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An agricultural green economy for South Africa

Vernacular languages as the medium of instruction at universities

Bt maize in smallholder agriculture

Food quality in the National School Nutrition Programme

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What is on the horizon for science, technology and education in 2015?

What developments or breakthroughs might we expect in science, technology and education in 2015? Scientists and scholars have a well-honed knowledge of the changes that will take place in their own fields, but what of the broader picture, and the developments that could well take longer than the public might be anticipating? Here is a sampling of just four areas of interest for 2015.

Over the past 2 years, the South African component of the Square Kilometre Array (SKA), its 64-dish MeerKAT element and MeerKAT's seven-dish KAT prototype have received justifiable and praiseworthy press coverage. The SKA was awarded jointly to South Africa (and its African collaborators) and Australia in 2012, and the design plans for the SKA are now well underway. In the meantime, considerable progress has been made in developing KAT-7 and MeerKAT. But ask any astrophysics postgraduate when they hope to start analysing data from the complex project, and you will probably receive an ambivalent and somewhat anguished reply: 'Maybe by the end of 2015? – at the earliest'. For although KAT-7 has been commissioned and is delivering images, MeerKAT was formally launched only in March last year, and the larger components of the SKA will be built between 2018 and 2020. So while some research work is being undertaken, the primary tasks are now those of the engineers and advisory scientists. What then might be expected in 2015? Certainly, progress on the design of the SKA, continuing development work on MeerKAT and, perhaps, the first serious streams of hard data towards the end of this year from the first 16 dishes. Dr Rob Davies has demanding tasks ahead of him as the project's Director Designate.

At both school and university levels, education in South Africa faces problems of overcrowding and levels of demand that go beyond existing capacities. In the school system, underqualified teachers add considerably to the problem. At university level, information and communication technologies have long been implemented and considerable progress has been made. In Gauteng, Panyaza Lesufi – the MEC for Education – has decided that the use of virtual learning techniques at school level will not only make the most effective use of the province's best teachers, but will also contribute to the erosion of racial differentiation in public schools.

Pairs of schools will be 'twinned' over the next 6 months using smart technology with Wi-Fi, interactive boards and tablets for pupils, as the chalk board gives way to the talk board. Technology aside, teachers in the twinned schools will be provided with the support they will need to ensure that the venture will have the best chance of success. Boitumelong Secondary in Tembisa and Kempton Park High will be the first schools to be 'merged virtually', and they will be followed by Sandown High and Alexandra High in Johannesburg, Hoërskoel Waterkloof and Mamelodi Secondary in Pretoria, and Hoërskool Noordheuwel and Kagiso Secondary in Krugersdorp. The province has made ZAR2 billion available for the project, and 80 000 tablets (tagged to limit theft) have been delivered. What might we hope will happen in 2015? A project so successful that it is taken to scale across the country would be an encouraging development.

Its operations suspended for 2 years (2013–2014) for maintenance and major upgrades, CERN's Large Hadron Collider (LHC) will start operating at 13 tera-electron volts (13 TeV), up from the 7 TeV and then 8 TeV at which it previously functioned. Since the shutdown, engineers and technicians have been repairing and strengthening the 27-km accelerator in preparation for its restart. Some 18 of the 1232 dipole magnets that steer particle beams around the accelerator have been replaced, and more than 10 000 electrical interconnections between the magnets have been strengthened. The LHC's vacuum, cryogenics and electronics systems have also been consolidated.

The collision energy of 13 TeV is a significant increase compared with the initial 3-year LHC operation. In addition, in the run that starts this year, bunches of protons in the accelerator will collide at briefer intervals – 25 nanoseconds (ns) instead of 50 ns – and the beams will be more tightly focused. All these factors are intended to optimise the delivery of particle collisions for physics research. With collisions at energies never reached in a particle accelerator before, the LHC will open a new window for discovery, including the possibility of solving the riddle of dark matter, finding evidence of a far-reaching cosmic concept known as 'supersymmetry' (the idea that for every matter particle there is also a corresponding force-carrying particle), and even discovering signs of extra hidden dimensions that help explain the mystery of gravity. All this will require not one but several Higgs bosons, providing a new quarry for the LHC scientists to pursue. Some scientists are sceptical, believing that this phase will not achieve any of these desiderata if, in fact, anything at all. This is, perhaps, the nature of the (currently) outer limits of physics and the LHC itself. Then again, the Higgs boson has been found to exist, so who knows what to expect once the LHC starts up again? Perhaps a new understanding of aspects of the universe?

In an entirely different realm, there is a story that reads, initially, a little like an adventure book for teenagers, starting with a Facebook job advertisement for individuals with 'excellent excavation skills' and a master's or PhD degree in areas of palaeoanthropology, who also are skinny, preferably small and fit, who have climbing experience, and who are not claustrophobic. The adventure book phase ended with six young women being hired to work on the project that became Rising Star. The story for teenagers ends with 'science tents', generators, lights, cameras, computers, funds from *National Geographic*, and 'somewhat larger, more senior' palaeoanthropologists installed at ground level while the six went underground. In 3 weeks, the underground team brought 1200 fossils to the surface – including, it is believed, more than 12 complete individuals. In the Leader of the next issue, Dr Patrick Randolph-Quinney, a member of the Rising Star team, will share background information about the project and, in the months that follow, research findings from the project will be published in *Nature*. What might we expect as *Nature* begins to publish early results from Rising Star? Another branch of the early hominids? A new piece in the jigsaw puzzle of evolution and the emergence of *Homo sapiens sapiens?* An explanation as to why so many fossils, and individuals, ended in so remarkable a concentration? The papers in *Nature* will surely reveal some of the answers in the course of 2015.

Few though they are, these examples suggest that 2015 will be a year filled with the promise of stimulating developments and discoveries. These will assuredly keep readers of the SAJS engaged and looking out for even more to follow in 2016.

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Approaches to large-class teaching

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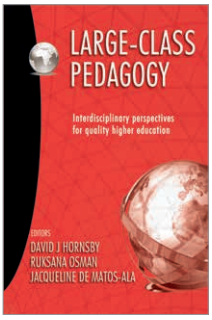

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As the late Wally Morrow[1] long ago pointed out, in South Africa the shift to a more equitable political dispensation would mean that academic teachers needed to think hard about their need to teach large classes in spite of dominant discourses which said 'small is best'. More than 20 years on, 'small is best' thinking continues to dominate South African higher education in spite of the fact that the system has almost doubled in size since the early 1990s and, if targets in the National Development Plan 2030[2] are reached, will swell even further in the next 15 years. Moreover, this growth will take place in the context of a shortage of academics, as many of the existing cohort move into retirement and new recruits to the profession are hard to find. In addition, given dominant neoliberal philosophies and the current economic climate, this growth probably will have to take place with no increase in funding for higher education in real terms. In this context, the publication of a book written by practising South African academics on large-class teaching is particularly welcome.

The editors of the book, David Hornsby, Ruksana Osman and Jacqueline de Matos-Ala – all from the University of the Witwatersrand – introduce the volume by arguing that management of the learning environment in large classes can result in better quality student learning. They, along with other authors in the volume, then draw on theory related to learning styles, most notably work on 'deep' and 'surface' approaches to learning, to make this argument.

The original work on 'deep' and 'surface' approaches to learning[3,4] established that the way students *perceived* the contexts in which they were studying led to the adoption of *approaches* to learning that were understood to bring the greatest reward (typically higher marks). This has then led to claims that manipulation of the learning environment, particularly in the direction of what Biggs[5] terms 'constructive alignment', can result in shifts in students' approaches to learning and, thus, better quality learning outcomes.

In spite of the popularity of such claims, their validity is undecided; although a large-scale review[6] of extant work, led by Frank Coffield of the London Institute of Education, found little good evidence to support them. As Haggis[7] also points out, the model of a 'deep' approach to learning, understood to be achievable through the manipulation of classroom contexts, actually describes the very sophisticated ways academics go about learning – ways that have taken many years, not a single course, to develop.

Of greater concern, however, is the phenomenon identified by Haggis[7] that sees the original construct of *approaches* to learning shifted into *types of learning* and even *types of learner* as work in this area has progressed. It is into this trap that some authors in the book fall, at least as far as identifying 'deep' and 'surface' *learning*. While semantic shifts of this nature are easily dismissed, their significance in South Africa is not to be underestimated. In moving away from an understanding of the way context shapes perceptions, and thus learning approaches, to the more fixed constructs of types of learning and learners, work on learning styles not only produces individualised, asocial and acultural concepts of learning but also, as Reynolds[8] points out in a trenchant critique of work on learning styles, 'obscures the social bases of difference in the way people approach learning'.

This critique of the use of theory on learning styles by no means undermines the usefulness of this book. The central section of the volume is devoted to a series of case studies of large-class teaching and learning in action. These are extremely valuable for anyone faced with the need to teach a large class regardless of the years of experience they may bring to the task. Brenner's chapter on the use of interactive classroom technology (or 'clickers') is particularly valuable, especially given the way the use of the technology is supported by social constructivist learning theory. Examples of questions used in an actual course show how the lecturer can move away from a focus on the dissemination of content knowledge to an interactive engagement with students that supports them as they make connections and engage in levels of thinking beyond merely trying to remember.

Also extremely valuable is Brenner and Nichols' account of the use of writing to promote critical thinking in large classes. The quality of students' writing is a perennial complaint in any university, which often is addressed, in South Africa at least, by stand-alone writing courses. Brenner and Nichols offer a very different solution, much more strongly supported by theory, in the form of Writing across the Curriculum, Writing in the Discipline and Writing Intensive approaches involving the use of writing as a tool for learning. Problems with introducing these approaches in South Africa are numerous and relate to lecturers' reluctance to see themselves as able to contribute to students' writing development alongside a fear, particularly in relation to Writing Intensive approaches, that any intervention on their part will result in even more work. The solution proposed by Brenner and Nichols involves reconstructing work on writing as 'Critical Engagement through Writing' – an approach which can 'successfully engage all students and help them to develop the necessary skills to learn to enquire, think together and learn to learn' (p.98). The validity of writing as a tool for learning has been established as a result of a long vein of research going back to the work of Janet Emig[9] in the 1970s. Brenner and Nichols draw on this work to explore the way writing can be used as a tool for learning in a large class. The practical examples provide real clarity on the way this sort of approach could be implemented elsewhere; these examples, coupled with the soundness of the approach itself, make the chapter essential reading for any academic daunted by the thought of reading through yet another pile of poorly written student scripts.

Brenner and Nichols' chapter emphasises the importance of support for lecturers attempting to engage with the challenges of teaching a large class – in this case support which includes the availability of tutors and expertise from individuals knowledgeable about writing. Elsewhere in the book, other kinds of support are indicated. Butcher and Hoosen's contribution – on the use of open educational resources to support learning in large classes – indicates the need for the technical expertise necessary to sustain the use of information and communication technologies. Similarly, Hornsby and de Matos-Ala describe a wide range of strategies used to promote student engagement in

a large class, noting the importance of a 'state of the art lecture theatre' without which 'it would be difficult to recreate this dynamic teaching environment'. They go on to argue that 'a well-equipped venue is a pre-requisite for interactive large class teaching' (p.85).

Statements such as this might well elicit a sense of despondency from those who work on campuses without such support and infrastructure. However, there is sufficient in the book to provide ideas and practical solutions regardless of context. If anyone in South African higher education is looking to begin reading on teaching, this volume is an excellent place to start.

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Dealing with the inevitable: Fire on Table Mountain

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Burning Table Mountain: An environmental history of fire on the Cape Peninsula

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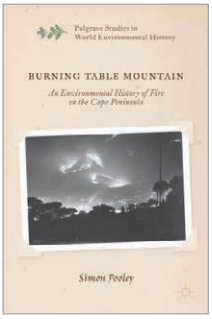

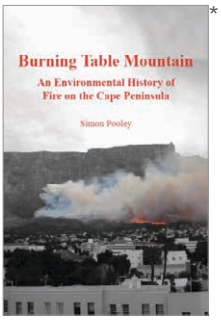

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Vegetation fires are the inevitable consequence of the co-occurrence of three vital ingredients – fuel to burn; hot, dry and windy weather; and a source of ignition. Table Mountain has all three, as early European colonists discovered very soon after their arrival at the Cape. Arriving as they did from the relatively fire-free regions of Europe, these colonists for centuries regarded fire solely as a destructive force. In ecological terms, however, fire is a natural feature of the Cape, regarded sometimes as a 'generalist herbivore' that indiscriminately consumes all plant species in its path. It is a process that shapes the structure and composition of vegetation communities in many of the earth's ecosystems. Managers of fire-prone landscapes therefore seek to influence fire regimes, both to protect lives and property from damaging wildfires, and to ensure the health of fire-adapted and fire-dependent species. This task has never been an easy one, as it requires trade-offs between the conflicting goals of biodiversity conservation and human safety, and in the case of Table Mountain is exacerbated by the divided opinions of a highly vocal and opinionated citizenry whose lives are closely affected by fires. It is thus extremely useful to have a historical account of how the understanding of fires and their management developed over time. Simon Pooley has produced an excellent review of this issue, using the Cape Peninsula as a case study.

As a background to the historical study, the book starts off with a review of the development of fire ecology in the fynbos. The science of fire ecology strives to understand and document the effects of fire on plants and animals, and the role that fire plays in maintaining healthy ecosystems. But managing fires requires more than just scientific understanding – it requires communication, consensus goal-setting, collaboration and coordination, all embedded in the humanities rather than in hard science. Fires (especially big fires) are also episodic and relatively infrequent. Big fire events are typically followed by highly visible postmortems, and usually culminate in promises to reorganise and improve fire management capacities. Equally typically, these promises are given lower priority as time passes, only to re-emerge again in dramatic form when there is another big fire. For example, the book quotes newspaper accounts of the 1982 fire as being 'the worst fire in almost four decades', when in fact equally large fires occurred only 10 years earlier. In Simon Pooley's words, these accounts 'reveal the fickleness of public memory, enhanced by an urge to dramatise current events'. Thus, although there has been a dramatic increase over the past 40 years in the understanding of the vital role that fires play in fynbos ecology, history shows how difficult it has been to use this knowledge in rational management.

