that bind to Pb^{2+}.

Another possibility is through the bonds that metals form with organic compounds. Pb^{2+} forms strong soluble and insoluble complexes with organic compounds such as tryptone, cysteine, neopeptone, casamino acid and succinic acid. Microorganisms release organic compounds such as short chain fatty acids and carboxylic acids, which are involved in nutrient absorption and energy regulation. When the organic compounds form a complex with metals, the metals are removed from the solution. Lead is also known to react with anions such as chlorides, phosphates and hydroxyl ions to form insoluble precipitates. Several microorganisms precipitate Pb^{2+} to lower the concentration of free Pb^{2+} by sequestering it as phosphate salts outside and inside the cell (Figure 1).

Other possibilities for how bacteria affect the bioaccessibility of Pb include the following:

- Some bacteria accumulate Pb^{2+} in their vacuoles.
- Microorganisms have metallothionein-like proteins that can bind metals, including Pb^{2+}.
- Extracellular enzymes, such as superoxide dismutase excreted by microorganisms, can also bind Pb^{2+}.



aq = aqueous phase; s = solid phase

Figure 1 Schematic showing possible microbial lead immobilisation processes

Conclusion

Our study showed that gut microbes decreased bioaccessibility of Pb, which is likely to affect its bioavailability, intestinal absorption and toxicity. These microbes can act as the 'guardians of the gut galaxy'. The effect of gut microbes on bioaccessibility may be attributed to the bioimmobilisation of Pb through adsorption, precipitation and complexation reactions. Therefore, bioaccessibility measurements must be done in the presence of gut microbes, especially for ingested contaminants.

It is important to point out that the human gut hosts many microbial species, including bacteria, fungi and archea. We looked at the effect of only 3 bacteria on the bioaccessibility of Pb. Future studies should focus on the effect of composite gut microbial culture on bioaccessibility and subsequent bioavailability of toxic metal(loid)s.

Nothing to sneeze at: endocrine-disrupting chemicals and their role in human allergies

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In this article, we look at the sources and pathways of endocrine-disrupting chemicals (EDCs) entering our bodies, the bioaccessibility–bioavailability–bioactivity continuum of EDCs, and how they may be associated with human allergies.

Endocrine-disrupting chemicals

EDCs are chemicals that can interfere with hormone-signalling pathways in the body. They are ubiquitous in the environment and can cause reproductive abnormalities, neurological defects, allergies and cancer. There is increasing evidence that EDCs contribute to the development of allergic diseases, or allergies. These are clinical conditions caused by hypersensitivity of the immune system to generally harmless foreign proteins and substances.

Humans are exposed to EDCs through food, personal care products, cosmetics, pharmaceuticals, pesticides, plastics, water and soil. The most common EDCs include brominated flame retardants such as per- and poly-fluoroalkyl substances (PFAS), halogenated aromatic compounds such as polychlorinated biphenyls, plasticisers such as dibutyl phthalate, and pesticides such as chlorpyrifos and atrazine. Cadmium is also considered to be an EDC because there is evidence that it harms the reproductive system. Although most EDCs are synthesised, they also exist naturally. For example, soy-based products are a rich source of naturally occurring phytoestrogens.

The bioaccessibility–bioavailability–bioactivity continuum

The toxicity of ingested contaminants – including EDCs – is determined by the bioaccessibility–bioavailability–bioactivity continuum (Figure 1), which is:

- the extent to which they are solubilised in the gut (bioaccessibility)
- their permeability to, and subsequent circulation in, the blood (bioavailability)
- their assimilation and metabolic action in any tissues that subsequently absorb them (bioactivity).

Bioaccessibility is usually evaluated in vitro by physiologically based extraction tests and gastrointestinal digestion procedures. Bioavailability, which expresses the fraction of the bioaccessible compound that enters the blood circulation, refers to the rate and extent to which the compound permeates through the intestinal epithelial cells. Bioactivity refers to the physiological and metabolic interactions between the compound and the human tissue or organ, which disturb homeostasis (the body's usual healthy equilibrium). EDC toxicity can be mitigated by reducing the permeability in the intestine, thereby reducing the amount of EDC entering the systemic circulation.

