July 2020

Environmental Chemistry Group

Bulletin

Covid-19. Tom Sizmur reports on our last pre-Covid-19 meeting: Early Careers; and Valerio Ferracci reflects on air quality in the time of Covid-19.

Bees. Continuing our series on bees, Robin MacArthur looks at the effects of mite acaracides on honeybee health.

Public Engagement. Laura Alcock outlines a wet scrubber public engagement activity, Laura Hobbs uses Minecraft to engage children with environmental chemistry, and Rowena Fletcher-Wood reviews training on Public Engagement with Impact.

Articles. Fereshteh Hojatisaeidi discusses porous boron nitride, Chinonso Ogbuagu looks at biochar for remediation, and Jamie Harrower at fugacity modelling.

Early Career Environmental Briefs. Nat Wood explores microplastics in soil and Ella Yarrow diesel particulate matter.

Also in this issue. Laura Alcock tells us about her role as a development chemist and Tom Sizmur reviews *Urban Soils*.

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Cover image: A pollution detector in the park with a group of people standing together and wearing face masks. Image via Shutterstock

ECG *Bulletin*

Environmental Chemistry Group

The ECG Interview: Laura Alcock

Laura Alcock is a committee member of the Environmental Chemistry Group. Her career, so far, has taken her through microbiology, metal ore analysis, material recovery, and quality compliance to her current role as a development chemist/ engineering support chemist at a manufacturer of exhaust gas management systems for the electronics industry.

What inspired you to become a scientist?

When I was around 5, my Mum gave me a book for my birthday – *Science with Dinosaurs*. It had descriptions and instructions for experiments to do at home using household items, all demonstrating various scientific concepts. Since then, I have been hooked on practical science. Every time I learnt something new about the way the world works, I became more entrenched in my passion for science.

How did you come to specialise in abatement combustion chemistry?

Whilst applying for University, I met the Head of Admissions to the School of Biochemical Sciences at Liverpool John Moores University, who advised me that their forensic science degree would suit my desire to study analytical science, including analytical chemistry, microbiology and physics. From there, my career led me through analytical microbiology, chemical analysis of metal ore concentrates, precious metal recovery and quality compliance, to my current role.

Could you describe your current job?

My day-to-day activities vary greatly. My role includes the development of the combustion chemistry inputs to achieve efficient and clean abatement of semiconductor process gases which would otherwise present a great risk to human life and/or the environment. I also investigate customer queries and problems, including root-cause analysis for product incidents. This can then lead to liaising with the Company's engineering teams to develop a solution to solve the issues or prevent further incidents.

What advice would you give to anyone considering a career in environmental chemistry?

Knowing what you like about chemistry is vital to ensuring you follow a career you enjoy. It is also important to remember that careers in academia or industry can provide opportunities for research and development.

What are some of the challenges facing the environmental chemistry community?

Half-considered conclusions and sweeping generalisations. With all aspects of our lives being examined and, in many cases, challenged, it is important that we combat premature solutions by considering all of their impacts (e.g. wind farms as a major electricity source can require nearly as much energy to maintain as they generate).

What is the most rewarding aspect of your career so far?

Being able to contribute to protecting our environment from manufacturing practices has been a seriously rewarding aspect of my career so far. Knowing that I have reduced the pollution released during the manufacture of everyday devices, as well as being able to raise awareness in the general public of the energy and potentially harmful materials involved in manufacturing these devices, provides me with a great sense of achievement.

If you weren't a scientist what would you do?

If I weren't a scientist, I would probably be a wedding and events planner. I coordinated a number of events for charity fundraising when I was at school and sixth form and really enjoyed it. Planning my own wedding illustrated to me how much I enjoyed the task and I gave it real consideration, but I enjoy science too much.

And what do you do when you are not working?

I have a vast series of hobbies, including sports – football, trail-cycling, squash, surfing, etc.; crafts – knitting, woodwork, embroidery; reading and writing. In fact, between my work, my hobbies and my activities with the RSC's Environmental Chemistry Group, I need to be careful that I get enough sleep!

Book Review

Urban Soils

Tom Sizmur (University of Reading, t.sizmur@reading.ac.uk)

Estimates of the global land area currently being covered by urban conurbations range from 0.5% to 3%, but our understanding of how soils function largely stems from research undertaken in semi-natural or farmed ecosystems. Urban soils are highly disturbed because they are used as waste dumps, exposed to air pollution, subjected to urban heat island effects, or sealed entirely by concrete or asphalt.

Urban Soils is part of the '*Advances in Soil Science*' series. This boasts an impressive collection of volumes, mostly edited, as this book is, by the Rattan Lal and B. A. Stewart. This book contains 18 chapters that span topics such as soil organic matter, food security, environmental contaminants, and ecosystem services in urban soils. I dipped into a few chapters that particularly appealed to me.

Chapters 3 to **6** deal with the impact of urbanisation on the soil carbon cycle. There is a lack of consensus on whether urban soils are a net sink or a net source of carbon. Globally, urban areas are more likely to be situated on soil types with lower than average soil organic carbon content (you don't find many cities built on peat bogs!), and so the potential to mineralise and emit large quantities of carbon to the atmosphere is limited. **Chapter 3** provides case studies based in Moscow to illustrate how land management through history can increase the carbon stocks of urban soils.

A new paradigm, describing how soil organic carbon becomes stabilised in soils is introduced. This points to the roles of microorganisms, environmental conditions, and the soil physical structure as key mediators. **Chapter 4** applies the new paradigm to urban soils. Urban environments are generally warmer, wetter, and enriched in aerially deposited nitrogen, which may accelerate microbial mineralisation of soil organic matter and the release of carbon from soils as carbon dioxide. Urban soils also contain elevated concentrations of heavy metals, which negatively impact plant productivity, thus decreasing the potential for urban soils to sequester carbon. However, a considerable portion of the carbon in urban soils is fossil fuel-derived black carbon (i.e. soot), which has a slower turnover in soils than plant litter. **Chapter 4** also highlights several direct anthropogenic drivers of the soil carbon cycle in urban soils related to changes in land use or land cover, and including the introduction of land management practices, such as the use of organic and inorganic fertilisers; the removal of above-ground biomass (i.e. mowing the lawn); compaction; topsoil removal; and/or sealing.
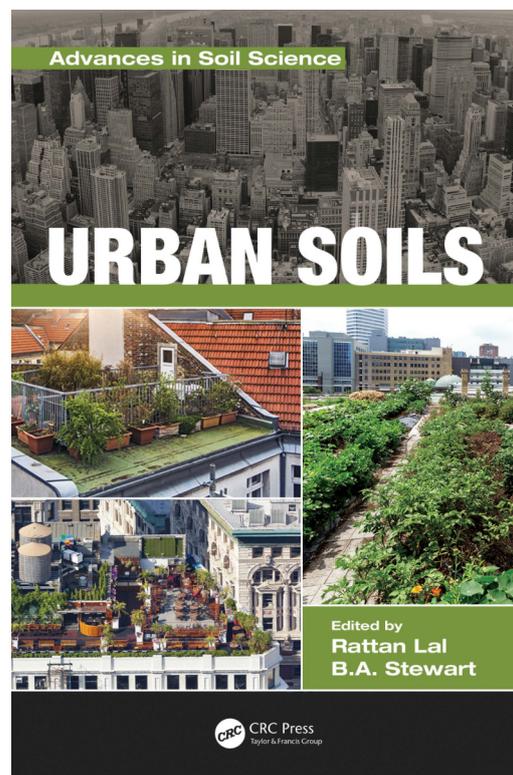
Chapter 5 discusses how the carbon and nitrogen cycles in urban soils underpin the delivery of ecosystem functions and services, such as the mitigation of heat stress, regulating the storage and flow of water, and providing space for recreation and a habitat for urban wildlife. The delivery of these ecosystem services (particularly the latter) is hampered by poor interconnectivity of urban soils that are isolated in patches across the urban landscape.

The relationships between urban soil organic carbon and soil forming factors (climate, parent material, time, vegetation and anthropogenic influence) are explored in **Chapter 6**. The chapter also compiles international datasets to estimate a global urban soil organic carbon stock of 6.57 Gt of carbon. However, the authors acknowledge that true stock may be much higher because most datasets only report carbon stocks in the uppermost 30 cm, highlighting a key knowledge gap.

One of the most well-studied aspects of urban soils is the elevated concentrations of contaminants they contain. While this is mentioned in several chapters of the book, it is dealt with directly in **Chapter 8**, where the bioavailability and fate of four common urban contaminants (lead, arsenic, cadmium and polyaromatic hydrocarbons (PAHs)) are discussed comprehensively. Lead is not readily taken up by plants, but poses the greatest risk to human health when lead contaminated soil is directly ingested or inhaled. The fate of arsenic in soils is often dictated by its valence, with arsenate, As(V), generally less mobile and bioavailable than arsenite, As(III). The extent to which cadmium leaches from urban soil is largely influenced by soil pH, with its mobility greatly increased in acidic conditions. Unlike lead, arsenic, and cadmium some PAHs may be remediated by microbial degradation. Their environmental fate depends on molecular weight, with low molecular weight PAHs more likely to be taken up by plants than high molecular weight compounds. Molecular structure, along with mass, determines their rate of microbial degradation.

Chapters 14 and **15** tackle the issue of food production in urban environments. While much attention and scientific research has been directed towards how we might produce food to feed a global population of 9-10 billion by 2050, much less attention has been focussed on how this food might be supplied to the approximately 6.5 billion people that are likely to be living in urban areas by this time. **Chapter 14** explains the role urban agriculture might play in satisfying the future demand for food. However, urban soils are generally less fertile than rural soils, primarily due to chemical and physical degradation. This degradation can include the presence of contaminants (e.g. heavy metals), compaction, and low levels of soil organic matter. As a result, many authors report lower yields of vegetable crops on urban farms compared to rural farms, although this is sometimes reversed if urban soils are irrigated or receive higher chemical inputs (e.g. fertilisers and pesticides). Urban soils are particularly well placed to benefit from nutrients from liquid and solid waste materials produced by the residents of urban areas through the

transformation of urban wastes into valuable products for soils (e.g. composts), as explained in **Chapter 10**.

Chapter 15 makes a strong case for empowering cities to meet their demand for food by exploiting hydroponics and aeroponics to establish vertical farming as a step towards fully integrated, resilient and sustainable cities. By contrast, **Chapter 14** highlights the need for more research before best management practices for urban soils and agriculture may be formulated and disseminated. **Chapter 18** urges us to look to the past and learn from the lessons (both successes and failures) of ancient civilisations (e.g. Mayan, Byzantine, Harappan, and Mesopotamian), and build upon this historic knowledge to restore our urban soils. It recommends that we should blend well-understood approaches (e.g. use of vegetation and compost) with more innovative ones (e.g. bioremediation, green roofs, and synthetic soils) to secure an urban food supply for an uncertain future.

> **[A]n ideal starting material for graduate students who wish to obtain a grounding in soil science within an urban setting.**

While the **Preface**, **Chapter 1** (Introduction) and **Chapter 18** (the final chapter) provide a global picture of urbanisation and the impact of future urbanisation on the functioning of urban 'Anthrosol' or 'Technosol' soils, the authors are largely drawn from the US, with contributors also from Russia, Poland, Mexico and India. As a result, the book lacks perspectives on how urbanisation impacts soils in South America, Africa, and South East Asia. This omission is particularly disappointing since almost all the future increases in urbanisation in the 21st century are expected to occur in developing nations (particularly Africa and Asia).

This book is a collection of papers by different authors and should be approached as such. Some of these chapters provide primary data, while others offer a review of the literature on a particular subtopic. The book is an ideal starting material for graduate students who wish to obtain a grounding in soil science within an urban setting. Some chapters will also be useful for city planners who need to consider urban soils, ecosystem services, natural flood management, green infrastructure and food security when planning the expansion of our cities. However, I do not recommend reading this book from cover to cover. Identify key chapters, as I did, that interest you the most.