Fire was seen by early colonists as a destructive force, and from the early 1900s was interpreted in terms of Clementsian succession as a process that retarded progress towards a (desirable) climax situation. Despite mounting evidence that fynbos plant species were adapted to fire, policies continued to promote fire exclusion. Calls by the influential Dr C.L. Wicht in 1945 to consider the use of fire in fynbos management went unheeded for more than two decades, against the background of a national concern about the detrimental effects of fire on soil erosion, and consequently on the ability of the nation to support itself. Bokkie the Grysbok, today the national symbol of wildfire awareness (and probably modelled on America's Smokey the Bear), was widely popularised in a fynbos fire-awareness booklet published in 1962, and helped to perpetuate the view of fires as agents of destruction. Today, the beneficial role of fire is widely recognised, but fire management remains controversial because of the need to simultaneously achieve the dual goals of protecting property and the public from wildfires while still allowing fire to play its necessary ecological role.

The management of fires on the Peninsula often fell to foresters, who established plantations of fire-sensitive trees in the fire-prone fynbos from the mid-1800s onwards. The history of tree-planting and forestry has also been characterised by opposing views regarding the value of trees. On the one hand, trees have over the years been seen as valuable sources of timber, as a means of protecting water resources, as providers of shade, and as an aesthetically pleasing cover for the mountain's bare slopes. On the other hand, concerns grew about the impact of foreign trees on the area's unique native flora, while evidence mounted that trees were detrimental rather than beneficial for water resources, and that they exacerbated wildfire effects. In addition, trees spread away from plantations – an invasion which was facilitated by wildfires. Concerns about these invasions were raised as early as 1888. In 1958, the Wild Flower Protection Committee of Kirstenbosch published a booklet entitled *Green Cancers of South Africa*, considerably raising awareness of the problem of invasion. The arguments about the value of foreign trees continue today, and opinions remain divided. However, the role of invasive trees in exacerbating the fire problem were brought to the fore following large fires in 2000, resulting in the focus of management on the Peninsula shifting from fire to alien plant clearing.

Pooley also documents growing concerns about the ecological effects of increasingly frequent fires, brought about by growing numbers of people with access to the mountain. The ownership of cars by private citizens increased from the 1930s onwards, and the latter half of the 20th century saw a substantial expansion of the Peninsula's

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road network, with the net result that previously inaccessible areas experienced considerable increases in visitor numbers, and of course in accidental fires. Pooley argues that it is this access, rather than the overall increase in Cape Town's population, that is driving increases in the frequency of fires.

Overall, this is an excellent and well-written book that has been thoroughly researched. Unlike scientific accounts, which rely heavily on the peer-reviewed literature, this account uses a myriad of additional sources, including newspaper articles, minutes of meetings, annual reports and interviews to produce an account of fire that reflects the evolving opinions and actions of scientists, policymakers, managers and the public at large. It is the first serious treatment of the interrelated development of fire science and fire policy in South Africa, and it takes the reader into the topsy-turvy world of divided opinion and competing institutions that ultimately have more influence on responses to environmental issues than does science. As such, it should be regarded as compulsory reading for students and practitioners of fynbos management.

Restoration of the world in one book

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Our once and future planet: Restoring the world in the climate change century

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AUTHOR:
Paddy Woodworth

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Shortly after the International Conference of the Society of Restoration Ecology in Madison, Wisconsin, USA in October 2013, Paddy Woodworth launched his book on restoration of environments from around the globe. Paddy Woodworth, who is a well-known investigative journalist from Ireland, has been following the world's restoration ecologists around for the last 8 years to get a first-hand account of their work. When I met him at the International Conference of the Society of Restoration Ecology in Spain in 2005 he had just started on the book and I suggested that he come to South Africa to look at restoration projects here. He subsequently did and I met him in Grahamstown to show him some of the restoration after removal of aliens in Grahamstown by the Working for Water (WfW) programme. His chapter on 'Greening the Rainbow Nation: Saving the World on a Single Budget' is surely the definitive account of the WfW project and a fascinating example of how the aspirations of numerous individuals have played out to result in clearing of aliens with the hopeful restoration of natural systems that will increase biodiversity and water and empower local people. The programme is not without its critics, but has nevertheless persevered, as is explained in this book.

Woodworth is an expert on all types of reporting and has made a thorough in-depth study of some 18 different restoration projects around the world. His investigations are from first-hand examinations of the ecological studies from extensive visits to the sites and discussions with the instigators of the projects, be they scientists, engineers or critics of the restoration work. Paddy grew up in this investigative environment in Ireland and has many projects to his credit. His first book, *Dirty War, Clean Hands: ETA, the GAL and Spanish Democracy* (Cork University Press, 2001), reached number two on the bestseller list in Ireland, and sells well in the UK, the USA and Spain.

Woodworth states that 'ecological restoration is a message the world is waiting to hear' and in this book he has provided a scholarly and most informed account of the current state of restoration ecology. The emphasis in this book is to inform both the lay reader and the experts of these many world-renowned restoration projects and also to give an up-to-date account of the state of the science. Essentially the book is an excellent critique of science at work. Ecological restoration is not an ivory tower academic subject but rather a nuts and bolts approach to the application of scientific methodology in a world that has been increasingly damaged by the pressure of the human population explosion and consequent damage to many environments and habits. Destruction of ecosystems has resulted in the displacement or destruction of many of the biota (plants, animals and microbes) that inhabited these sites. Restoration ecology is generally regarded as the way that plants are restored to degraded areas resulting in the re-creation of suitable habitats for animals and other organisms. Woodworth adopts a broader definition as to the way that nature or even individuals may be restored to be functional in today's world. Reading the book will make it apparent that this broader view is perhaps how we should look at the natural world. Ecologists need to emerge from their own small niche of ecological studies.

In some 515 pages of text and notes, this book fully describes ecological restoration and gives an account of restoration practices in many parts of the world. There are chapters on restoring (or conserving):

- migrating whooping cranes in North America
- the 'wilderness' in the precincts of the city of Chicago
- degraded ecosystems in South Africa
- the cultural landscape in northern Italy
- Irish forests and bogs
- natural vegetation in Western Australia
- tropical forests in Costa Rica
- natural animal populations in New Zealand
- rainforests and eco-agriculture in Mexico

The reader will be fascinated by these chapters as Woodworth describes the salient information in detail on how the restoration process has been undertaken, what the resultant end product is and how this fits in with the 'world concepts' of restoration practice. Ardent scientists may be disappointed to find few tables, figures or photographs that describe the process. However, the descriptions in the text of the way in which the process has been undertaken are very illustrative of the restoration problems and resulting methodology. The index is extensive and adequate to allow easy access to the topics covered in the book.

One failing of the book is the lack of a map to show the location of the restored sites, which are dotted around the world. I was also disappointed that the restoration accounts do not have adequate reference to the important plant species which are invaders or used in restoration projects. The species are mostly referred to by their common names, which may require further research to establish what these important species are and from where they came. For example, Jaragua, a small city in Brazil, has given its name to a tropical thatching grass from Africa – *Hyparrhenia rufa* – that has been introduced to replace the cleared rainforests in much of Latin America. Similarly, *Gmelina arborea* (Verbenaceae), a fast growing small Asian tree introduced into Costa Rica that outcompetes the invading grasses and is used as a pioneer for forest restoration, is simply called 'gmelina'. Practitioners will probably also find the book lacking in practical guidelines and approaches to ecological restoration. However, these guidelines are available elsewhere, including the Internet. The book is structured to explain the

practice and current state of the science of restoration ecology with many case studies, and is not a manual on 'how to do it.'

In the Preface, the structure of the book is described as being a personal exploration of restoration to give the reader access to all the main topics in restoration. The book is divided into four main strands:

- Strand one – 'Travelling toward Restoration' (Chapters 1–3) in which the basic tenants of restoration ecology are addressed in the way that the author has uncovered them.
- Strand two – 'On the Ground, Around the World' investigates the ecological, social and geographical context of restoration projects from around the world. This strand comes in two sections (Chapters 4–6 and 9–12) and is the most intriguing section of the book as Woodworth has made a thorough analysis of the science behind the projects and personalities involved as well as many of the pitfalls in the projects and how they have been addressed. He backs his study with numerous references and notes, many being emails or recorded discussions with the persons involved. From these project analyses one realises that ecological restoration is not just science.
- Strand three – 'Restoration begins at Home' (Chapters 7 and 13) explores the restoration of forest and bogs in Woodworth's native Ireland. This strand is essentially similar to the previous one but applies to Ireland.
- Strand four – 'Pause for Thought, Time for Theory' (Chapters 8 and 14), like the first strand, explains the theory behind restoration and the development of the science of restoration ecology as Woodworth's study of the subject has continued through the years. The processes and concepts of restoration ecology are clearly explained in words and diagrams in these sections, but, more importantly, Woodworth has examined the philosophies and concepts that have been developed by the current role players in the science. Unfortunately this book comes too late to contain the contributions of one of our most notable restoration ecologists – the late Professor Tony Bradshaw, whose ideas and models are carried on today, although their proponent is unknown to many younger researchers.

The concluding chapter sums up the content of the book, and looks at why we should restore. Woodworth surmises that the first lesson is psychological as one must overcome the barriers from despair to hope. Despair as one faces a destroyed landscape to hope in that restoration is possible. He sees ecological restoration as 'the capacity to galvanise individuals, communities and societies to action'…and that we can 'have a constructive relationship with the world around us'. The final sentences conclude: 'Some things are getting better. But there is still a lot of very hard work to be done.' We can but hope that the restoration ecologists and practitioners will take up the challenge.

Research Briefs

GENOMICS

Comprehensive mapping of African genetic variation

Working with 41 co-researchers (including scientists from the Universities of the Witwatersrand and KwaZulu-Natal), Deepti Gurdasani of the African Genome Variation Project and his colleagues have produced what they believe to be the most comprehensive map of African genetic variation available to date. The significance of their work lies in the possibilities that the mapping offers for understanding the currently unknown roles that genes play in diseases such as malaria, haemorrhagic fever, Lassa fever and hypertension in sub-Saharan African populations. The team gathered data from more than 1800 people, including 320 whole genome sequences from seven populations. In the seven sequenced populations, they found 30 million genetic variants, 25% of which had never previously been identified in any human population. In their conclusion, the authors note:

> *A critical next step will be the large-scale deep sequencing of multiple and diverse populations across Africa, which should be integrated with ancient DNA data. This would enable the Project to identify and understand signals of ancient admixture, patterns of historical population movements, and to provide a comprehensive resource for medical genomic studies in Africa.*

Gurdasani D, Carstensen T, Tekola-Ayele F, Pagani L, Tachmazidou I, Hatzikotoulas K, et al. The African Genome Variation Project shapes medical genetics in Africa. Nature. In press 2014 [published online 2014 Dec 03]. http://dx.doi.org/10.1038/nature13997

PHYSICS

New results in fundamental magnetism

André Strydom, a professor of physics and leader of the Group on Highly Correlated Matter in the Faculty of Science at the University of Johannesburg, initiated a project that has produced fascinating new results in fundamental magnetism. The work is recognised to have opened a new research field and was published on 19 November 2014 in *Physical Review Letters* – the flagship journal of the American Physical Society.

The work is a continuation of a project which Strydom started in 2008 on 1:2:10 structured rare-earth based ternary intermetallic compounds. His original 2009 paper is listed as the 5-year most highly cited work of the Elsevier journal *Physica B: Condensed Matter* (http://www.journals.elsevier.com/physica-b-condensed-matter/most-cited-articles/).

The most recent chapter in this research is a sequel to the PhD studies undertaken by P. Peratheepan, a former student of Strydom's and now Head of the Physics Department at the Eastern University of Sri Lanka. As a project which profited from a comprehensive investigative approach through joint research and international team work, the published work partners the University of Johannesburg with research institutes of the highest calibre in Germany, Taiwan and Korea.

In the study, a fascinating and unexpected interplay between electrons of two different energies and quantum mechanical states has been discovered. Traditionally, electrons pervade a metal freely in a manner described as itinerant or delocalised. This microscopic behaviour of electrons is responsible for macroscopic attributes of metals such as good electrical and thermal conductivity and metallic lustre. In the element iron, electrons occupying the spatially extended 3d atomic shell are responsible for its magnetic properties. By contrast, in chemical elements known as the lanthanide elements, the magnetic electrons are found in the semi-filled 4f shell. These are confined to a volume much closer to the nucleus and this type of electron produces, by contrast, the localised form of magnetism. The border between local and itinerant magnetism has become a source of intense activity in condensed matter physics as a result of an astounding variety of new physical properties and unpredictable elementary particle behaviour found at this juncture. Announcements of new discoveries and exotic phenomena continue unabatedly in this topic. The discovery accompanying this paper questions some of our most basic theories of metals.

In studies that Strydom conducted with collaborators at the Max Planck Institute in Dresden during 2012/2013, surprising behaviour was found at the confluence where wave functions of these two types of electrons come into contact with each other in the same metal. An extraordinary temperature-driven evolution among the two opposing kinds of magnetism was found. But, says Strydom:

> *Understanding the entangled behaviour proved to be very difficult and demanded a multi-parameter approach. Most unexpected in our studies was the transporting of one type of magnetism, namely the local-moment magnetism on the ytterbium ions with spin- and orbital forms of magnetism, into the spin-only type of magnetism on the Fe atoms. At very low temperatures, we found hints that a highly correlated state develops among the 3d electrons of Fe. This state develops spontaneously when Coulomb repulsion energy among quasi-localized electrons exceed their thermal kinetic energy. In our surveys of the very low temperature properties of matter we came across collective behaviour, and a way in which the electrons seem to act in union but in ways which defy some of our most well-founded concepts of metals.*

This strongly correlated state among 3d electrons is highly unusual and an emergent field of condensed matter physics. The work is expected to stimulate new directions in research that will explore how different types of atomic magnetism can work together, or compete.

