Science Last Fortnight

Uranium in Groundwater

Estimating from soil properties

High concentrations of uranium in drinking water can cause health issues: kidney damage, cancer, increased defective birth rate, early greying of hair and cardiovascular diseases. When rainwater and subsurface flow seep down the earth's crust, they carry a significant amount of uranium from the rocks and soils into groundwater, the source of drinking water for millions.

The migration of uranium into groundwater depends on its distribution in solid and liquid phases or dispersion coefficients. The dispersion coefficient is estimated by experimental methods which are tedious and time consuming. So, are there any alternative methods to quickly identify areas with uranium contamination in groundwater?

The dispersion coefficient is affected by a combination of soil parameters. So establishing the relationship between the dispersion coefficient and soil parameters can help determine its value more precisely. S. Manoj, M. Thirumurugan and L. Elango from the Anna University, Chennai now report determining the relationship.

They chose the uranium-mineralized region of the Yadgir district of Karnataka as study area.

'Intensive cultivation there and the nearby flow of two major rivers, the Krishna and the Bhima, make the region significant for the study', says Manoj.

The region has three types of rocks – igneous, sedimentary and metamorphic, and has all major soil types. The team collected soil samples from different locations. They air-dried, sieved and tested the samples for particle size distribution, porosity, acidic nature, electrical conductivity, calcium carbonate, cation exchange capacity and dispersion coefficient.

From the analysis, the team observed a positive relation between the texture, acidic nature and cation exchange capacity of the soil. There was no correlation between porosity, exchange capacity and calcium carbonate content of the soils.

The researchers collected rocks which included basalt, grey shale, purple shale, limestone, granite, schist and peninsular gneiss. They collected unweathered rock samples and estimated the dispersion coefficient of the samples.

The team also observed that a rock's dispersion coefficient was mainly controlled by surface area. So, along with decrease in grain size, the coefficient value increases.

The team performed multiple regression analysis to quantify the effect of various soil parameters acting simultaneously on the soil dispersion coefficient. They found the results satisfactory confirming the applicability of the equation in a global context.

'The multiple regression equation can be used to predict the soil dispersion coefficient based on limited soil properties which can be used in radionuclide transport models to predict the migration of uranium in groundwater', says Elango, Anna University.

This finding can help estimate uranium in groundwater. If its value remains within the permissible limit of 30 parts per billion then local governments can declare it safe for drinking purposes. Otherwise, take steps for building treatment plants for uranium removal.

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Resilience against Cyclones

Ecology and social demographics

The East Coast of India has been battered by cyclones over centuries. Early-warning systems, saline embankments, storm shelters, approach roads, and rescue and evacuation training for rapid action to manage storm hazards have slowly been set in place by the National Policy on Disaster Management, 2009. However, research on the vegetation cover as protection against cyclones remained focused on mangroves. The East Coast has many kinds of trees. Besides ecology, what social and demographic factors contribute to quicker recovery from the disasters?

Phailin in 2013 and *Hudhud* in 2014 gave scientists a chance to explore these questions. Armed with satellite data from the cyclones, Soudamini Das from the Institute of Economic Growth, Delhi and Nisha Maria D'Souza from EcoNiche Consulting, Bengaluru started piecing together the puzzle. They selected 15 villages in Visakhapatnam District near *Hudhud*'s landfall point. The villages were also affected by *Phailin.*

Image: Adityamadhav83 via Wikimedia

From 900 households, the team collected information about damage, time to return to normalcy, and demographic and economic aspects. More than 70% were illiterate. And about 98% were from socially and economically challenged communities; mostly fishers, fish vendors, salt producers, or manual labourers. A few were farmers.

Farmers and fishers suffered losses exceeding their annual income. Fishers lost boats, nets, engines and other fishing material besides fishing days. Farmers lost harvests. Salt water inundation and damage to property added insult to injury. More than a third lived in thatched houses and more than 70 per cent of these were damaged.

More than 80 per cent of the respondents felt that it would take at least two years to recover. About five per cent felt it would take more.

Analysis of the data revealed that female-headed households, households having secondary or higher-educated heads, and households with concrete houses had shorter recovery time.

The next question was about the vegetation cover needed to reduce cyclone impact. The researchers recorded species and approximate length of tree patches, parallel to coast and vertical to coast. The coastal area had forest belts consisting primarily of palmyra, coconut and casuarina. For further insights, the researchers took into consideration some *Phailin*-affected areas along the coast, with thick plantations of cashew, casuarinas, and other local species. They found that the greater width of vegetation between village and coast had protected houses from damage during *Phailin*.