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Review

CPD training course: Public Engagement with Impact

Rowena Fletcher-Wood (Freelance Science Communicator, rowena.fletcherwood@gmail.com)

In May 2020, public engagement professional, Dr Sophie Morris ran two 2-day training sessions on "*Engagement with Impact*", a programme that aims to equip its participants with the tools to employ the logic model framework to plan and execute a public engagement activity with impact – whether to serve the Research Excellence Framework or industrial outreach targets.

These training sessions, ordinarily delivered face-to-face, piloted use of the online platform Zoom. Although I regularly use online platforms for distance teaching, I found the training as much a tutelage in Zoom as impact. Whilst the platform itself was a bit glitchy with a full room of video participants, Dr Morris is a motivational trainer, who delivers her content with conciseness and clarity – essential online, where every task takes longer. She encouraged the concurrent use of chat to streamline feedback, as well as hands-up tools, feedback quizzes before, between and after the two sessions, and doodling on on-screen charts. It was my first experience using breakout rooms in Zoom, which have the advantage of nurturing networking, and the disadvantage of wrenching you abruptly out of spaces mid-sentence according to the timetable. Additional tools included email, and the resource sharing platform OneDrive.

The two training sessions were distinguishable in their styles, information density, and level of engagement. The first 2-hour session was primarily trainer-led, acting as an introduction to the logic framework. From the perspective of a participant for whom the training served as a reminder of best practice rather than guide to new material, it could have included more participation – listening alone can be exhausting. During part 2, however, we concentrated on the more participatory practical application of case studies and the evolution of our own projects, including reflection, discussion, and small group feedback. The differences between impact and outcomes were explored, and the relationship between these and inputs when it comes to planning engagement activities. Essential considerations including GDPR, ethics, and audience limitation arose, and tools for gathering feedback were specified and detailed in an e-handout.

This is not the only training Dr Morris offers. Her other programmes include "Public Engagement 101" and "Three Minute Pitch" – which are best suited to those new to public engagement and public speaking. Although there is not, at present, a follow up to "Engagement with Impact", more seasoned communicators could benefit from a third session exploring the history of, development of, and ongoing challenges in public engagement strategy. This, for example, might cover when and when not to evaluate (and the risks of over-interpreting evaluation data) and how to pitch the benefits of public engagement activities to the professionals who will deliver it. Dr Morris is currently in the process of upgrading her training provision, and offers tailored 1:1 courses.

> **I would recommend this training to … those who have previous experience in public engagement, but are yet to plan and execute their own activities.**

Recommendations

I would recommend this training to academic and industrial professionals, especially those who have previous experience in public engagement, but are yet to plan and execute their own activities.
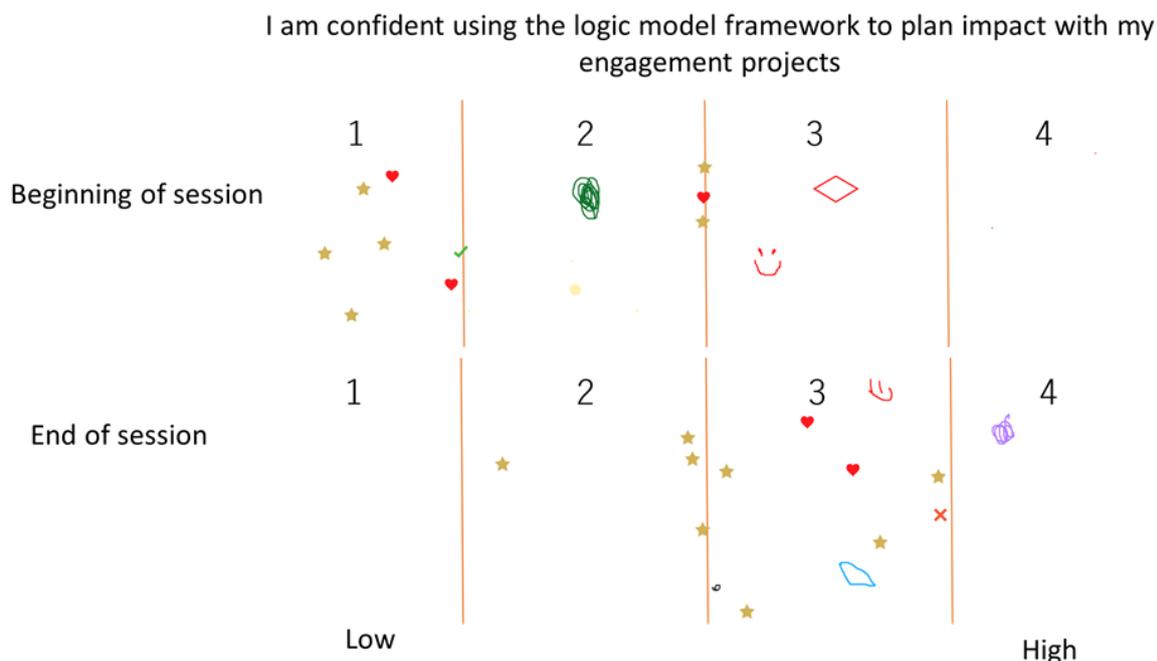
Training slide. Attendees were asked to tell themselves the statement "I am confident using the logic model framework to plan impact with my engagement projects". On a scale from 1 (being low) and 4 (being high) attendees were asked to reflect on how much they agreed with that statement by annotating a doodle of choice into the above columns.

Dr Sophie Morris' training suite

Public Engagement 101: *The what, why and how of public engagement*

A workshop designed for those new to public engagement, this course includes different methods of engagement, knowing your target audiences and tailoring engagement activities to them, and the role that public engagement plays in our society.

Three Minute Pitch: *Developing your elevator pitch to summarise the highlights of your work in three minutes*

A workshop for those working on communication and presentation skills. This course focusses on getting to know your target audience (and what they may want to hear), working out a pitch structure, and practising its execution.

Engagement with impact: *How to manage and evaluate your public engagement project to achieve impact*

This workshop uses a case study to teach practical public engagement project planning, including references to target audiences, budgeting and evaluation. It uses the logic framework approach to project management, and offers peer-to-peer feedback and networking.

Dr Sophie Morris has over 6 years of experience in public engagement and is an accredited educator in the higher education sector. After completing a PhD in Cancer Immunotherapies she went on to develop her skills in science communication, public engagement and research impact in various roles. Current work includes designing and delivering public engagement training for different organisations across the UK and beyond.

You can contact Sophie about her training provision at Drsophiemorris@outlook.com, or read more on her website https://drsophiemorris.com

Meeting Report

Environmental chemistry of water, sediment, soil and air: Early career researchers' meeting

Tom Sizmur (University of Reading, t.sizmur@reading.ac.uk)

On Wednesday 11th March, 24 early career researchers gathered at the RSC's venue in Burlington House, London, for what was the first, and probably last, in-person scientific meeting organised by the Environmental Chemistry Group in 2020. The day proceeded with 8 oral presentations (including two keynote lectures) separated by coffee and lunch breaks that provided an opportunity for delegates to discuss research findings showcased in 7 poster presentations.

The day started with a talk from **MD Hanif** (Imperial College, London), who presented research findings from the use of geochemical surface complexation models (D&M and CD-MUSIC) to simulate the competitive adsorption of Zn on ferrihydrite and goethite in saline Bangladeshi groundwater.

This was followed by a presentation by **AM Amira** (Hassan II University of Casablanca, Morocco) on the use of dolomitic $(CaMg(CO_3)_2)$ rocks from the Khenifra region of Morocco as adsorbents for cationic and anionic dyes (methylene blue and Congo red) from wastewater. Batch sorption reactions revealed very high and very fast removal of methylene blue, which followed 2nd order kinetics. This indicated chemical sorption, which increased with increasing temperature, mass of sorbate, and pH. The dolomitic rocks showed a high potential as low-cost adsorbents in wastewater treatment plants.

The next talk was given by **Chinonso Ogbaugu** (University of Reading), who presented experimental data on the construction of Langmuir isotherms for the adsorption of lead on biochars made from a variety of different source materials. A relationship between the C/N ratio of the biochar feedstock and the Langmuir sorption capacity was demonstrated, which indicates that feedstocks for making biochar with optimal sorption capacities could be selected based on C/N ratio without prior experimentation. Mr Ogbaugu was awarded the prize for the best oral presentation **(Figure 1).**
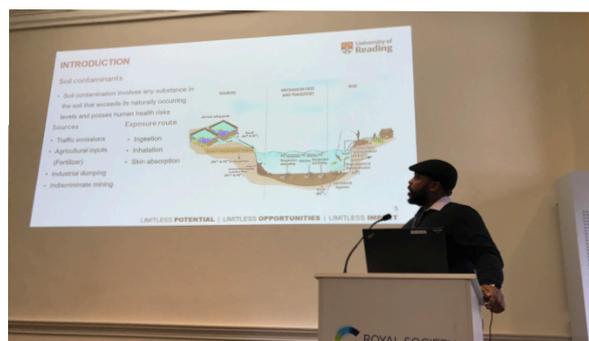
Figure 1. Chinonso Ogbaugu delivering his prizewinning oral presentation.

Before lunch, **Dr Laura Carter** (University of Leeds) delivered a keynote lecture that took the audience on a journey through her career path from her PhD at the University of York to a job in industry at Unilever, Postdocs in Adelaide and York, and finally her appointment as an Academic Fellow at the University of Leeds. In her recent article in the RSC journal Environmental Science: Processes and Impacts (*1*), for which she was recognised as an Emerging Investigator, Dr Carter highlighted that there is currently not enough data to generate thresholds for safe levels of pharmaceuticals in the environment. Her research to date has focused on how the physiochemical properties of pharmaceuticals, the soil type, and the environmental conditions affect their uptake and sub-lethal impact on plants. Dr Carter provided on-point and practical advice for early career scientists interested in an academic career **(Figure 2)**. Her future work will focus on scaling up her research to help understand how pharmaceuticals may impact pollinators within the landscape. After lunch, **Antony Poveda** (Mangorolla CIC) provided an

Figure 2. Top tips for academic careers from Dr Laura Carter.

Figure 3. Antony Poveda challenges the audience to communicate our science to non-academic audiences.

exciting introduction to 'I'm a Scientist, Get me out of here!', an online public engagement programme that pairs scientists with school children. Mr Poveda started by challenging us to compose one sentence to describe our research to a 13 year old **(Figure 3)**, illustrative of the tasks he uses to select participating scientists.

Mr Poveda explained that approximately 48% of the UK population live more than a 30 minute drive from a research-intensive institution, and schools that are more than 30 minute drive away are likely to receive half as many visits from a scientist (https://imascientist.org.uk/distance). *'I'm a Scientist, Get me out of here*!' therefore provides a valuable service to children who may have no other contact with scientists by raising their science capital and increasing the likelihood that they might go on to become a scientist or an engineer.

The scientific programme continued after a well-earned caffeine and poster break with a presentation from **Elmustapha Ennesyry** (Hassan II University of Casablanca, Morocco) on the development of a low-cost and non-hazardous catalyst using Moroccan oil shale for the green synthesis of hydroxyphosphonates for use as plant protection products. He was able to demonstrate regeneration and re-use of the catalyst up to 4 times with a 70% yield.

Christopher Wallis (Polymateria Limited) then provided an engaging introduction to the soil ecotoxicology tests he has carried out on additives to plastic products that have been designed to facilitate the complete biodegradation of the plastic in the environment. Tests conducted following OECD guidelines reveal that the additives that allow shrink wrap to degrade to less than 90% of the original mass in 266 days are not toxic to earthworms, plants, or water fleas.