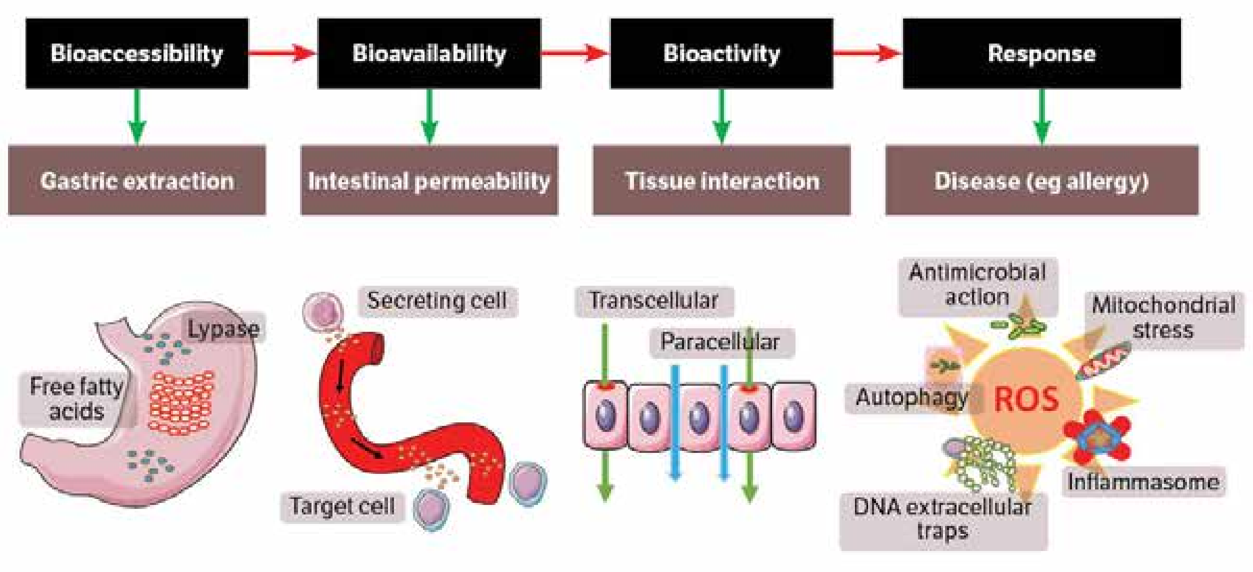
EDCs and the allergy link

Our team, in collaboration with Professor Yong Ok (Korea University), is examining the bioaccessibility–bioavailability–bioactivity continuum of EDCs, and their capacity to induce allergic disease.

EDCs interfere with hormone biosynthesis and metabolism, thereby altering normal homeostatic control or reproductive function. Animal models, human clinical observations and epidemiological studies implicate EDCs as a significant contributor to male and female reproductive abnormalities. Hormones such as oestrogen promote the release of histamine, which is responsible for such allergy symptoms as watery eyes, coughing and nasal congestion. If a person ingests EDCs that subsequently interfere with the synthesis and circulation of oestrogen, this can increase the allergic response. The hormone–allergy connection is further supported by the relationship between progesterone and cortisol. Cortisol, a natural anti-inflammatory hormone, is produced in the adrenal glands from progesterone. Any EDC-induced disturbance to, or imbalance in, this hormone system can trigger allergies.

Exposure to EDCs alone may not lead to allergies; however, co-exposure of EDCs with known allergens (eg ovalbumin from egg whites) can enhance the hypersensitivity response to that allergen. When a person is exposed to an allergen for the first time, the body becomes sensitised and produces antibodies against the foreign proteins as an immune response. When exposed to the allergen again, the immune system produces large numbers of antibodies that lead to activation of mast cells containing histamine, thereby causing allergy symptoms. Regular exposure to EDCs in food contaminants amplifies this allergic sensitisation through a form of oxidative stress (an imbalance in the body's ability to use antioxidants to counteract the harmful effects of free radicals) that promotes the development of allergic symptoms. Thus, EDC exposure may augment the allergic responses to other environmental allergens.

The cause of food allergy is unknown, although dietary chemicals have been suggested to play a role in sensitising our immune system. Our research linking EDCs to allergy will help us to understand some of the physiological and molecular mechanisms for EDC-triggered allergy symptoms. This work will inform future research that will help researchers and clinicians explore new avenues, methodologies and approaches to the mitigation and treatment of EDC-induced allergic diseases, eventually leading to improved clinical treatment and desensitisation of allergies.



