SCIENCE FOR SOUTH AFRICA

Quest

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Acid mine drainage

Blackwater systems of the southern Cape

Sinkholes, springs and early shelters

Ocean acidification

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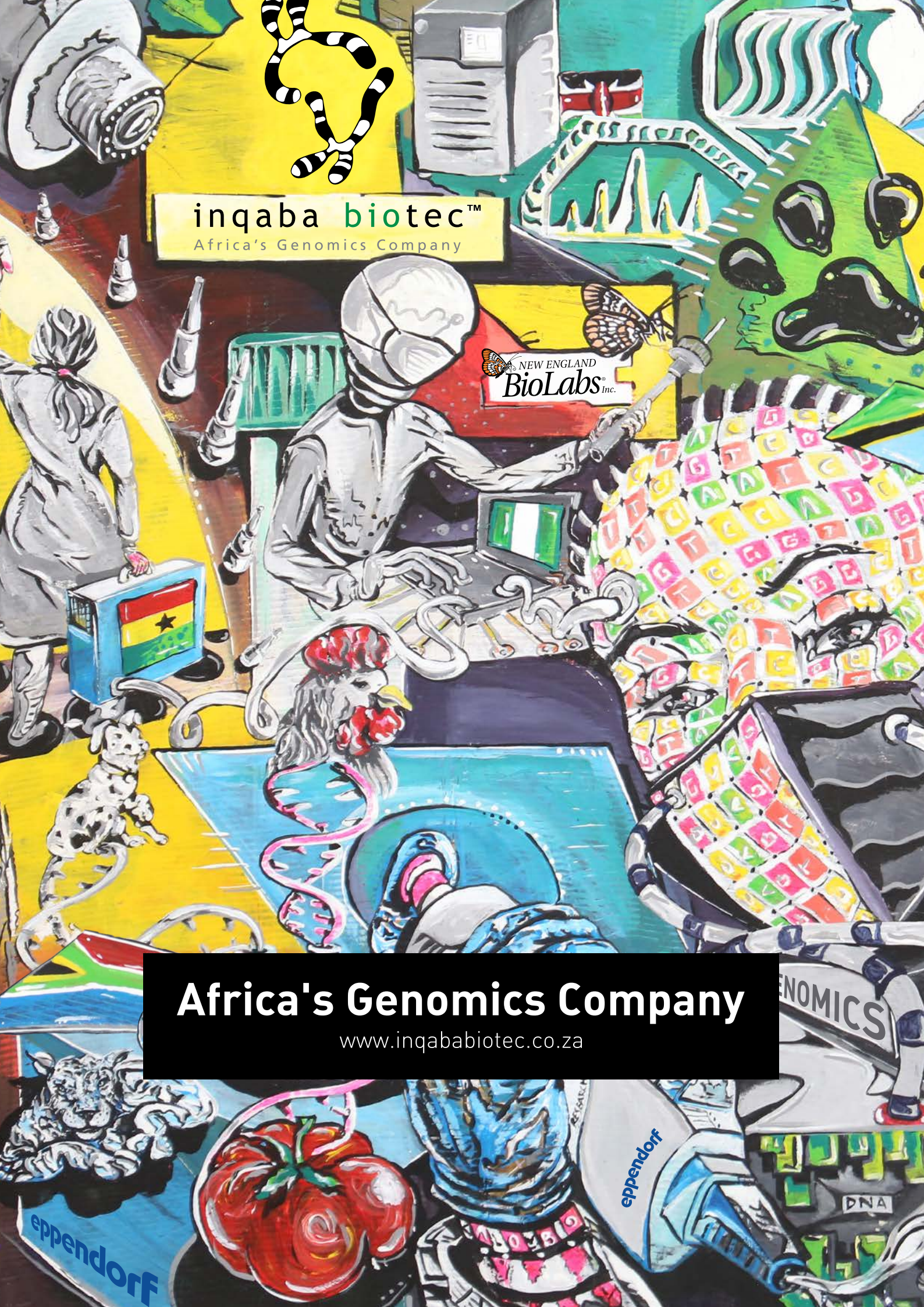
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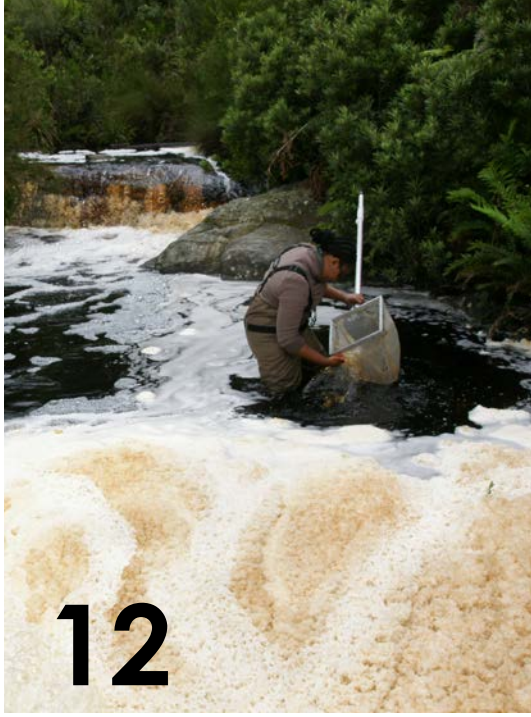

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Cover image
Canoeing on the Touws River
by Sue Matthews

Acid: The bottom end of the scale

Our cover photo shows a couple canoeing on the Touws River, having paddled upstream from the Ebb and Flow Rest Camp in the Wilderness section of the Garden Route National Park. The Touws River is one of the blackwater systems of the southern Cape, with dark, naturally acidic waters due to the presence of plant-derived humic acids and the influence of the underlying rock and soil.

In fact, rivers along much of South Africa's coast are naturally acidic to varying degrees because they flow over sandstone-derived soils. By contrast, many rivers in inland areas flow through areas with dolerite-derived soils, where calcium carbonate and magnesium carbonate dissolved in the water raises the pH, resulting in alkaline water. The high concentration of calcium and magnesium cations make this mineral-rich 'hard water', while the acidic waters of the Cape are considered 'soft' because the concentration of calcium carbonate is below 60 mg/L.

What are the implications of naturally acidic rivers for our water supplies? The gastric acid in our stomach is typically more acidic than water we might drink directly from a river, and most people are able to consume acidic citrus juices and carbonated beverages without ill effect. But water that is supplied by municipalities and water boards must be treated, and both the colour and the low pH present problems for the water treatment process that need to be addressed.

Water is treated to destroy microorganisms that could be harmful to consumers, to remove suspended solids, and to ensure its chemical composition is not damaging to the distribution system. Acidic, soft water may not only corrode water pipes and reservoirs, but also contaminate the supply with dissolved metals that might be dangerous to human health and will affect the water's taste.

The humic acids and other organic compounds imparting the dark colour must first be removed or they would react with the chemicals used for disinfection, such as chlorine, calcium hypochlorite, ozone or hydrogen peroxide. This would reduce the effectiveness of treatment while also increasing the concentration of disinfection by-products, many of which are toxic. Removal is achieved by coagulation and flocculation – adding chemicals that cause particles to clump together into aggregates large enough to settle out or to be filtered out.

Before or after disinfection, the water must be 'stabilised' before it enters the distribution system. The pH is raised by adding lime so that the water is slightly supersaturated with calcium carbonate ($CaCO_3$), which causes $CaCO_3$ to precipitate out and form a thin 'eggshell' layer on the surface of concrete pipes, protecting them from corrosion. If the water is then too alkaline, carbon dioxide (CO_2) is bubbled through the water to adjust the pH.

Of course, apart from the naturally acidic rivers and streams in South Africa and other countries, all watercourses as well as soils, plants, animals and even our oceans can be affected by human-induced acidification. This may be caused by diffuse sources such as rising CO_2 levels resulting in acid rain and ocean acidification, or point sources such as pipeline discharge of industrial effluents, or both as in the case of acid mine drainage. In this issue of *Quest*, we explore various naturally acidic environments and types of human-induced acidification, and consider the various implications.

Sue Matthews
Quest Editor

Isihloko salesiqephu se *Quest* simayelana ne asidi. Sigxila kwizindawo ezine asidi ngokwemvelo noma ngenxa yomshikashika wabantu.

Translated by Zamantimande Kunene

ACIDS, ALKALIS, AND THE pH SCALE

The pH scale is a way of gauging the acidity or alkalinity of a solution. It is calculated using: $pH = -\log_{10}[H^+]$. Adding an acid to water increases the H^+ (H_3O^+) concentration, and decreases the OH^- concentration. An alkali does the opposite.

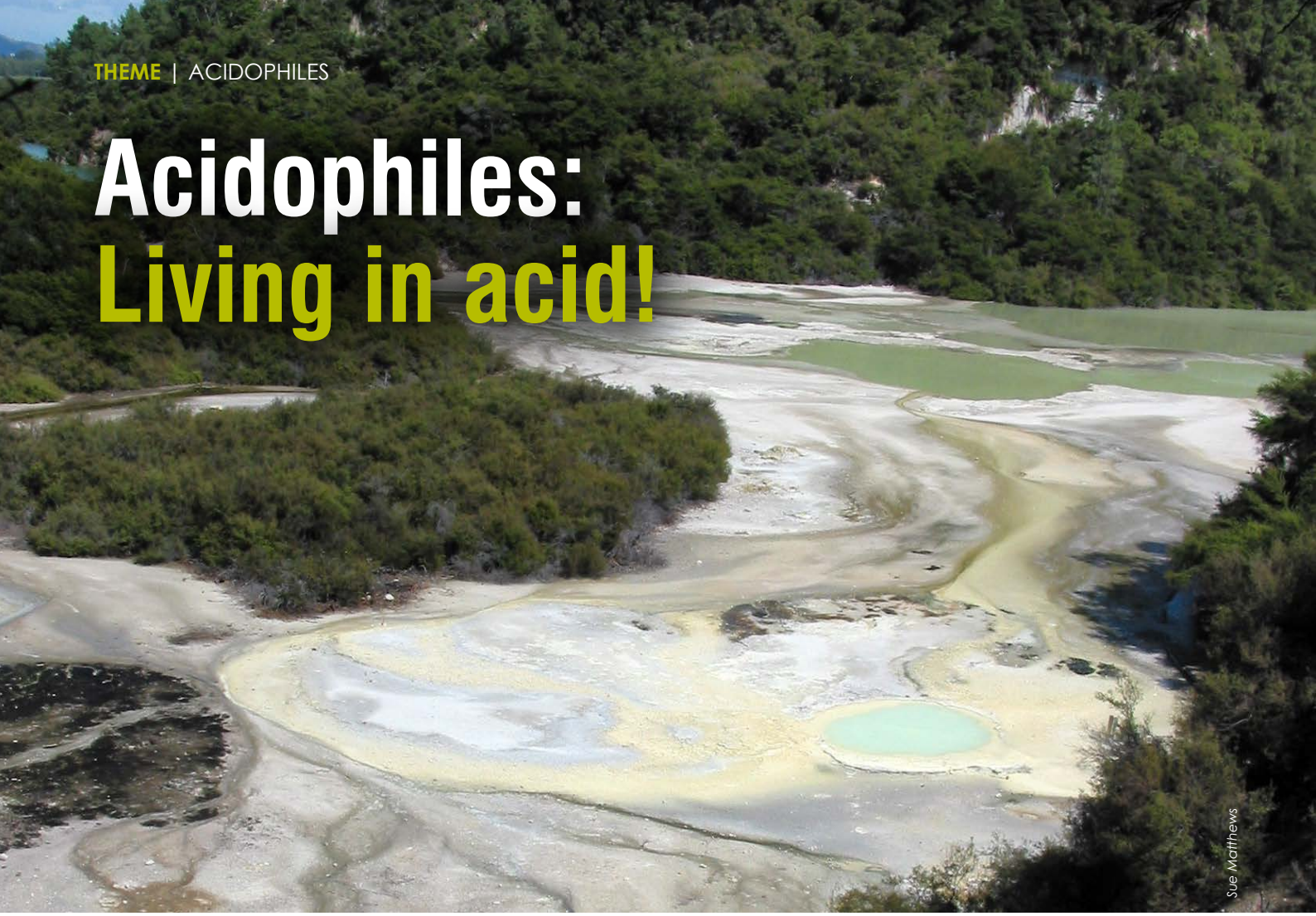
ALKALINE (Purple → Blue → Turquoise)

NEUTRAL (Green)

ACIDIC (Yellow → Orange → Red)

pH	H^+ CONCENTRATION (in moles per litre)	OH^- CONCENTRATION (in moles per litre)	EVERYDAY EXAMPLE
14	1×10^{-14}	1	Drain Cleaner 
13	1×10^{-13}	0.1	Bleach 
12	1×10^{-12}	0.01	Ammonia 
11	1×10^{-11}	0.001	Soap 
10	1×10^{-10}	1×10^{-4}	Antacid Tablets 
9	1×10^{-9}	1×10^{-5}	Baking Soda 
8	1×10^{-8}	1×10^{-6}	Seawater 
7	1×10^{-7}	1×10^{-7}	Pure Water 
6	1×10^{-6}	1×10^{-8}	Urine (average) 
5	1×10^{-5}	1×10^{-9}	Black Coffee 
4	1×10^{-4}	1×10^{-10}	Tomato Juice 
3	0.001	1×10^{-11}	Soda 
2	0.01	1×10^{-12}	Lemon Juice 
1	0.1	1×10^{-13}	Stomach Acid 
0	1	1×10^{-14}	Battery Acid 

Acidophiles: Living in acid!



Don Cowan gives an overview of microorganisms adapted to acidic environments

The world has many acidic environments, some man-made but most natural. The best known of the former would be acid mine drainage (AMD), the product of acid-releasing oxidation processes when mineral deposits are exposed to air as a result of mining activities. The pH of AMD can vary widely but is mostly between 2 and 6. Given that most terrestrial organisms are not adapted to living in even mild acid, AMD can have a devastating effect on local vegetation, as well as on aquatic life in contaminated surface waters, such as rivers and wetlands.

Of the natural acidic environments, the human stomach is probably the best known. The human gut, which includes the stomach, small intestine and colon, is home to a vast array of different microorganisms, but only the stomach is an acidic environment, normally with a pH range between 1 and 3. In the stomach, relatively few microbial taxa persist, represented by the genera *Streptococcus*, *Staphylococcus* and *Lactobacillus*. These organisms are mostly beneficial, and *Lactobacillus* is a well-known probiotic. Not all gut bacteria are beneficial, however: the gram-negative spiral bacterium, *Helicobacter pylori*, is the causative agent of chronic gastritis and peptic ulcers.

On a landscape scale, geothermal areas around the world typically have extensive acid-water streams and pools. These are mostly dominated by sulphuric acid, produced when reduced sulphur carried to the surface from the deep subsurface comes in contact with atmospheric oxygen and undergoes chemical and/or microbiological oxidation. Often the reduced sulphur is in the form of hydrogen sulphide (H_2S), which is why hydrothermal areas always smell of rotten eggs! The reaction can be described as follows:

$$H_2S + 2O_2 \rightarrow 2H^+ + SO_4^{2-}$$

The hot springs and geysers of such hydrothermal areas are created by the mixing of upwelled, superheated subterranean water with cold surface water to yield temperatures ranging from boiling to ambient.

Life at low pH

Many organisms have adapted to live comfortably in acidic environments. Such organisms are termed 'acidophiles', meaning acid-loving, and most of them are microorganisms – bacteria, fungi and archaea. At the more extreme end of the environmental acid scale (<pH 3), virtually all acidophiles are prokaryotes, being either bacteria or archaea. Two of the commonest acidophiles, found in acid mine drainage and natural acid springs, are the bacterial species *Acidithiobacillus ferrooxidans* and *Leptospirillum ferrooxidans*. Both have the ability to grow chemoautotrophically on ferrous irons (Fe^{2+}) and elemental sulphur (S_0). In other words, they acquire energy from the oxidation of Fe^{2+} or S_0 and use the energy to drive CO_2 fixation.

'Thermoacidophiles' are bacteria and archaea that have adapted to live in environments of both low pH and high temperature, a combination of extreme environmental factors that should impose huge stresses on microbial

Don Cowan

A boiling, acidic mud-pool at Whakarewarewa thermal area in New Zealand belches hydrogen sulphide.

survival. Nevertheless, organisms such as *Sulfolobus solfataricus* grow best at 80°C and between pH 2 and 4. The current leaders in the 'most acidophilic organism on Earth' competition are members of the genus *Picrophilus*, which can grow at a pH of −0.06 and a temperature of 60°C.

Comparatively little is known of low-temperature, or 'psychrophilic', acidophiles. *Acidithiobacillus*-like organisms have been reported from High Arctic soils, but cold acid niches are much less common on Earth than hot acid niches.

Survival strategies

Low pH is generally considered to be very damaging to biological molecules (many proteins denature at low pH, which is why lemon juice is used to 'cook' raw fish). The ability of acidophiles to thrive under such conditions suggests that these organisms have adapted structurally and physiologically to withstand high acid levels.

Several decades of research have uncovered some fascinating examples of such adaptation. Firstly, the cytoplasm of acidophilic microorganisms is not at equilibrium with the external environment. The internal pH of these organisms is often at near-neutrality. To achieve this, the cells have to expend a lot of energy to constantly pump protons out of the cell. Secondly, acidophiles have adapted the cytoplasmic membrane – the critically important barrier between the external environment and the sensitive cytoplasmic contents – to be resistant to acid. Their cytoplasmic membranes contain a lipopolysaccharide-type material called lipoglycan, which consists of an unusual tetra-ether lipid monolayer membrane annotated with mannose and glucose, rather than the normal ester-linked bilayer membranes of most organisms.

Roy Luck, CC BY 2.0

Yellowstone National Park in the United States contains more than 10 000 hydrothermal features. Sulphur Caldron is one of the most acidic hot springs, with a pH of approximately 1–2. In June 2016 a young man planning to take an illegal 'spa bath' in an area closed to tourists died after falling into a hot acid pool. When a rescue team returned to recover his body the following day, no remains could be found, so it was presumed he had dissolved overnight!