The final talk of the day was given by **Nina Schleicher** (Imperial College, London), who presented her research on the mercury concentrations in particulate matter in Beijing. She used data collected during the 2008 Olympic Games as a large-scale field experiment since several factories and power stations were shut down and vehicle use restricted during the two week period while the games took place. Her data indicated that the primary source of particulate mercury in Beijing air was from coal combustion. She also revealed that there was more mercury present in the smallest particles that are known to be more associated with human health impacts.

During the lunch and afternoon coffee breaks, posters were displayed by delegates on topics ranging from VOC emissions from personal care products to carbon sequestration in the alkaline waste materials of steel slag, and the synthesis of bionanocomposites for use as photocatalysts for the degradation of organic dyes. The prize for the best poster presentation was awarded to **Fereshteh Hojatisaeidi** (London South Bank University) for her work on the modification of porous boron nitride with nickel to increase its capacity to adsorb carbon dioxide as a novel low cost carbon capture technology with high thermal and oxidation resistance **(Figure 4)**.

Figure 4. Fereshteh Hojatisaeidi (left) receives the prize for best poster presentation from ECG Treasurer Valerio Ferracci (right).

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Article

Air pollution in the time of Covid-19

Valerio Ferracci (Cranfield University, v.ferracci@cranfield.ac.uk)

With strict lockdown policies enforced in many countries across the globe, the emissions of many atmospheric pollutants have decreased dramatically. What are the implications for urban and regional air quality, human health and the future of air pollution?

The ongoing Covid-19 pandemic, has had enormous and far-reaching repercussions across the globe in the first half of 2020. Nationwide lockdowns and social distancing have been enforced to prevent the spread of the virus and reduce the death rate. These measures have caused a rapid decline in economic activities, as well as road and air traffic, leading to dramatic changes in the emissions of atmospheric pollutants.

Analyses have focused on metrics commonly used for urban air quality monitoring, such as abundances of nitrogen oxides (NO_x, consisting of two rapidly interconverting species: nitrogen monoxide, NO, and nitrogen dioxide, NO_2) and particulate matter (typically with dynamic diameter < 2.5 µm, referred to as $PM_{2.5}$), both emitted primarily by vehicle exhaust.

The first signs of changes in air quality came from China, the first country to be hit by the virus. Satellite measurements revealed significant decreases (~40-60%) in NO_2 columns over urban and industrial regions in February and March 2020, relative to the same period in 2019 (*1*). This was confirmed by ground-level observations from the Chinese air quality monitoring network. In Wuhan, the first city where cases of Covid-19 were reported and to undergo strict lockdown, NO_2 and $PM_{2.5}$ concentrations were 54 and 31% lower respectively during lockdown than in the same time period in 2019 (*2*). However, ground level ozone, a secondary pollutant formed from the interaction of sunlight with NO_x and volatile organic compounds, rose by a factor of 2. This is due to the titration of ozone by NO, and a drop in NO_x will result in reduced ozone removal under the conditions found in most urban areas.

Similar trends were observed in other countries that enforced lockdowns, with reports of plummeting NO_2 levels in the Po Valley (Italy) and Madrid (Spain) among many others **(Figure 1)**. In the UK, data from the national monitoring network, analysed by the National Centre for Atmospheric Science, showed decreasing NO_2 and $PM_{2.5}$ levels in many cities relative to the 2015-19 average (*3*). In London, a recent report by King's College London paints a more complex picture: while NO_2

concentrations were falling across the whole city, $PM_{2.5}$ and ozone concentrations appear to have increased (*4*). As in Wuhan, the change in ozone is primarily driven by the reduction in NO_x (and also by the warm spring weather), while the rise in $PM_{2.5}$ is attributed to the prevailing easterly winds during the lockdown, transporting air from continental Europe and affecting particulate levels in the capital.

The "new normal" enforced by lockdown measures also resulted in people spending more time in their homes. This produces a knock-on effect on personal exposure as pollutants such as $PM_{2.5}$ are often more abundant indoors as a result of activities such as cooking, smoking and wood-burning (*5*).
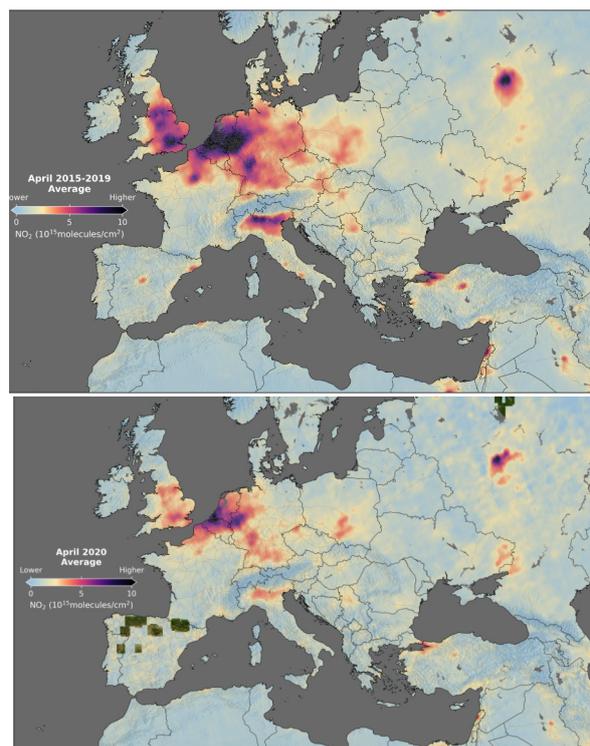

Figure 1: Nitrogen dioxide (NO2) columns over Europe as reported by satellite measurements. Large decreases were observed in April 2020 (bottom) relative to the April 2015-19 average (top). Credit: NASA,

https://so2.gsfc.nasa.gov/no2/no2_index.html

A number of recent studies (*6-8*) also highlighted the potential link between the Covid-19 fatality rate and poor air quality, as some of the worse-hit regions (e.g. Lombardy in Italy) are also chronically affected by air pollution. It is argued that the health conditions caused by exposure to poor air quality, such as cardiovascular disease, asthma and general chronic respiratory stress may contribute to an increase in the lethality of Covid-19. However compelling, there are also a plethora of other factors at play in densely populated areas severely affected by Covid-19 (e.g. income levels, access to services) that contribute to the incidence of the very same health conditions, and it might simply be too early to determine a clear effect of air pollution on the Covid-19 death rate (*9*).

With most economic activities brought to a near standstill during lockdown, the emissions of carbon dioxide (CO_2) have also decreased. As increasing atmospheric concentrations of CO_2 and other greenhouse gases due to anthropogenic emissions are driving the ongoing warming of the planet, trends in their emission rates are closely scrutinised (*10*). Flux measurements by the Centre for Ecology and Hydrology (CEH) in central London have shown that CO_2 emissions in the capital during lockdown decreased ~60% relative to the 2015-19 average, matching the observed reduction in road traffic (*11*). These were accompanied by similar trends in other European cities such as Berlin, Basel and Florence (*12*). However the overall global CO_2 emissions for the year 2020 are projected to be only 4-7% lower than those in 2019 (*13*). While this would be one of the largest drops in emissions on records, it also points out the difficult road ahead on the path to decarbonisation, and how systemic changes are needed to reach the milestones set by the Paris Agreement.

At the time of writing of this article, a number of countries are reporting a decline in infection and death rates. As a result, lockdown measures are being gradually relaxed and road traffic and industrial activities begin to bounce back. A number of different scenarios lie ahead, with a "business as usual" approach leading to a return of emissions to their pre-lockdown levels, or with more long-lasting changes in behaviour dictated by social distancing (e.g. more people working from home, less travel) leading to a lasting reduction in emissions from the transport sector. Whatever the outcome, the effects of the pandemic on anthropogenic emissions have offered an unprecedented glimpse into the air we might be breathing in the (near?) future as regulations become more stringent, and may also help draft more informed abatement policies in years to come.

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Article

Efficacy of treatments for *Varroa* infestation, and their side effects on honeybees

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Honeybees (the *Apis* genus) are insects known principally for producing honey and for their valuable service as pollinators (*1*). Pollination of agricultural crops (much of which is provided by honeybees) has been valued at $215 billion per year to the global economy (*2*). Honeybees are also a key part of many ecosystems around the world, especially in the regions where they are native (*3*). Despite their undeniable importance, honeybees face grave threats in the forms of pesticides (particularly neonicotinoids: see ECG *Bulletins* July 2015, February 2017, January 2019), habitat loss (due to the mechanisation of farming and the loss of many field-bordering hedgerows and natural spaces) and the global spread of various pests and parasites (*4*).

Honeybee colonies support a wide variety of other species (*5*). The reasons for this are obvious; any invader that can survive within the colony benefits from the stable environmental conditions maintained by the bees (e.g. the warmth and humidity of the colony interior), as well as the abundant stored foodstuffs (wax, pollen, honey and, for predatory/parasitic invaders, honeybees at all life stages, and other colony inhabitants) (*5, 6*). Since honeybees jealously guard their colonies against invasion from most organisms of similar size (such as wasps and bumblebees), the most common and successful co-habitants of honeybee colonies are mites (the *Acari* taxon). Mites have different lifestyles and effects on the honeybee colony: some are detrivores or fungivores, e.g. *Tyrophagus putrescentiae* (*7*), some are kleptoparasites (wax/pollen/honey thieves), e.g. *Melittiphis alvearius* (*8*), some are predators, e.g. *Parasitellus fucorum* (*7*), and some are direct parasites of honeybees, such as the internally parasitic tracheal mite *Acarapis woodi* (*6*).

Honeybees visiting flowers © Kevin Meehan.

The most infamous pest of European honeybees (*Apis mellifera*) is *Varroa destructor*, an external parasitic mite which feeds on honeybee brood and adults (*9, 10*). Somewhere in Japan or Korea around the mid-1900s, *V. destructor* spread from Asiatic honeybees (*A. cerana*), which can naturally resist and tolerate this mite species, to European honeybees, which cannot (*11*). This devastating parasite enters the colony through phoresy, i.e. the use of one organism by another for transportation (*12*). Once an unfortunate worker bee is boarded (typically during a foraging trip or while robbing from an infested colony) by an adult female *Varroa* mite and brings it within the colony, the mite detaches and enters an uncapped brood cell containing a developing honeybee larva (*10*). Once the cell has been capped, the mite lays several eggs, and the resulting offspring develop in roughly the same time it takes for the nearby larvae to reach the adult stage of development. Haploid male *Varroa* mate with their diploid sisters within the brood cell after both have matured, and shortly afterwards the males die. During this time the *Varroa* mother and her mobile offspring feed freely on the bee larva, and after the developed honeybee emerges the now mature and mated female *Varroa* mites will spread throughout the colony, parasitising other honeybees and their brood. *Varroa* mites prefer to invade drone (male) brood cells as the longer development time of drones

Varroa on a honeybee or developing brood. visiting flowers

allows for roughly twice as many *Varroa* offspring to develop compared to worker (female) cells. Drones also contain more fatty esters than workers, which makes them more attractive to the *Varroa* mites (*6, 9*). *Varroa* populations within honeybee colonies will grow exponentially as long as there are brood cells available to exploit (*6*). The typical feeding activity of *V. destructor* involves squeezing beneath a honeybee's abdominal sclerites (where the mite is relatively safe from being dislodged by grooming behaviour) or attaching to the back of the bee's head before piercing the soft intersegmental tissues to feed on the haemolymph and fat body within (*9*).

As you might expect, this is not good news for the honeybees. *Varroa destructor* acts as a vector for various diseases including Deformed Wing Virus (DWV), Sacbrood virus and up to 16 other viruses that can have serious negative impacts (*9, 13*). The open wounds left by their feeding mean that the parasitised honeybees are more susceptible to bacterial infections such as European foulbrood (*Melissococcus pluton*) (*14*). The spread and proliferation of *V. destructor* results in deformed and weakened workers and *drones*, encourages the spread of diseases, and can lead to the rapid decline and death of the colony as a whole in under a year if untreated (*15, 16*). This pathway of deterioration and disease in colonies infested by *Varroa* mites is called varroosis (*17*).