Commercial plantations of casuarina did not help protect from damage by cyclones. But palmyra and cashew-mixed forests seemed to provide protection from cyclones. Palmyra is local, selected over time by cyclones. Cashew plantations along tracks that do not have the protection of mangroves are perhaps a solution for long-term resilience.

Clear criteria for minimizing losses during cyclones have emerged from this study. While households can plant appropriate trees, for reforesting the commons on the East Coast, state governments have to step in. If adequate steps are put in place, we can perhaps stem further outmigration from these regions – especially of the educated and economically advantaged, in response to natural hazards.

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Baking Bread

Mathematics matters

The quality of bread depends on the history of the heat that it receives in the oven. The dough gets conductive heat from the tray, radiative heat from above and below and heat from air convection in the oven. Heat flux meters measure both radiative and convective heat and leave conducted heat altogether out of measurements. So, most bakers use more heat than necessary to err on the right side. If we could understand the contributions and roles of the three modes of heat transfer, we could reduce energy wastage.

Ashish K. Dutta and team from IIT, Kharagpur have been attacking this problem for some time now. The problem becomes complicated because bread rises and swells during baking. The carbohydrates and proteins on the outer layer react, turning into a hard brown crust. These transformations change the way heat is received by the outer layers and the manner in which hot gases diffuse inside the dough. The researchers now report overcoming these complications that confounded our understanding of heat transfers during baking.

The equations that govern heat and mass transfer are well known. Most of the parameters involved are easily measured or directly calculated. The researchers used finite element analysis in COMSOL Multiphysics to calculate the temperature at specified points within the bread.

What is unknown is the boundary heat flux of bread. The team decided to tackle this through an inverse method: measure the temperature inside the bread and work backwards to estimate the heat flux at the boundary.

Their experimental oven consisted of two heating coils: one at the top and the other at the bottom. Both had reflectors. The baking trays are kept between the two coils. Besides the natural convection, the team also used forced convection to cover different types of baking practices. They also baked breads of two different dimensions with thermocouples embedded in the dough at different points.

To model the deformation of bread during baking, they used a combination of methods used for the deformation of solids and fluids.

The researchers found that the centre point in bread, behaved linearly for the first 200 seconds or so. The thermocouple just below the top layer of dough is more sensitive to the nonlinear conditions of baking. So the researchers used the readings of the thermocouple just below the top layer, for further modelling.

Heat flux requirement is greater at the beginning and it reduces as baking proceeds. The reduction is more drastic in smaller breads than in breads with larger volume.

At the start of baking, radiative heat flux was greater than convective heat flux. However, convective heat flux is greater at the end of baking. Since the bottom and sides are in contact with the tray, the top part was more exposed to radiative heat – the reason for browning due to reactions between carbohydrates and proteins.

'The error between simulated and measured temperatures was less than one per cent', says Ravula Sudharshan Reddy, IIT Kharagpur.

'The error was greater for the first 200 seconds. This could be due to the initial adjustments of the product to ambient conditions in the oven', says Divyasree Arepally.

'In our experiments, bread deformation continued for about 300 seconds. The inverse 2D heat conduction is therefore a useful method to estimate the unknown boundary heat flux on the surface of bread during baking', says Ashish K. Dutta.

The findings of the team can now be used to optimise energy use in bakeries.

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Food Colorants from Fungus

Pick the pigment

Food that looks good appeals to appetite. And some food colours add value to food. However, there are concerns regarding toxicity, especially for some synthetic colours. Mohan Appasaheb Dhale and team from CSIR-CFTRI, Mysuru suggest sourcing food colouring from fungi. Recently, the team extracted a natural reddish pigment from a previously isolated fungal strain – *Talaromyces purpurogenus* CFRM02.

For pigment production, they used submerged fermentation using Bengal gram husk – a process standardised by Saritha Gopal Pandit, CFTRI. After 10 days of fermentation, they extracted the culture broth with methanol. After allowing most of the methanol to evaporate, they mixed the broth with hexane in a separating funnel to remove dissolved lipids.

The reddish pigment is water soluble. So they lyophilized the aqueous fraction.

Next, the team evaluated the toxicity of the extract by feeding different amounts of the pigment to Wistar rats. The extract was non-toxic even at high doses.

Then they tested the rats for subacute toxicity and checked for organ damage by feeding rats different concentrations of the extract for 28 days and comparing their health with that of rats that did not consume the pigment.