Khuntia P, Peratheepan P, Strydom AM, Utsumi Y, Ko K-T, Tsuei K-D, et al. Contiguous 3d and 4f magnetism: Strongly correlated 3d electrons in YbFe2Al10. Phys Rev Lett. 2014;113:216403 [published online 2014 Nov 19]. http://dx.doi.org/10.1103/PhysRevLett.113.216403

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Global trends and opportunities for development of African research universities

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It has been more than a decade since Jamil Salmi, former tertiary education coordinator at the World Bank, published his influential report *Constructing Knowledge Societies: New Challenges for Tertiary Education*.[1] In this report, he discusses the unprecedented challenges facing tertiary education globally, driven by the 'convergence of the impacts of globalization; the increasing importance of knowledge as a principle driver of growth; and the information and communication revolution'[1]. Since then, these factors have been further intensified by the rise of various global university ranking systems that are increasingly driving the choices of academics, students, industries and governments of where to invest their talents and funds.[2]

The demand for demonstrating the relevance and impact of research at higher education institutions is increasing at the same time, particularly in developing nations in which funders are becoming impatient with a perceived lack of results. In a recent visit to the University of Pretoria, the African Union Commission's chair, Dr Nkosazana Dlamini-Zuma, encouraged academic communities to participate more actively in the realisation of the developmental needs of the continent, with particular reference to the African Union Agenda 2063.[3] At the same time, research institutions around the world are deeply affected by greater global competition for talent and funding, while dealing with local and regional calls for relevance in addressing societal problems.

In reflecting on a global science context at the 2014 meeting of the world's largest general scientific society, the American Association for the Advancement of Science (AAAS), its CEO Alan Leshner and past president and Nobel Laureate in Medicine, Philip Sharp, summarised these trends in an editorial published in the journal *Science*[4]:

> *Searching for solutions (to todays' global challenges) requires that the scientific community operates in fundamentally new ways... Developing effective solutions requires converging approaches, such as the integration of knowledge from the life, physical, social, and economic sciences and engineering... Research-performing and training institutions, such as universities and research institutes, have critical roles to play...it is essential that they develop appropriate training programs and help stimulate multidisciplinary international collaborations.*

The call for a 'fundamentally new' approach to interdisciplinarity (collaboration between disciplines), transdisciplinarity (involving knowledge 'generators' beyond academia), internationalisation and social responsibility of research articulated in this statement appears to be central to virtually all discussions on the future of research institutions globally. In this opinion article we reflect on the challenges and opportunities that these developments hold for African research universities.

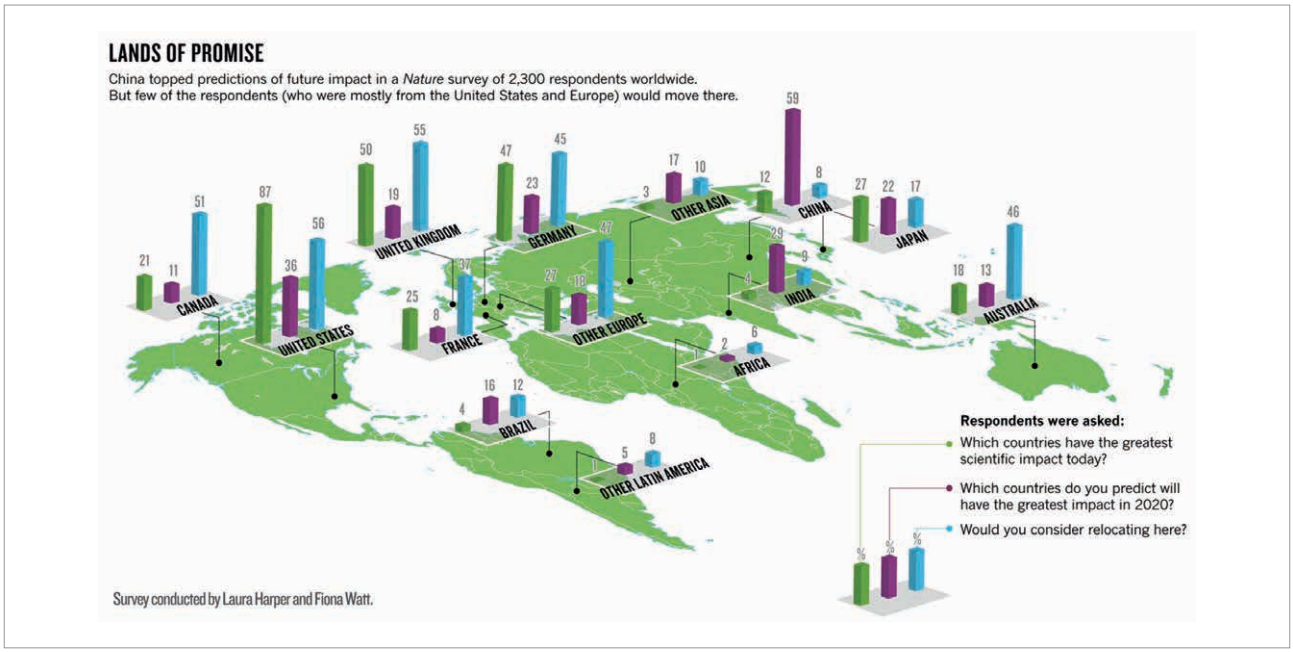
The rise of research networks

The journal *Nature* recently published the results of an investigation of global internationalisation trends in research. Findings were fascinating, if not completely surprising to those working actively in leading research institutions, and attested to the fact that 'a fundamental shift is taking place in the geography of science'[5]. The first key finding related to the numbers of authors of research papers. In the journal *Nature* itself, the number has increased 400% since the 1950s. Papers with 100 authors were rare in the 1980s, but today such papers are common, with a growing number of papers with over 1000 and even over 3000 authors. Secondly, collaborations between nations have skyrocketed in recent years. While no country shared more than 1000 joint papers with any other nation by 1980, today the USA shares tens of thousands with various nations. Importantly, regional networks, particularly in Asia, appear to be 'reinforcing the competence and capacity of emerging research economies, and changing the global balance of research activity'[5].

A second article in the same issue of *Nature* illustrated how extremely mobile the best research talent is today, and that these patterns of global movement are biased towards developed nations in particular, which have long benefitted from a skewed distribution and movement of researchers.[6] Although the trend is changing with increasing research opportunities in some developing nations, the analysis contained a warning that uncertainties about local research environments and culture may very well influence this change. For example, while China is seen to hold great research opportunities and future impact, few emerging researchers consider relocating there (Figure 1).

For those who take cognisance of these trends, there are opportunities to position themselves to retain and attract the best talent. Some Asian institutions in particular have made great use of this opportunity in recent years with a number of innovative initiatives.[7-9] These initiatives include establishing 'satellite labs' for excellent young researchers; focused programmes to attract ambitious and talented young stars; development programmes for local talented researchers in high-quality overseas laboratories; and partnerships with leading international institutions. The flip side of this trend of course is that those who are unable to compete for this global pool of talent also stand to lose their own best talent. Science in Africa has long suffered for this reason and our continent must urgently find ways to reverse its brain drain.

That is not to say that funding opportunities for international research networks and projects in Africa do not exist. They do, and they are increasing with many funders investing substantially in research on sustainable development.[5,10] Much of this funding is earmarked for developing international, interdisciplinary research networks and research projects.



Source: Van Noorden[6]

Figure 1: An assessment of current science impact (green), predicted impact by 2020 (purple) and attractiveness as a science destination for the respondents.

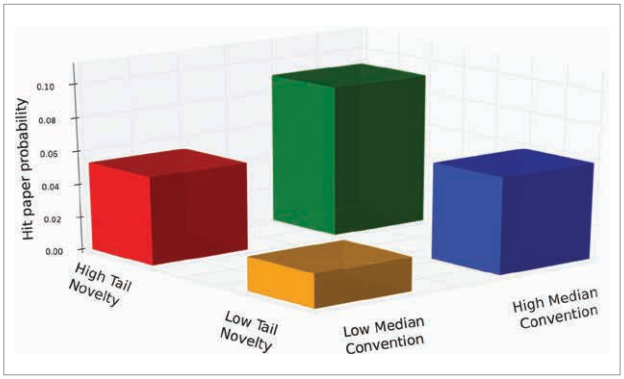
Interdisciplinarity

There is broad agreement that the scale and complexity of challenges facing society requires more than just the power of international research networks. It also requires investment in stimulating convergence between the engineering and the natural, human and social sciences.[4,11,12] Issues such as water sanitation and health, food security and environmental sustainability, climate change, natural disasters, conflict, poverty and displaced populations are all interconnected issues that transcend both national and disciplinary boundaries. For many of these problems technological solutions exist, but governance or social issues often block their effective use.

There are significant obstacles to the integration of knowledge and to the development of true engagement across and beyond scientific boundaries. The resistance (at least to some extent) has to do with the deeply ingrained structures and systems focused on disciplinary distinction that exist at established research institutions. Such boundaries are easier to overcome at younger universities, which some have used to their advantage. For example, Bertil Andersson, President of the Nanyang Technology University in Singapore, ascribes the meteoric rise of this institute to the 76th position on the Times Higher Education list of world universities to its research agility.[7] At this and other 'rising star' institutes, they have succeeded in implementing structures (from undergraduate teaching to research focus areas) that transcend traditional disciplinary boundaries.

The complexity of developing effective interdisciplinary projects should not be underestimated,[11,13,14] and interdisciplinarity should not be seen as a magic solution to all complex problems. Some issues will remain the remit of disciplinary focus and depth. Excellence in interdisciplinary science relies on effectively connecting disciplinary excellence, not replacing it. But making such connections effectively is a field of specialisation in itself; it requires expertise and time to define common goals, a shared understanding of different perspectives, a common purpose and the development of effective means of communication. Where effective, such interdisciplinary projects can, however, have far more potential to deliver novel insights and innovations which address complex problems than narrow disciplinary approaches.

The impact of interdisciplinary research has recently been demonstrated through retrospective analyses of almost 18 million papers spanning all scientific fields. In this study, Uzzi[15] and colleagues showed that the highest impact research is grounded in disciplinary excellence (i.e. relying on depth of knowledge in a specific field), but with a simultaneous lateral contribution from other fields (i.e. integrating ideas across fields). Such combinations made a paper almost 100% more likely to be classified as high impact (Figure 2). The authors concluded that scientific progress appears to require parallel efforts along two seemingly opposing, yet in reality complementary, extremes – conventionality and novelty.



Source: Uzzi et al.[15]

Figure 2: A unique combination of disciplinary depth (conventionality) and novelty significantly increases the impact of research papers.

Research teams

A number of recent studies[15-17] have also revealed the value of research teams. Firstly, these studies show a direct positive influence of larger teams on the output and impact of papers and patents, across all fields of science. They also show that the larger the teams, the higher the likelihood that the work is integrated across disciplines and the greater the impact of the papers and innovations. Not surprisingly, an increasing proportion of the most innovative research is done by larger research teams. This effect is even further increased when the collaborating teams include members from elite institutions, giving further motivation to the focus on targeted internationalisation described above.

The increased impact of teams is rooted in the collective capacity and abilities of research teams, which are also the same qualities that make them more attractive to large international research networks and give

them the capacity to develop and lead such international networks or projects. They serve as magnets for drawing other talented researchers for whom such capacity is vital to their career development.

Beyond interdisciplinarity to transdisciplinarity: A new frontier

Recent decades have vividly shown that traditional definitions of research excellence and training do not automatically resolve the complex problems facing the future of society and the planet. This situation has been called a 'crisis of research effectiveness', considering the lack of progress on a number of critical issues, such as climate change, biodiversity loss and environmental degradation, over the past two decades – a period in which more new knowledge was generated than ever before and significant international declarations such as the Rio Declaration on Environment and Development and the UN Millennium Development Goals were made.

This 'crisis' highlights the need for transdisciplinarity as a new frontier for research communities. This new paradigm strives towards a 'new form of learning and problem-solving involving cooperation between different parts of society and science in order to meet complex challenges of society'[18]. Transdisciplinarity 'starts with tangible, real-world problems' in a joint endeavour through which '[s]olutions are devised in collaboration with multiple stakeholders'[18]. This approach is also at the heart of the recently launched Future Earth project (www.futureearth.info) of the International Council for Science (ICSU), which attempts to embrace such a transdisciplinary approach to increase the impact of global change and sustainable development research. Without success in these endeavours, many believe that there will be little chance that the world can reverse the unsustainable collision course of current global change, resources use and development trajectories.

Kueffer and colleagues[13] from the Alliance of Global Sustainability at ETH Zurich (Switzerland) argue that transdisciplinarity will require a fundamental institutional and cultural re-orientation at research universities. In the first place, they argue that this will require a focus to stimulate the development of interconnected (both inter-institutional and interdisciplinary) research teams (as also highlighted above). But they also highlight the complexity of forming research partnerships with actors and experts outside academia, linked to an orientation of research programmes to societal problems. They argue that both institutional innovations and structural optimisations will be critical in achieving these goals, while at the same time it is necessary to preserve the traditional strengths of disciplinary excellence and scientific rigour.

Opportunities for African research institutions

In his book *The Challenge of Developing World Class Universities*, Salmi[1] concludes that, although there is a need for a range of institutional types:

> *…institutions will inevitably, from here on out, be increasingly subject to comparisons and rankings, and those deemed to be the best in these rankings of research universities will continue to be considered the best in the world.*

This factor, more than any other, will determine the future of universities, as it will increasingly impact the migration of talent, funding and opportunities. Salmi identifies four factors that can help universities maintain and improve their global competitiveness: a niche focus; internationalisation; innovative teaching and research systems; and a well-formulated and strategic plan.

African research institutions are well placed to build effective trans-disciplinary networks which focus on developmental issues. The problems faced by the continent have indeed placed particular emphasis on issues such as natural resource and diversity management, urbanisation and health, bioenergy, agricultural and forestry development, global change and food security. Many academics in these fields continue to work here, or return after time abroad, to be closer to the issues at hand. As previously noted, funding for transdisciplinary teams from this continent is also highly accessible.

The number of transdisciplinary networks with an African focus is growing. Examples include the Australia–Africa Universities Network which is currently hosted at the University of Pretoria and has a project portfolio covering food security, health, mining, education and public sector reform. The Universities of Zambia and Cape Town have collaborated with the United Nations to develop a master's degree in Sustainable Mining Practices, which takes a transdisciplinary approach. Other examples include those linked to climate change and adaptation and disaster risk reduction in which extensive university networks have been developed across Africa, e.g. Periperi U/Stellenbosch University (www.riskreductionafrica.org) and the African Climate Change Adaptation Initiative (Open Society Foundations, www.opensocietyfoundations.org), building both research and other academic capacity.