Common acaricides and their side effects

To combat the effects of *Varroa destructor* infestations on honeybee colonies, a range of treatments (called acaricides) have been developed to kill *Varroa* and other invasive mites. The most commonly used synthetic acaricides (and the products that contain them) are amitraz (Apivar and Varidol), coumaphos (Checkmite), flumethrin (Bayvarol) and fluvalinate (Apistan). These are often called the 'hard' acaricides, and are typically applied to colonies using specially treated strips of paper or card placed between combs. Various organic compounds are also used for this purpose such as formic acid (Apivarol and Miteaway), oxalic acid (Api-Bioxal), hops beta acid (Hopguard) and thymol (Apilife and

Apiguard), an aromatic extracted from thyme oil. These organics are commonly called 'soft' acaricides, and have a wider range of application methods. A comparison of available acaricides is provided in **Table 1**.

Alternative treatments and best practice

Non-chemical methods have been trialled to reduce *Varroa* infestations. These range from sticky boards placed beneath a mesh screen colony base, which capture and kill any *Varroa* mites which fall through the mesh, to tobacco smoke fumigation through the colony, and even the use of entomopathogenic fungi as a form of biological control (*10, 37*). The use of entomopathogenic fungi such as *Beauveria bassiana* appears to be the most promising of these methods, with great successes in laboratory experiments and limited success in field trials, though it seems that the conditions within honeybee colonies may inhibit the reproduction and spread of this fungus between *V. destructor* mites (*10, 37, 38*). None of these methods are thought to have significant impacts upon honeybee health, however, on their own they are far less effective in treating *Varroa* infestations than the chemical treatment options (*10, 38*).

Given that the 8 most common acaricides (**Table 1**) have varying effectiveness against *Varroa* mites (with some having negative effects on the honeybees and/or their stored honey) and that mite populations resistant to the 'hard' acaricides have already emerged, the recommended best practice for treating *Varroa* infestations is Integrated Pest Management (IPM). The use of a rotating range of different treatment options throughout the year should be utilised in order to prevent strong resistance to any one acaricide emerging in *Varroa* populations, and to keep *Varroa* infestations within honeybee colonies below the economic injury level throughout the year. Ideally, beekeepers should focus on using the 'soft' acaricides and alternatives such as biological control wherever possible. However, lower costs and ubiquity of the 'hard' acaricides combined with a lack of public knowledge relating to IPM and best practice for combatting varroosis make this an unlikely prospect for the time being (*10, 17, 37, 38*).

Honeybee with DWV, dead honeybees, or other to show negative effects.

Treatment	Chemical structure	Usage methods	Efficacy vs Varroa	Resistance?	Effects on honeybees	Effects on honey and wax	References
Amitraz		Strips, aerosol, bee feed, topical application	Effective against non-resistant mites	Widespread in USA	Damaged honeybee health and metabolism, weakened colonies, lowered brood survival	Residues present in honey and wax	(16, 18-23)
Coumaphos		Strips, bee feed, topical application	Effective against non-resistant mites	Reported in Europe, widespread in USA	Reduced drone sperm quality, lowered brood survival, effects on bee gut microbiome	Residues present in honey and wax	(22-29)
Flumethrin		Strips	Effective against non-resistant mites	Reported globally	Adversely effects honeybee metabolism, increased toxic stress biomarkers	Residues present in honey and wax	(10, 16, 22, 30, 31)
Fluvalinate		Strips	Effective against non-resistant mites	Reported globally	Adverse effects on drone health and survival, increased worker mortality	Residues present in honey and wax	(22, 23, 32, 33)
Formic acid		Fumigant tablets, gels, strips	Rapidly effective	No reported resistance	High concentrations harm brood	Trace residues in honey, does not bind to wax	(6, 10, 31, 32)
Oxalic acid		Direct application to honeybees in syrup	Effective over time	No reported resistance	Increased brood and adult bee mortality	No significant residues in honey or wax	(6, 10, 31, 32)
Hops beta acids		Strips	Moderately effective over time	No reported resistance	Increased adult bee mortality	No residues reported	(32, 34-36)
Thymol		Fumigant strips, tablets and gels, thyme essential oil	Effective over time	No reported resistance	Reduced brood numbers and brood area within colony, and increased brood mortality	No significant residues reported in honey, residues are present in wax	(10, 16, 31, 32)
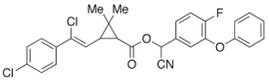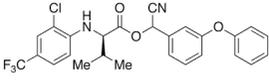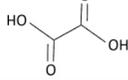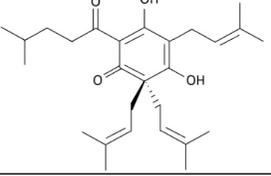
Table 1: A comparison of eight acaricide treatments used to reduce or eliminate Varroa destructor infestations within honeybee colonies. Due to the staggering numbers of studies conducted under an incredibly broad range of environmental and contextual conditions, the "Efficacy vs Varroa", "Effects on honeybees" and "Effects on honey and wax" categories are generalised and no specific figures are given.

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Article

Porous boron nitride: an effective adsorbent for carbon dioxide capture

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Carbon capture and storage (CCS) will be essential to implementing the Paris Agreement to limit global warming to 1.5 °C above pre-industrial levels (*1*). Adsorption-based materials are associated with lower energy consumption in carbon capture technologies compared with conventional solvent-based materials. These adsorbents, which are mostly porous solids, have been applied to CCS under a wide range of temperature and pressure conditions (*2*). Porous boron nitride (BN) materials are a promising class of solid adsorbents for carbon capture applications due to their low cost and ease of manufacture.

Global greenhouse gas emission

Greenhouse gas (GHG) emissions have brought about significant challenges, including, but not limited to, the rise of sea levels and devastating social effects. Carbon dioxide (CO_2) is the most common GHG emitted by human activities, particularly the burning of fossil fuels (**Figure 1**). Different approaches to reduce CO_2 accumulation in the atmosphere include using natural gas instead of coal, adopting renewable energies, and applying carbon capture and storage. **Figure 2** shows that the demand for fossil fuels doubled between 2000 and 2016. This massive increase calls for an increased efforts in carbon capture.
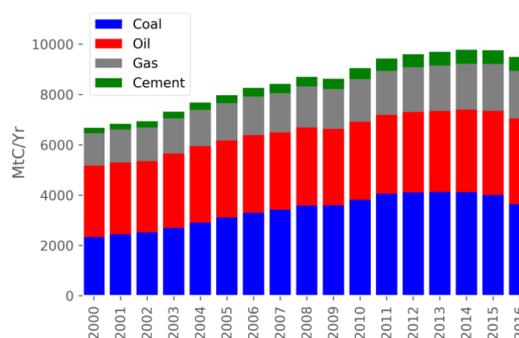
Figure 2. Annual global fossil fuel carbon emissions [4].

Technology based on adsorbents

Although there are a myriad of techniques in the literature for carbon capture (**Figure 3**), physical adsorption is the most effective process, owing to its fast kinetics, cycling capability, and low regeneration energy. It is crucial to develop a material with a high potential CO_2 adsorption and selectivity capacity. Porous materials are excellent candidates for physical adsorption because of their cost-effectiveness, high selectivity and high adsorption capacity (*5*). Among porous materials, hexagonal boron nitride (h-BN) has been a popular candidate for CO_2 adsorption due to its unique properties, including large surface area, total pore volume, polarity, and various structural defects. Despite these features, CO_2 adsorption on BN has been studied to a lesser extent than other technologies.

Figure 1. The interannual variation in radiative forcing by greenhouse gases [3].
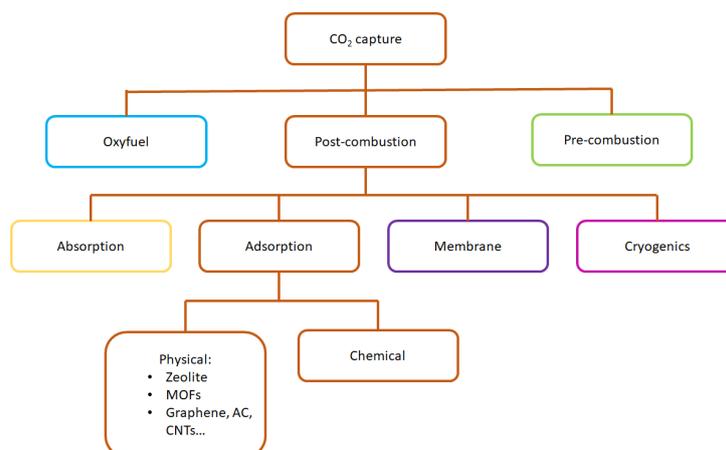
Figure 3. Different techniques of CO$_2$ capture [6].

Synthesis and surface modification of porous boron nitride

The porous structures of h-BN are synthesised via either template or non-template methods. The non-template method has relatively fewer steps as there is no need to remove the templates. Previous studies demonstrated that choice of synthesis method has significant effects on BN (*7*). One of the main targets for designing porous BNs is to achieve a material with a high surface area and porosity for CO$_2$ adsorption. In view of this, a surface modification strategy was applied to tune BN, aiming to enhance the adsorption performance. The results of our previous study indicated that modified BN increased the interaction between BN and CO$_2$ molecules by creating a higher level of porosity. The CO$_2$ adsorption and desorption performance of the BN sample were evaluated by thermogravimetric analysis (Mettler Toledo TGA/DSC 3+). The capacity of the sorbents was determined by measuring the mass uptake of the sample during CO$_2$ adsorption. The results showed that CO$_2$ uptake on modified BN was enhanced by about 34.5% relative to pristine BN (2.69 mmol g^{-1} for BN-P123 vs. 2.00 mmol g^{-1} for pristine BN under ambient conditions) (*8*). **Figure 4** offers a schematic representation of thermogravimetric analyser for capturing CO$_2$ using porous BN.
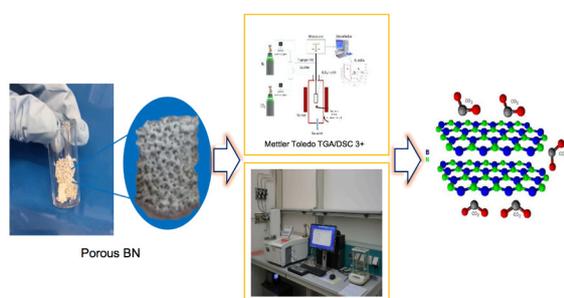

Figure 4. Schematic representation of CO$_2$ capture using porous boron nitride as an adsorbent.

Conclusion

An overview of research on carbon capture technology and the potential of BN-based materials as solid adsorbents in CO$_2$ capture has been presented in this report. Further study could investigate how to tailor the electronic properties of BN and introduce more active sites to increase CO$_2$ capture. The principal characteristics of porous BN for CO$_2$ adsorption (adsorption rate, adsorption capacity and ease of regeneration) offer other potential avenues of research.

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Article

Biochar for soil remediation

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Soil contamination is a global issue predominant in developing countries where heavy metals are found in the soil above their naturally occurring concentrations (*1*). A major source of heavy metals occurs as a result of anthropogenic activities (**Figure 1**), including point source emissions from metal mining, smelting, and industrial activities and diffuse source emissions from agricultural inputs such as fertilisers, composts, sewage sludge, pesticides, and organic manures (*2, 3*).