ROS = reactive oxygen species

Figure 1 The bioaccessibility–bioavailability–bioactivity continuum of endocrine-disrupting chemicals in relation to disease response

Unravelling the link between kidney disease and environmental contaminants in the North Central Province of Sri Lanka

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Chronic kidney disease of unknown etiology (CKDu) has been sweeping parts of Sri Lanka in recent years, mainly affecting farmers in the North Central Province, but also in the Northern Province, the Eastern Province, the North Western Province, the Uva Province and the Central Province. CKDu cannot be attributed to known factors such as diabetes, hypertension or glomerulonephritis.

Chronic kidney disease (CKD) has killed more people in the North Central Province than the 20-year-long civil war in the area. Over 20 years, up to 20 000 people have died as result of CKD and up to 400 000 more were ill. Some villages report that CKD is responsible for as many as 10 deaths a month.

CKDu deaths in the North Central Province

In the North Central Province and adjacent farming areas, CKDu has escalated to epidemic proportions. The North Central Province comprises the Pollonnaruwa and Anuradapura districts. In the Pollonnaruwa district, about 6580 people were reported to have CDK by the end of November 2017, and, of these, 1458 were CKDu (22%; Table 1).

Table 1 Chronic kidney disease patients in Pollonnaruwa district, by the end of November 2017

Medical Officer of Health area	Chronic kidney disease (no. cases)	Chronic kidney disease of unknown aetiology (no. cases)
Medirigiriya	1913	380
Hingurakgoda	669	158
Dimbulagala	1261	316
Lankapura	444	124
Thamankaduwa	1059	149
Elahera	827	257
Walikanda	407	114
Total	6580	1498

Possible causes of CKDu

CKDu is a toxic nephropathy. Research on CKDu has generated various hypotheses, but the most common one is environmental exposure to heavy metal(oid)s. The recent focus on increased productivity to enhance the local and national economy has resulted in significant increases in both fertiliser and pesticide use. Although these additives have led to a significant increase in crop productivity, they have also been linked to an increase in soil contamination and thus contamination of the food supply, causing several human health problems. Hence, our studies aim to quantify people's exposure to heavy metals.

Heavy metal(oid)s in drinking water

Exposure to heavy metals, such as arsenic (As) and cadmium (Cd), could be from contaminated drinking water. Scientists believe that farmers' consumption of contaminated water from shallow wells leads to kidney disease in the North Central Province.

Heavy metal(oid)s in irrigated rice

Some researchers believe that exposure comes from rice contaminated with heavy metal(loid)s and other toxins. However, some argue that, although there are high levels of Cd in Sri Lankan rice, zinc (Zn) is also present. Zn inhibits the toxic action of Cd. Some researchers have also found Sri Lankan rice to contain selenium (Se), which also nullifies the action of Cd.

Another argument against rice being the source of the heavy metal contamination is that not all the Cd in rice is bioavailable – only about 50% is. Since some of the remaining bioavailable Cd is nullified by Se and Zn, it is assumed that Sri Lankan rice is, in fact, safe for consumption.

Researchers found that rice cultivated in Sri Lanka is also contaminated with As. They discovered that agrochemical-dependent new improved varieties (NIVs) contain As in the range of 20.6–540.4 µg/kg. However, they have not observed any differences between As content in NIV rice samples from CKDu high- and low-prevalence areas. In addition, traditional varieties also contain toxic metal(loid)s if they are grown with pesticides and fertilisers.

Scientists believe that glyphosate–metal complexes play a role in the current CKDu epidemic in rice paddy farming areas of Sri Lanka. Similar kidney diseases have been reported in Andra Pradesh (India) and Central America. Glyphosate that has formed complexes with minerals or heavy metal(loid)s in drinking water may damage renal tissues, which could lead to fatal kidney disease.

Current research on CKDu

More research needs to be done on the possible cause of CKDu. Currently, Mr Rangana Kulathunga, a PhD student from the Global Centre for Environmental Remediation at the University of Newcastle, Australia, is working to identify possible causes of CKDu neuropathy, mainly in the North Central Province farming community of Sri Lanka. The work is being done under the supervision of Professor Ravi Naidu, Dr Ayanka Wijayawardena and Dr Morrow Dong.