Some of these efforts are, however, in their infancy and face a number of challenges. As noted by Adams[5], African networks tend to develop along historical and linguistic linkages rather than strategic ones. The opportunity to meet and discuss projects can be hampered by technological and cost constraints, and institutions struggle to attract and retain talent when competing with universities in the developed world.

Nonetheless, it is critical for African universities to persist with the development of transdisciplinary projects and networks, and for institutions to incorporate specific efforts in their strategic plans for this purpose. These activities will support higher impact research, which will in turn enable better rankings in the globalised and competitive higher education environment. Ultimately, the knowledge co-produced should help to foster development and address a number of critical challenges facing the continent.

Acknowledgement

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Is Bt maize effective in improving South African smallholder agriculture?

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There is intense debate about the role of genetically modified (GM) food crops in combatting low yields and food insecurity amongst smallholders in Africa. Bt maize is still the only commercialised GM food crop in Africa and thus provides an unique opportunity for an empirical evaluation on this matter. South Africa is the only country in Africa where farmers grow Bt maize. South African smallholders have been introduced to Bt maize through a number of private enterprise interventions and government programmes since 2001. Scientific publications on the effects of Bt maize on South African smallholders, from socioeconomic and ecological perspectives, are now starting to accumulate.[1-4]

Bt maize produces insecticidal proteins that provide resistance to the African maize stem borer (*Busseola fusca*) and the Chilo borer (*Chilo partellus*) which can cause significant yield losses in low-input African smallholder systems.[5] As maize is the dominant staple crop in Africa, and stem borer damage is a significant production problem to many African smallholders, Bt maize could have substantial positive impacts on the livelihoods and food security of smallholders. In this commentary, we argue, however, that the fact that Bt maize was originally developed for use in large-scale capital intensive farming is still reflected in its functioning, which currently results in it being of limited use to smallholders. In addition, the regulatory context in which Bt maize was introduced in South Africa, and the lack of information provided to smallholders with the introduction of Bt maize, further reduce the current possibility of smallholders benefitting from it. As an alternative, we see positive progress in public–private initiatives to develop new maize varieties, specifically for smallholders' preferences and circumstances, which, we argue, show greater potential to improve food security in smallholders' contexts.

The first aspect which negatively impacts on the possibility of Bt maize to be of benefit to smallholders is the economic risk that its adoption entails. To date, Bt maize seed has been supplied to smallholders through government-sponsored interventions – either for free or at greatly subsidised rates; smallholders therefore have not yet experienced the real costs of the seed. Bt maize is currently sold at about double the price of popular non-GM hybrids and five times that of the price of popular open pollinated varieties (OPVs). Despite the high prices, some economic studies on Bt maize have reported that, by averaging over a number of years, smallholders can benefit from adopting Bt maize compared with planting conventional hybrids.[2,6,7] However, stem borer pressure is highly variable between seasons[8]; therefore during years and at sites that experience low insect pressure, the economic benefit of planting Bt maize can be negative.[7] Resource-constrained smallholders who do not have an economic buffer are not able to absorb losses in years for which the cost of Bt maize seed does not pay off.

Further reinforcing economic risk taking, currently commercialised Bt maize varieties are developed to give high yields under good agricultural conditions (sufficient and timely rain, fertilisation and good storage conditions). Smallholders often do not have the economy to provide such an optimal farm environment, and commonly farm on lands that are less suited for agriculture. As a result, planting currently available varieties of Bt maize entails the risk that input costs will not be covered within any one year. Indeed, studies on Bt maize in South Africa indicate that commercial varieties into which the Bt trait is introduced are outperformed by locally used non-GM hybrids and OPVs, which are better adapted to smallholders' agro-ecologies, fluctuations in rainfall and suboptimal storage conditions.[1,2]

Other countries, such as India, China and Argentina, which report higher adoption of Bt crops by smallholders, have less monopolistic seed markets and lower prices for GM seed than South Africa does, and, as a result of lower regulatory control on GM crops, the Bt traits have also to a greater extent been incorporated into locally suited varieties. It must also be noted, however, that the lower regulatory control of GM crops in these countries has simultaneously led to the marketing of seed of dubious quality, which negatively affects farmers.[9-11]

Lack of transfer of information on Bt maize is found to be a key obstacle for successful adoption by smallholders. To successfully adopt Bt maize, farmers must be informed that it provides resistance to stem borers; and, for the sake of preserving the stem borer resistance, they need to be taught to plant a refuge of non-Bt maize next to their Bt crop. This refuge is provided by planting a specified area of non-Bt hybrids with the Bt crop, thereby providing feeding grounds for stem borers. In South Africa today, the main information channel on Bt crops to smallholders is through the private sector (seed companies and local seed retailers). Jacobson and Myhr[12] reported from the Eastern Cape Province that the information days on GM crops held by seed companies were insufficient for transferring all the necessary information and that the local seed retailers largely lacked the ability to transfer information on GM crops. We have recently (in September 2014) witnessed a similar situation in the Limpopo Province where Bt and Roundup Ready maize is about to be rolled out to smallholders through a government-funded programme, while seed retailers and local government authorities lack sufficient information on GM crops. Research shows that as a result of the current flaws in how information on Bt maize is transferred to smallholders, many smallholders planting Bt maize are not fully aware of what makes it different from other hybrid maize[12,13]; and they often do not understand the purpose of refugia, nor comply with the demand to plant them.[12] (To some extent, the lack of compliance with refugia plantings also applies to large commercial South African farmers.[14,15])

Regulations regarding Bt maize in South Africa also currently obstruct smallholders from fully benefitting. These regulations apply both to the patents for GM crops and the biosafety management practices that come with planting GM crops in South Africa. Both forms of regulation result in farmers not being allowed to recycle GM seed. While hybrid seed in general is unsuitable for recycling because of yield drop, resource-constrained smallholders

frequently use the possibility of recycling seed to be able to plant in years for which the budget does not allow for the purchase of new seed.[12]

In summary, current Bt maize varieties in South Africa are expensive, are not suited to planting in suboptimal agricultural environments and come with regulations that smallholders do not understand or with which they do not agree. Whilst some of these problems can be remedied, there are cheaper alternatives available that are more attuned both to smallholders' agro-ecologies and to their farming practices.

The South African government is currently, through the Agricultural Research Council – Grain Crops Institute (ARC-GCI), promoting the development and certification of maize OPVs suited to smallholder conditions and practices. The ARC-GCI is working in collaboration with the International Wheat and Maize Improvement Center (CIMMYT), initially through the Southern African Drought and Low Soil Fertility Project, and now through a breeding programme called Drought Tolerant Maize for Africa. These initiatives are working closely with smallholders and have resulted in the registration of a number of stress-tolerant maize OPVs on the South African Variety List. In addition to drought and low soil nitrogen tolerance, the varieties also possess such desirable traits as resistance to major maize diseases (e.g. turcicum leaf blight and grey leaf spot), superior tolerance to smallholders' storage conditions, early maturation and suitability for home processing.[16,17] These are features of maize that are repeatedly highlighted as important by smallholders in southern Africa.[16,18,19] As a consequence of the projected increase in moisture stress because of climate change, these varieties, and continued efforts to produce them, can also be expected to substantially contribute to food security in future. Smallholder farmers in the Limpopo Province have already adopted some of these varieties, and are currently growing and marketing certified seed of ZM 1421, ZM 1521 and ZM 1523. In the Eastern Cape Province, some of the OPVs showed very stable performance across different stress-prone environments and seasons, and produced yields that were not significantly different from hybrids.[18] Zero seed costs can be realised for some seasons, because of the option of recycling seed of OPVs without the yield penalty associated with recycling hybrids.

We argue that government money would be better spent on supporting further development and spread of these less costly stress-tolerant maize OPVs to smallholders which, we argue, have better prospects for increasing and stabilising smallholders' maize yields in economically sustainable ways.

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Imperatives for an agricultural green economy in South Africa

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Globally, there are social, economic and environmental challenges related to sustainable development; these challenges include climate change, the need to feed a rapidly increasing population, high rates of poverty and environmental degradation. These challenges have forced us to rethink the way in which development takes place, resulting in the emergence of the concept of a 'green economy'. A green economy results in improved human well-being and social equity, while significantly reducing risks to the environment. It is based on principles which integrate social, economic and environmental considerations. South Africa has adopted the principle of green economic growth, and agriculture is one of the sectors that will drive this growth. Agriculture could address some of the sustainable development problems, but there are challenges related to resource availability, environmental impacts of agriculture and climate change. For agriculture to support a green economy it has to be productive, contribute to economic growth and not undermine the environment, social and cultural systems. The information base and policies required to support a green economy in general, and/or an agriculture-supported green economy have not yet been developed, as the green economy is an emerging concept in South Africa as well as globally. The generation of such information requires analysis and synthesis of green economy principles and agricultural imperatives into generic principles and practices for facilitating agriculture's contribution to the green economy. In this paper, we conduct this analysis and synthesis and highlight the defining aspects of an agricultural green economy.

Introduction

Since the global financial crisis of 2008, and in particular in the lead up to the June 2012 United Nations Conference on Sustainable Development (Rio+20), the term 'green economy' has featured prominently in international discourse on environment and development. A green economy has been defined as 'one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities'[1]. A green economy is also characterised as being low-carbon, resource efficient and socially inclusive. Such an economy aims to reduce carbon emissions and pollution; enhance energy and resource use efficiency; and prevent biodiversity degradation and the loss of ecosystem services.[2] In the context of South Africa, emphasis is also placed on the potential of a green economy to promote social equity and improve human well-being, through addressing poverty and historical inequalities.

The prominence of the debate on the green economy in the last few years has been attributed to the belief that such an economy could provide a win–win solution for overcoming the current global climate, financial and other crises.[3] In South Africa, greening the economy in a socially inclusive way has become particularly important because of high levels of unemployment, as well as the carbon intensity of the economy.[4] South Africa can be considered to be one of the global front runners in engaging with the concept of a green economy. For example, in 2010, the country defined a New Growth Path, which aims to generate a more inclusive and greener economy through both macroeconomic and microeconomic interventions. As part of the New Growth Path, a Green Economy Accord was signed in 2011, through which the country committed to a green economy and job creation partnership involving government, business community, trade unions and civil society.

In developing countries, including South Africa, agriculture is a crucial sector for driving the green economy. Globally, some 60% of terrestrial land and 70% of the available fresh water is used for agriculture, and 40% of the world's population is directly dependent on the agricultural sector for their livelihoods.[5] A greener agricultural sector potentially offers solutions to some of the social, economic and environmental challenges that humans are currently faced with, such as achieving food security for a rapidly expanding population, lowering the risk of climate change and meeting the increasing demand for energy in the face of dwindling reserves of fossil fuels.[6] Agriculture is a significant contributor to African economies as it employs 65% of Africa's labour force and accounts for 32% of gross domestic product (GDP).[7] Agriculture in Africa is therefore integral to sustaining livelihoods, reducing poverty and contributing to economic growth and development. In a 2012 report, the Commission on Sustainable Agriculture and Climate Change recommended making sustainable, climate-friendly agriculture central to green growth.[8]

Agriculture alone cannot be expected to drive green economic growth and poverty reduction at all levels. As an inherently resource-intensive primary sector, agriculture's contribution to GDP will always be small relative to its use of land, water and other resources. However, a sustainable agriculture sector is critical to food security and livelihoods, which suggests that greening of the agricultural sector is a key component of a green economy, alongside other sectors. Furthermore, relative to other sectors, agriculture's contribution to national GDP may seem small, but at a local level the contribution could be significant. For example, primary agriculture contributes about 3% to South Africa's GDP,[9] while its contribution to local economies in some areas is much higher. Agriculture contributed 25% to the economy of the Greater Sekhukhune district in the Limpopo Province in 2012.[10] Experiences from other African countries also highlight the importance of agriculture to local economies.[11] In addition, as mentioned above, despite its relatively low contribution to GDP, the agriculture sector is important in terms of employment, and therefore for the provision of livelihoods and reduction of poverty.

Both smallholder and commercial agriculture could contribute to a green economy and contribute to employment and poverty reduction. In South Africa, agriculture currently employs 709 000 people.[12] However, it is estimated that around 8.5 million people are directly or indirectly dependent on agriculture for their employment and income.[13] Although employment in the agriculture sector has been on the decline in the last decade,[14] South Africa's National Planning Commission (NPC) estimates that agriculture has the potential to create 1 million jobs by 2030, with the majority of these jobs being in the smallholder sector.[15] The NPC asserts that agriculture has the potential to expand if the necessary environment can be created, and that job creation is achievable with successful land reform, employment creation and strong environmental safeguards. According to the NPC, expanding commercial agriculture has the potential to create 250 000 direct jobs and a further 130 000 indirect jobs, and this job creation would be achievable through specific agriculture sub-sectors in which both expansion in production and value addition are sustainable. Job creation could also occur through small-scale agriculture. The NPC also argues that 300 000 employment opportunities can be created through better utilisation of land in the former homeland areas, with a further 326 500 potential employment opportunities upstream and downstream of the agricultural sector.[15]

Job creation in the context of agriculture is also connected to agro-processing, as a robust agriculture sector linked to markets would expand agroprocessing opportunities. The NPC's National Development Plan and the Department of Trade and Industry's Industrial Policy Action Plan both highlight the important role of the agriculture sector in creating employment, specifically in the processing sector.[15,16] According to South Africa's Industrial Policy Action Plan,[16] the food-processing sector – with about 171 000 employees – is the largest manufacturing sector in employment terms. Furthermore, agroprocessing contributed 30% of the total real output of South Africa's manufacturing sector in 2012.[17]

Among the key sectors expected to drive South Africa's green economy are agriculture; food production and forestry; resource conservation and management; clean energy and energy efficiency; sustainable waste management; and sustainable transport and infrastructure.[18] Although the identified sectors are well established, the information base and policies required to support a green economy have not yet been developed, as the green economy is an emerging concept, both in South Africa and globally. South Africa's plans for and commitments to a green economy (such as the Green Economy Accord) outline the priorities and commitments for a green economy in broad terms. However, what is lacking is the detail to guide the implementation of the identified priorities. In considering initiatives for transitioning to a green economy supported by agriculture, it is imperative to take cognisance of all relevant South African policy and legislation relating both to agriculture and the green economy, because agricultural initiatives that could potentially be linked to the green economy should be supported by existing policy and legislation. Furthermore, initiatives which align with legislation and policy, which provide the enabling conditions for sustainable agriculture, present opportunities for a green economy.