Acidophiles and biotechnology

A number of acidophiles, particularly thermoacidophiles, have biotechnological applications. For example, in the field of biohydrometallurgy they allow high-value minerals such as gold, uranium and copper to be recovered from sulphidic ores. Basically, the thermoacidophilic microorganisms degrade the mineral sulphides, releasing the high-value minerals as soluble ions or metal particles that can then be separated out.

Heap-leaching involves spraying ore piles containing natural populations of acidophilic microorganisms with acidic water so that the leachate draining from the base of the pile can be collected and the solubilised mineral recovered. The process is commonly applied around the world, while some ore-rich countries have established more specialised stirred-tank reactor systems, often operating at high temperatures with populations of the thermoacidophilic archaea *Sulfolobus* and/or *Acidianus*.

Don Cowan

Bacteria in this acidic slimes dam in the Zambian copperbelt could potentially be used to recover valuable metals in waste ores, a process known as biohydrometallurgy.

To their credit, South African researchers and companies have been leaders in the development and commercial implementation of such technology. At Stellenbosch University Professor Doug Rawlings, who sadly passed away in May 2020, was an international leader in the development of biomining processes using the moderate acidophile *Acidithiobacillus*. This organism has the added advantage of exhibiting a very high resistance to the toxic anions of arsenic. This is particularly important because gold-bearing arsenopyrite ores are common but very difficult to process biologically due to the high arsenic content. The development of high-temperature biohydrometallurgical processes is continuing at the University of Cape Town's Centre for Bioprocess Engineering Research, under the leadership of Professor Sue Harrison.

Prof. Don Cowan is the director of the Genomics Research Institute and the Centre for Microbial Ecology and Genomics at the University of Pretoria. He was raised and educated in New Zealand, which is well known for its geothermal waters.

Chris Curtis

Mauro Lourenco tells us about acid mine drainage, and the secondary impacts associated with its treatment

Acid mine drainage (AMD) – the flow of contaminated water from both active and inactive mines – is a worldwide problem and one of the most damaging forms of water pollution. Apart from being highly acidic, AMD is likely to contain toxic heavy metals and radioactive particles, which are dangerous to human health and the natural environment. Heavy metals are metals and metalloids that have a relatively high density compared to water, and include lead, cadmium, chromium, mercury and arsenic as some of the most toxic examples. Some heavy metals, such as iron, copper and zinc, are essential trace elements for our health at very low concentrations but are toxic at high concentrations.

To understand how AMD occurs, one should imagine the processes occurring in a mine whilst it is still active. Mine workers dig deep into the earth, often below the water table, to extract mineral ore during mining operations, so water is constantly pumped out to ensure the mine does not get flooded and workers are kept safe and dry. Once the mineral ore resource has been depleted and the mine is abandoned, the need for pumping stops, and groundwater as well as ingress from rainfall runoff and surface streams slowly fill up the mine voids that were created during mining. Now the ore that has been locked away in the underground rock for millions of years is exposed to air and water, causing oxidation of metal sulphides such as iron sulphide – commonly known as pyrite or 'fool's gold'.

The chemistry of pyrite oxidation is complex and a number of different chemical reactions may occur in sequential stages, the reaction rate being dependent on the pH and the presence of certain bacteria. The overall process can be summarised by the following reaction:

$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 8SO_4^{2-} + 16H^+$
Pyrite + oxygen + water ⟶ 'yellowboy' + sulphate + acid

'Yellowboy', or ferric hydroxide, is a yellow-orange solid that precipitates out and discolours water. It is damaging to

Chris Curtis

The distinctive orange colour of acid mine drainage is due to 'yellowboy', a precipitate composed mainly of iron(III) hydroxide, also known as ferric hydroxide.

plant and animal life, and toxic to consume. The release of hydrogen ions lowers the pH, generating acidity. The acidic water then reacts with other minerals, releasing additional heavy metals and other elements, many of which stay in solution because the metals do not precipitate easily under acidic conditions. The water slowly moves through the mine voids, encountering other exposed rock faces, and eventually decants (pours out) at the surface.

What's more, as ore material from underground is brought to the surface for processing, mines typically store the ore waste – called tailings – in a tailings dam or mine dump. The tailings material is exposed to the elements, resulting in further oxidation and acidity generation.

Both sources of AMD may pollute the surrounding environment, often causing species decline or mass mortalities in rivers and wetlands, and eventually rendering them practically lifeless.

South Africa's mining legacy

In South Africa, AMD is mainly associated with gold and coal mines. Understanding the problem requires us to travel back in time and appreciate the context of mining in the rainbow nation.

Gold was first discovered in 1886 in the Witwatersrand Basin, triggering the Witwatersrand gold rush and the development of Johannesburg, aptly nicknamed The City of Gold. The discovery changed the country's identity from a principally agricultural economy and society into the largest producer of gold in the world – a title South Africa held until finally being overtaken by China in 2007. South Africa has since fallen out of the top 10 in terms of production.

Although small-scale commercial coal mining had begun in Molteno in the Eastern Cape in 1870, the gold rush dramatically increased demand for coal, and large quantities were extracted from new mines on the Highveld coal fields. South Africa still relies on coal for energy production and export revenue, and the coal sector employs over 90 000 people, but many mines have been

Chris Curtis

The Tweeloopiesspruit decant point in the Witwatersrand Western Basin in February 2017. Here the 'yellowboy' precipitate is a darker orange-brown colour.

https://www.dws.gov.za/iwrp/AMDFSLTS/

The mining basins of the Witwatersrand.

abandoned over the years, and more closures are on the horizon as countries transition to renewable energy sources.

AMD was reportedly recognised as a threat as early as 1903, but the issue came to a head after the Western Basin of the Witwatersrand gold fields began decanting in 2002. By 2010 the water level in the Central Basin was rising by about half a metre per year, so an Inter-Ministerial Committee on AMD was set up in September of that year and a team of experts appointed.

Both short-term interventions and long-term solutions were ultimately identified over the following three years, and the Department of Water and Sanitation (DWS) appointed the Trans-Caledon Tunnel Authority (TCTA) to implement them. Nevertheless, complete AMD treatment is difficult to achieve, and extensive rehabilitation and restoration is needed at each location, requiring water boards, water treatment companies, engineering firms and environmental groups to band together.

The Springs AMD story

The story of AMD treatment in the mining town of Springs started in 1996 and has not yet come to a conclusion. Springs is situated in the Eastern Basin of the Witwatersrand gold fields, and the Grootvlei Proprietary Mines Ltd operated a gold mine there from 1934 until 2010. The mine is located within the Blesbokspruit wetland – designated a Ramsar Wetland of International Importance in 1986 – and is upstream of the Marievale Bird Sanctuary.

The Grootvlei gold mine started major pumping in 1995 but was ordered to stop within a few months, after orange-red AMD sludge was observed in the Blesbokspruit wetland. Due to this contamination, in 1996 the wetland was placed on the Montreux Record, which lists threatened, degraded or endangered Ramsar wetlands, and it remains on this register today. Pumping was permitted to resume in 1996 on condition that Grootvlei treated underground water in a small high-density sludge (HDS) processing plant.

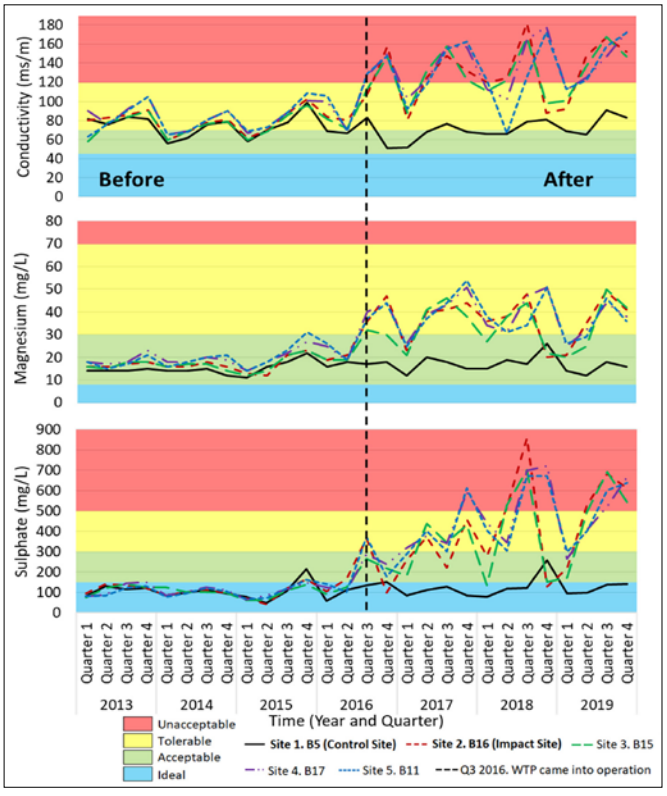
The HDS process is designed to raise the pH of the acidic mine water so that heavy metals precipitate out and can be removed. The original HDS plant improved the quality of effluent, which was discharged downstream after passing through settling ponds, but it still had a high dissolved salt content.

After closure of the mine in 2010, pumping ceased, which meant that AMD water would ultimately decant at the surface. In August 2016 the Eastern Basin AMD treatment plant was launched after two years under construction, at a total cost of R1 billion. The purpose of the plant, one of the largest of its kind in the world, is to prevent AMD decant and treat the pumped water through a bigger HDS plant.

The water is first mixed with limestone ($CaCO_3$) as a pre-neutralisation step, and then agitated and aerated to oxidise the ferrous iron and manganese. Lime ($Ca(OH)_2$) is added to raise the pH further, followed by polymers that act as flocculating agents – causing solid particles to aggregate – in the gypsum crystallisation tank. Here, metals precipitate as metal hydroxides, while sulphate ions and calcium ions form gypsum ($CaSO_4 \cdot 2H_2O$). In the thickeners section, the effluent is clarified as the solids are settled out as a sludge consisting of metal hydroxides and gypsum. Some of the sludge is recycled back to the start of the process to aid neutralisation and precipitation, and the rest disposed down the old Grootvlei No. 1 shaft. The treated effluent is discharged into the Blesbokspruit.

Impact of the treatment plant

Unfortunately, the current situation at Grootvlei is similar to when the original small HDS plant was operating. The issue is due to basic chemistry: when we neutralise something acidic – in other words, we add a base to an acid – we generate salt and water.



Lourenco and Curtis, 2021

Time-series charts for conductivity, magnesium and sulphate monitored by Rand Water at Blesbokspruit sites for the period 1 January 2013 to 31 December 2019. The colours on the charts correspond to the Blesbokspruit Forum water quality guidelines for each specific variable. The dashed black line indicates the quarter in which the treatment plant came into operation (Q3 2016).

AECOM/ NGAGE

The Eastern Basin AMD treatment plant, designed by AECOM for the Trans Caledon Tunnel Authority (TCTA), is one of the largest high-density sludge (HDS) plants in the world, with a maximum treatment capacity of 110 ML/d.

I researched the influence of the new treatment plant on the Blesbokspruit wetland for my MSc degree, awarded by the School of Geography, Archaeology and Environmental Studies at the University of the Witwatersrand. An analysis of data from Rand Water, which conducts regular sampling at a number of sites within the wetland as part of a monitoring programme, shows that all the sites had similar seasonal patterns of conductivity, magnesium and sulphate levels before the AMD treatment plant came into operation. After the treatment plant started, however, these parameters increased dramatically at sites 2, 3, 4 and 5, which are all downstream of the plant, and conductivity and sulphate have reached unacceptable levels. Site 1 is upstream, so it does not show evidence of changing water quality through time.

In general, salts that dissolve in water break into positively and negatively charged ions. The major positively charged ions are sodium (Na^+), calcium (Ca^{2+}), potassium (K^+) and magnesium (Mg^{2+}). The major negatively charged ions are chloride (Cl^-), sulphate (SO_4^{2-}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), nitrate (NO_3^-) and phosphate (PO_4^{3-}). Conductivity is the ability of water to conduct an electrical current, and the dissolved ions are the conductors. Salinity is a measure of the amount of salts in the water. Because dissolved ions increase salinity as well as conductivity, the two parameters are related.

The evidence of a highly saline environment downstream of the treatment plant are clear to all who visit Marievale Bird Sanctuary, as salt crusts can be observed on soil surfaces where water has evaporated. Highly saline environments are not only potentially damaging to species that cannot tolerate the salty conditions, but the Blesbokspruit is also a tributary to the Vaal River System, an important water source. Although the Blesbokspruit joins the Vaal River below the Vaal Dam, which is the main drinking water supply for the people of Gauteng, water already has to be released periodically from the Vaal Dam in order to dilute

Mauro Lourenco

At Marievale Bird Sanctuary downstream of the treatment plant, salt crusts can be seen on soil surfaces where highly saline water has evaporated.

water released from the Vaal Barrage further downstream, to ensure it is not too saline for irrigation and other uses. This means that increasing salinity in the Vaal River is a threat to water security because more water would need to be released from the Vaal Dam, rather than being stored for use in Gauteng. It is therefore important that the desalination process recommended as part of the long-term solution is implemented at the Eastern Basin AMD treatment plant in order to produce acceptable water quality for the area.

In September 2020 the Minister of Human Settlements, Water and Sanitation, Lindiwe Sisulu, gazetted the Reserve for the water resources in the Vaal Water Management Area. The Reserve includes the Ecological Water Requirements (EWR) and the Basic Human Needs Reserve (BHN) for the rivers in the management area. As such, it stipulates the water quality ecological specifications – including the concentration of various inorganic salts – that must be maintained at an EWR site on the Blesbokspruit below the Eastern Basin AMD treatment plant, and also makes recommendations to improve the ecological state of the wetland.

Historical issue: future problems

AMD is a historical mining issue in South Africa. The numerous problems associated with many abandoned mines and some of the largest tailings dumps in the world, including acidity, biodiversity loss, threatened water resources and health risks, were born over 100 years ago and are predicted to continue for the foreseeable future. In our water-scarce nation, these AMD impacts cannot be ignored, and will require ongoing management action.

- Lourenco, M and Curtis, C 2021. The influence of a high-density sludge acid mine drainage (AMD) chemical treatment plant on water quality along the Blesbokspruit wetland, South Africa. *Water SA* 47(1): 35-44. https://doi.org/10.17159/wsa/2021.v47.i1.9443

Mauro Lourenco is a PhD student at the University of the Witwatersrand's School of Geography, Archaeology and Environmental Studies. His doctoral research explores carbon sequestration in the peatlands of the Angolan highlands.

Chris Curtis

Acid drainage also flows from tailings – the ore residues after mineral processing – and in South Africa this is typically referred to as acid rock drainage (ARD).

Chris Curtis

Mauro Lourenco collecting water samples at Marievale Bird Sanctuary in 2018.

Chris Curtis

Chris Curtis

The blackwater Skeinsbos River flows through fynbos and forestry plantation in the Diepwalle section of the Garden Route National Park, while the less-acidic, 'white' Petrus Brand River flows through its indigenous forest.

SOUTHERN CAPE STREAMS

Chris Curtis reports on the Garden Route's naturally acidic black and white streams

Acidic pollution arising from either point sources, such as acid mine drainage, or more diffuse sources, such as acid rain, is a major threat to freshwater ecosystems in many parts of the world.

In some regions, however, slow weathering of certain rock types – including granite and quartzite – may result in naturally acidic soils that give rise to acidic surface waters draining their catchments. In addition, many wetlands generate acidic water through slow decomposition processes that release humic and fulvic acids and other organic compounds. The water often has a characteristic dark brown colour, and such peat-stained waters are associated with wetlands in many parts of the world and a few areas of South Africa.

Uniquely, in the fynbos biome of the southern Cape, there are many naturally acidic, brown streams that are not associated with the presence of wetlands. Known as blackwater streams, they are recognised for their endemic, acid-tolerant fauna.

As the streams merge into rivers downstream, they are affected by the landscapes through which they flow, as well as human activities. Higher total dissolved solids (TDS) and turbidity in the lower reaches of rivers result in more alkaline, buffered systems that are not as brown. This is why the darkest, most acidic rivers are those that originate in coastal mountains and drain straight into an estuary or directly into the sea, such as the Storms River in Tsitsikamma. By contrast, rivers with well-developed zones – mountain stream, foothills, lower river and estuary – are less acidic and relatively clear. These so-called 'white rivers' tend to be longer and include the Petrus Brand River, which rises near Diepwalle in the mountains north-east of Knysna and joins the Bitou River that discharges into the Keurbooms River estuary at Plettenberg Bay.

The causes of the dark coloration in blackwater streams have been the subject of a few studies but are only partly understood. More than 40 years ago, King et al. (1979) called for further research on the relationship between pH, colour and humic acids and the relative influences of geology, soils, vegetation and aspect for southern Cape streams. The endemic fauna and unique chemical characteristics of these streams mean they are extremely vulnerable to anthropogenic pressures such as invasive species, land cover change and acid rain.

Garden Route stream study

A recent study funded by South Africa's National Research Foundation (NRF) and the Research Council of Norway to investigate the relationships between acid deposition, streamwater chemistry and potential ecological risk for aquatic invertebrates included a comparison of 30 acidic streams of the Outeniqua Mountains, the Cape Fold Belt range behind George, Knysna and Plettenberg Bay. The Outeniqua Mountains are a Strategic Water Source Area, providing 95–100% of the water supply to the Mossel Bay, George and Wilderness areas, and many of the streams lie in the Garden Route National Park areas managed by SANParks. Some of these areas were historically transformed from indigenous fynbos and Afromontane forest to forestry plantations of pine and eucalyptus species. In recent years there has been a move towards removal of some of the plantation areas and the regeneration of natural vegetation, so the study site streams included a range of land cover types, from mountain fynbos and indigenous forest to pine plantation and rehabilitated former plantation areas, with both blackwater and white rivers sometimes in close proximity to each other.

All 30 streams, sampled over a two-year period, were moderately to very acidic, with 22 of them having a mean pH <5 and nine with a mean pH <4. The most acidic stream sampled, with a mean pH of 3.6, was the Swart River, which flows past the Nelson Mandela University campus at George. Stream colour and its relationship with dissolved organic carbon (DOC) in the water was also tested, since DOC is expensive to analyse while colour, represented by absorbance of ultraviolet radiation, can easily be measured in the laboratory with a spectrophotometer.