Studies have shown that plants grown on contaminated soils tend to accumulate more heavy metals compared to plants grown on uncontaminated soil (*4, 5*). When consumed, these plants serve as a major pathway for heavy metals into the food chain. Adverse health problems can also result from direct ingestion or inhalation of contaminated dust (*6*).
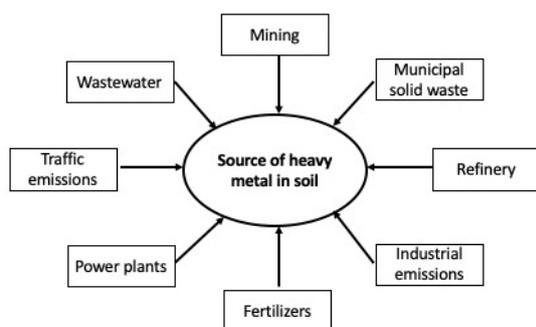

Figure 1. Main sources of heavy metals in soil

Heavy metal contamination of soil in China is responsible for a decrease in 20 million hectares of arable land, accounting for 20% of the total agricultural land in China (*7*). A study carried out in Guangzhou found rice samples on the open market with Cd levels above health standards (*8*). The consumption of contaminated produce has been linked to accumulated heavy metals in humans, which causes adverse health issues. In Nigeria, soil contamination arises mainly from the mining and extractive industries due to the indiscriminate waste management methods. A study by the United Nations Environmental Programme has

reported that Nigeria has the highest burden of pollution in Africa. For example, a United States Centre for Disease Control and Prevention study carried out in Zamfara State observed widespread lead poisoning (*9*). The study reported the death of over 735 children and elevated concentrations of lead in their blood. This outbreak was traced to artisanal gold mining and processing in the villages (*10*). Another study (*11*) observed elevated concentrations of lead in different vegetables grown in a farm close to a lead mine in Enyigba, Ebonyi State, Nigeria.

The persistence of heavy metals in the environment, necessitates sustainable remediation methods that can be applied to large areas of contaminated soils in low resource settings. There have been several 'hi-tech' approaches developed to treat and remediate contaminated soils, such as excavation, thermal treatment, bioremediation and soil vapour extraction (*12, 13*). However, major drawbacks to their application are their high cost and low efficiency.

What is biochar?

In recent years, biochar has received considerable attention due to its effectiveness for carbon storage, improving soil productivity, mitigating climate change, and as an adsorbent for environmental contaminants in soil and water (*14-16*). Biochar is a carbon-based material obtained from the pyrolysis of feedstocks under anaerobic conditions (*17*). The process of biochar production also serves as a waste management approach for dealing with large amounts of organic waste biomass (*18*). China alone produces approximately 30 million tons of sewage sludge (*19, 20*) and 998 million tons of dry agricultural biomass annually (*18*). Similarly, Nigeria produces approximately 168 million tons of agricultural waste annually (*21*). The use of agricultural biomass waste for biochar production shows promise as a cost-effective way to remediate contaminated soil by adsorbing and immobilising heavy metals.

Farmers can prepare biochars by burning agricultural wastes in low-oxygen conditions using a modified oil barrel with holes at the bottom, which regulates the inflow of oxygen (**Figure 2**). The holes underneath the barrel facilitate the in-flow of primary air, and larger, L-shaped holes on the top sidewalls of the barrel facilitate the flow of secondary air. An opening is cut into the lid to support a tall chimney made from a metal pipe.

As the pyrolysis temperature increases, moisture is lost via evaporation, volatile matter is released, and decomposition of lignocellulosic material occurs,

depending on feedstock type. Additionally, P, K, Ca, and Mg minerals are enriched after pyrolysis (*22-24*).

Figure 2. Picture of a pyrolysis kiln, locally made in Nigeria, from an oil barrel.

Biochar as a heavy metal adsorbent

Studies on the use of biochar for soil remediation have shown that different biochars have different capacities to reduce the bioavailability of heavy metals and corresponding uptake in plants (*18, 1*). Effectiveness for soil remediation depends on biochar physiochemical properties, such as cation exchange capacity (CEC), surface area, elemental composition, pH, and functional groups (*14*). The difference between biochars in terms of adsorption of heavy metals can be linked to feedstock properties (*25*). The major properties of feedstocks that affect metal sorption include its C/N ratio, phosphate content, and lignin content. Biochars produced from the pyrolysis of plant-based materials will have more lignin compared to biochars produced from manure.

The C/N ratio of the biochar feedstock has been observed to influence the sorption capacity, with an increase in the sorption of Cu and Zn increasing with a decrease in the biochar feedstock C/N ratio (*25*). Biochar production from materials with high lignin and carbon, and with low nitrogen content favour the development of macropores on the biochar surface, which collapse as pyrolysis temperature increases, thus blocking sorption sites on its surface (*15, 22*). Biochar feedstocks with lower lignin content demonstrated this differently, with greater microporosity enhancing metal sorption (*26*). A decreased C/N ratio may be linked to the presence of low lignin content on the biochar feedstock. Conversely, greater sorption capacity has been observed from biochars produced from manure, which have high carbonate, nitrogen, and phosphate content. High sorption capacity for this these biochar types may be attributed to the mineral components, which serve as additional sorption sites (*27*).

Biochar physiochemical properties and heavy metal adsorption

Generally, increasing pyrolysis temperature leads to an increase in the surface area of the biochar, which carries a considerable negative charge and demonstrates a strong affinity for metal cations. Thus, biochars reduce the concentration of metals in soil solutions. Increasing pyrolysis temperatures (to 300-500°C) increases the pH of the resulting biochar, due to the transformation and release of basic alkali elements like Ca^+, Mg^{2+}, and K^+ from the feedstocks (*22, 24, 28*). Therefore, the application of biochar to soil increases soil pH and the sorption of heavy metals to both the biochar and soil due to the deprotonation of pH-dependent cation exchange sites on soil and biochar surfaces (*29*). Its surface functional groups also affect metal sorption. Oxygen-containing functional groups that exist on the surface of biochars are pyrolysed at lower temperatures, but decrease in abundance with increasing pyrolysis temperature and are dependent on feedstock type. Greater adsorption at lower pyrolysis temperatures could be due to the deprotonation of oxygen-containing functional groups (carboxyl and hydroxyl), and adsorption by complexation with metal ions (*30, 31*).

Application of biochar to contaminated soils
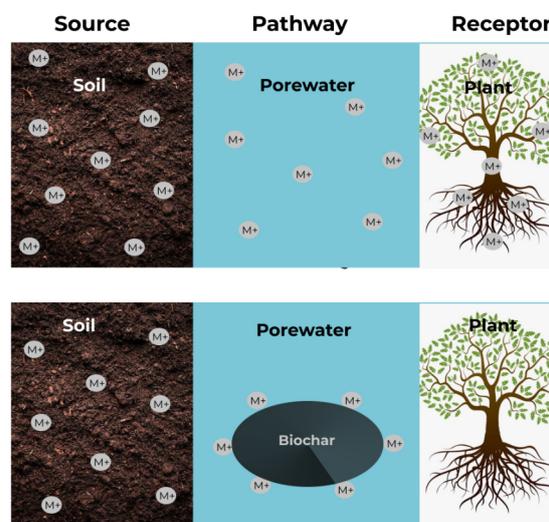
Figure 3. Conceptual model showing remediation of contaminant using biochar to break the source-pathway-receptor linkage

The use of biochar in heavy metal contaminated sites achieves remediation by limiting the mobility and fate of the metals in the soil. The reduction in the mobility of metals decreases their bioavailability for plant uptake. By immobilising contaminants, biochar breaks the source – pathway – receptor linkage (**Figure 3**), thus reducing contaminant availability to the receptor (*29*). Several studies have demonstrated that biochar application to contaminated soils reduces and immobilises metals, eliminating the pathway to receptors (*3, 13*). However,

one of the major drawbacks to the use of biochar for soil remediation is the presence of volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) within the biochar itself. These compounds pose concerns and can have a major impact on organisms and the environment (*32, 33*). Studies have shown that the concentrations of VOCs and PAHs in biochars is dependent on the feedstock type, pyrolysis temperature, and time (*34*): greater concentrations of PAHs were observed with shorter pyrolysis duration and lower pyrolysis temperatures. This was attributed to the condensation of the PAHs produced on the biochar itself.

Research gaps

Overall, the literature to date suggests that pyrolysis temperature and feedstock type play an important role in the adsorption of heavy metals from the soil by biochar due to their impact on pH, surface area, elemental composition, and surface functional groups. However, several knowledge gaps and uncertainties remain regarding the type of feedstock, pyrolysis temperature, and application rate to optimise sorption capacity. In addition, there is a need to pay attention to the production of biochars that meet the needs of remediation without introducing organic contaminants (PAHs and VOCs) that may have deleterious effects on the environment.

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Article

Elements of construction – Minecraft and the Periodic Table

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Minecraft is a popular computer game that allows the construction of almost limitless creations, and is used in learning contexts around the world. The widespread appeal and familiarity of the game makes it ideal for engaging children and young people with topics that might not otherwise interest them. With this in mind, the Science Hunters project, with support from a Royal Society of Chemistry (RSC) Outreach Fund grant, developed five Minecraft-based informal learning and engagement sessions about the periodic table, carbon, helium, uranium and gold, as part of the 2019 International Year of the Periodic Table (IYPT).

Minecraft is a construction-based, open-world game in which players can move freely and build items, placing and breaking blocks with a wide range of appearances and properties. Not only are the possibilities almost endless, but the game is extremely popular; it is the second-best selling game in the world (*1*). When asked, 95% of UK school students across all year groups had heard of it (*2*). It has been described as one of the most important games of the current generation (*3*).

There are many real-world analogies in Minecraft which, combined with its popularity, make it a great tool for communicating scientific concepts (*3-5*). Science Hunters, an outreach project based at the Science Communication Unit at UWE Bristol and Lancaster University's Environment Centre, uses Minecraft to engage children with science. Sessions take place in schools, at public events and in dedicated Minecraft Clubs for specific groups under-represented in science (*5-7*). Not only do participants greatly enjoy these sessions (*6*), they also increase their subject knowledge and understanding (*7*). Minecraft enables active construction of knowledge, interaction, and team working. It is simple, affordable, and accessible, making it viable for classroom use (*8*). Detailed descriptions of Minecraft and its application in a range of formal educational settings can be found elsewhere (*3, 8*).

Engagement with chemistry and the IYPT

Results of the 'Public Attitudes to Chemistry' report (*9*) suggest that chemistry could benefit from communication through the novel use of media that children already enjoy and associate with leisure. Overall, public engagement with chemistry was reported as low, and the subject was commonly associated with lessons, chemicals and medicines. School was cited as putting off 25% of respondents. Therefore, to promote positive perceptions of chemistry in young people, in 2019 (IYPT), the RSC funded Science Hunters to create five Minecraft sessions about the periodic table and four selected elements, explained from an environmental science perspective. The sessions were developed for and delivered to the project's Minecraft Clubs for children with Special Educational Needs (Lancashire) and Looked After Children (Cumbria and Worcestershire).

The element 'Sophium' (Sh) as created by a Minecraft Club participant and added to the periodic table, during a 'Periodic Table' session.

Science Hunters 'elements' sessions

The Periodic Table

In this session, the periodic table, how it is constructed, and basic atomic structure (protons, neutrons and electrons) are introduced visually using a small number of presentation slides. Participants are provided with small items to lay out the subatomic structure of a selected atom (for example, sweets can be used for this activity due to the variety of shapes and colours available) and then build atoms of other elements in

Minecraft, using the hands-on activity to plan if desired. Since elements with low atomic numbers are simpler to build, these are suggested initially. Selected elements can be related to real-world uses to demonstrate the practical relevance of chemistry. Popular examples include hydrogen (space rocket fuel), helium (balloons), lithium (batteries) or beryllium (structural material for high-speed aircraft). Participants may wish to create their own elements as an extension activity. For example, children taking part in one of the Science Hunters clubs created an element named Sophium (after the session leader) and identified its use as 'making bananas explode'. They assigned it a symbol (Sh), atomic mass and atomic number, and added it to a copy of the periodic table.