The Medirigiriya Medical Officer of Health area reported the highest number of CKDu patients. Therefore, this area was selected for studying possible factors relating to CKDu in the North Central Province.

The main objectives of this study are to:

- quantify environment exposure to heavy metals through food and drinking water
- map the heavy metal distribution
- investigate the relationship between body mass index and the estimated glomerular filtration rate.

Determining some of the environmental factors affecting CKDu could help farming communities and policy makers to make reliable decisions to overcome this epidemic.

A patient undergoing dialysis in Sri Lanka

Research

Wealth to waste, and waste to water in Sri Lanka: characterising leachate from dump sites

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Uncontrolled population growth, rapid urbanisation, the rise in community living standards and poor planning have accelerated the rate of generation of municipal solid waste (MSW) in Sri Lanka. Waste is ending up in open dump sites and, subsequently, water sources. Drinking water quality is a significant determinant of health; hence, water quality deterioration causes health, social and economic problems.

MSW management is one of the biggest challenges of the 21st century. Whereas developed countries consider how MSW affects the environment, most developing countries, including Sri Lanka, use open dumping to dispose of MSW, which can pollute the environment. Open dumping of waste with high organic content further aggravates pollution problems, because large amounts of highly contaminated liquid leachate are formed. Leachate is one of the major sources of toxic metals, organic carbon compounds and nitrogenous compounds that can contaminant the environment, including water bodies that supply drinking water.[1,2]

A contaminated waterway in Sri Lanka

A m unicipal solid waste site in Sri Lanka

Wealth to waste: waste load and composition

Sri Lanka is an island in the Indian Ocean, with a total area of 65 525 km^2 and a population of 20.2 million. At present, average solid waste generation in Sri Lanka is 6500–9000 tonnes/day. Recent studies show that the waste generation rate in most urban parts of Sri Lanka is close to 1 kg/person/day.[3] Dump sites have no weighing facilities; hence, there are no proper records on MSW generation, and all data are estimates. More than 60% of the MSW in Sri Lanka is organic matter, and paper (12%), wood (10%), plastic (7%), metal (4%) and glass (3%) make up the rest.[4]

Uncontrolled dumping resulted in a devastating MSW slide at one of the largest dumps in Colombo (Meetotamulla), which buried around 300 people in April 2017.

Waste to water: landfill leachate

Leachate mainly forms when rain percolates through the surface of, and into, the material in a landfill. Hence, more leachate is formed during periods of high rainfall. In addition, the moisture content of waste influences the amount of leachate generated from a dump site. MSW landfill leachates are variable and complex materials, reflecting the composition of solids dumped in the landfill. It is a common source of many contaminants, and MSW leachates often have high concentrations of:

- heavy metals (eg lead, cadmium, nickel, chromium, zinc, manganese, copper and iron)
- dissolved organic carbon components (eg humic, fulvic and hydrophilic acids)
- inorganic ions (eg NO_3^-, NH_4^+, NO_2^-, PO_4^{3-}, SO_4^{3-} and Cl^-)
- xenobiotic organic compounds (eg halogenated hydrocarbons, aromatic hydrocarbons, phenols, benzene and chlorinated aliphatics).

The characterisation of the landfill leachate plays an important role when determining the treatment method. Landfill leachate in the humid tropics may differ from that in temperate and arid regions,[2] and there may be different chemical components, stemming from different consumer waste patterns. Most leachate characterisation studies are for developed countries. Thus, we have characterised the landfill leachate from a major dump site in Sri Lanka – the Gohagoda open dump site.

End point of leachate: polluted drinking water

Study site: Gohagoda open dump site

The city of Kandy has been sending its waste to the Gohagoda open dump site since the 1960s.[5] Currently, about 130 tonnes of MSW are being dumped per day, without any sorting or pretreatment. Waste comes from slaughter houses, fish markets, households and hospitals. The amount of leachate produced at Gohagoda is estimated to be 30 304 m^3/year. Untreated leachate flows from the dump site through the existing drainage channel and adjoining lands, directly into the River Mahaweli, the largest river in Sri Lanka. This could lead to adverse environmental and health effects for the people in nearby urban areas using the river as a water supply.

We collected landfill leachate from the Gohagoda site from June 2011 to October 2012 from 4 sampling points of the leachate drainage channel. GS1 and GS4 were at the starting and end points of the channel, and the GS2 and GS3 points were in the middle (Figure 1).