Streams and the carbon cycle

The role of rivers and streams in the carbon cycle is not well understood, especially in South Africa, but the blackwater streams of the southern Cape have some of the highest DOC concentrations in the world, with a mean value of 48 mg/L in one stream and spot values exceeding 100 mg/L on occasion. These very high levels of DOC suggest that Cape streams may have an important role in delivering terrestrial organic carbon into estuaries and the coastal zone. In fact, the fluxes (per unit area of land) of DOC from some of the studied streams also appear to be among the highest in the world from undisturbed systems,

Chris Curtis

Several studies have found that colour increases while pH decreases during high-flow events. This is presumably due to displacement of accumulated organic compounds in soil waters, which may also lead to natural foaming on the water surface.

exceeding 200 kg/ha/yr in some catchments and reaching over 400 kg/ha/yr in a very wet year. These fluxes are approaching those measured in streams draining highly disturbed and degraded swamp forest peats under oil palm plantations in Sarawak, Malaysia, considered to be among the highest of any systems in the world.

While the darkest streams with highest DOC and lowest pH are generally associated with the mountain fynbos catchments, there are some indications that land cover change – whether conversion to forest or rehabilitation to fynbos – may affect both the storage and transport of carbon. Any changes in water colour and DOC transport could have implications not only for biodiversity but also for local domestic water supplies, since DOC can impart a taste to drinking water and bind to toxic pollutants that are both difficult and expensive to remove.

The links between indigenous vegetation, land cover change and the possible impacts of climate change on river flows, water colour and carbon fluxes are the subject of ongoing analysis and planned future research, and could be of interest to SANParks and other local land managers. Research opportunities may also be provided by new research infrastructure under development by the Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON) in the Garden Route and Cape Town areas. Such research is urgently required to understand the possible impacts of global change processes, such as climate change and land cover change, on these precious aquatic ecosystems, about which there is still a great deal to learn.

Prof. Chris Curtis is with the Department of Geography, Environmental Management and Energy Studies at the University of Johannesburg, having moved in mid 2019 from the University of the Witwatersrand, where he supervised the theses of Mauro Lourenco and Londiwe Khuzwayo, the authors of other articles in this issue of Quest. Prior to that, he was Principal Research Associate at University College London, and ran the United Kingdom's national programme on freshwater critical loads for 14 years.

ACID RAIN

Quest explores how it became a catalyst for global cooperation in tackling environmental issues

In the 1970s and '80s, one of the environmental issues dominating news headlines internationally was 'acid rain', although scientists in Europe and North America had been researching the problem since the 1950s. In fact, the first documented use of the term was by the British chemist Robert Angus Smith in his book *Air and Rain: The Beginnings of a Chemical Climatology*, published in 1872.

"It has often been observed that the stones and bricks of buildings, especially under projecting parts, crumble more readily in large towns, where much coal is burnt, than elsewhere," he wrote. "I was led to attribute this effect to the slow, but constant, action of the acid rain."

He suggested that the acidity was caused by sulphuric acid resulting from intensive coal use in towns, as well as by nitric acids associated with the burning of biomass such as wood and peat in rural areas.

Fast forward to 1960, when Eville Gorham in Canada reported that air pollution from a smelter was causing acidification of nearby ponds. Three years later, Gene Likens and his team in the United States found that rain at the Hubbard Brook Experimental Forest was very acidic, although they were uncertain of the cause. It was only after a Swedish scientist, Svante Odén, published an article in his country's leading newspaper in October 1967 that the issue started receiving attention.

Dr Odén had been monitoring the chemistry of surface waters in Scandinavia, and had found that lakes were becoming more acidic. He attributed this to acid precipitation caused by air pollution emanating from the United Kingdom and central Europe – the International Meteorological Institute in Stockholm, Sweden, had taken over the coordinating role of the European Air Chemistry Network in 1956, so he had the data to back up his claims. He reported that lake acidification was the probable cause of declining fish catches and mass mortality events reported by fisheries officers and anglers, and suggested that soils would be affected too if they lost their neutralising ability, with negative impacts on crop production and forest growth.

Nino Barbieri, CC BY SA 3.0-

Acid rain dissolves the calcite in marble and limestone, causing damage to buildings and statues.

What is acid rain?

Acid rain is caused primarily by emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) associated with the burning of fossil fuels. The SO_2 and NO_x react with water, oxygen and other chemicals in the atmosphere to form acids such as sulphuric acid (H_2SO_4) and nitric acid (HNO_3), which fall to the ground in rain or other forms of wet (snow, fog or hail) or dry (particles or gases) deposition. For this reason, acid rain is more typically referred to as acid deposition nowadays.

While normal, unpolluted rain has a pH of about 5.6 because atmospheric carbon dioxide (CO_2) reacts with water to form carbonic acid (H_2CO_3), acid rain usually has a pH of 4–5. And since the pH scale is logarithmic, acid rain with a pH of 4.6 is ten times more acidic than normal rain.

The main sources of emissions linked to acid deposition are coal-fired power stations, metal smelters processing sulphide ores, other industry, vehicle exhausts, domestic coal- and wood-burning, and agricultural biomass-burning, but natural sources such as volcanoes, lightning and forest fires also contribute. Polluted air can be transported by wind over long distances and across national borders, making acid deposition a transboundary problem.

The publication of this rather alarming article in the same month as the release of two books by prominent Swedes on environmental degradation and overexploitation of natural resources triggered widespread public and political interest in the country. By the end of that year, Sweden had proposed that a conference be convened by the United Nations General Assembly to facilitate coordinated action on "the extremely complex problems related to the human environment".

The United Nations Conference on the Human Environment was duly held in Stockholm in June 1972. One of the first

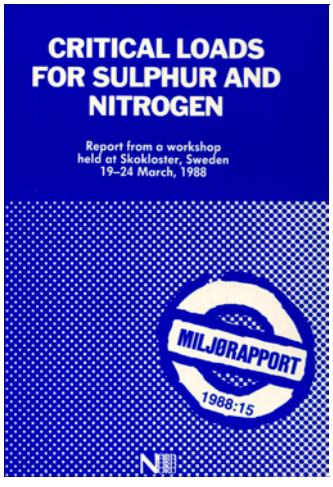
resolutions of the conference was to establish an annual World Environment Day on 5 June – a 'special day' that is still celebrated today, almost half a century later – but numerous recommendations were made and an action plan drawn up.

Prior to the conference, the secretariat had asked participating governments to prepare a national report on the state of environment in their countries, and had invited submission of papers and case studies on particular topics. Well before the conference, Sweden circulated as examples its own national report and a case study titled 'Air pollution across national boundaries: the impact on the environment of sulphur in air and precipitation', which built upon the more formal report Dr Odén had compiled a year after his headline-grabbing newspaper article.

As a result, by the end of 1972 the Organisation of Economic Cooperation and Development (OECD), which at that stage consisted of 19 European member countries plus the United States, Canada, Japan and Australia, had started a collaborative project to measure the long-range transport of air pollution over western Europe, with 11 OECD countries taking part. The project findings, released in 1977, confirmed that sulphur compounds were indeed being transported across borders and affecting the air quality of neighbouring countries.

Other projects conducted by individual countries focused on the environmental and health impacts of acid rain and air pollution. In 1979 the World Health Organisation published its first environmental health criteria for sulphur oxides and suspended particulate matter, and 30 countries and the European Union signed the world's first multilateral agreement on limiting air pollution – the Convention on Long-range Transboundary Air Pollution (CLRTAP) – negotiated under the auspices of the United Nations Economic Commission for Europe (UNECE).

The United States and Canada were among the signatories of CLRTAP, but they also signed their own Memorandum of Intent to develop a bilateral agreement on transboundary air pollution in 1980, having been engaged in a cross-border dispute over acid rain. In the same year, the US Congress passed the Acid Deposition Act, which established the 10-year National Acid Precipitation Assessment Programme (NAPAP).



The critical load concept was adopted for the Convention on Long-range Transboundary Air Pollution in 1988. The critical load was defined as 'a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge'. The quantitative estimate is expressed as the total atmospheric deposition of sulphur, nitrogen or other pollutants in kilogram per hectare per year.

Virginia, Flickr, CC BY-NC 2.0

Dieback of forests in North America and Europe in the 1980s was thought to be due to acid rain, but later attributed to the effects of drought and invasive pests.

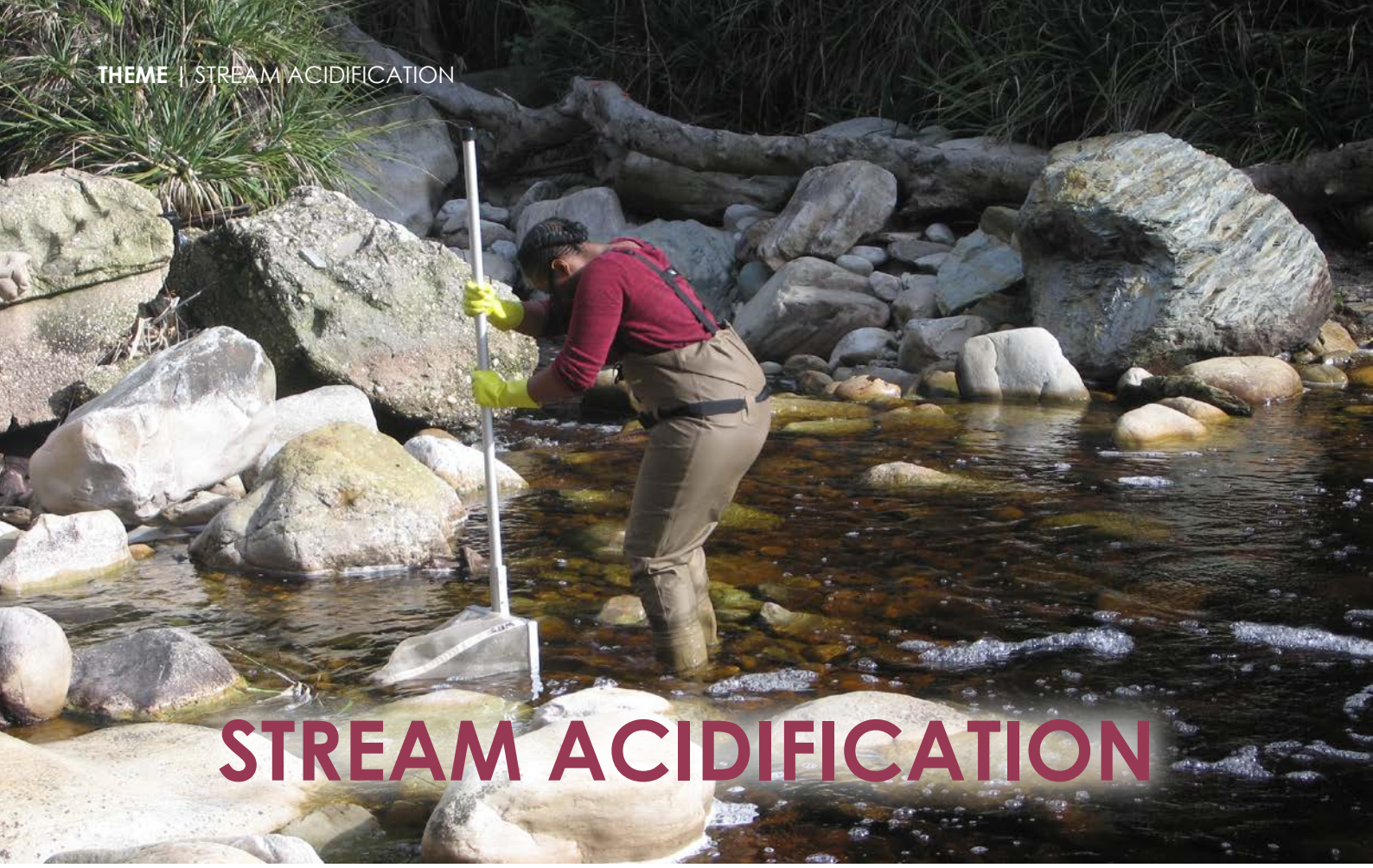
During the early 1980s, media attention on acid rain ramped up following extensive dieback of forests in both North America and Europe, particularly in the 'Black Triangle' of the Communist Bloc nations Poland, East Germany and Czechoslovakia, where outdated power stations were emitting massive quantities of air pollutants. Ultimately, however, NAPAP and European research programmes concluded that there was insufficient evidence to attribute the forest dieback to acid rain, and it was more likely caused by the 'double whammy' of drought and invasive pests.

Nevertheless, the effects of air pollutants on human health and aquatic ecosystems had been well established. In 1985 the CLRTAP's Helsinki Protocol was adopted to reduce European sulphur emissions or their transboundary fluxes by at least 30% from 1980 levels, and a similar protocol was adopted for nitrogen oxides in 1988. Canada also launched its Eastern Canada Acid Rain Programme in 1985 with reduction targets to achieve a regional cap on sulphur dioxide emissions, and in 1990 the Amended Clean Air Act was enacted to reduce emissions of sulphur dioxide and nitrogen oxides in the United States. The two countries signed a bilateral Air Quality Agreement in March 1991 to deal with acid-forming emissions and other transboundary air pollutants.

Additional protocols introduced during the 1990s committed countries to more stringent emission limits. Today, thanks to this collaborative approach in tackling the problem, emissions of sulphur dioxide have been reduced by 80–95% from 1980s levels in both Europe and North America, and those of nitrogen oxides by 50–65%.

Written by Sue Matthews drawing on the following reference and numerous other sources.

Grennfelt P, Engleryd A, Forsius M et al. 2020. Acid rain and air pollution: 50 years of progress in environmental science and policy. Ambio 49: 849–864. https://doi.org/10.1007/s13280-019-01244-4



STREAM ACIDIFICATION

Londiwe Khuzwayo shares her research on acid deposition in South African streams

The Mpumalanga Highveld, where approximately 80% of South Africa's coal-fired power stations are located, has previously been shown to have acid deposition rates comparable with those linked to soil and water acidification in European countries. We also know that air from the Highveld – together with its pollutants – can be transported in different directions and over long distances.

This tells us little about which areas are vulnerable to acidification, though, because soil type has a major influence. For example, soils derived from granite and quartzite rock, which weather very slowly, are more sensitive to acidification because they have relatively low concentrations of certain minerals that can neutralise strong acids. By contrast, limestone-derived soils are rich in calcite, a mineral form of calcium carbonate ($CaCO_3$), which allows them to counteract acidification.

The thickness of the soil layer over the underlying rock also affects the buffering capacity – the capacity to resist pH change. But even resilient soils may lose their ability to neutralise acid if minerals are leached away through acid deposition faster than they are replaced by weathering processes. Furthermore, inorganic aluminium leached from soils is toxic to plants and aquatic animals.

The maximum amount of acid deposition that ecosystems can tolerate without being damaged is called the critical load. In South Africa, the damaging effects of acid deposition are largely unknown, so I aimed to help address this in my PhD research by assessing the sensitivity of aquatic macroinvertebrates to acid deposition in headwater streams.

Why study macroinvertebrates?

Macroinvertebrates are commonly used to assess degradation of aquatic ecosystems caused by human activity such as urbanisation, industrialisation and agricultural practices. What's more, although acid deposition was shown to have a dramatic effect on fish life in Europe and North America in the past, it was subsequently discovered that particular types of aquatic insects disappeared before fish populations started declining.

A consensus was therefore reached among freshwater ecologists to use aquatic insects as early indicators of acidification. Aquatic insects are highly diverse and include species with a wide range of habitat and ecological preferences. The lifespan of most aquatic insects consists of two phases, the aquatic juvenile phase and the adult terrestrial phase. The adult insects, including dragonflies, mayflies, caddisflies, stoneflies and non-biting midges, live for only a short time, from less than a day to a few weeks, but the aquatic phase can last for a few weeks to several years, depending on the type of species and the physico-chemical properties of the water.

Previous studies have shown that different species display different tolerance levels to a variety of pollutants. For

A handheld vacuum pump was used to filter water samples for laboratory analyses.

instance, most mayflies are known for their low tolerance to pollution and are often the first organisms to disappear when a water body is polluted. A water body that lacks these sensitive taxa, but supports more tolerant taxa, is likely polluted. Even so, it's possible for an organism that's been shown to be sensitive to, for example, organic pollution to have a completely different response to changes related to other types of pollutants. Nevertheless, species that are able to survive harsh environmental conditions such as acidification tend to be resilient to a number of other adverse changes in the aquatic ecosystem.

Overall, acidified waters are generally characterised by a decline in productivity, species number and diversity, with increased dominance of acid-tolerant taxa, such as stoneflies, and a decline or absence of sensitive taxa, such as mayflies.

What was the research approach?

At the outset of my PhD research, I applied Geographic Information System (GIS) tools to identify three regions in South Africa that are potentially vulnerable to acidification. These regions – the Mpumalanga Highveld, Waterberg and the southern Cape – represent high, medium and low acid deposition loads respectively, based on the distribution of coal-fired power stations and the presence of acid-sensitive soils and waters.

Within these regions, 84 sampling sites on 80 mountain streams were then identified, with 21 sites in the Mpumalanga Highveld, 33 in the Waterberg and 30 in the southern Cape. These sites were selected on the assumption that they had no direct human influences on water quality, having no mining or intensive agriculture within their catchments, in order to focus the research on impacts related entirely to atmospheric deposition. Macroinvertebrate samples were collected from only 56 of these sites, due to habitat suitability, but water chemistry was investigated at all 84 sites. This involved measuring water temperature, dissolved oxygen, conductivity and pH with a multiprobe instrument, and collecting water samples for laboratory analyses of dissolved organic carbon (DOC) and major anion and cation concentrations.

The pH, temperature, dissolved oxygen and conductivity of streams was measured with a multiprobe instrument.

The ion concentrations are important because they are used to determine acid neutralising capacity (ANC), which has been shown to be the best correlate with biological response to stream acidification by aquatic insects. It is calculated by subtracting the sum of strong acid anions (SO_4^{2-} + NO_3^- + Cl^-) from the sum of base cations (Ca^{2+} + Mg^{2+} + Na^+ + K^+). Low base cations will lead to a low ANC, meaning that the stream has little ability to neutralise acid deposition and is therefore more susceptible to acidification and ecological impacts.