Uranium

The properties of uranium, its discovery, radioactivity and 235U application in nuclear power generation through fission are introduced briefly through a slideshow. Common samples emitting low and safe levels of radiation, such as granite rock and bananas, are used alongside a Geiger counter to demonstrate radioactivity. In Minecraft, children are provided with a prebuilt map, made with the Minecraft modification ('mod') Big Reactors. They can complete the build of a nuclear reactor, mine 'Yellorium ore' (the Minecraft equivalent of uranium ore) from the quarry, then process it to make Yellorium ingots. These are then placed in the reactor to generate heat, creating steam which turns the turbines and then the generator, producing electricity.
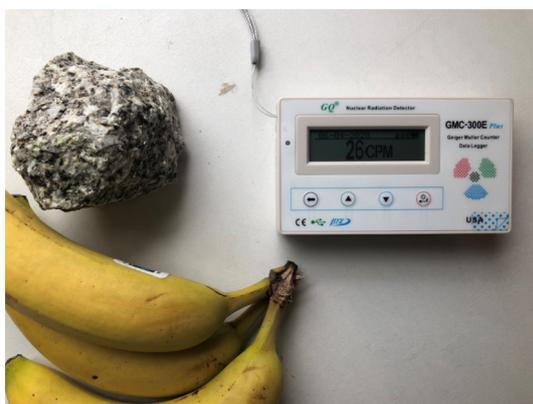
Geiger counter indicating low levels of radiation emitted by granite and bananas, used as a demonstration during the 'Uranium' session.

Helium

The properties and uses of helium are introduced. Relevant examples are given, including cooling properties, as used in MRI machines and cryostats, and buoyancy, demonstrated with balloons. Where appropriate, links can be made with the uranium session to explain the difference between fission and fusion, and the gold session as cryostat plates are gold plated to provide shielding for sensitive samples from radiation. Images of the sun are used alongside an explanation of how nuclear fusion turns hydrogen into helium,

releasing energy in the form of heat and light. The subsequent Minecraft challenge is to build an item that contains helium, using examples from the introduction. This could be party or weather balloons, or blimps; model MRI machines, particle accelerators or satellites; or the sun. There is also the option of building the chemical symbol as it is shown in the periodic table.

A Cryostat, where liquid helium is used as a coolant and gold plating shields sensitive samples from radiation. Photo credits Andrew Guthrie.

Carbon

Elemental carbon can be introduced including its symbol, atomic mass and atomic number. Samples of different forms of carbon are used to give physical examples that participants can hold, interact with and use. These include a diamond, graphite, and a sample of coal. Participants can even draw the carbon atom using the graphite samples. Global warming and its consequences are discussed in the context of anthropogenic carbon dioxide release from burning coal and other fossil fuels. The reason that carbon is often described as 'the element of life' is also explained alongside a video explaining carbon-based lifeforms. Images of the different forms of carbon and molecular modelling kits are distributed amongst participants to help them build a structure in Minecraft. To do this, they can either choose blocks to represent carbon atoms and bonds, or use forms of carbon that exist in Minecraft, such as building a structure out of diamond blocks or mining for diamonds.

Gold

A brief slideshow introduces the atomic structure, position in the periodic table, properties and uses of

Figure 4. Diamond and graphene models using molecular modelling kits.

gold. Key phrases such as 'transition metal', 'conductive', 'malleable', and 'corrosion' are explained within the discussion. Common uses, such as in jewellery and smartphones, are explained alongside physical examples for participants to examine. Lesser known uses, such as in dentistry, in equipment in laboratory experiments and as radiation protection in space, are included.

A 'Badlands' biome (known for containing plentiful gold) Minecraft world is set to survival mode, and participants are given the challenge of mining for gold. Extensions to the challenge based on interest and ability include using gold to build craft-powered rails to speed up mining and crafting different forms of gold (ores, nuggets, ingots and blocks). Participants are also free to build items related to any of the examples of uses of gold covered in the introduction.

Evaluation

In order to gauge how engaging the sessions were, 44 participants were asked to indicate their level of interest in the topic both before and after the session, ranging from '0 – not at all interested' to '3 – very interested'. Changes in responses were analysed as a measure of engagement efficacy. Participants were aged between 7 and 13 years and attended Minecraft Clubs for under-represented groups. Attendees were invited to provide written feedback, the contents of which were also evaluated. Mean interest before taking part in a session was 1.9 ± 0.2 (63% on a scale of 0-3). After the sessions, mean interest was 2.3 ± 0.1 (77%), which was a statistically significant ($p < .001$) increase.

Qualitative feedback from children, parents and carers was assessed against Generic Learning Outcomes (10) and mainly indicated outcomes related to 'Knowledge and Understanding' (e.g. "they are all types of atoms", "O is Oxygen", "arsenic is highly poisonous", ""the periodic table is made up of different elements that make up the world e.g. gold (Au), carbon (C) and titanium (Ti)"). Additionally, comments revealed aspects related to 'Behaviour and Progression' ("I'm still learning and trying to understand"), 'Attitudes and Values' ("I really enjoyed the introduction and I found it interesting") and 'Enjoyment, Inspiration and Creativity' ("it is the best thing ever", "They really enjoyed the video and we even had tears of joy"). 'Evidence of Skills' (e.g. perseverance,

cross-referencing information, handling materials) was recorded observationally.

Overall, the developed sessions presented an effective method for engaging children with chemistry. There is much scope for future development of resources utilising the Science Hunters approach and Minecraft's function and appeal to inspire younger generations about a subject that many are known to have less positive experiences with in school.

Acknowledgements

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Article

Multimedia modelling of organic pollutants: The fugacity approach

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Organic Pollutants (OPs) have been a major concern for the environment for decades due to their persistence and toxicity. Up until the 1990s, non-polar hazardous compounds, persistent organic pollutants (POPs) (*1*), were priority pollutants and, as a result, intensive monitoring campaigns were conducted. These pollutants are still very important to monitor because of their detrimental ecological effects and persistence (long half-lives). In recent years, however, there has been more focus on emerging organic contaminants (EOCs) (*2*), which include pharmaceuticals, personal care products, pesticides and endocrine disrupting compounds (EDCs). EOCs and POPs enter the environment through various sources including wastewater treatment plants (WWTP), landfill sites, agricultural run-off and industry/hospital effluent.

Monitoring OPs in the environment can be challenging because of the considerable time and resources required to conduct field and lab work, and the complex matrices which can interfere with analysis. A selective extraction and clean-up step is required to ensure analytical instruments can detect contaminants at very low levels (ppb/ppt).

Concept of Fugacity

Compound fate in the aquatic environment can be determined using mathematical models known widely as fugacity calculations. The concept of fugacity was first developed by Lewis in 1901 (*3*). Then Donald Mackay applied this concept to multimedia models in environmental chemistry to describe the processes controlling the behaviour of chemicals in environmental media (*4,5*).

The term Fugacity describes a chemical's escaping tendency (5). Therefore, when modelling compounds in the environment, fugacity describes the ability to move between two different environmental compartments.

Equal fugacity is expected in both phases, as is the vapour pressure of the compound. The relationship between fugacity (f), concentration (C, $molm^{-3}$) and fugacity capacity (Z, $molm^{-3}Pa^{-1}$) is shown below (**Eq. 1**). The Z value is specific to a chemical and is dependent on the phase. A compartment with a higher fugacity capacity can accept a higher concentration of a given micropollutant.

$$C = Z \times f \qquad\qquad \text{Eq. 1}$$

Fugacity models become more complex as more data becomes available, and are assigned as different levels (*1, 2, 3, 4*). These calculations can also be applied various systems including quantitative water air sediment interactions (QWASI), sewage treatment plants (STP) and equilibrium criterion models (EQC). These will be described in more detail later. Chemicals flowing into a (dynamic) system, contained in water, sediment, biomass solids, and air, are driven by processes such as degradation and advection (more detail later). The rates of these processes can be described using D values ($molh^{-1}Pa^{-1}$). In order to fully develop a fugacity mass balanced model, determination of D values is necessary. To determine D values, Z values are required, as well as specific information on the compounds being studied (physicochemical properties)/rate constants, and site-specific information on the STP, such as effluent discharge and size of STP. D values can be thought of as transport parameters, with units of $molh^{-1}Pa^{-1}$.

Given the scope of multimedia modelling, this article will briefly discuss level 1, 2 and 3 models, and describe specific applications of fugacity models.

Partition Coefficient

A key parameter in fugacity calculations is K_{ow}, the partition coefficient (**Eq 2**), which is derived from thermodynamics or can be measured experimentally.

$$K_{ow} = \frac{\text{Conc}(L^{-1})(\text{organic})}{\text{Conc}(L^{-1})(\text{water})} \qquad \text{Eq 2}$$

Octanol is chosen as the solvent because it provides suitable conditions as the organic layer, mimicking fatty/lipid biological tissues (*6*). In most cases, the partition coefficient is written as $logK_{ow}$, and measurements are taken of the neutral compound only in each layer. The shake flask method, outlined by the OCED guidelines (*6*), is a simple method to accurately measure $logK_{ow}$. A known concentration of compound is spiked into a

system of specified ratios of octanol and water (which have been saturated with one another). The two layers are mixed thoroughly until equilibrium is obtained and allowed to separate. The aqueous layer is then carefully sampled and analysed using a technique such as High Performance Chromatography (HPLC) or UV-Vis Spectroscopy (*7,8*).

Ionisation of Organic Compounds

Compounds with ionising protons in their structure must be considered when using fugacity calculations. Charged structures can be formed at environmental pH levels which, in turn, can impact environmental partitioning. This is due to multiple acid dissociation constants and the wide range of physicochemical properties that some pharmaceutical drugs, such as antibiotics, pain killers and anti-inflammatories, contain. In contrast, non-polar compounds, such as polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAH) and polybrominated diphenyl ethers (PBDE) are also frequently found in the environment. Compounds such as these do not ionise at environmental pH values and, therefore, only one species (the neutral) of the compound is considered. PCBs have relatively high $\log K_{ow}$ values, and are described as hydrophobic, whereas antibiotics such as ciprofloxacin, have low $\log K_{ow}$ values (**Figures 1-2**).
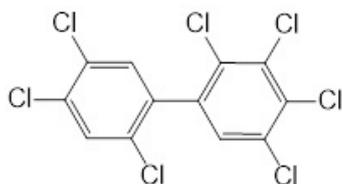

Figure 1. Chemical Structure of PCB-180

Therefore, their chemical behaviours will differ in-situ. Ciprofloxacin, unlike PCB-180, is able to form charged structures and zwitterions at environmental pH levels.
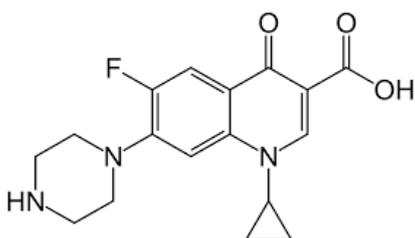

Figure 2. Chemical Structure of Ciprofloxacin

Level 1 Model – Closed System

A level 1 model describes a compound's fate in the environment by making the following assumptions:

1. The system is closed, the volumes of the compartments are fixed, and the total amounts of chemicals distributed amongst the compartments are constant (**Figure 3**).

2. The system is in an equilibrium steady state, meaning that the concentration of a chemical within a compartment is uniform, and the chemical potentials of a given species in different compartments are equal.