Figure 1 Gohagoda municipal solid waste open dump site in Kandy, Sri Lanka

Results

The analytical results for many parameters such as biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), pH and level of ammonium nitrogen show that many old landfills across the world produce similar leachate (Table 1). The BOD_5 and COD values for Gohagoda are almost 50 times and 10 times higher than the permissible levels for wastewater, respectively (Figure 2). Gohagoda leachate is rich in volatile organic compounds such as phenol, xylene and benzene, which are carcinogenic and mutagenic to human cells.

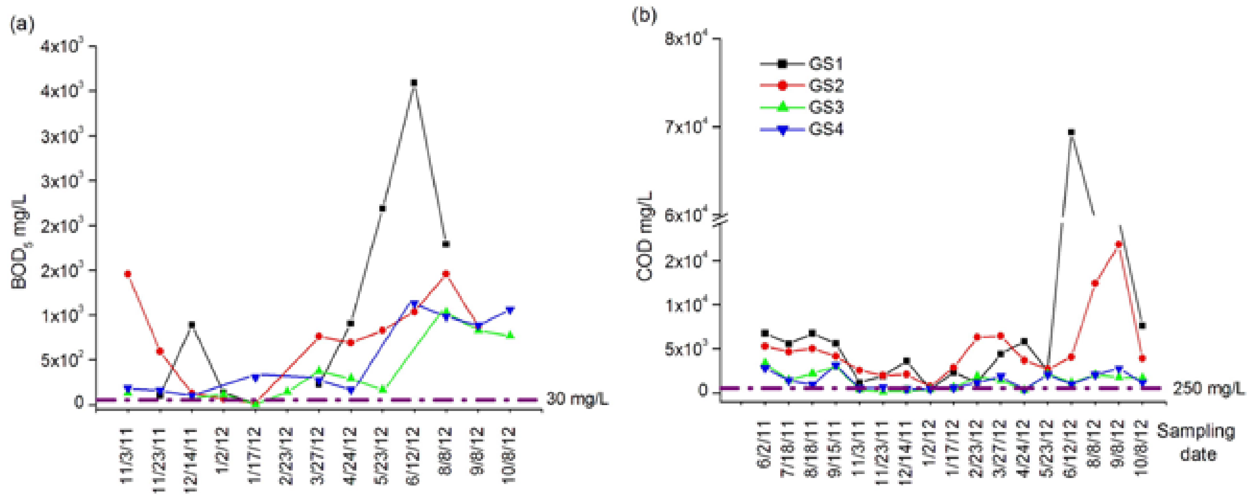
The demonstrated values for concentrations of ammonium nitrogen, phosphate, solids and some heavy metals were much higher than Sri Lanka's permissible levels for wastewater discharge (Table 1). Even though some parameters were below the permissible values, extensive pollution is still occurring due to cumulative discharge to the river every year.

A municipal solid waste site in Sri Lanka

Table 1 Landfill leachates in Gohagoda open dump site (GS1 and GS4), compared with reported data and standards

Constituent	Gohagoda leachate[a] GS1	Gohagoda leachate[a] GS4	Acetogenic leachates[b]	Methanogenic leachates[b]	CEA standards
pH	8.12	8.16	5.5–7.0	7.5–8.5	6.0–8.5
BOD_5 (mg/L)	1090	528	4000–30 000	<500–1000	30
COD (mg/L)	13 248	1425	10 000–50 000	2000–6000	250
TSS (mS/cm)	1730	126	na	na	50
Alkalinity (mg/L)	8890	2589	2000–10 000	10 000–30 000	na
Ammonia nitrogen (mg/L)	1113	330	750–2000	1500–3000	50
Nitrate nitrogen (mg/L)	128	32	<1	<1	na
Phosphate (mg/L)	107	54	5–20	1000–3000	5
Chromium (mg/L)	0.13	0.09	<0.1–0.1	<0.3–2.0	0.1
Lead (mg/L)	0.18	0.14	<0.1–<0.5	<0.05–0.20	0.1
Zinc (mg/L)	1.15	0.3	5–20	<0.01–0.05	5
Nickel (mg/L)	0.33	0.11	<0.1–<1.0	<0.05–0.10	0.1
Cadmium (mg/L)	0.40	0.01	<0.1–<0.2	<0.02–0.01	0.1

BOD = biochemical oxygen demand; CEA = Central Environmental Authority; COD = chemical oxygen demand; na = not applicable; TSS = total suspended solids
a Annual average value
b Data from Robinson 2007[2]



Note: The Central Environmental Authority permissible limit for each parameter is indicated by the purple dashed line.