Unfortunately, determining the extent to which the three study regions are affected by acid deposition proved to be very difficult, because each differed greatly in terms of the type of aquatic insects occurring there, as well as the rainfall patterns, rock and soil formation processes, and overall response to environmental change in the short term (e.g. drought) and long term (climate change). The Mpumalanga Highveld sites had very high pH, probably because of pollution, while southern Cape streams are naturally acidic, so their macroinvertebrates are adapted to low pH. In addition, research effort on aquatic biodiversity has to date been more intensive in the southern Cape than in the Mpumalanga Highveld and Waterberg, where much of the aquatic insects remain undescribed. This created gaps in knowledge that could not be addressed within the time limits of a doctoral study.

In order to fully understand the impact of acid deposition in South Africa, more long-term research is needed as well as a collaborative approach across disciplines to avoid repetition and instances where data goes uninterpreted due to time constraints and lack of funding. The best approach would be to carry out research on the effect of acid deposition at a provincial level before attempting to address it on a national scale.

Dr Londiwe Khuzwayo completed her PhD at the University of the Witwatersrand towards the end of 2019. In April 2020 she joined the Pietermaritzburg-based Grasslands-Wetlands-Forests Node of the South African Environmental Observation Network (SAEON) as a postdoctoral researcher, focusing on the Thukela system.

Blackfly larvae on the underside of a rock.

Daniel O'Neil, CC BY 2.0

Sinkholes, springs and early shelters

Nick Baglow and Ponani Mthembi explain their acid connection

The dolomite rocks of the Transvaal Supergroup originated some 2.5 billion years ago, when this small part of the landmass that later became the African continent lay beneath a shallow sea. Cyanobacteria, also known as blue-green algae, in the water column and on the mudflats altered their surrounding chemical environment and induced the precipitation of calcium carbonate, although the mechanism is still the subject of debate. Requiring light for photosynthesis, the cyanobacteria colonies on the seafloor constantly grew through the calcium carbonate that settled out on top of them, while other bacteria began decomposing the dead and dying cells, forming dense microbial mats.

Paul Morris, CC BY-SA 2.0

Stromatolites are known mainly from the geological record, but these living examples at Shark Bay in Australia show how sedimentary rock can form from layers of cyanobacteria mats, sand and calcium carbonate. Living stromatolites also occur along the coast of South Africa.

This process resulted in layers of bacteria, calcium carbonate and sediment slowly building up to form structures called stromatolites. At some point, magnesium replaced some of the calcium carbonate in these sedimentary layers, in a process known as dolomitisation, and over geological time the layers were compressed and cemented to form hard rock.

Chemical formulae, minerals and rocks

Calcium carbonate is a chemical compound with the formula $CaCO_3$, as it is formed by the elements calcium, carbon and oxygen. It occurs in pure form as the mineral calcite. Calcite is the main constituent of the sedimentary rock known as limestone.

Dolomite is a mineral consisting of the chemical combination of calcium and magnesium carbonate, and has the formula $CaMg(CO_3)_2$. The sedimentary rock known as dolomite in South Africa is in fact 'dolomitic limestone', as it consists of the mineral dolomite mixed with calcite (calcium

carbonate, $CaCO_3$) and magnesite (magnesium carbonate, $MgCO_3$). Portions of the rock may be richer or poorer in either of the latter minerals.

Both limestone and dolomites are known as carbonate rocks. Younger deposits, mainly limestone, are found in the extreme north-west and south of South Africa. Their calcium carbonate is typically derived from the shells or skeletal material of marine zooplankton and larger invertebrates.

Karst landform

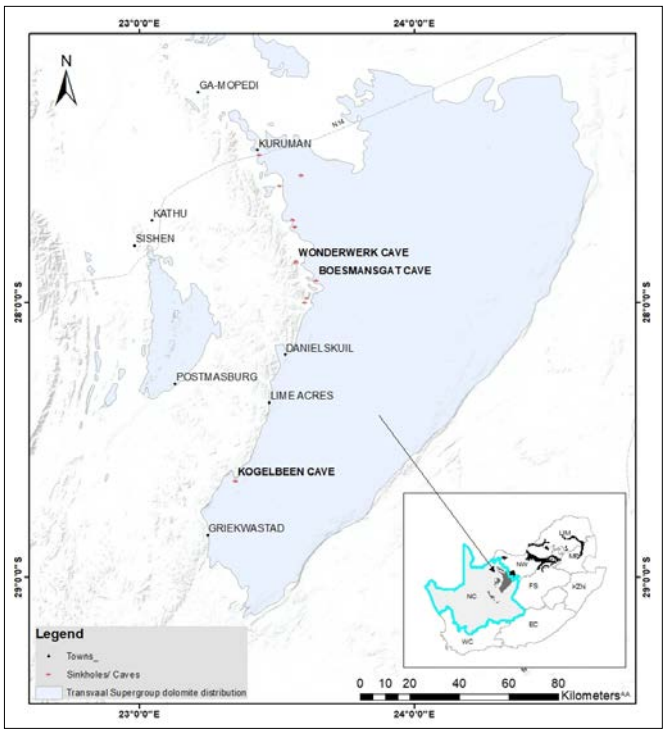
Areas underlain by carbonates are often described as having a karst landform. What is karst, and why does it occur?

Rain water (H_2O) takes up carbon dioxide (CO_2) in the atmosphere before landing on the soil surface. As it infiltrates through the soil, more CO_2 may dissolve in it, since respiration by soil organisms means that the concentration of this gas may be up to 90 times greater than in the atmosphere. The reaction of H_2O and CO_2 results in a weak carbonic acid (H_2CO_3), making the groundwater slightly acidic.

As the groundwater circulates along tension fractures, faults and joints in the rock below, it causes leaching of the carbonate minerals, effectively 'dissolving' the limestone or dolomite rock. The resulting bicarbonate-rich water may emerge at springs as naturally carbonated – or 'sparkling' – mineral water. The process may be represented as follows:

dolomite: $CaMg(CO_3)_2 + 2H_2CO_3 \rightarrow Ca(HCO_3)_2 + Mg(HCO_3)_2$

calcite: $CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2$



Council for Geoscience

The Ghaap Plateau dolomites include major karst features such as Wonderwerk Cave and Boesmansgat Cave, one of the deepest submerged caves in the world. The inset shows the distribution of the main dolomite units nationally.

@precision_tow

Mark Olalde

Sinkholes are natural geohazards in areas underlain by dolomite rock, but they are often triggered by human activities that lower the water table or cause water saturation of the soil.

This chemical weathering process, known as dissolution, progresses very slowly but results in cavities in the rock over geological time. Eventually the overlying land, lacking the support of solid rock, may subside or collapse into these cavities, creating features that are subject to further erosion. Karst is the term used to describe this uneven, pockmarked terrain in areas underlain by carbonate rock. Karst landscapes are characterised by subsidence, sinkholes, caves, springs and subterranean streams and aquifers.

Subsidence and sinkholes

The Council for Geoscience (CGS) has been investigating karst in the Ghaap Plateau, as one of the activities within its regional mapping programme. Situated in the Northern Cape, the Ghaap Plateau forms part of the Transvaal Supergroup dolomites, and the area between Kuruman and Daniëlskuil has significant karstic features. Aerial photos and satellite imagery were used to help identity depressions that were indicative of subsidence, and standard geotechnical work was carried out. The results will be used to map geohazard potential and the associated land-use risk.

Subsidence in dolomitic formations takes place in one of two ways: as a gradual or caving subsidence, called a doline,

or a rapid and catastrophic sinkhole. The risk of subsidence occurring is influenced by a variety of factors, including topography and drainage, the nature and thickness of the surface deposits and dolomite units, the depth and fluctuations of the groundwater level, and the presence of structural features such as faults, fractures and dykes.

However, subsidence events are most often triggered by a concentrated ingress of water that causes saturation, or a lowering of the water table. While either may occur naturally during floods and droughts, they are drastically accelerated by human activities, such as those that alter runoff, cause water ingress via leaking water pipes, or a drawdown of the water table through overabstraction of groundwater or dewatering for construction or mining purposes.

Not all occurrences are reported, but more than 3 000 sinkhole and subsidence events have been recorded in South Africa. About 98% of these occurred in Gauteng, the most highly urbanised and extensively built-up of the provinces, so most research into subsidence as a geohazard has focused on this region. For instance, the use of integrated geophysical applications has proved to be highly effective in delineating dangerous karstic features and mapping sinkhole vulnerability in the West Rand. An innovative early warning mechanism is currently being developed by the CGS to assist in the detection of signs of possible future collapses and allow for remote monitoring of such areas.

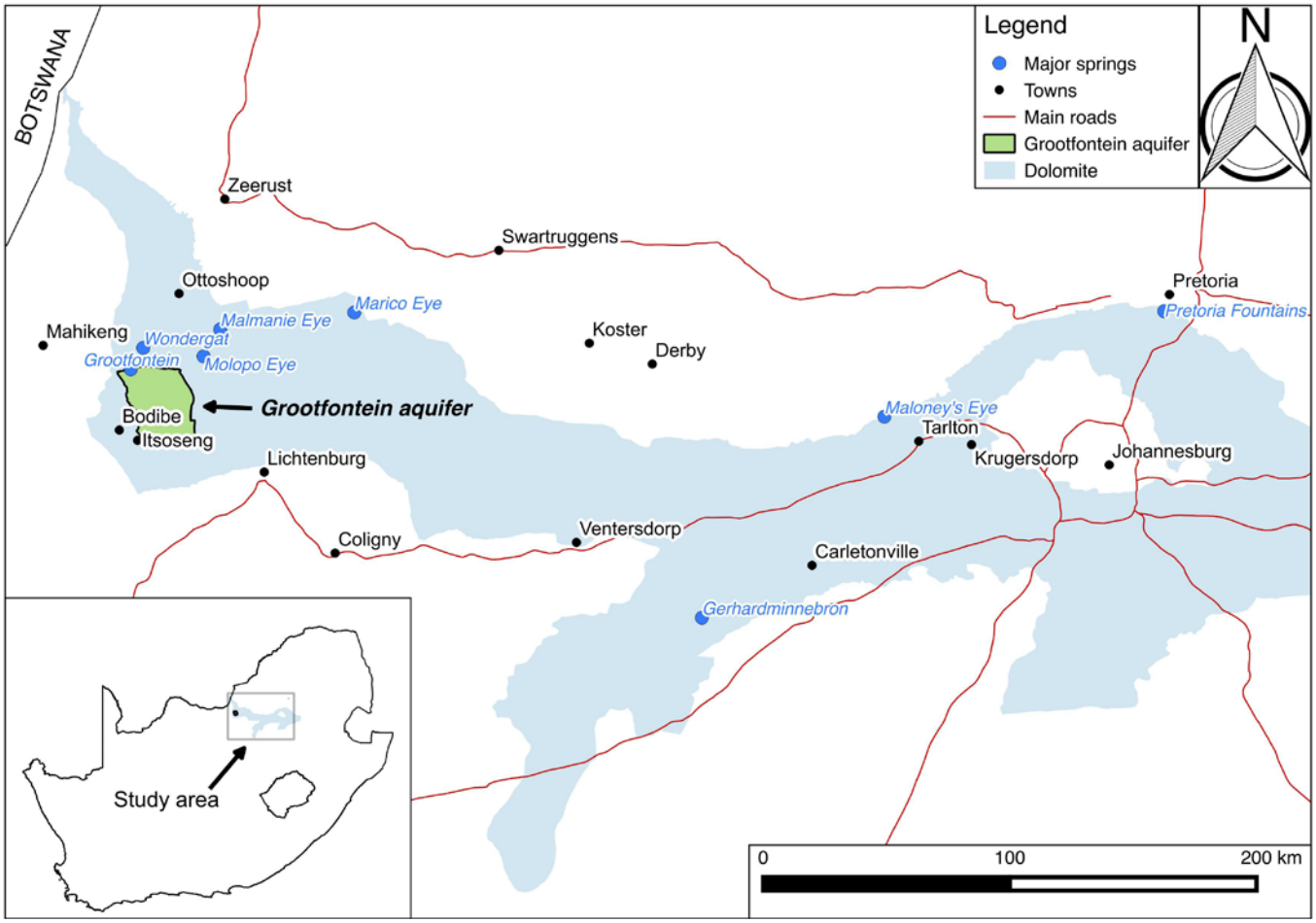
Aquifers and springs

Although the cavities in karst present a potential geohazard, they may also store large volumes of water. Indeed, karst aquifers in dolomites are recognised as the most important type of aquifer in South Africa, providing water for urban and rural households, livestock and crops, as well as industry and mining.

Lani van Vuuren

Dolomite aquifers contribute to Tshwane Municipality's water supply. Pretoria originally developed around the Fountains Upper and Lower Springs, which lie within the Fountains Valley Resort in the Groenkloof Nature Reserve. These and other springs and boreholes still provide 5–10% of the city's water supply today.

Fissures in the rock, such as faults and joints, provide a pathway for water flow, allowing dolomite aquifers to be rapidly recharged by rainfall, although this also means that the aquifers are vulnerable to contamination from pollution sources on the surface. Fortunately, South Africa's dolomite aquifers are subdivided into compartments by dykes – impermeable



Cobbing 2018. Water SA http://dx.doi.org/10.4314/wsa.v44i1.07

Mahikeng relies heavily on groundwater from the North-West dolomites, with about 40% of the city's water supply provided by the spring known as the Molopo Eye, and about 20% abstracted via boreholes targeting the Grootfontein aquifer.

Council for Geoscience

Wonderwerk Cave, on the eastern side of the Asbestos Hills near Kuruman, is a National Heritage Site because it contains significant archaeological deposits spanning almost two million years. These include simple stone tools, evidence of the use of fire, burnt animal bones, as well as more recent rock art.

'walls' of igneous rock formed from intrusions of magma, or molten rock – and this is taken into account in groundwater assessment and management.

For example, the city of Mahikeng relies heavily on groundwater from the North-West dolomites, with about 40% of the water supply provided by the spring known as the Molopo Eye, and about 20% abstracted via boreholes targeting the Grootfontein aquifer, but these sources are in different compartments. Likewise, the Fountains Upper and Lower Springs in Tshwane, which were the sole water source for the first 75 years of Pretoria's existence after its founding in 1855 and still contribute to the city's supply today, lie in different aquifer compartments, even though they are less than a kilometre apart.

Minor karst aquifers also occur within the Cango Caves Group in the Oudtshoorn area, where the karst is well known thanks to the popularity of the Cango Caves, a tourist site and Africa's largest 'show cave'.

Caves and cultural heritage

Many other such subterranean caves occur in the karst of the dolomitic limestones in the interior. Even where the surface terrain does not reflect a karstic landscape, the presence of caves is reflective of the karstic hydrology that prevailed. Caves that developed below the water table are characterised by large, flat, discoidal chambers and complex mazes of passages. These may be at a constant

Welkom Underwater Diving Club

Wondergat, near Mahikeng, is an ancient sinkhole created by the collapse of the roof of a cavern in the North-West dolomites. Fed by groundwater and more than 50 m deep, it is a popular scuba-diving site.

elevation, suggesting strong control by the former water table, as at Wonderwerk Cave near Kuruman. In other cases, large cavities can be found at great depth below the water table. For example, Boesmansgat is one of the deepest submerged caves in the world, extending to 280 m below the surface. It has been the site of a number of world diving records over the years, as well as some fatalities associated with these endeavours.

Caves are of particular interest in that they have often been used by mammals and early humans as shelters. Besides Wonderwerk Cave, other well-known examples include the Makapan's (near Mokopane) and Sterkfontein (Cradle of Humankind) caves. These deposits have been extensively investigated as they provide essential data on hominid palaeontology and climates of the recent past.

CURRICULUM CORNER

GEOGRAPHY: GRADE 10
Geomorphology: sedimentary rocks

LIFE SCIENCES: GRADE 10
Fossil formation: stromatolites

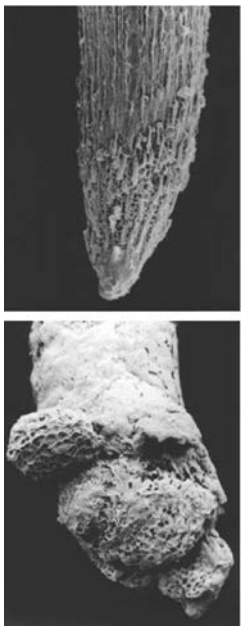
PHYSICAL SCIENCES: GRADE 10
Chemistry: reactions in aqueous solutions

Nick Baglow is chief scientist in the Mapping Geoscience Unit in the Polokwane regional office of the Council for Geoscience. Ponani Mthembi is a geoscientist in the same unit.

SOIL ACIDIFICATION

Jean-Pierre Pellissier and Pieter Swanepoel discuss its implications for agricultural systems

Soil, the matrix beneath our feet and a natural resource essential for life on Earth, is facing human-induced repercussions. Roughly 37% of all land area is classified as agricultural land intended to feed the global population, currently totalling some 7.8 billion people and increasing all the time. But with long-term intensive agriculture comes various consequences for soil health, one of these being soil acidification.



CSIRO

Microscopy reveals the difference between a normal root (top) and one affected by aluminium toxicity due to severe soil acidity.

Soil pH is considered a master variable affecting numerous chemical and biological processes within the soil. For example, the ability of plant roots to flourish and penetrate deep soil layers is greatly affected by soil pH, so it is essential for the sustainability of crop-production systems that optimal soil pH is maintained.

Causes of acidification

Two balances govern soil pH, namely the balance of acid ions and base cations on the surfaces of soil particles, and the balance of acid (H^+) and alkaline (OH^-) ions in soil-water solution surrounding soil particles. Acid soils can be ascribed to an imbalance, where H^+ ions exceed OH^- ions, resulting in low soil pH. During these conditions, base cations on soil particle surfaces are often displaced by H^+ ions, which leads to further soil acidification.

Soils acidify naturally through processes of soil formation. Weathering of soil minerals yields H^+ ions, causing a decreasing pH over time. Furthermore, even unpolluted rain has a naturally acid pH of roughly 5.6, and therefore contributes to the process of soil acidification. When mineral-rich soil is exposed to excessive rainfall, the base cations calcium, magnesium, potassium and sodium are often leached from the soil profile, resulting in an acid-base imbalance. The same applies if farmers overirrigate their crops, so this is one mechanism of human-induced soil acidification.