Calculations then determine the partitioning of chemicals between compartments labelled a, w and s (air, water, and sediment respectively) with volumes V_a, V_w and V_s respectively. The respective concentrations C_a, C_w and C_s in each compartment can be used to calculate the partition coefficient (K_{aw}, K_{ws}).
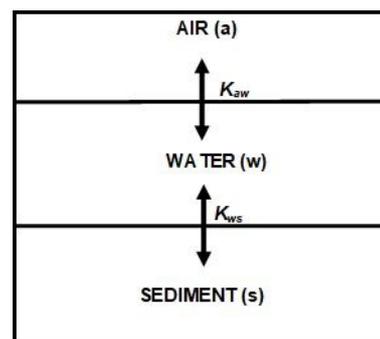
Figure 3. Illustration of a simple 3-compartment Level 1 model.

Studies demonstrating environmental level 1 fugacity modelling calculations include one on bisphenol A (BPA) in sewage sludge amended soil (*9*). In the study, a three-compartment soil matrix model (level 1) was described and the total concentration of BPA in the soil was predicted. The results of the fugacity model indicated that the majority of BPA (~96%) present remained strongly attached to the sewage sludge amended soil (following application of sewage sludge to soil). When considering the physicochemical properties of BPA, these

results support the behaviour demonstrated by BPA within the environment – low vapour pressure, moderate water solubility, and high octanol-water partition coefficient and organic carbon coefficient (K_{ow}, K_{oc}).

Level 2 Model – Dynamic Environment (equilibrium assumed)

A level 2 model describes a dynamic environment with inflows and outflows of chemicals through the compartment such that, at any given instant, the different phases are in equilibrium with one another (5). Partition coefficients can be used to describe the distribution of chemicals between the compartments. The main assumptions of a level 2 model are:

1. The system is open, meaning that, although the volumes are fixed, the total mass of chemicals distributed amongst those compartments may vary with time, or there may be equal inflows and outflows of chemicals that lead to steady state distributions.

2. The distributions of chemicals amongst the compartments at any given instant is determined by the conditions of the chemical equilibrium and equilibrium partition coefficients, K, even if there is a throughput of chemicals.

In essence, it is assumed that the diffusion of chemicals within and transfer between compartments are so fast compared to the rate of reaction/degradation/advection that the Nernst partition law is satisfied at all times (5). The total chemical within the environmental region interest may vary in time due to the following two general processes (5):

- **Advection**; a chemical is transported into or out of the region of interest by the flow of a supporting medium. The rate of advection (N = molh^{-1}) (Eq. 3), is the product of the flowrate of the advecting medium (G = m^{3}h^{-1}) and the concentration of the chemical in that medium (C = molm^{-3}) (5).

- **Degradation and chemical reactions**, which lead to a change in the total chemical within the region of interest.

$$N = G \times C \qquad \text{Eq. 3}$$

Under this assumption, there is no need to specify which compartment the chemical is being introduced into; instead the net influx is specified.

Level 3 Model – Dynamic Environment (equilibrium not assumed)

Level 3 calculations include the transport by diffusive processes. For instance, a chemical takes time to diffuse within a compartment, driven by a concentration gradient. At equilibrium, the concentration profile is uniform and there is no net diffusion. This allows us to consider the introduction of some chemical at different rates into each compartment, which causes a non-equilibrium distribution of the chemical and, hence a net flow between them; this is intermedia transport. One study applied Level 3 fugacity calculations to predict the concentrations of antibiotics in a number of water basins in China (10). This study proved that the model was comparable with the available field data at specific sites.

Application of Fugacity models

Based on the theory of the fugacity calculations, researchers have developed many other models for systems. Among them are the EQC model, STP model and QWASI model.

The Equilibrium Criterion model

The EQC model was designed and based on evaluative level 1-3 fugacity models, described by Mackay *et al.* (11). It may be employed to systematically reveal general features of the behaviour of a chemical in a generic environment. The model enables progression through the sequence of levels 1-3 for a variety of chemicals. The model also separates chemicals into categories based on different properties including the ability to partition into different environmental compartments, volatility and water solubility (12). The chemicals are broadly divided into Type 1 (common pollutants – such as PCBs, PAHs), Type 2 (cations, anions and involatile chemicals), and Type 3 (long chain hydrocarbons, silicones and polymers). An important advantage of the EQC model is the ability to treat a greater range of chemicals than other models, but it is primarily utilised for non-polar species (12).

The Sewage Treatment Plant Model

The STP model was developed by Clark *et al.* (13), and is aims to understand the chemical behaviour and fate of contaminants in a conventional WWTP. The model is based on mass balances produced at each stage of the WWTP, which correlate and predict steady state phase concentrations, and process stream fluxes and the fate of micro pollutants. A limitation of this model is its inability to correctly model ionised compounds. As such, the model was upgraded to STP-EX, incorporating an ionic/neutral factor to upgrade Z values based on the compound under investigation, its pK_a, and the pH of

the wastewater (*13*). The STP and STP-EX model have been applied to conventional WWTPs all over the world, and used as a screening tool for risk assessments (*14-16*).

The Quantitative Water Air Sediment Interaction Model

The QWASI level 3 model was developed by Mackay and is used to predict contaminants behaviour in dynamic environments, such as rivers and lakes. Since its development, the QWASI model has been further modified (*17*). Based on fugacity calculation concepts, the model has been used to investigate a range of chemicals in lakes, and proved to be accurate compared to onsite measurements (*18*). Since its development, the QWASI model and modified versions have been applied to many studies to simulate the concentrations, distributions, transfer fluxes and bioaccumulation of chemicals in lakes and river systems (*17-23*).

D values and the fugacity are highly important in QWASI calculations. These are used to calculate rates of the contaminant (molh^{-1}), where D values are calculated by multiplying G values (m^{3}h^{-1}) by the Z values(molm^{-3}Pa).

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Public Engagement How To:

Wet Scrubbers

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A fantastically visual way to explain the science behind wet scrubbers, this demonstration can be used to stimulate discussions around their many applications in industry and research.

Theory

Wet scrubbers are used to remove harmful, water soluble gases from an air flow by dissolving them in water or in aqueous solution. In some cases, where the primary gases are acidic, the water will be dosed with sodium hydroxide. This prevents the release of these gases into the atmosphere and, by capturing them in solution, facilitates the process of neutralising and treating harmful compounds, so they can be safely disposed of.

Kit List

- Clear tube (preferably acrylic), no more than 7 cm in diameter, approximately 30 cm long
- Funnel – to fit, snugly, over the end of the tube
- Adhesive – epoxy resin advised
- Sieve plate to fit in funnel, at bottom of tube
- Clear beads to fill the tube
- Small spouts
- Aquarium pump
- Flexible tubing to fit aquarium pump and spouts
- Large liquid container for draining
- Dreschel bottle
- Clamp stand with clamps
- Household ammonia
- Red cabbage water (and vinegar in hard water areas)
- Beaker for pouring
- Tray to hold the apparatus in case of spillage

Set up

1. Drill a hole in the side of the funnel, below the seat point of the tube (test fit). Using the epoxy adhesive, fit the spout at an angle to prevent water draining in.
2. Fit the sieve into the funnel and fix it to the end of the tube, using plenty of the epoxy adhesive. When the adhesive has cured, fill with water and block the spouts to ensure that the assembly is water tight.
3. Fill the tube with the beads, leaving 5 cm at the top of the tube empty. Holding the tube upright with the clamp stand, fit a flexible tube to the funnel tip, the end of which is in the liquid container to be kept on the floor below the demonstration for drainage.
4. Fill the Dreschel bottle with household ammonia and fit another flexible tube to the angled spout, the other end of which should be fitted to the Dreschel bottle outlet. A third flexible tube should connect the Dreschel bottle inlet to the aquarium pump outlet. You will need the pump set to its highest speed.
5. Hold the tube and the Dreschel bottle into the tray to catch any spills. Fill the beaker with cabbage water.
6. Turn on the pump and explain the application you have in mind for the wet scrubber (i.e. dissolving acidic fumes from a fume hood in an analytical prep lab). It will take around 30 seconds (depending on the volume of the tube) for the ammonia to fill the tube to a visible level.
7. Pour a solution of slightly acidic red cabbage water into the open top of the tube. Ensure that the water is well pigmented or the colour change will be difficult to see. As the ammonia dissolves, the water will change from red to blue.

Exhibition Cost

Around £40-£50. All components, except cabbage water and ammonia will be reusable and a 500 mL bottle of ammonia is usually enough for a 4-day event with demonstrations every 15-20 minutes.

Exhibition Weight

5-10 kg, depending on size of tube and amount of cabbage water prepared.

Exhibition Size

Would fit into a carry-on sized case.

Resources Required

Electrical power for the aquarium pump.
Fresh water to rinse the kit at the end of each day.
Drainage for disposing of the water at the end of the day.

Things to look out for

Do NOT let anyone sniff the ammonia, it can cause serious injury if the fumes dissolve in the lungs. Ensure you disconnect the pump between demonstrations to avoid ammonia fumes from escaping. If the ammonia fumes are taking longer to fill the tube, you may need to drain the Dreschel bottle (gas wash bottle) into your waste solution, neutralise with vinegar, and add fresh ammonia. It is worth having plenty of paper towel for mopping up spills.

Early Careers Environmental Brief   **(ECGECEB No 7)**

Microplastics in soil: an important issue

Nat Wood (University of Reading BSc Environmental Science student)

Whilst the intrusion and subsequent impacts of microplastics on the hydrosphere are widely realised, less is known about their effects within the pedosphere. This environmental brief focuses on the sources and impacts of microplastics in soil.

Microplastics, along with larger plastics, have become an integral tool for the efficient functioning of 21st Century society. Commonly defined as a synthetic, chemically stable material smaller in length than 5 mm, microplastics can be a variety of different shapes and sizes, but the most frequently used microplastic polymers are polystyrene, polyethylene and polypropylene, all of which contain carbon (*1, 2*). Their resistance to decomposition, along with the length of the chains that polymers form, explains why most microplastics last for so long in the environment (*1*).

Microplastic contamination of soils is a significant issue, as soils are a vital global resource. Among other things, they are essential for carbon sequestration, flood prevention and food production. Any contamination of soil must be studied in order to understand the effects this contamination may have as well as how to prevent further contamination.

Sources

If soil microplastic pollution is to be reduced, their sources must first be identified (**Figure 1**). The formation of microplastics falls into two distinct categories – primary microplastics, those which have been intentionally manufactured to the size they are, and secondary microplastics, which form from the breakdown of larger plastic particles (*1*).