Both the United Nations Environment Programme (UNEP) and the United Nations Economic Commission for Africa (UNECA) highlight the importance of creating an enabling policy and implementation environment for achieving a transition to a green economy. According to UNECA[19], a clear, predictable and stable policy environment can create the confidence required to stimulate private investment. UNEP[20] highlights that enabling conditions for a green economy include national regulations, policies, subsidies and incentives, as well as international market and legal infrastructure, trade and technical assistance. It is essential that governments create the enabling policies and conditions for a green transformation.[19] Although the green economy is explicit about enhancing human well-being, it should not be assumed that a green economy spontaneously brings about the systems required for stable social systems that can sustain economic growth and foster improvements in human well-being. Hezri and Ghazali[21] highlight that social sustainability is not a given benefit in the transition to a green economy, as focusing on green growth does not automatically lead a community to sustainability pathways. Social sustainability considers questions of governance, voice and participation within decision-making.[21] However, given the fluidity of the concept of social sustainability, it is an elusive ideal to attain and should be consistently addressed in the implementation of a green economy.

In the case of South Africa, apart from general statements of intent, there are no formal instruments of any kind specifically designed to ensure that the green economy becomes a reality. However, there is a number of agricultural and environmental regulatory instruments which are relevant to a green economy; among them the *Conservation of Agricultural Resources Act (CARA) 43 of 1983*, *Sustainable Utilisation and Protection of Agricultural Resources (SUPAR) Bill (2003)* and the *National Environmental Management Act 107 of 1998*. Although agriculture has been identified as one of the sectors that should support the green economy transition in South Africa, currently there is a paucity of information to support green economy policymaking and implementation. The information base required to adequately inform and guide the transition to and implementation of an agricultural green economy is lacking. This situation is also the case for the rest of the African continent. The lack of information is problematic in regard to both the overarching green economy and specific sectors, including agriculture. The generation of this critical information requires appropriate analysis and understanding of both green economy principles and agricultural imperatives. This understanding is vital for building generic principles and practices for enabling and supporting agriculture's contribution to the green economy.

In this article, we review key green economy principles and agricultural imperatives in South Africa, and examine the agricultural and green economy aspects that should be considered in defining the parameters of agriculture as a sector which can support a green economy. In this way we provide critical information for enabling and supporting the contribution of agriculture to the green economy in South Africa and the rest of Africa, and also inform the research and analysis that should go into the development of policy and implementation instruments for an agricultural green economy.

South African and African commitment to a green economy

Many African countries, including South Africa, have adopted the principle of green economic growth, based on a green economy. Over the last few years, African leaders have, through various joint decisions and pledges, expressed their commitments to green economic growth. One such commitment is the Bamako Declaration on the Environment for Sustainable Development (June 2010), adopted by African ministers of environment.[22] In this declaration, ministers recognised the need to take advantage of the opportunities provided by a growth and development trajectory that embraces a green economy model. Another example is the Seventh African Development Forum held in Ethiopia in October 2010. At this forum, representatives called on African governments to

> *prioritize and promote a green economy as a vehicle for addressing the challenges of climate change impacts on ecosystem sustainability and harnessing the opportunities provided by its vast and diverse ecosystems and natural resources.*[23]

It has also been recognised that there is a need to ensure that the adoption of a green economy takes into account the particular social and development imperatives of African states. At a meeting of African Union heads of state and government held in Equatorial Guinea in June 2011 (in the context of negotiations for the United Nations Conference on Sustainable Development), it was decided that member states would be urged to 'ensure that Africa's interests on the green economy issues within the context of sustainable development and poverty eradication, and institutional frameworks for sustainable development are defined and taken into account'[24] [Decision on Africa's preparations for the United Nations Conference on Sustainable Development]. At the Fourth Special Session of the African Ministerial Conference on the Environment held

in Bamako in September 2011, African environment ministers adopted a decision on the green economy in the context of Africa, outlining African views and perspectives on the subject.[25] The Bamako Ministerial Conference also decided to

> *welcome the green economy as offering new opportunities to advance the achievement of Africa's sustainable development objectives and to recognize that the green economy is a means to achieve Africa's objectives of sustainable development, employment creation, economic growth and poverty.*[25]

In South Africa, green economic growth has been prioritised as one of the key economic drivers in the country's Medium Term Strategic Framework 2009–2014. One of South Africa's priorities in developing a green economy[26] is the creation of 'green' jobs. Green jobs are defined as work in agricultural, manufacturing, research and development, administrative, and service activities that contribute substantially to preserving or restoring environmental quality. Green jobs include those that help to protect ecosystems and biodiversity; reduce energy, materials and water consumption through high efficiency strategies; decarbonise the economy; and minimise, or altogether avoid, generation of all forms of waste and pollution.[18] Recently, South Africa's Department of Environmental Affairs and UNEP produced the South African Green Economy Modelling report, which assessed national targets and the effects of investing in a green economy in South Africa.[27]

Principles of a green economy

A transition to a green economy requires changes within all sectors of the economy. For any sector to support a green economy, it is necessary to first understand the basic functioning of that sector. This understanding is crucial for ensuring that the sector is aligned to operate in a way which is compatible with the principles and objectives of a green economy. In the lead up to Rio+20, several organisations (the Green Economy Coalition[28], the Stakeholder Forum BioRegional and Earth Charter[29], International Chamber of Commerce[30] and a number of others) attempted to develop a universal set of green economy principles. The United Nations Department for Economics and Social Affairs identified and consolidated the most common green economy principles, from a review of eight published sets of principles, as follows[31]:

1. *The Green Economy is a means for achieving sustainable development.*
2. *The Green Economy should create decent work and green jobs.*
3. *The Green Economy is resource and energy efficient.*
4. *The Green Economy respects planetary boundaries or ecological limits or scarcity.*
5. *The Green Economy uses integrated decision-making.*
6. *The Green Economy measures progress beyond GDP using appropriate indicators/metrics.*
7. *The Green Economy is equitable, fair and just – between and within countries and between generations.*
8. *The Green Economy protects biodiversity and ecosystems.*
9. *The Green Economy delivers poverty reduction, well-being, livelihoods, social protection and access to essential services.*
10. *The Green Economy improves governance and the rule of law. It is inclusive, democratic, participatory, accountable, transparent and stable.*
11. *The Green Economy internalises externalities.*

These principles highlight that the focus of the green economy is not simply on the link between the economy and the environment (as the term 'green economy' might imply). Instead, the principles place as much emphasis on the social as on the economic and environmental dimensions of sustainable development. The principles highlight that in the green economy context, the economy has to be conceived in a broader sense than that recognised by neoclassical economics, as including a range of formal and informal economic activities involving reproduction, production, distribution, exchange and consumption.[32] The economy also has to be conceptualised as extending beyond the cash economy into a wider set of linked social and material processes including labour, work, material flow, energetic exchange and value creation.[33] Green economy principles highlight the strong linkages between social and economic systems. Economic sociology emphasises that the economy is socially embedded, and according to the concept of socio-materiality, the social and the material are considered to be inextricably related – there is no social that is not also material, and no material that is not also social.[34]

Agriculture as a driver of the green economy

The United Nations Economic Commission for Africa (UNECA)[19] acknowledges that most African economies are highly dependent on natural resources, and argues that a pathway to a green economy requires capitalising on natural capital and exploiting opportunities for industrial growth. Agriculture is a sector that is highly dependent on natural resources, and as such has a significant role to play in the green economy. The crucial role of agriculture in the green economy has also been highlighted by the United Nations Food and Agriculture Organization (FAO) in a concept note prepared for the Rio+20 conference:

> *As the single largest sector using 60% of the world's ecosystems and providing livelihoods for 40% of today's global population, the food and agriculture sector is critical to greening the economy. There will be no green economy without agriculture.*[5]

The key role of agriculture in African economies has been affirmed by African heads of state and governments in their declaration of 2014 as the Year of Agriculture and Food Security in Africa. The high-level focus is meant to encourage countries to increase food security, reduce poverty, promote economic growth and create wealth through agricultural improvement.[35]

Agricultural production has to expand to meet rising demands for food and other commodities for a burgeoning human population, expected to reach 9 billion by 2050. The required agricultural expansion entails increasing output per unit area and/or increasing the land area under agriculture. Given the fact that it is a growing sector, agriculture will inevitably play an important role in the green economy, although there will clearly be a need to reduce the environmental impacts of agriculture. In addition, agriculture is largely a rural activity, and agriculturally based green economy initiatives therefore present real opportunities for addressing rural poverty. This opportunity is particularly important because poverty disproportionately affects rural areas. Globally, of the 1.4 billion people living in extreme poverty (defined as those living on less than USD1.25/day) in 2005, approximately 1 billion (or around 70%) lived in rural areas.[36] In South Africa, poverty rates (based on the food poverty line) are higher in rural (30.7%) than in urban areas (11.9%).[37]

Agriculture is particularly relevant to the green economy in developing countries, as it holds the potential to address some of the problems of poverty and rapid urbanisation which occur in many countries, including South Africa. It has been noted that agriculture can contribute to poverty reduction in rural areas. The World Bank estimates that GDP growth from agriculture generates at least twice as much poverty reduction as any other sector.[38] Green economic initiatives in the agricultural sector therefore have the potential to transform the lives of a large number of people. Currently, 65% of people in developing countries are involved in agriculture, of whom 1.3 billion are small farmers who could benefit from improvements in agriculture and the associated economy it supports.[39]

It has been documented by UNEP[40] that during the transition to a greener agriculture sector (a requirement for agriculture to support a green economy), food production in high-input industrial farming may experience a modest decline, while triggering significant positive responses in more traditional systems run by small farmers. This projection lends significant potential strategic importance to the role of small-scale farmers in the transition to a green economy supported by agriculture in South Africa. A green economy based on agriculture has the potential to impact on a significant proportion of South Africa's population. South Africa's 2011 census results show that 2.9 million households in South Africa (20%) were involved in agriculture, mainly subsistence and smallholder farming, with the largest percentage of agricultural households located in KwaZulu-Natal (25%), the Eastern Cape (21%) and Limpopo (16%) Provinces.[41] These households could potentially participate in the green economy through agricultural activities. Experiences from other developing countries highlight the central role of small-scale farmers in the green economy. UNEP reports that in Uganda, 85% of the population was engaged in agriculture, mainly small-scale organic agriculture, contributing 42% of the national GDP and 80% of the export earnings in 2005/2006.[42] In Cuba, public policies supported urban organic agriculture in Havana, resulting in 350 000 new well-paying jobs (out of a total workforce of 5 million), 4 million tons of fruits and vegetables produced annually in Havana (a tenfold increase in a decade).[42]

Rapid urbanisation and increasing urban poverty are pressing issues for developing countries, including South Africa. In 2001, 56.2% of the national population of South Africa lived in cities, increasing to 60% in 2009, with an expected increase to 70% by 2024.[43] This rapid urbanisation poses challenges in the form of urban sprawl, which destroys agricultural land and increases the demands for energy, water and food. Furthermore, rapid urbanisation has transferred rural poverty problems into urban areas – a problem which has manifested throughout the world and which continues to grow. Ravallion[44(p.16)] reports that 'among those living on no more than [USD]1 a day, the proportion found in urban areas rose from 19% to 24% between 1993 and 2002'. One of the manifestations of urban poverty is food insecurity. Food insecurity is high in the urban areas of southern Africa and South Africa.[43]

A 2010 UN report notes that raising agricultural production (in particular in food-deficit countries), while at the same time improving the livelihoods of smallholder farmers and preserving ecosystems, would contribute to rural development and slow the trend towards urbanisation and the attendant stress it places on public services in urban areas.[45] Agriculture-based green economy initiatives could offer an alternative to the migration to urban slums by providing opportunities for sustainable livelihoods in rural areas. However, it must be borne in mind that although agricultural green economy initiatives could potentially reduce rural poverty, in many situations, agricultural production is not high and/or sustainable enough to drive poverty reduction by itself. The potential of agriculture-based green economy initiatives to improve human well-being should therefore be grounded in reality, as an agriculture-supported green economy will not automatically improve social and economic conditions. Some of the challenges are discussed in the following section.

Challenges of agriculture in supporting green economic growth

While agriculture presents opportunities for supporting green economic growth, there are challenges which must also be acknowledged. These include the scarcity of resources to support agricultural production, especially for poor rural farmers; the relatively low market values of agricultural commodities, and therefore the limited potential for low levels of agricultural production to impact on local economies; the impacts of agriculture on the environment; and changing climatic conditions.

In South Africa, a major challenge for agriculture's ability to expand production to meet the food security needs of a growing population and to support a green economy is the rising scarcity and degradation of land, soil and water resources. Although South Africa has a relatively large total land surface area (122 million ha), only about 14 to 16 million ha, or around 11% of the total, is arable (i.e. suitable for crop production), excluding the area under commercial forestry. Furthermore, 'soil erosion and degradation of agricultural land through overexploitation and inappropriate and unsustainable farming methods pose a threat to the country's food security'[27(p.8)]. The rate of land degradation is high, estimated at 70%, with potential negative implications for food production.[46]

Furthermore, South Africa has a relatively low annual rainfall, and a rapidly increasing demand for water, exacerbated by poor water quality in some areas, such that demand is expected to exceed the available supply by 2025.[27] Other factors potentially exacerbating these issues include changing climatic conditions and government's commitment to mandatory blending of biofuels in the liquid fuels market in South Africa,[26] for which the potential impacts on food security, land use, carbon emissions and water use need to be carefully assessed.

The number of farms and the land area being used for crop production in South Africa has declined significantly since the 1990s,[47] but there has been no corresponding decline in overall production. The World Wide Fund for Nature asserts that this discrepancy points to an intensification of production entailing increased water use for irrigation, increases in the use of fuel, agrochemicals, fertilisers and mechanisation, as well as a growing dependence on genetically modified seed. This increase in intensity, particularly where it is not managed properly, is causing cumulative damage to soil fertility, increasing erosion, contaminating water sources, producing toxic effects on biota and on people working on farms, weakening the resilience of ecosystems and contributing to climate change.