The main human-induced mechanism, though, is through the use of ammonium-based fertilisers, commonly used in commercial agriculture to add nitrogen to the soil. After ammonium fertiliser is applied, ammonium molecules (NH_4^+) undergo biological oxidation to nitrates (NO_3^-). During this process, the transformation of a single ammonium molecule to a nitrate molecule yields two acid (H^+) ions, contributing to acidification of the soil.

Even without fertilisers, intensive agriculture disrupts natural nutrient cycles. Particularly where a single crop type is produced season after season, soil tends to get depleted of specific essential plant nutrients. When harvesting a crop, nutrients absorbed via plant roots and incorporated into seed or fruit are removed, resulting in loss of soil calcium, magnesium and potassium in the long term. Depletion of these base cations leads to soil acidification over time.

Jean-Pierre Pellissier establishes treatment blocks with different forms and sources of lime to create a randomised block design field trial, like the one for wheat shown in the aerial photo taken with a drone.

Impacts on agriculture

Soil acidity has immense implications for agricultural sustainability as most crops grow optimally in the pH range 5.8–6.5. Soil pH below 5.5 tends to decrease a soil's crop-production potential.

Soil pH ultimately controls nutrient availability to plant roots. Although a soil's nutrient content might be sufficient for a specific crop, soil pH regulates whether nutrients are accessible to crop roots. Therefore, soil pH truly regulates crop nutrition. Farmers often inadvertently overfertilise their crops, causing nutrient pollution of nearby watercourses, because their crop plants are showing signs of nutrient deficiencies, not realising that the problem is soil pH rather than insufficient soil nutrients.

Soil biology is also adversely affected by acidification. Under acidic conditions, fungal communities tend to dominate whilst bacterial communities diminish. Soil bacteria play an essential role in nutrient recycling of soil organic material, so conversion of organically bound nutrients to plant-available nutrients is retarded in very acidic soil. In addition, soil bacteria are vital for biological nitrogen fixation, a process whereby nitrogen is sequestered from the atmosphere and converted to plant-available forms of nitrogen within the soil. For these reasons, soil acidity requires increased dependency on synthetic fertilisers for nutrients.

What's more, at low soil pH the elements aluminium, manganese, zinc and iron become soluble. High levels of these soluble elements can be toxic to plant roots, which further decreases a soil's crop-production potential. Aluminium toxicity, in particular, is commonly observed in acid soil. It causes shallow, poorly developed root systems, which reduce yield by restricting access to water and nutrients.

Mitigation measures

Mitigation of soil acidification is achieved by addition of agricultural lime, a natural product derived from limestone. Agricultural lime neutralises excess H^+ ions in the soil via a chemical reaction with carbonate molecules to form water and carbon dioxide.

Regular soil sampling and analyses, every one to three years, is essential to estimate an accurate amount of lime required to alleviate soil acidity. Since lime is fairly immobile within the soil and does not solubilise readily, it needs to be applied at appropriate intervals to be effective.

Nowadays, conservation agriculture is being adopted in an effort to rehabilitate soil health and ensure the sustainability of our farming systems. The conservation agriculture concept relies on three fundamental principles – minimum mechanical soil disturbance (i.e. no-tillage/ploughing), permanent organic soil cover, and diversification of crop species. In the long term, however, no-tillage leads to acidic pH stratification, meaning an increase in acidity in subsoil layers because liming has only neutralised the topsoil. As a result, plant roots are often limited to the topsoil layers with little to no subsoil penetration, a phenomenon known as J-rooting.

Pieter Swanepoel

An example of J-rooting of a canola plant due to subsoil acidity in a long-term no-tillage system.

Ensuring the sustainability of crop-production systems to feed our ever-growing population requires a greater focus on soil health. While conservation agriculture aims to address the degradation of our soils, the approach has potential limitations. More research is therefore needed on ways of slowing down soil acidification, and mitigating its adverse effects.

Jean-Pierre Pellissier is conducting his MSc project at Stellenbosch University on alleviation of acidic pH stratification in no-tillage conservation agriculture systems.
Dr Pieter Swanepoel is one of his supervisors and is head of the Stellenbosch University Agronomy Department.

Jeremy Bishop, Pexels

Ocean acidification

Carla Edworthy tells us about the threat to the world's marine environment, and research advances in South Africa

It is now widely accepted that ever-increasing emissions of carbon dioxide (CO_2) from fossil-fuel burning and other human activities are causing global climate change. Some of the better-known consequences for our oceans are increasing temperatures, sea level rise and more frequent or intense storm events. But by continuously releasing CO_2 into the atmosphere, humans are significantly altering the chemistry of the oceans too. Although it is not as widely known, ocean acidification is considered the 'evil twin' of global climate change.

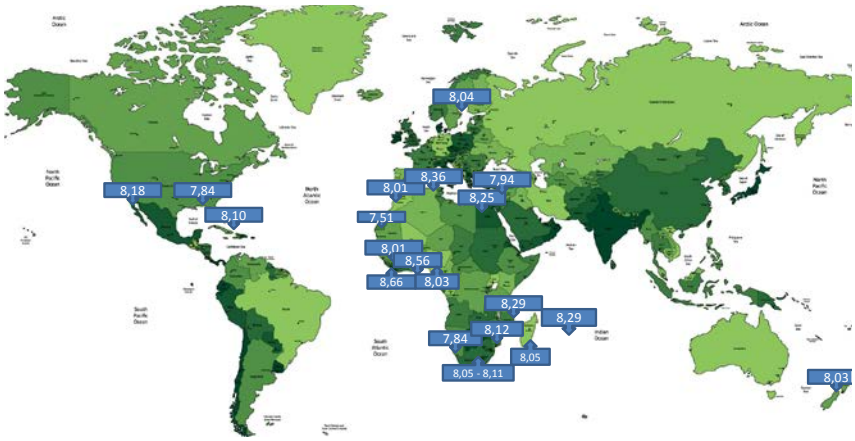
The oceans act as a giant sink for carbon because CO_2 dissolves rapidly in seawater, initiating a succession of chemical reactions. The ultimate result of these reactions is a decline in the pH of seawater. Although the global average pH is currently about 8.1, this is slowly decreasing as CO_2 continues to be absorbed by the oceans from the atmosphere. By the end of the century, the global average pH is predicted to fall to approximately 7.7 if global CO_2 emissions continue unabated, which is considered a worst-case scenario. Since pH is measured on a log scale, a drop in pH of one unit actually represents a tenfold decrease in acidity. This means that even a small change in pH significantly changes the acidity of seawater.

Changes in pH, and the resulting changes in seawater chemistry, throw everything out of balance for marine organisms by altering their external and internal acidity levels. Marine organisms are adapted to live within a range of specific environmental conditions. Different species survive and thrive within different optimal ranges of temperature, oxygen concentration, depth, light, pressure and pH. Any change in environmental conditions may affect their energy metabolism, growth, behaviour and reproduction – and ultimately threaten their survival.

In the case of pH, research has shown that even a small reduction can be detrimental to organisms that use calcium carbonate to build their shells or skeletons, such as sea urchins and corals. Furthermore, organisms not adapted to regulating internal pH levels need to allocate more energy to maintaining their internal pH, which can come at a cost to their growth and other survival processes. Many marine organisms also use chemical signals that may be disrupted at low pH levels, either by affecting the signal molecules themselves or by affecting the organisms' chemosensory receptors that allow them to detect the signals. Experimental studies have shown that reducing the pH of seawater changes the behaviour of some fish and crabs, for instance, by affecting their ability to smell or hear, which would compromise

Carla Edworthy

This device, which measures seawater pH and temperature every half hour, is deployed in shallow water in Algoa Bay (Port Elizabeth / Gqeberha) for a few days at a time to monitor ocean acidification.



OA-Africa Network

This map summarises the pH data collected by scientists and citizens in Africa and supporting countries on OA-day in 2017, organised by the OA-Africa Network.

routine survival activities like finding food, avoiding predators or selecting a mate.

Despite the negative impacts of acidification, organisms that are tolerant of low pH conditions do exist. For example, in some coastal environments where pH is typically lower than the rest of the ocean, species are adapted to tolerate large pH fluctuations and relatively low pH levels. These organisms have the energetic capacity to withstand changing pH levels in the environment by using mechanisms to regulate their internal pH. However, there is still uncertainty around long-term changes in pH that will occur with ocean acidification in these environments, and whether organisms will be able to tolerate persistently lower pH levels predicted for the future.

Although relatively little data on ocean acidification has been collected in Africa to date, research in the region is steadily gaining momentum. A network called OA-Africa has been established with the assistance of international advisors to coordinate and promote ocean acidification research in Africa, and this forms part of the broader Global Ocean Acidification Observing Network (GOA-ON).

In South Africa, researchers from the west, south and east coasts are collaborating to monitor local ocean acidification in coastal and oceanic environments, by measuring pH and other environmental parameters on a regular basis. They also use both field and laboratory experiments to identify the impacts of future ocean acidification conditions on key seafood species, as well as species that are integral to maintaining functional ecosystems such as coral reefs.

Researchers from South Africa have participated in several training events and capacity development programmes hosted by international organisations, such as GOA-ON and regional networks, and are contributing data on ocean acidification and its impacts to international databases. Target 14.3 of the Sustainable Development Goals adopted by the United Nations member states is to "minimise and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels" and its indicator requires that pH is measured at an agreed suite of representative sampling stations. Various online data platforms have therefore been set up internationally to facilitate the submission, collection, storage and sharing of data on ocean acidification and biological responses.

In June 2017 researchers in South Africa, in collaboration with international organisations, participated in an event called 'OA-day', aimed at increasing awareness of ocean acidification in science communities and society. Several activities were organised, including a coordinated effort from both scientists and citizens across the country to measure pH at multiple locations along the coastline. Videos, social media posts, popular articles and interviews on national radio and television were shared in order to spread the word about ocean acidification. The event was hosted concurrently in a number of other African countries and was considered a huge success. Similar events are planned for the future to continue the momentum of creating awareness of ocean acidification within society.

Much research still needs to be done, in South Africa and internationally, in order to understand the rate at which acidification occurs in the various marine environments and how it will affect marine ecosystems in future. The only real solution to ocean acidification is to reduce CO_2 emissions on a global scale. Increased awareness of ocean acidification and other climate change issues is imperative to encourage both personal and governmental action in reducing emissions. Such action is vital to mitigate the impacts on marine ecosystems as well as coastal communities, who look to the oceans as a source of food, economic benefit, cultural identity and recreation.

Richard Llewellyn

Carla Edworthy (in red jacket, standing) with other scientists participating in OA-day in 2017 by measuring the pH of seawater at a coastal site in Algoa Bay.

Dr Carla Edworthy submitted her doctoral thesis on 'Coastal pH variability and the eco-physiological and behavioural response of a coastal fish species in light of future ocean acidification' at the end of 2020, and was awarded her PhD by Rhodes University in April 2021. She is currently a postdoctoral researcher at the South African Institute for Aquatic Biodiversity (SAIAB), monitoring ocean acidification and its impacts in coastal environments and vegetated habitats.

Tshwane University of Technology

We empower people

THE FOLLOWING HEQSF ALIGNED QUALIFICATIONS ARE PRESENTED

- Bachelors of Architecture APS≥(25)
- Bachelor of Architecture (Extended) APS≥(25)
- Diploma in Industrial Design APS≥(21)
- Advanced Diploma Industrial Design (consult Prospectus for Admission Requirements)

- Diploma in Building APS≥(25)

- Bachelor of Engineering Technology in Chemical Engineering APS≥(28)
- Bachelor of Engineering Technology in Metallurgical Engineering APS≥(28)
- Bachelor of Engineering Technology In Materials Engineering in Polymer Technology APS≥(28)

- Higher Certificate in Construction Engineering: Construction Material Testing APS≥(20)
- Higher Certificate in Construction Engineering: Water and Wastewater APS≥(20)
- Bachelor of Engineering Technology in Civil Engineering APS≥(28)

- Bachelor of Geomatics APS≥(25)

- Higher Certificate in Electrical Engineering APS≥(20)
- Diploma in Electrical Engineering APS≥(28)
- Bachelor of Engineering Technology in Electrical Engineering APS≥(30)

- Higher Certificate in Industrial Engineering APS≥(20)
- Bachelor of Engineering Technology in Industrial Engineering APS≥(28)

- Higher Certificate in Mechanical Engineering APS≥(20)
- Bachelor of Engineering Technology in Mechanical Engineering APS≥(28)

- Bachelor of Engineering Technology in Mechatronics APS≥(28)

The introduction of the Higher Education and Qualification sub framework (HEQSF) in the Higher Education sector required all public and private higher education institutions (HEIS), including Tshwane University of Technology (TUT), to revise all its qualifications to ensure alignment with the HEQSF.

Entrance requirements: NSC, NCV, etc. Consult the latest Prospectus of the Faculty of Engineering and the Built Environment for detailed entrance requirements.

The following new HEQSF-aligned qualifications are planned in future

- Bachelor of Engineering Technology Honours in Civil Engineering
- Bachelor of Engineering Technology Honours in Mechanical Engineering
- Bachelor of Engineering Technology Honours in Mechatronic Engineering
- Bachelor of Engineering Technology Honours in Electrical Engineering
- Bachelor of Engineering Technology Honours in Chemical Engineering
- Bachelor of Engineering Technology Honours in Metallurgical Engineering
- Bachelor of Engineering Technology Honours in Polymer Technology

ADMISSION REQUIREMENTS

Higher Certificate in Engineering

A National Senior Certificate, or an equivalent qualification, with at least **4** for English, **4** for Mathematics/Technical Mathematics and 3 for Physical Science/Technical Science. A total APS of **20** will be considered for the Higher Certificate.

Diploma in Building

A National Senior Certificate with a bachelor's degree or a diploma endorsement or an equivalent qualification, with an achievement level of at least **4** for English (home language or first additional language), **3** for Mathematics or Technical Mathematics and **3** for Physical Science or Technical Science. Total APS of **25**.

Diploma in Industrial Design

A National Senior Certificate or an equivalent qualification with at least an adequate achievement of **4** for English. Total APS score **21**. In order to be considered for admission to this qualification, you must first meet the minimum academic requirements. All the applications should be supplemented with a portfolio.

Diploma in Electrical Engineering

A National Senior Certificate or an equivalent qualification, with a bachelor's degree or a diploma endorsement, or an equivalent qualification, with an achievement level of at least **4** for English (home language or first additional language), **4** for Mathematics or Technical Mathematics, and **4** for Physical Sciences or Technical Sciences. Total APS of **28**.

Bachelor in Geomatics

A National Senior Certificate with an endorsement of a bachelor's degree or a diploma, or an equivalent qualification, with an achievement level of at least **4** for English, **5** for Mathematics/Technical Mathematics and **4** for Physical Sciences/Technical Physical Sciences. A total APS of **25** may be considered.

Bachelor of Architecture

A minimum score of **4** for English is required with a minimum of **25** APS score. Admission is subject to the completion of a Potential Assessment Test and available space. The purpose and intention of the assessment is to select only students who are likely to be successful in their studies in Architecture. The University reserves the right to select the best candidates for this programme. This is a six-hour written test.

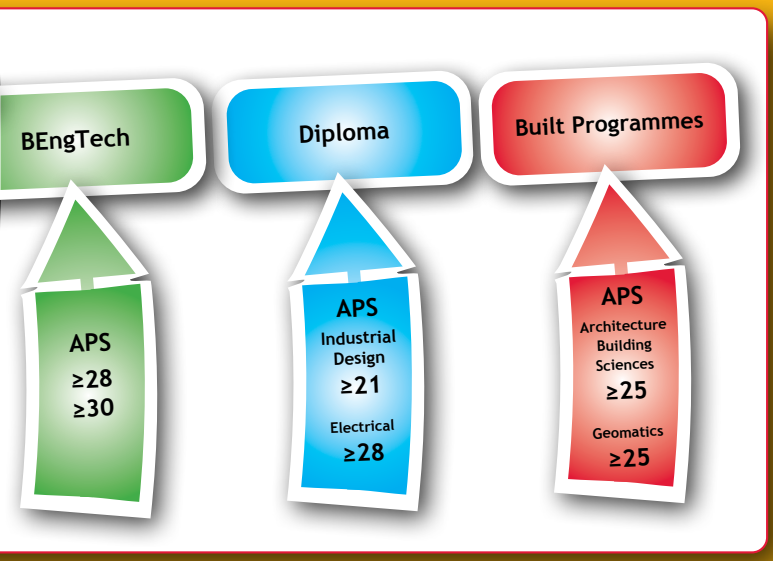
Bachelor's of Engineering Technology

A National Senior Certificate (NSC - completed Grade 12 in and after 2008), with an endorsement of a bachelor's degree or an equivalent qualification, with at least a *substantial achievement* of **4** for English, **5** for Mathematics/Technical Mathematics and **5** for Physical Science/ Technical Science. Total APS score **28**.

For the Baccalaureus Technologiae: Engineering: Electrical a total APS is of **30** is applicable. This is a three-year qualification (integrated theory and practical).

Faculty of Engineering and the Built Environment

2021 New Qualifications



Admission requirements

Bachelor of Engineering Technology Honours Degree
The following HEQSF-aligned qualifications are planned in future. The Bachelor of Engineering Technology Honours Degree is a postgraduate qualification that prepares students for industry and research. This qualification typically follows a Bachelor's Degree, Advanced Diploma or relevant NQF level 7 qualification and serves to consolidate and deepen the student's expertise in a particular discipline and to develop research capacity in the methodology and techniques of that discipline.

Master of Engineering
A Baccalaureus Technologiae in Engineering, Bachelor of Engineering Technology Honours, Bachelor of Engineering or a Bachelor of Science in Engineering (in any related field), or an NQF level 8 qualification in Engineering (or any related field), with an aggregate of 60% for the final year of study obtained from an accredited South African university

Master of Building Sciences
A Baccalaureus Technologiae: Construction Management or Quantity Surveying, or an NQF Level 8 Bachelor, or Honours qualification in Construction Management or Quantity Surveying obtained from an accredited South African university or any other relevant NQF Level 8 qualification considered acceptable by the Department.