Whilst agriculture depends heavily on healthy soil, it is one of the major sources of soil microplastic pollution – studies estimate that annually, 63,000-430,000 tonnes of microplastic pollution is deposited in European agricultural soils (*3*). Water treatment plants remove nearly 90% of plastics from wastewater, concentrating microplastics in the sewage sludge that remains (*4*). Sewage sludge, containing both primary and secondary microplastics, is widely used as a soil amendment to improve crop yields, with as much as 50% of the total sewage sludge produced in North America and Europe later applied to fields (*3*).
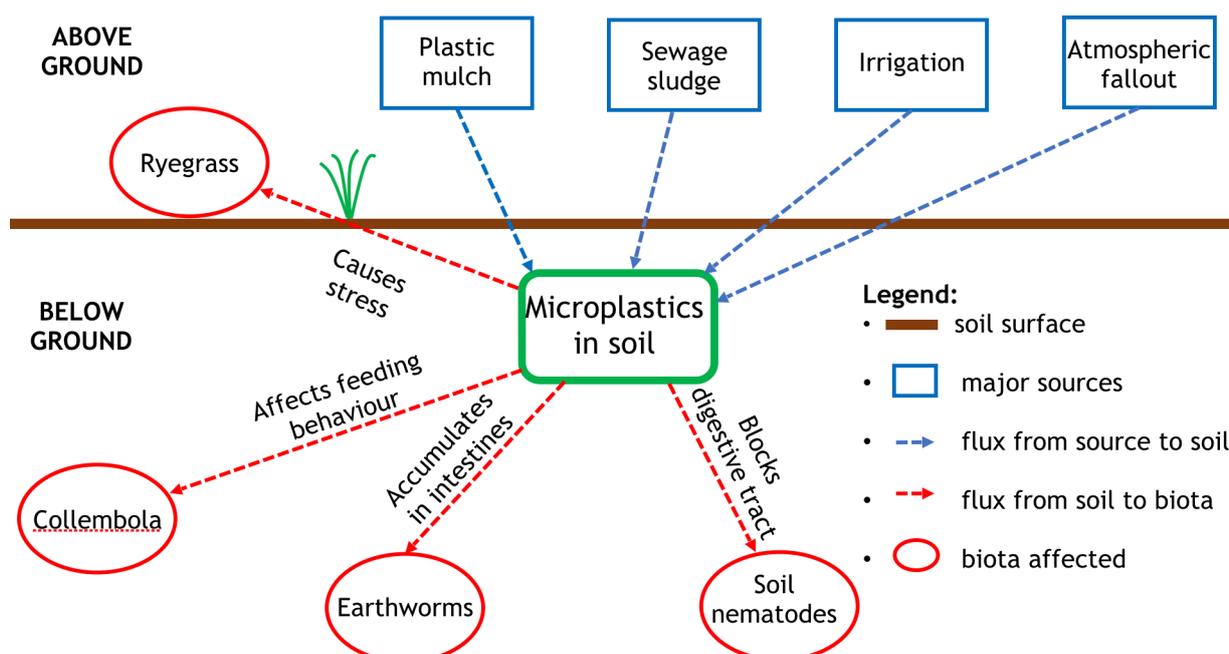

Figure 1. Sources of microplastics in soil and some effects on biota.

Other major agricultural sources of microplastic pollution in soils stem from the use of plastic mulch (*3*). Used to conserve soil moisture and prevent competition from weeds, China is the largest plastic mulch user, swathing over 20 million hectares of land in plastic film (*1*).

Irrigation is utilised on 18% of the world's agricultural land – 7% is irrigated with untreated wastewater (*4*). This attempt to provide water to facilitate optimal plant growth inadvertently creates an unregulated flux of plastic pollution into soils.

Outside of agriculture, microplastic fallout from the atmosphere can enter even remote soils far from a large populace. Tire abrasion on road surfaces generates tire dust, which can be washed off into soil by rain; in Sweden, anual tire dust emissions total nearly 1000 tonnes (*4*).

Impacts – biota

Microplastics can have impacts both on belowground soil organisms and on plants (**Figure 1**). The presence of microplastics in soil has been shown to cause significant stress in perennial ryegrass (*5*). Seed germination decreased, whilst increases in root biomass and chlorophyll a/b ratios were observed (*5*). Whilst no directly toxic effects were observed, these responses demonstrate that ryegrass behaviour is forcibly changed by the presence of microplastics.

Furthermore, a decrease in earthworm biomass was observed when microplastics were present (*5*). Since earthworms consume soil, they unintentionally swallow microplastics (*5*). Any microplastics that pass through the digestive system are expelled in casts, distributing microplastics further down the soil profile where they can be consumed by other organisms. If they remain inside the worm, microplastics can obstruct the digestive tract, causing decreased nutrient adsorption, weight loss and death (*5*). As a keystone species, a reduction in earthworm populations can have devastating knock on effects to the entire soil ecosystem, as well as plants.

Impacts – soil properties

As well as the indirect effects that microplastic pollution may have on soil properties through reducing earthworm biomass, there are several direct impacts.

For example, a lowered soil pH was observed when microplastic particles were present (*5*). Soil microbial communities are particularly sensitive to pH; these are essential for various biogeochemical cycles, including the nitrogen cycle. Nitrogen is converted to plant available nitrates by soil microbes, the optimal pH range of which lies between 6.6-8.5 – any change outside of these limits could be detrimental to plant growth (*7*)

Plastic films in soil have also been shown to create channels, which aid water movement, resulting in increased evaporation (*6*). This causes soil drying, an effect that may be most prevalent in water scarce areas (*6*). With global temperatures expected to rise by 1.8 °C, widespread soil drying could be worsened further by the presence of microplastics hindering crop production (*8*).

Conclusions/further research

The pathways through which microplastics enter soil are numerous (**Figure 1**). However, many of the sources, particularly in agriculture, are essential for crop production. Microplastics in soil have been shown to have several detrimental effects and so, where possible, sources should be reduced. Further research should continue to assess the damage inflicted by microplastics upon the pedosphere, as well as researching whether alternative, less damaging materials can be used instead of microplastics to carry out the same function.

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Early Careers Environmental Brief   (ECGECEB No 8)

Diesel particulate matter

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We are becoming increasingly aware of the risks that diesel particulate matter (DPM) poses to humans and the environment. This environmental brief gives an overview of what is already known about DPM and how it can be controlled.

Source and formation

DPM is produced by compression ignition engines and released from diesel exhausts. Diesel engines are popular due to their energy efficiency, durability, reliability, and low-operating costs compared to petrol engines (*1*). They are extensively used for commercial transport (trains, cars, buses, ships, trucks) as well as for industrial activities (mining equipment, agriculture, construction) (*2*). DPM is formed because of incomplete combustion within a diesel engine. Fuel is injected into the combustion chamber at high temperatures and pressures, where it is then atomised. The droplets are not dispersed uniformly, resulting in local oxygen deficient regions around some fuel particles. These conditions lead to incomplete combustion and the formation of DPM through a series of steps (*3*):

1. **Pyrolysis** – The oxygen deficient and high temperature conditions cause the organic compounds within the fuel to undergo a change in molecular structure. This produces acetylene molecules, which then combine to make benzene rings and dehydrogenate to form polycyclic aromatic hydrocarbon (PAH) precursor molecules.

2. **Nucleation** – Hydrocarbons are deposited on the surface of the precursor molecules, which develop to form the nuclei. This process results in the production of numerous small particles less than 3 nm in size (*4*).

3. **Surface growth** occurs within 0.05 ms after the formation of nuclei. Hydrogen molecules are stripped from the nuclei and form spherules, which significantly increase the size of particulate matter (now 20-50 nm), and therefore create soot.

4. **Coalescence** – Inter-particle collisions lead to the formation of agglomerated spherules. The size of these primary spherical particles depends on the engine operating conditions.

5. **Oxidation** – The hydrocarbons are oxidised and then condense on the soot to form DPM.

Structure and composition

DPM is a mix of solid and liquid particles suspended in a gas and formed as agglomerates of primary spherical particles (*1*) (**Figure 1**).
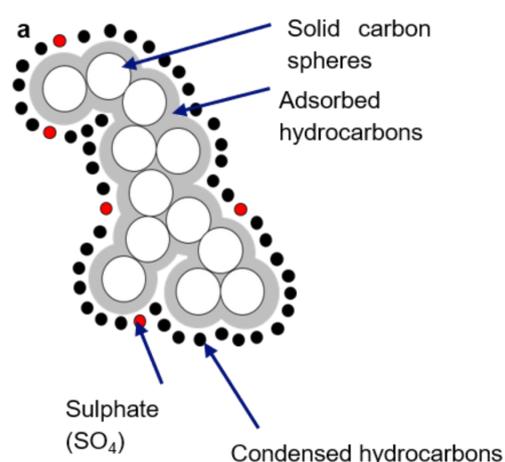

Figure 1. A diagram, redrawn with permission from Mohankumar and Senthilkumar (3), of the structure of DPM.

The exact chemical composition of DPM is difficult to quantify because it is dependent on several factors (fuel structure and/or composition, lubrication oil quality, combustion conditions, and engine type). In general, DPM consists of three main fractions: carbonaceous (soot) fraction, non-volatile insoluble fraction (IF), and volatile soluble organic fraction (SOF). IF is composed of ash content (a mixture of oxides, sulfates, carbonates, metals and non-metals) and other impurities. The SOF consists of organic carbon, sulfate and nitrate compounds which are derived from the lubricating oil, unburned fuel, and compounds formed during combustion (*1*).

Impacts

Most DPM is classed as 'ultrafine' $PM_{0.1}$ as its particles tend to have a diameter of < 100 nm ($0.1\mu m$) These can penetrate deep into organs and even enter the bloodstream (*2, 5*). Humans and animals are primarily exposed to DPM pollution through inhalation, where the particles are deposited within the respiratory system, causing acute inflammation of the lungs. The toxicological effects of DPM depends on the exact size and surface area of the particles as well as the presence of absorbed transition metals or other organic materials. For example, PAHs, which are usually present within DPM, are known human carcinogens, capable of altering the DNA within lung tissue. In addition to respiratory

illnesses, DPM may cause adverse health effects in other organs through translocation, whereby DPM particles migrate to a secondary organ post inhalation. Research has shown evidence of this exposure within the brains of monkeys and rats, causing neurological effects (5).

Controls

Diesel Oxidation Catalyst (DOC) – DOCs are catalytic converters with an open monolith honeycomb structure. They decrease the mass of DPM through catalytic oxidation of hydrocarbons that would otherwise be adsorbed onto the solid carbon sphere. Harmful exhaust emissions such as CO, PAH, and the SOF can also be neutralised through oxidation within the DOC through the following reaction:

$$C_nH_{2m} + \left[n + \frac{m}{2}\right]O_2 \rightarrow nCO_2 + mH_2O \qquad \text{(Eq1)}$$
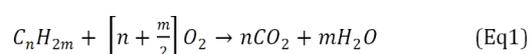
Diesel Particulate Filter (DPF) - DPFs physically trap particulate matter (PM) from the exhaust stream and prevent it being released into the atmosphere. They ensure the entrapment of PM with blocked channels at alternate ends, forcing the PM through the porous substrate (with an efficiency of > 90%). Over time, DPFs accumulate PM and become saturated which can lead to engine failure if left untreated. DPFs must be 'regenerated' to prevent this build up by oxidising the soot at high temperature.

DOCs and DPFs are both well established and popular post combustion DPM control techniques. Since February 2014, MOT tests in the UK have included a check for the presence of a DPF; 'A missing DPF, where one was fitted when the vehicle was built, will result in an MOT failure'. In May 2018, rules were then made much stricter: diesel vehicle exhausts were measured using a diesel smoke meter (*6*).

Biodiesel – Recently, there has been an increasing number of studies investigating DPM emissions from biodiesel fuels. Overall, findings (*7*) show the following:

1. PAH emissions and carcinogenic potency is less with biodiesel compared to regular diesel;

2. PM concentration released from biodiesel fuel is less than regular diesel with increasing load (**Figure 2**);

3. Biodiesel PM primary particle size is smaller and has a more amorphous structure; and

4. Using a blend of biodiesel may improve the ease of DPF regeneration.
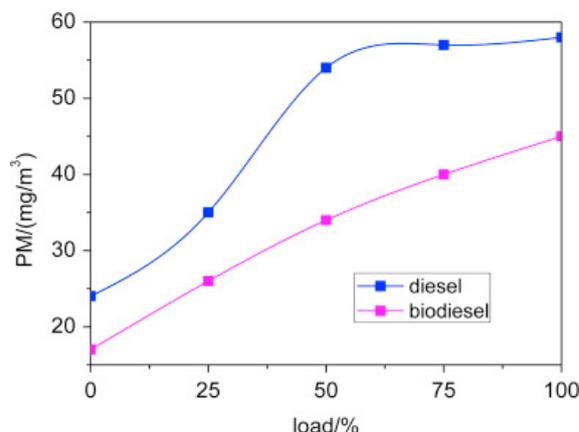
Figure 2. Effect of engine load on PM, reproduced with permission from Wang et al. (7).

Despite these findings, relatively little is known about the toxicology of PM emissions from biodiesel fuel use. Therefore, there is a need for further research to determine whether using biodiesel could be considered an effective DPM control technique in a real world context.

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