Figure 2 Concentrations of (a) biological oxygen demand (BOD) and (b) chemical oxygen demand (COD) variation in the analysed leachate samples

Risks to the public

The landfill leachate that is discharged to the River Mahaweli is rich in dissolved organic compounds and complex toxic heavy metals. The river allows these contaminants to be easily transported to water supplies. Sri Lanka most commonly uses chlorine to treat potable water. Dissolved organic carbon from landfill leachate may contribute to the formation of various disinfection byproducts, such as trihalomethane and haloacetic acids, during the disinfection process with chlorine. These carcinogenic byproducts may threaten the health of the general public. The context may become even more severe due to the disposal of hospital waste into the landfill. The leachate may pollute water supplies to an extremely dangerous level beyond redemption.

Conclusion

The physicochemical composition of landfill leachate illustrates the extent of pollution of the receiving water bodies and risks associated with using their water. A leachate treatment facility is urgently needed, to reduce the public health risk from contaminated water.

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Publications update

This section contains publications from research institutions, regulators and industry groups that have been published since the last issue of *Remediation Australasia*. Email us at RAmag@crccare.com if you have any publications to be considered for inclusion (no promotional material).

CRC CARE has published one new Technical Report, which is available for free download, along with all of those previously published, at www.crccare.com/publications/technical-reports.

- Technical Report 40 – *Weathered petroleum hydrocarbons* (silica gel clean-up)

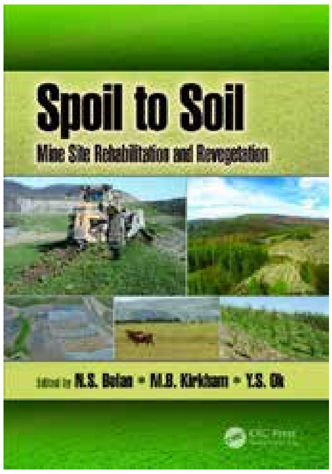
Tool for estimating subsurface LNAPL distributions and transmissivity

Drs Bob Lenhard, Greg Davis and John Rayner from CSIRO Land and Water have published *A practical tool for estimating subsurface LNAPL distributions and transmissivity using current and historical fluid levels in groundwater wells: effects of entrapped and residual LNAPL* in the October 2017 issue of the *Journal of Contaminant Hydrology*. The publication, which stems from a CRC CARE–supported project, is one the most downloaded articles from the journal in the past 90 days. It has been downloaded more than 550 times worldwide, including more than 100 times in Australia.

The same authors, along with Dr Kaveh Sookhak Lari, also published *Evaluating an analytical model to predict subsurface LNAPL distributions and transmissivity from current and historic fluid levels in groundwater wells: comparing results to numerical simulations* in the Winter 2018 issue of *Groundwater Monitoring & Remediation*, published by the US National Ground Water Association.

Risk communication around contaminated sites

Dr Kate Hughes published *Do remediation experts have what it takes to explain empirical uncertainty?* in the Winter 2017 issue of *Remediation Journal*. The paper examines how poor risk communication endangers our health and costs us money, and what we can do about it.



New book on mine site rehabilitation

Professor Nanthi Bolan, Environmental Chemistry, Global Centre for Environmental Remediation, University of Newcastle, is lead editor of *Spoil to soil: mine site rehabilitation and revegetation*, with co-editors MB Kirkham, Kansas State University, United States, and YS Ok, Kangwon National University, Korea. The book, published by CRC Press, covers the fundamental and practical aspects of three major themes:

- characterisation of mine site spoils
- remediation of chemical, physical and biological constraints of mine site spoils
- revegetation of remediated mine site spoils.

Each theme includes case studies about mine sites around the world. The book is a complete narrative of how inert spoil could be converted to live soil.

Training and events calendar

Public consultation on the National Remediation Framework (NRF)

The NRF will harmonise guidance and best practice in the remediation and management of contaminated sites in Australia. CRC CARE is seeking feedback from the public on the latest round of NRF documents. View them at www.crccare.com/knowledge-sharing/national-remediation-framework.