Masters of Engineering in Engineering Management
Any Baccalaureus Technologiae in Engineering, or a Bachelor Honours in Engineering Technology in Engineering, or a Bachelor of Engineering or a Bachelor of Science in Engineering, or a NQF Level 8 qualification in Engineering (or related field), obtained from an accredited South African university, with an aggregate of 60% for the final-year of study.

Doctor of Engineering
A Magister Technologiae: Engineering, Master of Engineering, or a Master's degree at NQF Level 9 in a related field obtained from a South African university.

Visit the website at **www.tut.ac.za**
for detailed information on the various courses and access the Faculty of Engineering and the Built Environment page.

For more information:
Faculty Marketer: Ms Zelda Janse van Rensburg
(JanseVanRensburgZ@tut.ac.za)
http://www.facebook.com/TUTengineeringfaculty
http://twitter.com/TUTEngineering

PROFESSIONAL RECOGNITION

Higher Certificate (HC)

With a *Higher Certificate* qualification, the undergraduate will be able to work in *engineering support occupations* such as, draftspersons, installers and maintainers of engineering equipment and systems, engineering sales and marketing, site and production supervisor, etc.

Diploma

The *Diploma* enables students to register as *professional engineering technicians* with the Engineering Council of South Africa (ECSA), after having gained a minimum of three years' practical experience once they have qualified. Since these diplomas are internationally recognised through the Dublin Accord, qualified graduates can work as *engineering technicians* in co-signatory countries. An engineering technician is a competent engineering practitioner with sound technical knowledge who is able to convert ideas into workable plans, contribute to practical knowledge and solve well-defined engineering problems.

Bachelor of Engineering Technology (BEngTech)

The BEngTech degrees enable students to register as *professional engineering technologists* with the Engineering Council of South Africa (ECSA), after having gained a minimum of three years' practical experience after they have qualified. Since these degrees are internationally recognised through the Sydney Accord, qualified graduates can work as engineering technologists in co-signatory countries. In the UK, for example, an engineering technologist can work as an incorporated engineer (IEng) after registration with the Engineering Council of the United Kingdom (ECUK).

The Bachelor of Engineering Technology (BEngTech) degrees have a strong application and practical focus and engineering technologists are competent engineering practitioners who are able to innovatively apply and modify engineering practices, solve broadly defined engineering problems, give managerial inputs and work independently. The BEngTEch degrees differ from BEng degrees, which allow registration as professional engineers, in the sense that the focus is more on the application of technological knowledge than on the derivation of knowledge from first principles.

Engineering-support qualifications

TUT also offers qualifications for surveying technicians and technologists. A route exists for engineering surveying technologists to register with the South African Geomatics Council (SAGC) as professional engineering surveying technologist (not to be confused with professional land surveyors).

Built Environment qualifications

In Building Sciences, TUT offers qualifications in quantity surveying and construction management for technicians and technologists who can register with the South African Council for Quantity Surveying Profession (SACQSP). After having gained enough practical experience and having passed professional examinations, candidates may register with the SACQSP as professional quantity surveyors. There is also a route for construction management students to register with the Chartered Institute of Building (CIOB) as chartered members.

In **Architecture** TUT offers qualifications for professional architects and architectural technologists and is accredited by the South African Council for the Architectural Profession (SACAP) and the Commonwealth Association of Architects. It is the only school of architecture at a university of technology that offers a fully accredited professional course.

In **Industrial Design** talented individuals who successfully complete this programme will be able to provide junior level industrial design-related services. This may include being a member of a design and development team or a junior design entrepreneur.

Werner Siemens Foundation, Felix Wey

The evolutionary history of **our oral bacteria**

Our mouths are a microecosystem for a community of microorganisms that live in different habitats, occupy specific niches and play particular roles in our biology and health. An international team of researchers recently investigated the oral microbiomes of Neanderthals, primates and humans, and discovered unexpected clues about human evolution.

The study, published in the *Proceedings of the National Academy of Sciences* (PNAS) in May, involved analysing the fossilised dental plaque of humans and Neanderthals spanning the past 100 000 years, and comparing it to that of wild chimpanzees, gorillas and howler monkeys. Led by scientists from the Max Planck Institute for the Science of Human History in Germany, the research team included representatives of 41 different institutions in 13 countries. One of these was Associate Professor Victoria Gibbon, a biological anthropologist in the Department of Human Biology at the University of Cape Town (UCT).

"In recent years, the human microbiome has become a popular topic," she says. "Using bacterial DNA obtained from tooth plaque from South African people who lived thousands of years ago has contributed to the better understanding of human history, human evolution and our early diets."

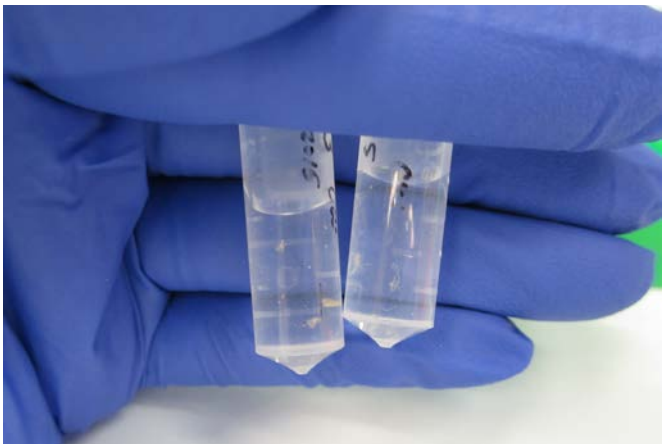
More specifically, the study suggested that the shift to a diet based predominantly on starch occurred much earlier than previously thought. This conclusion was based on the discovery that a subgroup of *Streptococcus* bacteria present in both modern humans and Neanderthals appears to have adapted to consume starch quite early in *Homo* evolution. Starchy foods – such as roots, tubers and seeds – are rich sources of energy, and previous studies have argued that a transition to eating such foods may have helped our ancestors to grow the large brains that characterise our species. But the current finding suggests that starchy foods became important in the diet even before the evolution of modern humans.

The other kind of calculus

Plaque is the sticky film that constantly forms on teeth but can be removed by brushing and flossing. It's made up of millions of bacteria, so scientists typically refer to it as 'dental biofilm'. Acids produced by the bacteria as they digest sugars cause tooth decay and gum damage. If allowed to build up, plaque precipitates minerals from saliva and calcifies into tartar, also known as 'dental calculus'. This is the harder, yellow or brown deposit that cannot be brushed or flossed away, and requires a visit to the dentist or dental hygienist for removal.

Before the time of toothbrushes... a Neanderthal tooth with a severe case of calculus.

Werner Siemens Foundation, Felix Wey



Werner Siemens Foundation, Felix Wey

Dedicated cleanroom facilities were used to prepare dental calculus samples for DNA extraction.

Given its longevity, it was dental calculus that the scientists targeted in the study, analysing samples and drawing upon previously published data from more than 120 individuals representing key points in primate and human evolution.

A challenging jigsaw puzzle

Working with DNA tens or hundreds of thousands of years old is highly challenging. Like archaeologists reconstructing broken pots, archaeo-geneticists have to painstakingly piece together the broken fragments of ancient genomes in order to reconstruct a complete picture of the past. For this study, researchers had to develop new tools and computational approaches to genetically analyse billions of DNA fragments and identify the long-dead bacterial communities preserved in archaeological dental calculus.

Using these new tools, researchers reconstructed the 100 000-year-old oral microbiome of a Neanderthal from Pešturina Cave in Serbia, the oldest oral microbiome successfully reconstructed to date by more than 50 000 years.

They were also able to identify 10 groups of bacteria that have been members of the oral microbiome for over 40 million years and that are still shared between humans and their closest primate relatives. Many of these bacteria are known to have important beneficial functions in the mouth and may help promote healthy gums and teeth.

Paleolithic connections

Although humans share many oral bacteria with other primates, the oral microbiomes of humans and Neanderthals are particularly similar. Nevertheless, there are a few small differences, mostly at the level of bacterial strains. When the researchers took a closer look at these differences, they found that ancient humans living in Ice Age Europe shared some bacterial strains with Neanderthals. Because the oral microbiome is typically acquired in early childhood from caregivers, this sharing may reflect earlier human-Neanderthal pairings and child rearing, as has been previously indicated by the discovery of Neanderthal DNA in ancient and modern human genomes.

The researchers found that Neanderthal-like bacterial strains no longer occurred in humans after about 14 000 years ago, a period during which there was substantial population turnover in Europe at the end of the last Ice Age. They point out that our microbiome is a particularly sensitive indicator of such major events, given that bacterial genomes evolve more quickly than the human genome.

Lead author of the PNAS paper, titled 'The evolution and changing ecology of the African hominid oral microbiome', was James Fellows Yates, a doctoral candidate at the Max Planck Institute for the Science of Human History.

"The tools and techniques developed in this study open up new opportunities for answering fundamental questions in microbial archaeology, and will allow the broader exploration of the intimate relationship between humans and their microbiome," he says.

Based on press releases issued by the Max Planck Institute for the Science of Human History and the University of Cape Town. Read the paper at https://doi.org/10.1073/pnas.2021655118

Katerina Guschanski

Dental calculus was sampled from these gorilla specimens at the Royal Museum for Central Africa in Tervuren, Belgium.

Graeme Kruger

Chris King

Become a shark citizen scientist

Chantel Elston explains how ELMO uses public participation for the conservation of sharks and rays

When somebody says 'shark' to you, perhaps the *Jaws* music starts to play in your head and you envision a scary great white shark. But did you know that South Africa is a global hotspot for shark and ray diversity? We have a little over 200 species in our waters, including pyjama sharks, hammerheads, bronze whalers, short-tail stingrays, honeycomb rays, twin-eyed skates – and the list goes on!

Unfortunately, the diverse lives of these animals remain a mystery to us. Simple questions like "how many individuals are there?" or "where do they like to live, and why?" remain unanswered. One thing we do know, though, is that many of these species are in trouble. The sad reality is that about 30% of sharks and rays in South Africa are considered at risk of extinction. How can we hope to protect these animals if we know so little about them?

This is why ELMO – short for Elasmobranch Monitoring South Africa – was born. (Elasmobranch is a group name for sharks and rays within the cartilaginous fish class, Chondrichthyes.) The overarching goal of ELMO is to use public participation to collect vital information on the sharks and rays that live in South Africa's waters. Gathering data in a traditional scientific manner is time-consuming and expensive, but beachgoers, fishers, boat operators, drone pilots, scuba divers and snorkelers may encounter sharks and rays on a regular basis.

Tatjana Good

ELMO collects two major types of data from members of the public – animal sightings and eggcase finds. For animal sightings, we want to know about the species encountered as well as the date and location of the encounter. This goes into our database, helping us to monitor population trends and to figure out where these species live.

But collecting information on eggcase finds is just as important as spotting the animals themselves. Some shark and all skate species lay eggs rather than giving birth to live young. The eggcases, popularly known as mermaids' purses, often wash ashore after the young have hatched. Finding out where and when these eggcases come ashore doesn't only tell us which species live in an area, but could also suggest which areas are important nursery grounds for those species. Identifying nursery grounds and protecting them is one of the best ways we can conserve sharks and rays in our waters.

ELMO partners with a number of local NGOs that also collect information on sharks and their eggcases, so our database now contains more than 5 700 eggcase finds and over 25 000 encounters, spanning the entire South African coastline. This is a treasure trove of information and some of the data has already been provided to scientists working on the conservation of these animals.

So if you encounter a shark or ray, or one of their eggcases, please let us know about it! Send a WhatsApp message with the photo, date and location to 076 897 5474. Our website (www.elmoafrica.org) contains useful information, such as guides on how to identify eggcases, and we are active on Facebook (@elmoafrica) and Instagram (@elmo_africa).

Dr Chantel Elston completed her PhD on stingray community ecology at Rhodes University in November 2018 and is now a postdoctoral researcher with the South African Institute of Aquatic Biodiversity (SAIAB), investigating the distribution and movement patterns of rays along South Africa's coastline.

Matie microbiology students KICK BUTTS

It's been estimated that 5.6 trillion cigarette butts are discarded worldwide every year. In South Africa, cigarette butts were the most abundant litter item collected during the 2020 International Coastal Clean-up event, having been washed down rivers and stormwater canals but also simply tossed on the sand by beachgoers.

Apart from being unsightly, this type of litter is a significant environmental pollutant anywhere that it occurs. Discarded cigarette butts exposed to the elements leach nicotine, metals and other chemicals – many of them toxic – into the surroundings. The filters, introduced in the 1950s in an attempt to reduce the health hazard of smoking, are made of cellulose acetate. This is essentially plant-derived cellulose that has undergone a chemical process known as acetylation, and may have had plasticisers added for bonding. As a result, cigarette butts also release microplastics as they break down, typically over a period of a few years.

Several companies are now marketing 'biodegradable' cigarettes, which they claim are more environmentally friendly because they break down over a matter of months and have filters made of 'plastic-free' hemp, cotton or wood pulp. But a group of third-year microbiology students from Stellenbosch University (SU) questioned whether such cigarettes would simply leach their pollutants into the environment faster, and hence have greater impact.

They tested their hypothesis in a research project conducted as part of the third-year Microbial Ecology module in the Molecular Biology and Biotechnology programme at SU, and presented their findings at a mock-up academic conference. Their method involved using inductively coupled plasma mass spectrometry (ICP-MS) to analyse leachate from both biodegradable and non-biodegradable butts, and testing the effect of the two types of leachate on bacterial communities in soil through a DNA-fingerprinting technique.

Aluminium, iron and zinc were found to be the dominant elements in both leachate types, but arsenic, boron, barium, cadmium, cobalt, chromium, copper, mercury, manganese, molybdenum, nickel, lead, antimony, selenium, tin, strontium and vanadium were also detected.

Wilda Fourie-Basson

These Stellenbosch University students published a peer-reviewed paper from their third-year microbiology project, which showed that even biodegradable cigarette butts have a negative impact on the environment. They are (from left to right) Aza Mqulwa, Sidney Reed, Elizaveta (Lisa) Koroleva, Zahraa Tambe and Scott Norris-Jones. All are currently pursuing postgraduate degrees in microbiology or biochemistry at the university.

The leachate from the biodegradable butts had a significant impact on the composition of the microbial community of the soil sample, while the leachate of non-biodegradable butts did not. This could be attributed to the much higher concentrations of metals and metalloids in the biodegradable butt leachate.

The group published their findings in the journal *Environmental Science and Pollution Research*. Prof. Karin Jacobs, their lecturer and a co-author of the paper, says of particular concern is the fact that bacteria exposed to heavy metal contamination are known to develop metal resistance, which has been found to correlate with the development of antibiotic resistance.

"We are, of course, very proud of this group of students with their first paper," she adds. "This is certainly a first for our Faculty of Science."

Based on a press release issued by Stellenbosch University.
Read the paper at https://doi.org/10.1007/s11356-021-13152-w

Jeff Samsonow, CC BY-SA 2.0

Alex Schoeman

Dating BOKONI

Ruby-Anne Birin, Alex Schoeman and Mary Evans explain how pots, sand and stone walls helped them date an ancient South African settlement

If you go for a walk in the green hills of Mpumalanga in the north-east of South Africa, you may stumble across some stone walls. Either stubbing your toe or appearing through the grass at about chest height, these walls direct and disrupt your path.

Climbing to the top of these gentle slopes, your eye is drawn to circular and linear patterns. From above you quickly realise these patterns are the remains of towns – clusters of homesteads, traditional households, terraces and roads. These ruins are the remnants of the Bokoni polity, a region that contains the southernmost collection of stone-terrace farming sites in Africa.

Archaeologists study the Bokoni sites as they are a marvel of urban-farming innovation and ingenuity.

In our research we have broken new ground about the Bokoni sites, and solved a mystery that's puzzled scientists for decades – when the first sites were built. Our findings were made possible with techniques and technology usually used in geology.

The search for the beginning

Archaeologists, in collaboration with historians, have defined four phases of occupation for Bokoni. Oral histories provide particular insight into Phase II, the zenith of the Bokoni's urban growth and planning, when the larger towns were occupied.

For instance in 1936, as part of his research into the seKoni language, linguist CW Prinsloo mapped the extent of Bokoni in the 1800s and indicated earlier capitals. Pedi oral traditions recorded by missionaries in the 1960s refer to the Marateng (Pedi) royals encountering seKoni speakers in approximately 1650CE.

But there are no known historical accounts of Phase I. So, until now, it hasn't been known exactly when the Bokoni emerged. But, by turning to the material record and archaeological science, our research has solved this enduring mystery.

We applied a technique called luminescence dating to resolve the origins of this tradition. We now know that Bokoni Phase I was built as early as the 15th century – before the arrival of European colonisation or trade reached the interior. And that the Bokoni farmers continued to thrive for centuries despite the turmoil that was arriving at nearby shores.

These findings disrupt past narratives that decry the presence and ability of African farmers before and during colonisation.

Alex Schoeman

A lightproof tube is used to collect a sediment sample for luminescence dating once back in the laboratory.

They also offer new ways of understanding individual lives and familial patterns. This research helped us reconstruct when people began to build these incredible structures, how long a household was occupied before abandonment, and how their successors interacted with the structures they left behind.

Four phases

The four phases identified by researchers as being key periods in the Bokoni polity are as follows.

Phase I marks Bokoni's emergence (the date of which remained unknown until now). Phase II, in the 17th and 18th centuries, saw the peak of Bokoni's urban growth and planning. During this period, most Bokoni residents would have been urban farmers, first in and around the capital called Moxomatsi, and later at the succession capitals Mohlo-Pela and Khutwaneng, which lies in modern-day Mpumalanga.

Phase III marks the start of the upheaval that resulted in Bokoni's decline in the 19th century, while Phase IV documents the diaspora from the mid 19th century onwards. Bokoni broke apart because of regional conflict in the early to mid 1800s.

Given the dearth of written or oral history from Phase I, we turned to the science of dating in our search for answers.

Dating methods

Only two radiocarbon dates exist for sites from this period and region. This is because radiocarbon dating is not ideal for Bokoni. Radiocarbon dating measures the radioactive carbon isotope in organic remains. The technique provides the date of death by measuring the remaining radiocarbon component of organic remains like bone or wood. But in certain conditions the soil does not preserve organic remains.