The New Partnership for Africa's Development (NEPAD) noted with concern the environmental degradation caused by agriculture in many parts of Africa. NEPAD indicated that, in many places, environmental degradation and unsustainable exploitation of natural resources threatened to reduce the future productivity of agriculture and natural resources, and that a major challenge for African countries was to ensure that agriculture does not degrade the underlying natural resource base.[48] Similar concerns have been expressed by the Millennium Ecosystem Assessment. According to the Millenium Ecosystem Assessment[49], two-thirds of the earth's ecosystem services are in decline. The resources humans depend on for much of the world's food supply are finite, declining and, in some cases, disappearing. Fresh water is becoming scarcer, land is degraded and ecosystems are in decline. Farming practices must be adapted to manage natural resources wisely and conserve biodiversity and ecosystem services if agricultural production is to increase in the face of increasing demands, climate change and limited resources.[50]

The environmental impacts of agriculture are not limited to large-scale commercial agriculture. Small-scale farming, although it utilises lower levels of inputs and little machinery, also has adverse effects on the environment. According to the FAO[51], in Africa, soil degradation caused by poor agricultural practices, among other issues, is undermining the very resources on which African farmers depend for their survival. In South Africa, soil degradation has been reported to be most severe in many communal croplands and grazing lands,[52] where small-scale agriculture is practised. South Africa has grappled with land degradation caused by agriculture for many decades, and the negative environmental consequences of agriculture have been widely documented.[53-56]

The contribution of the agricultural sector to climate change is significant. Agriculture is an emitter of greenhouse gases associated with land-use change, fertiliser use and enteric fermentation among livestock. Globally, agriculture accounts for around 15% of global greenhouse gas emissions. Agriculture will have to reduce these emissions substantially and contribute to climate change mitigation if it is to contribute to a green economy.

For agriculture to support a green economy, the many environmental problems associated with the sector have to be addressed. Plans for the green economy recognise this need. At South Africa's Green Economy

Summit held in 2010, there was an acknowledgement that, according to the definition of green jobs:

> *Some of the employment opportunities in agriculture, forestry and fisheries cannot be classified strictly as 'green' as they can be environmentally damaging. For the sector to become sustainable more capital and knowledge must be directed towards improved natural resources management.*[46]

In addition, so-called green jobs (in the agricultural and other sectors) will in many cases require technically skilled labour. The question remains whether South Africa can meet this skills requirement,[4] and thus fulfil the promise of green job creation and poverty alleviation.

Changing global conditions and climate change

Although agriculture could potentially contribute to a green economy in South Africa, changing climatic conditions present challenges both for the sector as a whole and, particularly, for green economy initiatives premised on agriculture. Climate change projections for South Africa indicate increased temperatures across the country, an increase in precipitation in some parts of the country and a decline in precipitation in other parts, as well as increases in the magnitude and frequency of extreme events such as floods and droughts.[57] These changes have implications for ecosystems and their capacity to provide services such as water and for crop production and yields[58-60]; implications which will in turn affect the country's food security. Climate change is already threatening the ability of some rain-fed agriculture-dependent regions to maintain levels of agricultural production and food security, and is destabilising markets.[45] Climate change poses a threat to agriculture-based green economy initiatives, especially in southern Africa, where it is estimated that yields from rain-fed agriculture could be reduced by up to 50% between 2000 and 2020.[61]

Based on the variation in the direction and magnitude of changes in climate across South Africa, Gbetibouo et al.[62] show that there is spatial differentiation in the vulnerability of South Africa's farming sector to climate change, with vulnerability intrinsically linked with level of socio-economic development. The most vulnerable provinces were found to be areas of low socio-economic development, i.e. largely rural areas, with a high share of small-scale farmers who rely on rain-fed agriculture, characterised by a high level of soil degradation and low levels of employment, among other factors. While agriculture-based green economy initiatives present opportunities for poor rural areas, the high vulnerability of these areas to climate change should be considered and planned for accordingly. Changing global climatic conditions will result in unpredictable availability (as a result of wide variation in growing conditions and extreme weather events), quality and price of agricultural products, which will affect profitability and thus sustainability of agriculture-based green economy initiatives.

It is important to ensure that risks and opportunities associated with changing climatic and other global conditions are understood and addressed in the context of agriculture in a green economy. UNEP's fifth Global Environment Outlook (GEO-5) report[63] highlights that, in terms of the current state and trends of the global environment, population growth, economic development, urbanisation and globalisation are driving degradation, which can be measured across numerous environmental indicators. According to UNEP[27], environmental pressures will increase for the foreseeable future, causing major changes not only in physical landscapes, but in social, political and business landscapes as well. These changes have to be understood and planned for in the context of a green economy. In addition, flexible and responsive policies are required to encourage and support sustainable agricultural and economic practices. Similarly, climate impacts, resource scarcity and resulting changes in population migration may have broader systems-level effects, destabilising regions or entire countries and thus the political and socio-economic contexts in which the green economy operates.

Imperatives for an agricultural green economy

Alongside the concept of an agriculture-based green economy is the concept of 'green agriculture'. A UNEP report[40] defines agriculture based on sustainable farming practices and technologies as 'green'. The report lists five main principles of green agriculture:

- use of naturally and sustainably produced nutrient inputs;
- diversified crop rotations;
- livestock-crop integration;
- environmentally friendly pest and weed management practices; and
- waste reduction through use of post-harvest storage and processing facilities.

The concept of a green economy based on agriculture is, however, broader than simply green agriculture. Whereas green agriculture focuses exclusively on agricultural production techniques, a green economy based on agriculture has to incorporate the principles of green agriculture and the principles of a green economy. The World Farmers' Organisation[64] has put forth four primary goals for agriculture in the context of the green economy:

- produce more with less;
- use a knowledge-based approach of best practices;
- reward farmers for adopting sustainable practices; and
- break the poverty cycle.

Given the environmental challenges facing the world, agriculture must be multifunctional if it is to support a green economy, as it not only has to meet demand for food and other non-commodity goods and services, but must do so while minimising its environmental footprint, creating sustainable livelihoods for farmers and others along the supply chain,[65] and providing other ecosystem goods and services in addition to food. It must also not disrupt social and cultural systems and must contribute to economic growth. Food insecurity and large poor rural populations persist in many developing countries. Basing green economy initiatives on agriculture in these contexts would be beneficial, given its potential to achieve the triple goals of a secure food supply, poverty reduction through improved rural livelihoods, and environmental sustainability through a reduced production footprint.[65]

The Farming First Coalition, for example, highlights that[65]:

> [A]*griculture in a green economy has to adopt a broad-based, knowledge-centred approach. Such an approach would be achieved through:*
>
> - *Addressing implementation gaps through support for knowledge sharing and advisory and training services;*
> - *Ensuring agricultural policies are based on science; and*
> - *Supporting productivity through innovation and best practices.*

In addition, making agriculture a dynamic sector which can underpin green economic initiatives will require some of the following[65]:

- *The adoption of supportive frameworks and investment in infrastructure and markets.*
- *Access to markets at the local, regional and global level in order for farmers to sustain a livelihood from their activities – in some areas, this means improving access to transport, storage and market facilities.*
- *Maintaining and increasing farm productivity and profitability.*
- *Producing food and agricultural goods and services on a sustainable basis.*

- *Reducing negative externalities and gradually creating positive ones.*
- *Rebuilding ecological resources such as soil, water, air and biodiversity.*
- *Reducing pollution and using resources more efficiently.*
- *Maintaining ecosystem services on a sustained basis.*

Conclusions

For agriculture to support green economic growth, the sector has to operate in a way that integrates the principles of a green economy with those of sustainable and green agriculture. This synthesis of principles has to bring about a distinct set of principles for South Africa's agricultural sector in the context of a green economy. Such a fusion of principles has to be informed by South African realities and should not only be based on international theories and principles. This fusion will necessitate adjustments to the way in which agriculture is conceptualised and practised. The adjustments need to occur at all levels, from policy to practice, and should involve all stakeholders, including farmers, government, the private sector and civil society working together to create the right conditions for facilitating change. These conditions include enabling policies and institutions, relevant information and skills, innovations to support sustainable agricultural production, and social and economic systems. Appropriate incentives to encourage change from business as usual to practices which support a green economy and its ideals of environmental protection and social inclusion are also required. It is also critical to put in place mechanisms for managing risks and opportunities associated with changing climatic and other global conditions, so as to minimise negative impacts on (and generate benefits for) a green economy.

The process of change needs to be carefully planned. At the centre of the process are agricultural stakeholders who need to embrace the idea of changing their thinking and practices. Effecting the change requires a multi-pronged approach of educating, informing, training and capacity building. Much thought needs to go into processes for achieving the requisite change. As such, it would not be sufficient simply to list the required changes; the actual processes that need to be followed should be elucidated in detail. It will be necessary to move beyond the obvious to interrogating and developing practical processes for addressing different issues, for example social inclusivity and equity, which are critical in South Africa and in a green economy, but are not necessarily central in the agricultural sector. In addition to technical agricultural production issues, innovative ways of addressing the core issues of governance, decision-making and networking which underpin the functioning of social systems need to be addressed. The processes would have to be informed by both theoretical principles and the practical experience which the agricultural and other sectors in South Africa have accumulated. An agricultural sector that supports a green economy would need to be backed by appropriate agricultural and economic innovations which would be relevant to South Africa and also enable the country's green economy to be globally competitive.

A green economy does not operate in isolation. The green economy is fundamentally about managing the interaction of humans with the biophysical environment, in a complex social ecological system. Human and biophysical factors must therefore be considered in an integrated manner, with particular attention given to the relationships between them. The agricultural sector in a green economy therefore has to be appropriately situated and be in tune with social, economic and biophysical conditions in order to be sustainable and deliver planned benefits in the face of changes in these variables. The Africa-wide commitment to agriculture and to the green economy provides opportunities for countries to share experiences in transitioning to a green economy supported by agriculture.

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Authors' contributions

C.M. was the project leader; she conceptualised and drew up the framework of the paper and wrote the sections on the technical aspects of agriculture. K.N. contributed the social review. B.K.M. and A.N. provided the economic review and analysis while B.d.W. was responsible for the environmental review and synthesis.

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Energy efficiency and the law: A multidisciplinary approach

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South Africa is an energy-intensive country. The inefficient use of, mostly, coal-generated energy is the cause of South Africa's per capita contribution to greenhouse gas emissions, pollution and environmental degradation and negative health impacts. The inefficient use of the country's energy also amounts to the injudicious use of natural resources. Improvements in energy efficiency are an important strategy to stabilise the country's energy crisis. Government responded to this challenge by introducing measures such as policies and legislation to change energy consumption patterns by, amongst others, incentivising the transition to improved energy efficiencies. A central tenet underpinning this review is that the law and energy nexus requires a multidisciplinary approach as well as a multi-pronged adoption of diverse policy instruments to effectively transform the country's energy use patterns. Numerous, innovative instruments are introduced by relevant legislation to encourage the transformation of energy generation and consumption patterns of South Africans. One such innovative instrument is the ISO 50001 energy management standard. It is a voluntary instrument, to plan for, measure and verify energy-efficiency improvements. These improvements may also trigger tax concessions. In this paper, the nature and extent of the various policy instruments and legislation that relate to energy efficiency are explored, while the interactions between the law and the voluntary ISO 50001 standard and between the law and the other academic disciplines are highlighted. The introduction of energy-efficiency measures into law requires a multidisciplinary approach, as lawyers may be challenged to address the scientific and technical elements that characterise these legal measures and instruments. Inputs by several other disciplines such as engineering, mathematics or statistics, accounting, environmental management and auditing may be needed. Law is often described as the catalyst for change, building bridges between different academic disciplines, and driving behavioural changes that are not only enforced by government, but that are also voluntarily adopted by the users themselves.

Introduction

Each day South Africans are bombarded with images and messages in printed and electronic media challenging them to reduce their energy consumption and to introduce energy-efficiency measures in their households and workplaces. However, few South Africans realise the complex scientific, technical and multidisciplinary challenges that underpin these calls. Energy efficiency is no longer the sole domain of engineers, as lawyers, auditors, mathematicians, accountants, environmental managers, chemists, economists and many other scientists from the natural and social sciences and humanities alike are involved in attempting to bring about a green economy[1] that includes improved energy efficiencies.

The importance of energy efficiency was again reiterated by the member states at Rio+20 (para 128 & 129)[1] with the following declaration:

> *We recognize that improving energy efficiency, increasing the share of renewable energy and cleaner and energy-efficient technologies are important for sustainable development, including in addressing climate change. ...We also recognize the importance of promoting incentives in favour of, and removing disincentives to, energy efficiency and the diversification of the energy mix, including promoting research and development in all countries, including developing countries.*

The law is one of the disciplines that bridge the divide among the natural sciences, engineering and the other disciplines. It is often also the catalyst to initiate and drive change by providing incentives and disincentives. Environmental and energy law must by necessity be multidisciplinary as it has to translate scientific and engineering principles and knowledge into policy and law. Such law is often underpinned and informed by the sciences and engineering disciplines, while the law often also frames and directs the sciences and engineering disciplines. This symbiotic relationship among the law, the sciences and engineering should not be ignored, especially in complex fields such as energy management and energy efficiency.

Command and control measures (i.e. law and the enforcement thereof) often fail to achieve the desired change. A combination of a number of alternative policy instruments is often deployed in parallel with the law to support the legal instruments and measures to bring about such change. One such alternative policy instrument is voluntary international standards that may be adopted and used by organisations from the public and private sectors alike as a consequence of their corporate fiduciary and social responsibilities.[2-4] These international standards are mostly voluntary requirements, but they are often also included into law, making conformance mandatory as specified.

The South African government has, since 1998, included demand side energy management and energy-efficiency measures in policy documents and legislation. The most recent policy document, the *National Climate Change Response White Paper* of 2011,[5] highlights energy efficiency as one of its principal goals. Both the *National Energy Act 34 of 2008* and the *Electricity Regulation Act 4 of 2006* include measures pertaining to energy efficiency.