There were no changes in daily feed intake or body weight of animals consuming the extract. The animals did not show any signs of toxicity in vital organs like heart, liver, kidney, etc. The haematological profile, activity of metabolic enzymes, creatinine and uric acid levels were also normal.

The team purified the pigment extract using column chromatography and characterized components with mass spectrometry. They could identify several secondary metabolites with antimicrobial, antioxidant and other pharmacological and nutriceutical activities.

This could indeed be a boon for foodies as the food industry could use such natural colorants that add value to foods.

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Cool Buildings

Using heat reflective paint

All of us would like to live in healthy environments. But we design buildings that trap heat giving rise to urban heat islands. The use of optimum wall-window ratio and appropriate construction material can reduce these effects to some extent. Infra-red reflective paints can also be used to reduce heat absorption by buildings. But most infra-red reflective paints are either unattractive or unstable.

Sumathi Shanmugam and V. Elakkiya, from VIT Vellore now report a yellow coloured infra-red reflective paint that is stable. Their starting material was gahnite – $ZnAl_2O_4$.

Sumathi and Elakkiya prepared gahnite by stirring zinc nitrate and citric acid solutions. To this, they added aluminium nitrate and continued stirring till the solution turned gelatinous. After heat treatment and calcination, they got gahnite in the form of a white powder.

Gahnite-based pigments are highly stable in various chemical and high temperature environments. But gahnite does not reflect the infrared as much as it does visible light. So Sumathi and Elakkiya thought of incorporating iron and cerium. Cerium enhances infrared reflectance and iron atoms provide a nice yellow hue.

Now the problem was to introduce cerium or iron, as dopant and co-dopant, instead of aluminium. For metal doping, the researchers repeated the process of making gahnite, but added iron nitrate and cerium nitrate to the solution.

They verified the presence of the dopants in the gahnite from the shifts in patterns of X-ray diffraction and in the infra-red spectrum. The change in binding energy of the electrons ejected on X-ray collision also confirmed the presence of cerium and iron.

The team then tested the doped gahnite by exposing it to acid and alkaline environments and found it very stable.

'Metal doping broadens the absorbance peak in the ultra-violet and blue regions, making it look yellow', explains Elakkiya, VIT Vellore.

To check the heat reflecting ability of the 1000 nanometre-sized gahnites, the researchers recorded the reflectance of near-infrared in the solar spectrum.

'At this size, the metal co-doped gahnite reflects 86% more solar photons than undoped gahnite', says Sumathi, his colleague. She recommends this stable and aesthetically pleasing pigment to keep buildings cool.

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Biodiesel Engine Performance

Sunflower and soybean oils

Fossil fuel is a depleting source of energy. And oil price fluctuations impact economy. Replacing fossil fuels with transesterified vegetable oils blended with fossil fuels for use in existing engines without modification is, therefore, seen as critical to stabilise the economy against such fluctuations.

Researchers from the Government Engineering College, Patan, Gujarat, and the Kongu Engineering College, Erode collaborated with researchers from Qatar, Egypt, and Oman to maximise biodiesel production from sunflower and soybean oils. Sunflower and soybean are widely cultivated oil crops in India. So using these oils as a source for biodiesel production can make a significant contribution to easing the need for fossil fuel imports.

Fuel yield depends on the methanol to oil ratio, catalyst concentration, mixing speed, and reaction time. The researchers used twenty-nine different combinations of these factors to find the most efficient recipe for maximizing production.

The optimal reaction condition gives an optimum biodiesel yield of more than 93%. The scientists say that the model has about 98% accuracy.

After optimising the reaction parameters, the researchers used central composite design methods to optimise engine performance and emissions. They also used a response optimiser to optimise biodiesel reaction and engine operation parameters.

The scientists validated the model with the experimental engine output. The error percentage, they found, was below 5.

Sunflower/soybean oil is a good combination for biodiesel, suitable for internal combustion diesel engines. This optimized biodiesel offers 70% blending with pure diesel.

Moreover, when we use this fuel, the original fuel system of the engine does not require any modifications, say the scientists.

India is one of the largest importers of crude oil. India is also one of the largest importers of edible oil. Edible oil production in India should also grow significantly to make biodiesel as fuel feasible.