The deadline for public comment is 13 May 2018.

2018

12 April

Mine Rehab Conference
Tom Farrell Institute / University of Newcastle
www.tomfarrellinstitute.org/mlrc2018

1–3 May

5th New Zealand Contaminated Land Conference
Australasian Land & Groundwater Association / Christchurch, New Zealand
http://landandgroundwater.com/conference/5th-contaminated-land-conference-nz

3–4 May

Environment Professional's Management Workshop
Australian Sustainable Business Group / Sydney
www.asbg.net.au/index.php/seminars/nsw-seminars/445-environment-professional-s-management-workshop-3-4-may-2018

8–10 May

Ozwater '18
Australian Water Association / Brisbane
www.ozwater.org

8–10 May

Waste 2018
Impact Environmental / Coffs Harbour
www.coffswasteconference.com.au/QuickEventWebsitePortal/2018/waste

10–13 June

BEEM 2018 (Bioresources, Energy, Environment, and Materials Technology)
Korean Society of Environmental Biology / Hongcheon, Korea
www.beem2018.org

3–4 October

Waste Expo Australia
Reed Exhibitions / Melbourne
www.wasteexpoaustralia.com.au

21–25 October

1st Global CleanUp Congress
CRC CARE / Coimbatore, India
http://gcc2018.cleanupconference.com/

Is your site contaminated by firefighting foam?

Known as aqueous film-forming foams (AFFFs), some firefighting foam used for many years at airports and fire training facilities contained the potentially toxic chemicals PFOS and PFOA. In many cases, these chemicals have spread to groundwater, drinking water, plants and animals.

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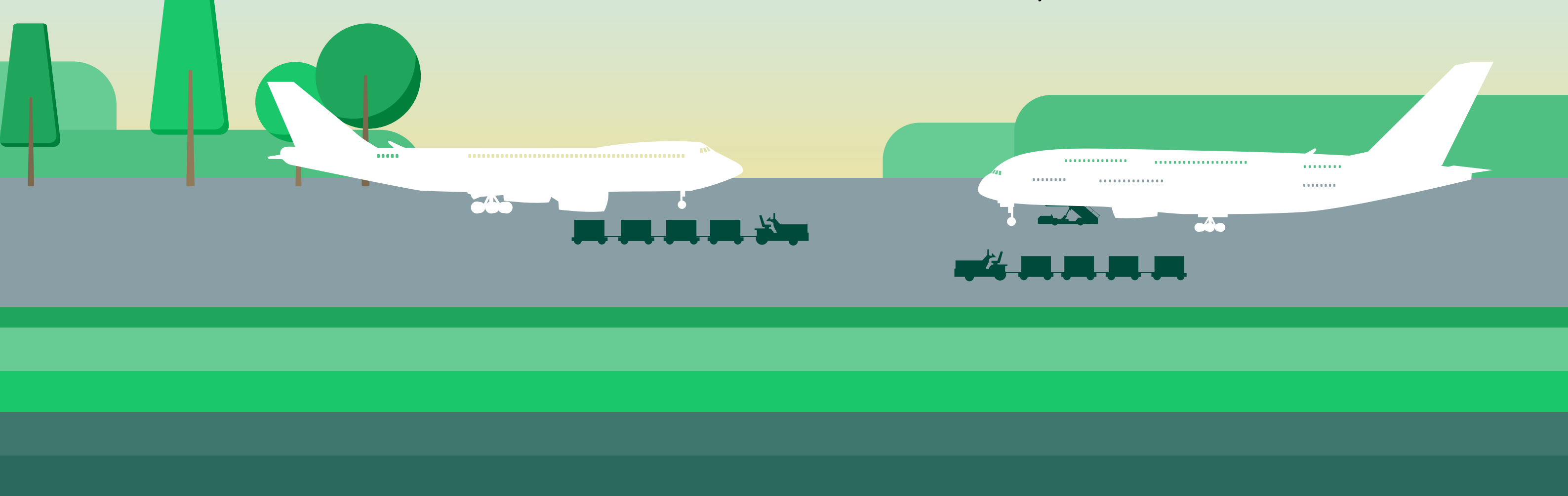

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