Some of these measures apply to government institutions such as municipalities, while others apply to the private sector.

In July 2011, the South African National Standard SANS 50001:2011 (referred to as SANS/ISO 50001) was published. It is a voluntary energy management system (EnMS) standard providing for improvements in the energy performance, efficiency, use and consumption patterns of organisations. The aim of the standard is to 'lead to reduction in greenhouse gas emission and other related environmental impacts and energy cost through systematic management of energy'[2].

Natural and social scientists, engineers and developers, for example, should take note of these energy-efficiency measures that are contained in both law and voluntary instruments when designing, developing and implementing new technologies and infrastructure and managing existing processes and facilities. They should take note of the potential interactions between the voluntary standard, as well as policies and legislation to guide and change their behaviour by contributing to an improved energy future. It is therefore the aim of this article to explore the interactions between energy law and the ISO 50001 voluntary instrument for energy management systems to answer the following research question: What are the linkages between and the principal provisions for energy efficiency as provided for in South African energy law and policy and the SANS 50001 standard that should be understood and adopted by scholars and practitioners from diverse academic and technical disciplines in order to support the country's transition to a greener economy and a more sustainable future?

This article is based on a literature survey of the most important literature, laws and policies in the field of energy efficiency. The legal discourse is informed by literature from other disciplines. Kroeze[6] states that 'law is a hermeneutic and professional discipline', which directs the methodologies used, the research questions posed, the assumptions made and the hypotheses postulated. As Areeda[7] states:

> *The needs and purposes of the law are not necessarily the same as the interests and objectives of the expert*[s] *pursuing* [their] *own discipline*...[t]*he proper legal result may turn on statutory interpretation, characteristics of the legal system, or other matters of policy on which* [another] *science has little to contribute. It is for those reasons that outside disciplines are not the law, but only illuminate it.*

According to Kroeze[6] and Areeda[7], lawyers 'borrow' from other disciplines and translate the knowledge acquired from other sciences into law. Subject matter experts from other disciplines often argue that the law is too generic, ignoring the detail and complexities that characterise specific scientific sub-disciplines and their fields of expertise. Areeda[7] comments:

> *While the other disciplines seek truth for its own sake, the law is more skeptical about finding it and uses only as much of it as is helpful to guide our prudential policy choices in this untidy world.*

This article proceeds from the premise that environmental law in general and energy law in particular are complex fields of inquiry requiring a new approach to multidisciplinary research. Lawyers need to progress from mere 'borrowing' scientific knowledge to inform the law, to work in multidisciplinary teams with researchers from a variety of applicable disciplines to generate new law, and implement and enforce existing law in order to address these growing complex systems. Energy efficiency is used to illustrate this complexity.

Energy efficiency, energy use and energy consumption in South Africa

In this section, legal definitions are compared to definitions found in other policy documents and literature to determine whether the legal and scientific definitions correlate. Some statistics with regard to energy consumption in South Africa are also provided and the drivers for the introduction of energy-efficiency measures are discussed.

SANS/ISO 50001:2011[2] defines 'energy efficiency' as the 'ratio or other quantitative relationship between an output of performance, service, goods or energy, and an input of energy' and provides as an example the 'conversion efficiency, energy required or energy used, the output or input; the theoretical energy used to operate or the energy used to operate'. The *National Energy Act 34 of 2008* (section 1) defines 'energy efficiency' as the 'economical and efficient production and utilisation of an energy carrier or resource'. Barton[8] describes it as 'a ratio of function, service, or value provided in relation to the energy converted to provide it' or 'the amount of work done in relation to the energy used'. Xia and Zhang[9] identify four energy efficiency classes, namely technology efficiency, equipment efficiency, operational efficiency and performance efficiency. They describe the 'performance efficiency of an energy system' as being 'determined by external but deterministic system indicators such as production, cost, energy sources, environmental impact and technical indicators'. They also indicate that all of these efficiencies may be affected by 'technical, human and time factors'. Deciding when to use energy may, for example, affect the efficiency of the technology used.[8]

The SANS/ISO and Barton definitions clearly indicate a relationship between the ratio of the output or performance and the input of energy, while the legal definition of energy efficiency focuses mainly on the result that is achieved, namely the economical and efficient utilisation or production. The examples of energy efficiency outcomes provided for in the SANS/ISO document and the four energy efficient elements identified by Xia and Zhang[9] add a dimension which can be used to describe the result as set out in the Act. It may also be necessary to redefine the term 'energy efficiency' in the Act, taking the scientific, engineering and other definitions into account to provide a more comprehensive legal definition. The legal definition should at least relate to the ratio or relationship between the input and output of energy as well as to the outcome or possible outcomes of the input and output ratio.

SANS/ISO 50001:2011 also defines 'energy consumption' as the 'quantity of energy applied', and 'energy use' as the 'manner or kind of application of energy' that may, for example, include 'ventilation; lighting; heating; cooling; transportation; processes; production lines'. 'Significant energy use' refers to 'energy use accounting for substantial energy consumption and/or offering considerable potential for energy performance improvement'[2]. These definitions are not included in the *National Energy Act* or the *Electricity Regulation Act* and if energy-efficiency measures are to be introduced in South Africa, which is the case in relation to tax measures, the question is whether these definitions should not also be included in the legislation.

Energy may also be divided into primary, intermediate and final forms of energy. Primary energy is 'extracted or captured directly from natural resources' and may be renewable or non-renewable. Intermediate energy is 'primary energy converted into other forms and final energy is the one consumers buy or receive in order to carry out desired activities'[10]. Energy efficiency deals with the final energy form. Again this distinction is not made in law.

It is also necessary to define energy management. 'Energy management' in relation to information technology is defined as

> *a set of functions for measuring, modelling, planning, and optimizing networks to ensure that the network elements and attached devices use energy efficiently and* [are] *appropriate for the nature of the application and the cost constraints of the organization.*[11]

While an 'energy management system' relates to

> *a set of systems or procedures upon which organizations can develop and implement an energy policy, set targets, action plans and*

> *take into account legal requirements related to energy use, an EnMS allows organizations to improve energy performance and demonstrate conformity to requirements, standards and/or legal requirements.*[2]

The definition of an EnMS becomes important when such a system is introduced to ensure energy efficiency and to measure its outcomes. South Africa has introduced regulations referring to energy management systems and tax incentives[12] which may necessitate the introduction of this terminology into law. It is important to note that a legal definition often does not correspond with a scientific definition and it is therefore important for scientists to explore legal definitions and for lawyers to explore scientific definitions. A court of law will adhere to a definition in an Act, but if a term is not defined, or is vaguely defined, the court has to refer to other definitions in dictionaries; but as science comes to play a more important role in environmental and energy legislation, the court will soon also have to begin to refer to scholarly articles in scientific journals to find solutions.[13]

Ward and James[14] state that 'through globalization there has been an increasing shift of energy-intensive manufacturing from industrialized countries to developing countries and, with that shift, a shift of emissions'. South Africa's energy is mostly generated by the coal-fired generation utilities of the public supply company Eskom.[15] In 2010, the Department of Energy[16] stated that South Africa has an energy-efficiency potential ranging from 20% to 30% across various segments in the public and private sectors. The end users of electricity at that time included 'the domestic sector (17.2%), agriculture (2.6%), mining (15%), industry (37.7%), commerce (12.6%), transport (2.6%) and other (12.3%)'[16].

What are the drivers to support energy efficiency management by these sectors?[8,17] Economic and cost factors are almost always a key determinant of change, while safety and environmental requirements for pollution control and the reduction of climate change impacts also remain important drivers.[8,18-20] The contribution of the transition to a green economy (referred to above) remains to be determined. Incentives are often also a reliable driver for change, while taxes and the cost of energy may also initiate and drive change.[8,21] The cost of energy will significantly increase should South Africa's proposed carbon tax be introduced at the rate of ZAR120 per tonne CO_2 in 2015.[22] It was estimated in 2011 that, should a carbon tax of ZAR110 per tonne of CO_2 be levied, the increases in costs to a cement factory would translate to an additional ZAR265 per tonne of coal, 28c per litre of diesel and 11c per KWh of electrical energy used. It was estimated that, even without the carbon tax, the cost of energy could increase by 45% in a cement factory as a result of the increase in diesel, coal and electricity-related costs.[23] To stay competitive, the cement industry indicated that it would have to become more energy efficient at an operational level.[23] Barton[8] also identifies energy security (or rather insecurity) as a possible driver.

The International Energy Association introduced 25 Energy Efficiency Recommendations in 2011.[24] (South Africa is not a member of the International Energy Association.) Recommendation 21 states that governments should require large energy-intensive industries to conform to ISO 50001 or an equivalent energy-management protocol and should encourage other industrial energy users to do the same. Governments should expect of industries to report on their energy savings. According to the Recommendation, energy management measures should include[24]:

> *Identifying and assessing energy saving opportunities by benchmarking, measuring and documenting energy consumption;* [i]*mplementing actions to capture identified energy saving opportunities;* [and] [p]*ublicly reporting the energy-saving opportunities identified and the actions taken to capture them.*

A study by the United Nations Environment Programme, the Global Environment Facility and the International Energy Agency indicated that the phasing out of incandescent bulbs alone might result in a reduction of 5% in global electricity consumption and 6% in the output of carbon dioxide, which translates into the 'equivalent of more than 450 coal-fired power plants or more than 122 million mid-sized cars'[24]. Government may also introduce command and control measures such as standards or punitive measures to enforce energy-efficiency measures.[8]

There is therefore a drive towards energy efficiency and a need to implement measures to enforce it. The implementation of such measures may still be a challenge as the legal measures do not necessarily correlate with other scientific literature. It is therefore necessary to determine if a policy framework is in place to introduce energy efficiency.

Policy measures

In 1998 the South African government published a *White Paper on the Energy Policy of the Republic of South Africa,*[25] referring to energy efficiency not only in households but also in the industrial, mining and commercial sectors. At this stage, government had already committed itself to promote improved energy efficiencies by way of 'cleaner energy end-use technologies, environmental performance auditing and incorporating environmental costs' in the end price of energy. The need to address energy efficiency in the transport and agricultural sector has also been referred to.[25] In 2004, the *White Paper on Renewable Energy*[26] indicated a link between energy efficiency and the introduction of renewable energy.

The *Climate Change Response White Paper*[5] provides for mitigation and adaptation responses. The government proposed the introduction of a few Near-term Flagship Programmes to address some of the climate change challenges. An Inter-Ministerial Committee and Intergovernmental Climate Change Committee were to be established to oversee and implement the programmes. The adaptation programmes include the introduction of 'regulatory measures, market-based instruments, tax incentives and fiscal subsidies, information and awareness initiatives'[5]. The regulatory measures include, for example, energy efficiency targets 'complemented by appropriate standards'[5]. The Renewable Energy Flagship Programme (para 8.3) is another driver to enhance the introduction of locally produced renewable technologies. The Energy Efficiency and Energy Demand Management Flagship Programme (para 8.4) foresees a more aggressive implementation of green building construction in both the commercial and residential sectors, for example, by setting standards for controlled ventilation and using recycled materials and solar power. All government buildings and facilities are to be audited to set indicators and benchmarks. The White Paper states that regulatory measures will be introduced in all spheres of government – national, provincial and local. Government must also review their legislation and policies to align them with the White Paper.

In December 2010, the Department of National Treasury published a Discussion Paper on Reducing Greenhouse Gas Emissions: The Carbon Tax Option. In this paper, the Department acknowledges that although South Africa is a non-annex 1 developing country in terms of the Kyoto Protocol, it is ranked as 'among the top 20 countries measured by absolute carbon dioxide (CO_2) emissions'[27]. In 2009, South Africa announced that it will reduce its greenhouse gas emissions by 34% by 2020 and 42% by 2025.[27] In May 2013, the National Treasury published an updated version of the *Carbon Tax Policy Paper*[22] for public discussion. The paper indicates that one of the outcomes of carbon taxes should be the introduction of more energy-efficiency measures. The policy document favours a 'carrot-and-stick' approach as it introduces tax measures (punitive measures) as well as tax incentives for energy-efficiency measures and the introduction of renewable energy. On 1 January 2014, a carbon tax was to be introduced at ZAR120 per tonne CO_2-eq, and provision was to be made for tax-free thresholds and offsets. The tax would have been introduced for 'emissions that result directly from fuel combustion and gasification, and from non-energy industrial processes ...[including] carbon dioxide, methane, nitrous oxide, perfluorocarbons, hydrofluorocarbons and sulphur hexafluoride'. The tax would have been increased at a rate of 10c per annum until 31 December 2019, with a new tax regime to be introduced on 1 January 2020. The gradual increases in carbon taxes should have allowed large intensive energy users to reduce their scope 2 energy emissions (indirect emissions resulting from the

use of purchased electricity, heat or steam) and to introduce more energy-efficiency measures. The introduction of the proposed carbon tax measures was again postponed for further consultation until 2016.[28] In addition to the carbon tax in 2012 the National Treasury proposed the introduction of an electricity levy on non-renewable sources to fund energy-efficiency initiatives.[29]

The Department of Energy's *Policy to Support the Energy Efficiency and Demand Side Management Programme for the Electricity Sector through the Standard Offer Incentive Scheme* of May 2010[16] proposes various tools or measures to ensure energy efficiency, such as an Energy Conservation Scheme. According to this Scheme, certain key industrial electricity customers with a monthly consumption above 100 GWh per annum per site were required to submit their 'historical baseline consumption profile…in Gwh points spread over one year over any 12-month period'[16] to the licencee by June 2010. The licencee negotiates a baseline with the customer and the baseline is ratified by the National Energy Regulator of South Africa (NERSA). The Minister of Energy then sets a reduction target for each industrial sector. NERSA accordingly determines a tariff on a punitive scale using the baseline information as its point of departure. If less energy than the baseline is consumed then a standard rebate would be offered.

Policies are not enforceable. They are political statements of intention of what government would like to introduce. From the discussion it is clear that the policies are in place and that government is committed towards introducing measures to enforce energy efficiency. It is therefore necessary to determine whether the legal framework sufficiently provides for measures to regulate the introduction of energy efficiency.