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Onion Peel Supercapacitor

Eco-friendly power bank

Supercapacitors are electrochemical energy storage devices. They can be charged faster than batteries and fuel cells. The performance of a supercapacitor depends on its electrodes. Recently, electrodes prepared from agro-waste such as peanut shells, sugarcane bagasse and grapefruit peel have been found to exhibit high electrochemical performance. Low-cost

and eco-friendly supercapacitors have high demand in portable electronics. So there is a need to evaluate agro waste sources of electrodes.

Last fortnight, scientists from the Nagpur University reported making a supercapacitor with carbon electrodes derived from onion peels!

They collected onion peels from a local farm and dried the peels at 80 degrees centigrade for 12 hours and then pre-carbonised the dried peels at 300 degrees centigrade for an hour in a muffle furnace.

The carbonised onion peel powder was kept in a double crucible assembly and pyrolysed at 800 degrees centigrade for an hour without air contact. The pyrolysed fine powder was rinsed with hydrochloric acid solution to remove inorganic salts and the acid was washed off with deionised water.

Using X-ray diffraction and microscopy analyses, the team confirmed that the fine onion peel powder had a graphitic microporous structure. Then they prepared electrodes by mixing the onion peel powder with acetylene black and polyvinylidene difluoride – a polymer binder.

The team tested the performance of the electrode in three- and two-electrode device configurations at an electrochemical workstation. The two-electrode device configuration exhibited an energy density of more than 13 Watt hour per kg at the power density of about 200 Watts per kg.

The system had remarkable electrochemical stability and showed capacitance retention above 100% over 14,000 cycles.

The researchers attribute the performance to the microporous structure of the electrode which allows greater surface area for the wetting of the electrodes with the electrolyte.

The new electrode from onion peel is easily synthesised and suitable for low-cost energy storage devices.

Someday soon, such supercapacitors may help us create transportation systems without pollution and carbon dioxide emissions.

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Bose–Einstein Condensate

Engineering soliton dynamics

Solitons are solitary waves which do not lose energy when propagating. They behave as if they were particles. The most popular example of a soliton is the tsunami.

Solitons are found not only in water but also in plasma. Optical pulse travelling along a fibre used for telecommunication, energy transmission along a protein chain – solitons have been described in varied media.

Soliton structure depends on the nature of the medium through which it is propagating. So, solitons in an optical fibre have structures that are quite different from those found in ocean tsunamis. But how about solitons in Bose–Einstein condensate – considered the fifth state of matter?

Amitava Choudhuri from the University of Burdwan, West Bengal and collaborators from six other countries reported tackling the problem recently. It is not easy to conduct experiments with solitons even in water or optical fibres. When dealing with Bose–Einstein condensate, it is even more difficult.

Scientists can now create the coldest condition in the universe, near absolute zero. A few bosonic atoms can indeed be brought together in a small space and constrained to stay almost still. But it is simpler to treat the problem theoretically.

Bose–Einstein condensate is not completely homogenous. There are local variations due to contact repulsion and dipole–dipole attraction which can cause nonuniformity in the condensate. Amitava and team investigated the conditions of formation of solitons and the behaviour of solitons on the surface of the condensate under local non-uniformity. For this the scientists considered slightly elongated cigar-shaped Bose–Einstein condensate as a medium for soliton propagation.

The equation for the wave function of Bose–Einstein condensate has the form of a multidimensional nonlinear Schrödinger equation and is described best by the Gross–Pitaevskii equation. So they derived soliton solutions by transforming the time-dependent Gross–Pitaevskii equation to a stationary nonlinear equation and deduced a set of expressions that interrelate various time varying inhomogeneities, amplitude and the peak position of the soliton. Interestingly, they found that one of the solutions represents solitons that are snake-like. Such solitons have been reported earlier in graded-index grating waveguides.

When they examined the effect of various dispersion terms on the soliton's structure, they found that, in the presence of inhomogeneities, the soliton's amplitude remains constant if there is no gain or loss in the condensate. But the peak position oscillates giving a snake-like movement to the soliton.

When there is a gain in the medium, the amplitude increases. By periodically varying the gain in condensate, periodic increases in amplitudes can be achieved.

'Thus, by controlling gain and dispersion in Bose–Einstein condensate, we can engineer and tune the nature of the solitons', says Amitava, University of Burdwan, West Bengal.

The researchers could also identify a compressed shape of solitons for pure quadratic nonlinearity. There are two types of nonlinearities – one which defocuses and the other that focuses. Soliton behaviour is the result of the competition between these quadratic and cubic nonlinearities.

These insights will help us manipulate soliton structures in other non-homogeneous media and will be useful for optical communications.

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