Luminescence dating was far more suitable for the Bokoni site. Optically stimulated luminescence is a dating technique that measures when quartz or feldspar grains within the soil were last exposed to light or heat. This timestamp tells us when these minerals were buried (or trapped in an object like a pot).

Alex Schoeman

Remnants of a jar exposed during archaeological excavation of a Bokoni homestead.

Alex Schoeman

The two Bokoni homesteads dated by the team lie in Komati Gorge Village, set amongst the rolling hills of Mpumalanga.

When quartz grains are exposed to light, their electrons become excited and leave their correct orbitals; this is called bleaching. At the point of bleaching, the grain has age zero. Once the grain is buried, it uses the radiation within the surrounding soil to return its electrons to their correct orbital.

Scientists then measure the dose absorbed by the grain and divide it by the rate at which that dose was absorbed. This value provides the date of the last exposure to light, which allows us to determine when a material or surface became buried, or when a pot was last fired.

Our team used this technique at two homesteads in Komati Gorge Village, a southern town within Bokoni. We already knew that one homestead was older than the other because many of its stones were repurposed to build the more recent settlement.

Our results indicate several periods of occupation, abandonment and new construction. The older homestead was occupied from as early as 1489CE until it was abandoned around 1577CE. The builders of the younger homestead reused the older from approximately 1682CE to 1765CE. The younger homestead itself was reused at some time between 1738CE and the early 20th century.

Future work refining our understanding of the occupation periods of Bokoni may also allow us to better reconstruct the environmental and political landscape people lived within.

Ruby-Anne Birin is a DPhil student in Archaeological Science at the University of Oxford, United Kingdom.
Prof. Alex Schoeman is an associate professor in the School of Geography, Archaeology and Environmental Studies at the University of the Witwatersrand (Wits).
Dr Mary Evans is a senior lecturer in Physical Geography and Geochronology at Wits.

Visit the original article for a GIF animation showing the optically stimulated luminescence dating process.
https://theconversation.com/how-pots-sand-and-stone-walls-helped-us-date-an-ancient-south-african-settlement-161213

The sky's the limit for **UKZN rocket scientists**

The Aerospace Systems Research Group (ASReG) within the Discipline of Mechanical Engineering at the University of KwaZulu-Natal (UKZN) has two aims: to develop aerospace technologies related to rockets and space vehicles, and to develop human skills in aerospace engineering. Apart from its existing research-based master's and PhD programmes, a module on rocket propulsion for fourth-year engineering students was introduced in 2020.

The ASReG team celebrated a momentous achievement in March, with the launch of the latest version of the Phoenix hybrid rocket. Hybrid rockets are propelled by a combination of solid fuel and liquid oxidiser, and offer advantages over solid motors, such as improved safety and the capacity for throttling.

Hybrid rocket smashes African altitude record

UKZN's much-anticipated Phoenix hybrid rocket test flight at the world-class Denel Overberg Test Range in the Western Cape was a resounding, record-breaking success. The flight took place on 8 March when a gap in the weather provided suitable launch conditions and the Phoenix-1B Mk IIr vehicle soared to a new high-altitude mark for hybrid rockets, beating the previous African record of 10.3 km.

"The team was delighted to see all of their hard work come to fruition with a picture-perfect flight, which exceeded our expectations," said ASReG leader Dr Jean Pitot. ASReG's Phoenix Hybrid Rocket Programme is a skills development initiative that focuses on suborbital launch vehicle design and testing.

"Internationally, sounding rockets continue to play a crucial role in the facilitation of experiments conducted in a wide variety of scientific disciplines, including bio-technology, astronomy, astrophysics, materials science and meteorology, among many others," explained academic leader for mechanical engineering at UKZN, Professor Michael Brooks. "They also serve as valuable test platforms for aerospace technologies related to commercial satellite launch vehicles."

The ASReg team at the Denel Overberg Test Range, near Arniston in the Western Cape.

The Phoenix-1B Mk IIr rocket blasts off.

After signing the fins of the Phoenix-1B Mk IIr pre-launch – a tradition in rocketry research – the team retreated to a mission control blockhouse from where the nerve-wracking countdown started. At 4.47 p.m. Mk IIr blasted off – and the exultant team broke into cheers as the rocket reached an altitude of 17.9 km, setting a new African record.

Said Pitot: "The Mk IIr rocket is a high-performance version of our initial Mk I rocket, and demonstrates low-cost and robust construction methodologies, coupled with advanced fabrication and propellant technologies."

Brooks acknowledged substantial funding received from the Department of Science and Innovation (DSI) for the project. "This funding has enabled the development of key expertise in the engineering disciplines of rocket propulsion technology, launch vehicle design and flight dynamics modelling as well as the development of appreciable scarce skills. It has also enabled unique cooperation between the University and industry," he said.

The ASReG team included 18 postgraduate and under-graduate students who contributed to the success of the launch through their innovative research. These students are products of ASReG's DSI-funded transformation-centred talent pipeline programme.

Lead engineer on the Phoenix campaign was UKZN PhD student Kai Broughton, a winner of the prestigious Engineering Council of South Africa (ECSA) merit medal and a *cum laude* UKZN MSc Mechanical Engineering graduate who has been named among the African Space Industry's 'Top 10 Under 30s' by the Space in Africa news agency.

Written by Dr Sally Frost, public relations manager for UKZN's College of Agriculture, Engineering and Science, and republished from NdabaOnline Vol 9 (7).

Watch a video about the launch at https://engineering.ukzn.ac.za/news/weflyrockets/

Propelling Africa's rocket systems forward

The Aerospace Systems Research Group (ASReG) at UKZN is developing the talent of the next generation of rocket scientists to drive South Africa's space industry forward.

Master's candidate Thabang Mdhluli, from the village of Phiring in the Limpopo Province, is one of those furthering the mission of ASReG through his research on developing an injector test rig for gelled propellants, supported by a bursary from the Department of Science and Innovation. This rig will be used to visualise and quantify flow characteristics of several gelled propellant analogues – important work as gelled propellants are increasingly being applied to rocket and ramjet propulsion systems, and offer advantages over conventional liquid and solid fuel variants.

Mdhluli said gelled propellants will enhance the performance of future propulsion systems and provide improved handling and storage safety. His work will aid in obtaining useful quantitative and qualitative data to facilitate an optimum injector design for a flight vehicle using gelled propellants.

An early fascination with the workings of vehicle engines was helped along by an introduction to the fundamentals and principles of mechanical engineering through his diesel mechanic brother's textbooks. Taking engineering graphics and design as a subject in high school further developed Mdhluli's interest.

While Mdhluli acknowledges that the intensive mathematics necessary for engineering makes it daunting, he finds its principles straightforward. Although it requires higher-order thinking and the retention and understanding of intricate concepts and ideas, translating the science into engineering and producing designs is where the challenge ultimately lies.

Aiming for a career where he could work through the engineering process from design to development and assembly, Mdhluli enrolled for his degree in mechanical engineering at UKZN. His interest in rocket science and propulsion systems was stimulated in his second year when meeting postgraduate students in ASReG who were presenting one of the Phoenix sounding rockets at the annual mechanical engineering Open Day. This led to him enrolling for a master's with the group after completing his undergraduate degree in the minimum time, with four certificates of merit to his name.

His final-year group design project involved designing a pressure vessel for a water rocket demonstration kit for use in explaining rocketry principles to high school learners and encouraging an interest in science, technology, engineering, and mathematics (STEM).

Thabang Mdhluli with a one-half scale model of the rocket payload fairing of a commercial launch vehicle being designed by ASReG.

Mdhluli advised high school students interested in rocket science to work hard at their STEM subjects and to try and gain understanding of the applications of their work, while also seeking out more information about the industry and participating in as many additional engineering education programmes as possible.

The work he put in over his four-year degree has been a source of pride for his family, and the demanding course with its considerable workload required focused commitment, discipline and strict time management from Mdhluli – a keen rugby player who still looks for time on the pitch to balance his physical and academic activities.

"ASReG helped me see that conducting research on aerospace systems, while it seemed far-fetched, was attainable for me," said Mdhluli. "I hope that the work we do will one day add South Africa to the list of countries excelling in space activities and help it develop its own launch capability."

Mdhluli was recently awarded a scholarship through the Department of Higher Education and Training's Nurturing Emerging Scholars Programme (NESP). He will receive mentorship with a view to moving into academia once he completes his master's degree at UKZN.

Written by Christine Cuénod, journalist for UKZN's College of Agriculture, Engineering and Science, and republished from NdabaOnline Vol 9 (4).

Read the UKZN Newsletter, NdabaOnline, at https://ukzn.ac.za/media-publications-reports/ukzn-ndabaonline/

Find out more about the Aerospace Systems Research Group (ASReG) at http://aerospace.ukzn.ac.za/

Warp drives

Les Bossinas, NASA

Mario Borunda reports that physicists give chances of faster-than-light space travel a boost

The closest star to Earth is Proxima Centauri. It is about 4.25 light-years away, or about 40 trillion km. The fastest ever spacecraft, the now-in-space Parker Solar Probe, will reach a top speed of 450 000 mph (almost 725 000 km/hr). It would take just 20 seconds to go from Los Angeles to New York City at that speed, but it would take the solar probe about 6 633 years to reach Earth's nearest neighbouring solar system.

If humanity ever wants to travel easily between stars, people will need to go faster than light. But so far, faster-than-light travel is possible only in science fiction.

In Isaac Asimov's *Foundation* series, humanity can travel from planet to planet, star to star or across the universe using jump drives. As a kid, I read as many of those stories as I could get my hands on. I am now a theoretical physicist and study nanotechnology, but I am still fascinated by the ways humanity could one day travel in space.

Some characters – like the astronauts in the movies *Interstellar* and *Thor* – use wormholes to travel between solar systems in seconds. Another approach – familiar to *Star Trek* fans – is warp drive technology. Warp drives are theoretically possible if still far-fetched technology. Two recent papers made headlines in March when researchers claimed to have overcome one of the many challenges that stand between the theory of warp drives and reality.

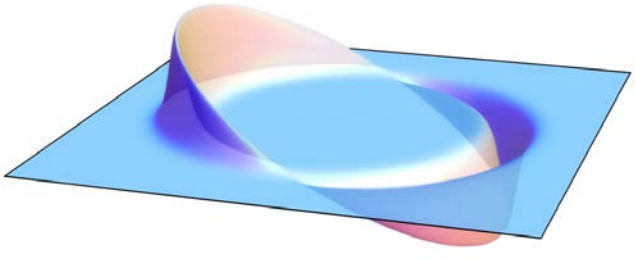
But how do these theoretical warp drives really work? And will humans be making the jump to warp speed anytime soon?

Compression and expansion

Physicists' current understanding of spacetime comes from Albert Einstein's theory of general relativity. General relativity states that space and time are fused and that nothing can travel faster than the speed of light. General relativity also describes how mass and energy warp spacetime – hefty objects like stars and black holes curve spacetime around them. This curvature is what you feel as gravity and why many spacefaring heroes worry about 'getting stuck in' or 'falling into' a gravity well. Early science fiction writers John Campbell and Asimov saw this warping as a way to skirt the speed limit.

What if a starship could compress space in front of it while expanding spacetime behind it? *Star Trek* took this idea and named it the warp drive.

In 1994 Miguel Alcubierre, a Mexican theoretical physicist, showed that compressing spacetime in front of the



AllenMcC, CC BY-SA 3.0

This two-dimensional representation shows the flat, unwarped bubble of spacetime in the centre, where a warp drive would sit surrounded by compressed spacetime to the right (downward curve) and expanded spacetime to the left (upward curve).

spaceship while expanding it behind was mathematically possible within the laws of general relativity. So, what does that mean? Imagine the distance between two points is 10 metres. If you are standing at point A and can travel one metre per second, it would take 10 seconds to get to point B. However, let's say you could somehow compress the space between you and point B so that the interval is now just one metre. Then, moving through spacetime at your maximum speed of one metre per second, you would be able to reach point B in about one second. In theory, this approach does not contradict the laws of relativity since you are not moving faster than light in the space around you. Alcubierre showed that the warp drive from *Star Trek* was in fact theoretically possible.

Proxima Centauri here we come, right? Unfortunately, Alcubierre's method of compressing spacetime had one problem: it requires negative energy or negative mass.

A negative energy problem

Alcubierre's warp drive would work by creating a bubble of flat spacetime around the spaceship and curving spacetime around that bubble to reduce distances. The warp drive would require either negative mass – a theorised type of matter – or a ring of negative energy density to work. Physicists have never observed negative mass, so that leaves negative energy as the only option.

To create negative energy, a warp drive would use a huge amount of mass to create an imbalance between particles and antiparticles. For example, if an electron and an antielectron appear near the warp drive, one of the particles would get trapped by the mass and this results in an imbalance. This imbalance results in negative energy density. Alcubierre's warp drive would use this negative energy to create the spacetime bubble.

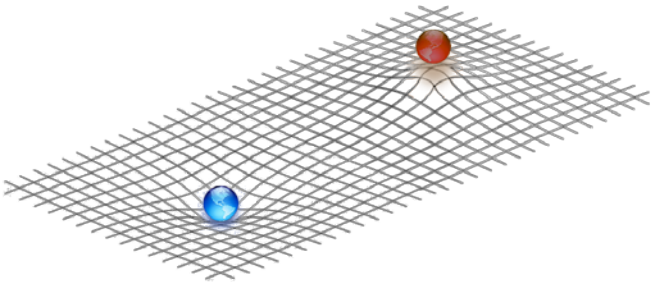
But for a warp drive to generate enough negative energy, you would need a lot of matter. Alcubierre estimated that a warp drive with a 100-metre bubble would require the mass of the entire visible universe.

In 1999, physicist Chris Van Den Broeck showed that expanding the volume inside the bubble but keeping the surface area constant would reduce the energy requirements significantly, to just about the mass of the sun. A significant improvement, but still far beyond all practical possibilities.

A sci-fi future?

Two recent papers – one by Alexey Bobrick and Gianni Martire and another by Erik Lentz – provide solutions that seem to bring warp drives closer to reality. Bobrick and Martire realised that by modifying spacetime within the bubble in a certain way, they could remove the need to use negative energy. This solution, though, does not produce a warp drive that can go faster than light.

Independently, Lentz also proposed a solution that does not require negative energy. He used a different geometric



Tokamac, CC BY-SA 4.0

This two-dimensional representation shows how positive mass (left side, blue Earth) and negative mass (right side, red Earth) curve spacetime in opposite directions.

approach to solve the equations of general relativity, and by doing so, he found that a warp drive wouldn't need to use negative energy. Lentz's solution would allow the bubble to travel faster than the speed of light.

It is essential to point out that these exciting developments are mathematical models. As a physicist, I won't fully trust models until we have experimental proof. Yet, the science of warp drives is coming into view. As a science fiction fan, I welcome all this innovative thinking. In the words of Captain Picard, things are only impossible until they are not.

Prof. Mario Borunda is an associate professor of physics at Oklahoma State University in the United States.

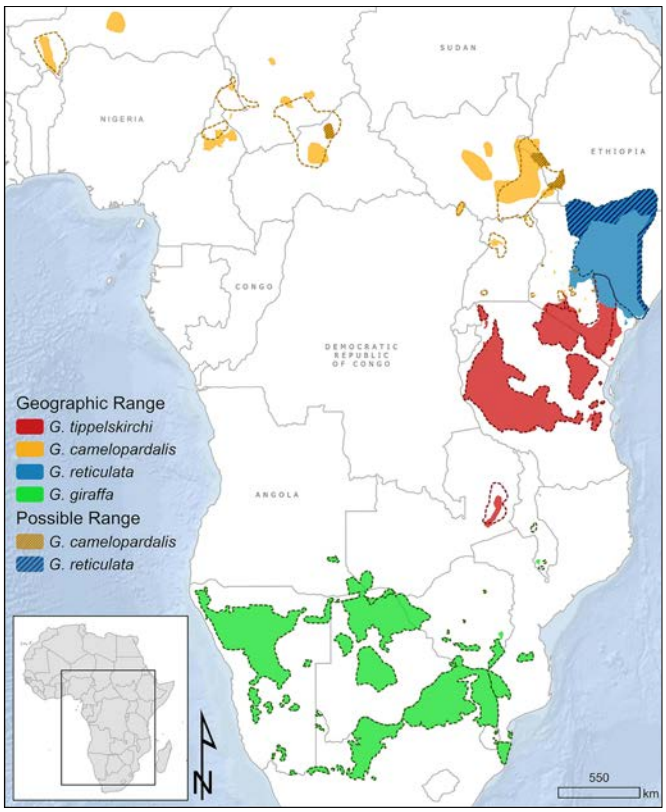
Jamie Paulse

COMBING THE GIRAFFE

Harriet Box asked Jamie Paulse about her MSc study on behaviour and feeding ecology of giraffe in the Klein Karoo

Peigner la girafe is a French expression that translates to 'combing the giraffe'. In essence, one is wasting one's time on a pointless task. While Jamie Paulse, an MSc graduate from the University of the Western Cape (UWC) and a junior lecturer and PhD candidate in Animal Science at the University of the Free State, did not entirely waste her time combing a giraffe, she did spend countless hours observing the animals feeding by day.

But the task was not pointless. Thanks to her study, game farmers in the Oudtshoorn area can determine how much food is available to ensure giraffes can survive there.



O'connor et al. 2019, Mammal Review, https://doi.org/10.1111/mam.12165

The natural range for giraffe species in sub-Saharan Africa.

What did your study entail?

Giraffe are extralimital in the Western Cape, which means they do not occur in the region naturally. This is the key factor around which the study was conducted, since the effects of these animals on indigenous fauna and flora are not well known, particularly in a sensitive vegetation type such as the thicket vegetation of the Little Karoo.

In order for any effects to be investigated, knowledge of the behaviour and diet of the species is needed. The study therefore provided valuable baseline information for farmers and government or private conservation agencies to use in future impact studies, as well as long-term monitoring projects in the area.

In this study there were a few aspects that needed to be explored, which meant that it was split into three parts. The first part dealt with the activity budgets of giraffes. This was all about determining the time giraffes spend on different activities, such as foraging (eating), walking, defecating, ruminating or lying down. It was important to look at the giraffes' behaviour compared to their behaviour in their natural ranges.

The second part dealt with diet. We could see that the giraffes spent most of their time foraging, so we wanted to find out what plant species they ate. This was essential because we conducted the study in the thicket biome, which has vegetation very different to that found in their natural ranges.

The third part of the study looked at the browsing capacity – the food available – of each area we surveyed, and the goal here was to establish the density of giraffes the area could sustain. This was a vital component of the study, as farmers needed to know how many animals they could keep.

Clement Cupido

Clement Cupido

Long days were spent watching the giraffes and recording their activities. Chilly winter mornings were a particular challenge.

How did you go about it?

The study was done on two farms in the Little Karoo, more specifically in the Oudtshoorn area where game farms are becoming quite prevalent. Every season we observed giraffes for four days to monitor their activity and diets. This we did from sunrise to sunset – for us the cold winter in Oudtshoorn was particularly challenging!

We used the scan interval method, where we scanned the herd every five minutes and documented what each individual in the herd was doing. If an animal was foraging, we noted the species it ate, as well as the level it was feeding at.

What was the experience like?

It was quite intensive, especially the hours, but it was also exciting. To do fieldwork on a game farm all day, you get to see many kinds of animals and experience nature in a very different way. On one of the farms, there was a free-roaming leopard. There was one season where we didn't have an adequate vehicle, so we had to do the observations on foot. We could hear the distant growls of a leopard and even came across a venomous snake. It was definitely a scary but at the same time quite exhilarating experience.

Why did you choose your field of study?

My love for animals and the environment started at a young age, and my dream was always to become a vet. Unfortunately, due to my strong emotional attachment to animals and my inability to cope with blood, I could not pursue this career. So my passion steered me towards an undergraduate degree in conservation biology. My goal was only to obtain my BSc degree, but the exposure to various aspects of the environment – and my parents' consistent support – motivated me to continue with my studies.

How did you decide on your MSc project?

After studying Biodiversity and Conservation Biology at UWC, I was employed as an intern through the Professional Development Programme of the Agricultural Research Council. I was based at UWC, and I was required to complete a master's degree. During this period, I was fortunate enough to work with my mentor, Dr Igshaan Samuels, and supervisor, Mr Clement Cupido. They told me about the need for research on the feeding habits of giraffe in the Little Karoo, because the animals were being introduced on private game farms there.

The fact that giraffes naturally occur in savannah-type areas but were being introduced into vegetation types such as

Clement Cupido

Jamie needed to familiarise herself with the plants in the area so she could identify the giraffes' food species.

A number of private game reserves in the Klein Karoo are offering game drives and walking tours to view giraffe.

mixed thicket was quite interesting, and we were intrigued to see how they adapted to their new environment. At this point I decided to proceed with a master's project to investigate this – it was the very first large-herbivore study to be conducted in the department.

What have you been doing since?

I graduated with a master's degree (*cum laude*) in Biodiversity and Conservation Biology from UWC in April 2019. Since 2017, I've been employed as a junior lecturer in the Department of Animal Science at the University of the Free State in Bloemfontein. I am currently proceeding with my PhD at UFS, majoring in Grassland Science.

I am also working on a smaller project looking at the nutritional value of forage sampled from my study sites. I have been involved in various giraffe projects at UFS, such as the *50/50* clip focusing on the decline of natural giraffe populations in Africa.

CURRICULUM CORNER

LIFE SCIENCES: GRADE 10
Environmental studies: biomes

LIFE SCIENCES: GRADE 11
Environmental studies: population ecology

I also had the privilege to be part of an international collaboration of scientists assisting a film crew documenting one of the largest successful capture, GPS collaring, and release of a wild giraffe population. The documentary, *Catching Giants*, won multiple prestigious awards at international film festivals.

Finally, what's the secret of your success?

I was fortunate enough to be raised by two hard-working parents who provided me with all the opportunities I could have asked for. And I have learnt so much from my mentors, and am so privileged to have had them mould me into the academic I am today. Dr Samuels' work ethic and persona taught me how to be hard-working, while Mr Cupido was a constant source of encouragement and taught me to constantly push through any obstacle. He also taught me how to deal with failure, which was not always one of my strong attributes!

This impacted my life in such a great way. It changed me into a confident academic, not afraid to tackle any challenge. I cannot thank them enough.

Harriet Box is the communications officer for Institutional Advancement at the University of the Western Cape.

Raising awareness on **indigenous knowledge**

In 2020 the North-West University (NWU) joined forces with the Department of Science and Innovation (DSI) to position, develop and promote indigenous knowledge systems (IKS) in South Africa, particularly the Indigenous Knowledge Act (IK Act) and the Bio-cultural Community Protocol (BCP).

The awareness campaign kicked off last year in the Northern Cape and Gauteng, and was recently extended to Caguba in the Port St Johns district and Ngqeleni in the Nyandeni district of the Eastern Cape.

The campaign was spearheaded by officials from the DSI's National Indigenous Knowledge Systems Office (NIKSO) and Legal Service Unit, together with Lesley Mashego and Otsile Maditsi from the NWU's Centre for Indigenous Knowledge Systems. The team also included facilitators employed by the DSI in response to the recommendation by Parliament that the campaign should be conducted in the language(s) of the various communities.

The awareness-raising sessions in the Eastern Cape were well attended.

In Caguba a rigorous and positive engagement was held with the amaMpondo tribe of the Eastern Cape. The audience included community development workers, traditional leaders and healers, as well as members of the community.

During these sessions the team explained the purpose of the IK Act and the BCP. The IK Act focuses on the protection, promotion, management and development of indigenous knowledge in the country, and the BCP was adopted by the DSI as a tool to enforce the act. A BCP is a document that is developed after a community undertakes a consultative process to outline their core cultural and spiritual values and customary laws relating to their traditional knowledge and resources.

"The BCP is meant to provide clarity to community members about their rights and responsibilities, and outlines appropriate behaviour of both the community and those interacting with them," explains Lesley. "Adherence to these community protocols helps to ensure social cohesion and reinforces customary laws, values and decision-making processes."

Information was also shared about NWU's Bachelor's degree in Indigenous Knowledge Systems (BIKS).

"The NWU is the first tertiary institution to offer a BIKS degree as a strategic intervention in the development of human capital in indigenous knowledge systems," says Otsile. "We want to encourage young people to actively participate in the promotion and preservation of indigenous knowledge, and to consider the BIKS degree as a possible profession over and above the orthodox careers."

Written by Belinda Bantham, communications officer at North-West University.

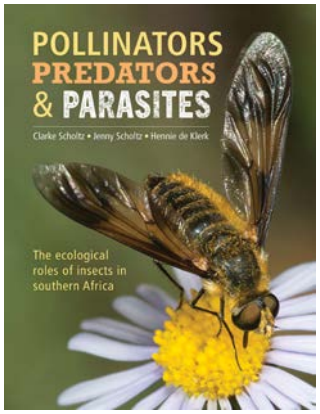
IKS Job Summit

At the end of March, a National IKS Job Summit – themed 'Exploring decent work, productive employment and sustainable entrepreneurship prospects for IKS graduates: Cultivating grounds for grassroots innovation' – was held online over two days. Currently, four universities have registered bachelor's degrees or are in the process of doing so, but the vast majority of IKS graduates have been unable to find employment in their field. In his keynote address, Minister of Higher Education, Science and Innovation, Dr Blade Nzimande, said that the summit provided a platform to brainstorm and find strategies and plans to address this problem. He suggested that a database of all unemployed and underemployed IKS graduates be compiled to assist government, in partnership with other stakeholders, to provide intervention measures through work integrated learning, internships, job opportunities and training in entrepreneurship.

Books

Pollinators, Predators & Parasites:
The ecological roles of insects in southern Africa

By Clarke Scholtz, Jenny Scholtz & Hennie de Klerk.
Struik Nature.



A book like this comes along only once every few decades in South Africa, so while it's a pricey purchase for the average reader, it's a must-have for insect lovers, natural history buffs and academic libraries. It's also a great 'coffee table book', given the many colourful photographs, fascinating facts, and sub-sections with attention-grabbing headings that make it easy to dip into. The latter includes numerous boxes, such as those on Bushman arrow poison, commercial use of wild silk, feeding mechanisms in aquatic insects, and floral adaptations for pollen attachment.

Rather than having chapters ordered by taxonomic groupings of insects – like the classic *African Insect Life* written by Dr SH Skaife in 1953 and updated by Dr John Ledger in 1979 – this book is structured around southern Africa's biomes. There is an introduction on insects and their ecological role, and then chapters dedicated to the Fynbos, Succulent Karoo, Desert, Nama-Karoo, Grassland, Savanna, Indian Ocean Tropical (Coastal) Belt, Albany Thicket and Forest Biomes. Four additional chapters focus on freshwater habitats, caves, the coastal zone and the urban environment. The taxonomy isn't neglected either, because an appendix at the back of the book provides the names and short descriptions of the 25 orders of insects that occur in southern Africa, listed in evolutionary sequence.

The authors explain in the preface that they have tried to highlight some of the interesting aspects of insect life history in these biomes and other areas, and to emphasise their environmental importance as ecosystem service providers. So the content isn't limited to pollination, predation and parasitism as suggested by the title, but also covers other ecological processes such as soil modification and nutrient recycling.

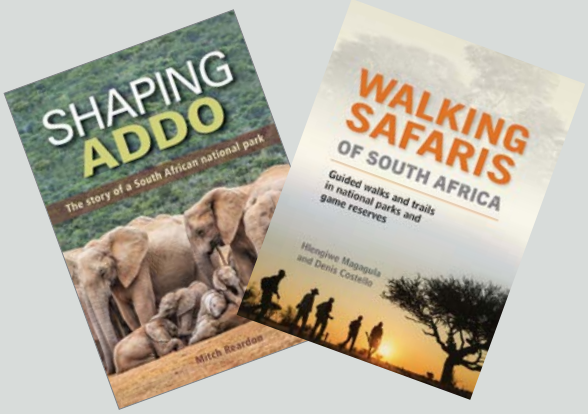
The lead author, Clarke Scholtz, is an emeritus professor of entomology at the University of Pretoria, where he continues to teach undergraduates, supervise postgraduates and conduct entomological research. Jenny Scholtz studied nature conservation and worked for a conservation NGO before her focus turned to the study of insects. Hennie de Klerk took the vast majority of the book's more than 1 600 photographs; although he studied and worked in the field of metallurgy, he dedicates his leisure time to capturing creatures on camera, with a focus on insects and birds.

The recommended retail price (RRP) of the book – a 448-page hardcover – is R590, but it is also available as an eBook for R399.

Struik Nature also recently released two books that should appeal to visitors to South Africa's national parks and private game reserves.

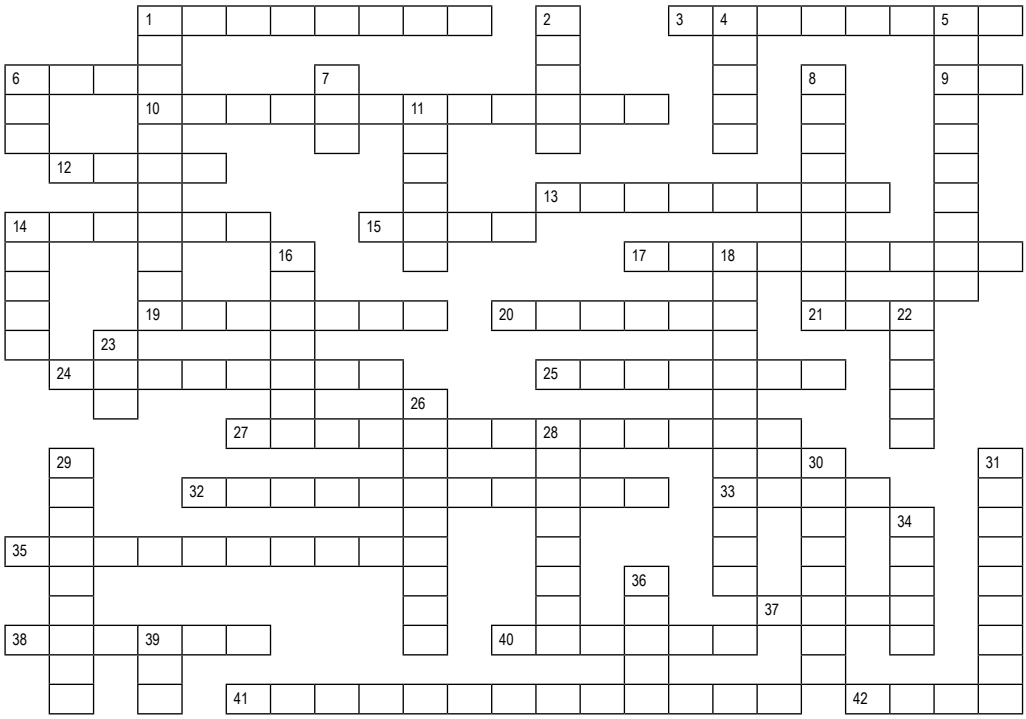
Shaping Addo: The Story of a South African National Park, by Mitch Reardon, is a highly readable account of how a small sanctuary for elephants – established when hunting had reduced the Eastern Cape population to just 16 individuals – was transformed into a successful mega-park that stretches from the Bird Island marine protected area inland to Darlington Dam and beyond. This means that Addo now hosts the 'Big Seven': elephant, lion, leopard, buffalo, rhino, great white shark and southern right whale, along with numerous other species. Today there are about 650 elephants in the park, as well as large herds of other herbivores such as zebra, red hartebeest and kudu. The book's RRP is R320.

Walking Safaris of South Africa, by Hlengiwe Magagula and Denis Costello, covers 59 guided walks and trails in 21 national parks and game reserves, two of them in eSwatini and one in Botswana. Each entry includes a useful box detailing the walk type (day walk, backpacking trail or wilderness trail), operator, cost category, minimum and maximum group size, minimum age and the best time to go. Apart from an account of what to expect, there are interesting articles written by Hlengiwe Magagula, a seasoned travel writer and blogger, about her first-hand experiences on the trails. 'The pharmacy of the dunes', for example, relates what she learnt from her guide about the useful plants in the Kgalagadi Transfrontier Park. The RRP of this book is R270.



Test your knowledge

All of the answers can be found in this issue of *Quest*



ACROSS

1 *Streptococcus* and *Lactobacillus* are examples of these microbes
3 Hydrogen ___ smells of rotten eggs
6 A substance that can react with acids and neutralise them
9 A measure of the relative amount of free hydrogen and hydroxyl ions in solution
10 A sedimentary formation made by layers of cyanobacteria
12 The critical ___ is the maximum amount of a deposited air pollutant that will not cause significant harm to specific elements in the environment
13 Another term for tooth tartar
14 A global convention for wetlands of international importance
15 A ___hole may be caused by the sudden collapse of the ground surface
17 The precipitate that discolours water after iron sulphide oxidation
19 Refers to mechanical agitation of the soil to prepare it for planting
20 A small watercourse that becomes a river
21 A term for a spring that is the source of a river
24 The rock type that contains South Africa's most important aquifers
25 The name of the UKZN rocket launched in March
27 The popular term for the eggcase of a shark or ray
32 These microorganisms thrive in acidic environments
33 A citizen science project for elasmobranch monitoring in South Africa
35 Describes dark, acidic watercourses and wetlands
37 This is added to agricultural fields to reduce soil acidity
38 An early agropastoral society in the Mpumalanga region
40 A rocket type that uses a combination of solid fuel and liquid oxidiser
41 Rising levels of carbon dioxide are causing ocean ___
42 This may form when water containing high concentrations of dissolved organic matter is agitated

DOWN

1 A submerged cave famous for deep-diving records
2 A type of acid associated with decaying plant matter
4 *Helicobacter pylori* may cause a digestive tract ___
5 Acid rain is nowadays known as wet ___
6 The acronym for a protocol developed with a community during an IKS consultative process
7 The acronym for a type of water pollution associated with mining
8 The plant substance that is plasticised for use in cigarette filters
11 The term describing cloudy or opaque water with high levels of suspended solids
14 The geographical area a species occurs in
16 The mineral form of calcium carbonate
18 A dating technique that measures how long ago mineral grains were last exposed to light or heat
22 Giraffe in the Western Cape are ___limital
23 The acronym for nitrogen oxides
26 *Star Trek* fans are familiar with this fictional method of faster-than-light travel
28 Describes the concentration of salts in water or soils
29 Another name for the mineral pyrite
30 Fertiliser application of this form of nitrogen contributes to soil acidification
31 A chemical element that becomes soluble at low pH and is toxic to plants and aquatic organisms
34 These rock walls separate aquifers into compartments
36 Describes terrain where carbonate rock has been dissolved by acidic groundwater
29 Tailings are the residue after minerals have been extracted from this

BRAINTEASERS

This is what food costs at Mama B's café.
1 curry and 1 tea cost R40.
2 curries and 2 desserts cost R90.
1 dessert and 2 teas cost R20.
What do you have to pay in total for 1 curry, 1 dessert and 1 tea?
What does each item cost on its own?

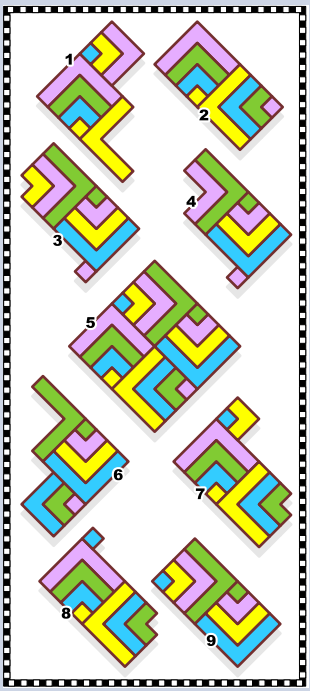
Last year my age was a square number.
Next year it will be a cube number.
How old am I?
How long must I wait until my age is both a square number and a cube?

Answers to Brainteasers in Vol. 17 No. 1

Sipho paid R20, R40, R60, R10 and R80 for the five presents.
Nasreen bought 4 angelfish and 8 goldfish.

PICTURE PUZZLE

Which two pieces were used to make the pattern 5?



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