Legislation

South Africa's legislation already makes provision for the possibility of introducing energy-efficiency measures. One of the aims of the *Electricity Regulation Act 4 of 2006* is to promote energy efficiency. In section 15(1)(u), the Act allows NERSA to place conditions in licences dealing with energy-efficiency standards and demand-side management. NERSA may also place energy-efficiency conditions on the licencee and may amend them from time to time to adapt to national energy priorities as set out in policies. In terms of GN R721 of 2009,[30] energy efficiency must be taken into account when an integrated resource plan is developed. The Integrated Resource Plan 2010–2030 was published in 2010 and introduced, amongst other things, an energy efficiency and demand-side management financial incentive scheme (a standard offer).[31,32] It is also foreseen that public facilities and housing programmes introduced by government should be energy efficient (by making use of insulation, efficient lighting, motion sensors, for example).[33] Measures will also be introduced for 'commercial buildings (offices, hotels and the hospitality industry, employee compounds at mines, refineries, power stations)'. Government has subsequently introduced green building standards on a local government level and incentives for installing solar-water heating.[34]

The *National Energy Act 34 of 2008* defines 'energy efficiency' as the 'economical and efficient production and utilisation of an energy carrier or resource' and also allows the Minister to issue regulations pertaining to energy efficiency, including (section 19(f)-(n)) measures dealing with minimum levels of energy efficiency in each sector of the economy; the steps and procedures necessary for the application of energy efficiency technologies and procedures; and measures for the labelling of household appliances, devices and motor vehicles indicating their energy-efficiency levels. The Minister may also prohibit the manufacture, importation or sale of electrical and electronic products and fuel-burning appliances for reasons of less than expected energy efficiency and publish standards and specifications for energy carriers as well as energy efficiency standards for specific technologies, processes, appliances, devices, motor vehicles and buildings. He or she may introduce energy conservation measures during energy shortages, 'which may include but [are] not limited to the amount of energy to be saved, the duration for such measures and penalties associated with non-compliance to such measures'. The Minister has not issued regulations dealing with energy efficiency yet. The Minister has, however, issued regulations in terms of the *Electricity Regulation Act 4 of 2009*. In terms of this Act, the Minister may make regulations on the types of energy sources from which electricity must be generated, and the percentages of electricity that must be generated from different energy sources (section 35(4)(k)-(l)).[34] The *National Environmental Management: Air Quality Act 39 of 2004* may further be used to set national, provincial and local standards for air quality, priority areas, controlled emitters and energy carriers. The legislation does not regulate the detail of energy efficiency but allows the Minister to deal with the specifics in regulations which will need the inputs of various specialists.

Other market-based measures (economic incentives) have also been introduced to address environmental issues and may be regarded as measures that address climate change.[5,35] They include 'the electricity generation levy, motor fuel levy, motor vehicle emissions tax, the levy on incandescent light bulbs, tax incentives supporting renewable energy measures (biofuels, solar panels etc.) [and the] Cleaner Development Mechanism projects'[5]. In 2013, the Department of Energy introduced Regulations on the Allowance for Energy Efficiency Savings in terms of section 19 of the *National Energy Act 34 of 2008*.[12] In terms of the regulation, a person (including an industry) may claim a tax allowance in terms of section 12L(5) of the *Income Tax Act 58 of 1962* for energy-efficiency savings. The person must register with SANEDI (the South African National Energy Development Institute established in terms of section 7 of the *National Energy Act*) in respect of any energy-efficiency savings he or she may want to claim (regulation 2(1)). The person must also appoint a measurement and verification (measurement and verification as applied in terms of ISO 50001, para 4.6.1)[12] professional to compile a report containing the energy-efficiency savings for the year for which the allowance is claimed. A measurement and verification professional is someone who acts under the auspices of a measurement and verification body that is accredited by the South African National Standards (SANS) and who may inspect, measure, report and verify energy-efficiency savings (regulation 1 – a body accredited in terms of section 22 of the *Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act 19 of 2006*). This report must be submitted to a committee of SANEDI (appointed in terms of regulation 3). This committee may obtain independent professional advice to confirm that the report complies with SANS 50010:2011 and that it is a true reflection of the energy savings that are claimed (regulation 3(3)-(4)). SANEDI must then issue a certificate (regulation 3(2)) containing 'the baseline at the beginning of the year of assessment for which the allowance is claimed, derived and adjusted in accordance with regulation 5 and determined in accordance with' ISO 50001 (regulation 4). The baseline calculation must be made in accordance with regulation 5 and in accordance with the methodology in ISO 50001. The study must also refer to the energy used at the end of the year, the annual energy savings expressed in kilowatt hours determined in accordance with ISO 50001, the name of the measurement and verification body that certified the professional who conducted the report, etc. (regulation 4). The tax measures are seen as an incentive for industry to introduce energy efficiency practices.

Gunningham[36] foresees that market-based instruments/economic incentives may be 'one component of a broader mix of energy policy initiatives'. However, economic measures alone will not achieve energy-efficiency targets. It is necessary, as indicated above, to introduce voluntary measures such as ISO 50001[2,8] as well as legal and policy measures to effectively change behaviour.

In order to implement and enforce these regulations, various specialists (for example, engineers, economists, energy management specialists, auditors and lawyers) would need to be involved as indicated. As ISO 50001 has been introduced as part of the law, it is necessary to understand how it came about and what it entails.

SANS/ISO 50001:2011

The USA and Denmark developed energy management standards in 2000. Sweden followed in 2003, the Netherlands in 2004, Ireland in 2007, and Korea and Thailand in 2008. In 2009, China had a draft standard.[37] The voluntary programmes targeted large industrial plants

with the idea of recognising outstanding performers. Financial incentives and training were provided.

Driven by the debate around climate change, the idea of an international energy management system standard was suggested by the United Nations Industrial Development Organization to the International Organization for Standardization secretariat in 2007.[38] Discussions were held between developed and developing countries. The ISO Technical Management Board approved the project to generate the ISO 50001 standard in February 2008, and it was finally introduced in June 2011. The ISO Committee is also developing ISO standards on Energy Baseline General Principles and Guidance; Guidance for the Implementation, Maintenance and Improvement of an EnMS; Monitoring, Measurement, Analysis and Verification of Organizational Energy Performance, Energy audits, Energy management system audits and auditor competency; and Energy Performance Indicators, General Principles and Guidance.[39]

The South African SANS/ISO 50001:2011 standard is based on ISO 50001 drafted by the ISO/PC 242, the Energy Management Technical Project Committee of the International Organisation for Standardisation. The South African standard was approved in June 2011. In the introduction[2] it is stated that '[t]his International Standard is applicable to all types and sizes of organizations, irrespective of geographical, cultural or social conditions' as well as any type of energy user.[2] Like the ISO 14001:2004 Environmental Management Standard, the ISO 50001:2011 standard is based on the Deming management Plan-Do-Check-Act model.[10,39]

SANS/ISO 50001:2001 correlates with the other ISO management system standards and can be integrated, for example, with environmental or occupational health systems as well as general quality systems. Annexure B of SANS/ISO 50001:2011 indicates, for example, the correlations between the different standards: ISO 50001:2011 (Energy Efficiency Management Systems); ISO 9001:2008 (Quality Management Systems); ISO 14001:2004 (Environmental Management Systems) and ISO 22000:2005 (Food Safety Management Systems). An organisation may use the standard in order to obtain certification from ISO or may register with ISO. It may also use the standard to ensure and declare that the organisation's practices conform to the international standard. The organisation commits to its own energy policy as well as to its obligation to comply with legal and other requirements.

As in other management systems, the main requirements of the energy management system include general requirements, the responsibility of management, the formulation of an energy policy, energy planning, implementation and operation, and checking and review.[2] In this review, the focus is on indicating where legal requirements play a role in the energy management system process and therefore on the linkages between law, science, engineering and energy management.

According to the standard[2], an organisation must 'establish, document, implement, maintain and improve an energy management system in accordance with the international standard'. It must 'define and document the scope and boundaries of its energy management system' and 'determine how it will meet the requirements' of SANS/ISO 50001:2011 in order to '…achieve continual improvement of its energy performance and of its environmental management system'.[2] ('Energy performance' is defined as 'measurable results related to energy efficiency, energy use and energy consumption' – para 3.12.) The 'boundaries' of the organisation are the 'physical or site limits and/or organizational limits', which may include, for example, 'a process, a group of processes, a site, an entire organization, [or] multiple sites under control of an organization', while 'scope' refers to the 'extent of the activities, facilities, decisions that the organization addresses through an environmental management system, which can include several boundaries'. It may for example refer to 'energy related to transport' (para 3.1 and 3.26). The boundaries and the scope of the organisation will determine the legal obligations to which the organisation must adhere and which will form the bottom line for certification.[40]

Top management must truly commit to the energy management system and ensure that the necessary resources are available, otherwise the system will fail (para 4.2.1). To ensure effective implementation of the energy management system, an organisation must appoint a management representative with the necessary skills and competence (para 4.2.2.). Hilliard and Jamieson[41] describe the skills such a person should have as 'technical and analytical abilities which should include knowledge of power electrics, thermodynamics, and statistics, with an aptitude for modelling and analysis'; business literacy that includes the ability to 'concisely and authoritatively contribute to management decision-making for assessing EM investment', and 'social skills and agreeability'.

Top management must draft an energy policy stating the organisation's commitment to achieve energy performance improvement. This policy must be 'appropriate to the nature and scale of the organisation's energy use and consumption' and must amongst other things include 'a commitment to comply with applicable legal requirements and other requirements to which the organisation subscribes related to its energy use, consumption and efficiency' (para 4.3(a) and (d)).

The organisation must further 'conduct and document an energy planning process' which coincides with its energy policy. The energy planning process includes the identification of all legal and other requirements that may be applicable to the organisation (para 4.2.1). The organisation must determine 'how these requirements apply to its energy use, consumption and efficiency and shall ensure that these legal requirements and other requirements to which it subscribes are considered in establishing, implementing and maintaining' the energy management system (para 4.2.2). It is interesting that the standard does not refer to legal compliance as such, but only to the commitment of the organisation to comply with the laws.

The organisation must conduct an energy review, which may include an analysis of the current energy sources and energy use and consumption. The organisation will have to be able to demonstrate an improvement in energy efficiency, which means it will have to quantify its improvements – a task that a lawyer will not be able to perform. Various models have been developed to assist organisations in this regard.[8,42] In relation to the energy baseline, ISO 50001:2011 (A 4.4) states[2]:

> [A] *suitable data period means the organisation accounts for regulatory requirements or variables that affect the energy use and consumption. Variables can include weather, seasons, business activity cycles and other conditions.*

This information (compiled by energy specialists, engineers, accountants, etc.) will form an energy baseline against which future energy use and consumption could be measured (A 4.4).[2] The review must also include an identification of the facilities, equipment, systems, processes and personnel (e.g. contractors, part-time personnel and temporary staff) that may significantly affect energy use and consumption and an estimation of future energy use and consumption (A 4.3).[2] The energy use and consumption may be prescribed by legislation or may be defined by the organisation itself.[43] The main aim of the review should be to 'define areas of significant energy use and to identify opportunities for improving energy performance'[2] (A 4.3). One should provide for human error in the interpretation of data. Timescales may also influence the interpretation of the data and the interpretation may be influenced by the loss of institutional memory. The model that is used for capturing energy data should not only be cost effective but should also correlate with human understanding: 'Energy models with finer data may be more useful but a model that few understand is dangerous and a model that falls out-of-date is worthless.'[41]

The organisation must establish energy performance indicators 'appropriate for monitoring and measuring its energy performance'. According to SANS/ISO 50001:2011 (A 4.5), an energy performance indicator could be a simple ratio or a complex model such as 'consumption per time, energy consumption per unit or production, or multi-variable models'[44]. The organisation must record and review the methodology used to determine these indicators (para 4.4.5). In addition, the organisation must 'establish, implement and maintain documented

energy objectives and targets at the relevant functions, levels, processes or facilities of the organisation'. The objectives and targets must coincide with the energy policy and the objectives with the targets. The targets must be linked with a time frame. SANS/ISO 50001:2011 states clearly that legal and other requirements, amongst others, must be considered when the objectives and targets are considered. The legal requirements may include international, national and provincial laws and bylaws. Other requirements may include voluntary principles or codes of practice or voluntary practices to which the organisation subscribes (A 4.2).[2] The views of interested parties must also be considered. The objectives and targets must be translated into an action plan (para 4.4.6).

In order to ensure implementation of the action plan, the organisation must employ skilled people and train them in the importance of conformity to the energy policy, procedures and requirements of the energy management system. The employees must also be aware of their roles and responsibilities in terms of the energy management standard and must understand what the impact and consequences of their activities and behaviour are, or could be, on energy use and consumption as well as on the energy objectives and targets set (para 4.5.2).

The organisation must communicate internally on its energy performance and may decide to communicate externally on its energy policy and performance (para 4.5.3). The communication could include non-compliance with legislation, although compliance is not an explicit requirement. The organisation must have a proper document control system in place, which must include objectives, targets and action plans. However, in most instances it will be necessary to document the legal requirements as well, and to review and update them regularly (para 4.5.4.1 and 4.5.4.2).[2] The organisation must ensure that the correct version of the legal requirement is available. The organisation must also identify those operations and activities that are related to its significant energy uses and ensure that they are carried out under the specified conditions. These operations include emergency and contingency plans (para 4.5.5).

In the design of new, modified or renovated facilities, equipment, systems and processes, an organisation must consider energy-performance opportunities if such a facility, equipment, system or process may have a significant impact on its energy performance. The result must be incorporated into the 'specification, design and procurement activities of projects' and recorded (para 5.4.6).

The organisation must when it obtains energy services, equipment or products inform suppliers that procurement is evaluated on the basis of energy performance. If the legislation does not provide specific criteria, the organisation must establish and implement criteria to assess energy use, consumption and efficiency 'over the planned or expected operating lifetime when procuring energy products, equipment and services which are expected to have a significant impact on the organisation's energy performance' (para 4.5.7). ISO 50001 could be used to ensure that procurement is used to 'improve energy performance through the use of more efficient products and services. It is also an opportunity to work with the supply chain and influence its energy behaviour' (A 5.7).[2]

An important aspect of the energy management system is checking (para 4.6). One of the components of checking is the evaluation of compliance with legal requirements and other requirements (para 4.6.2). The results of such evaluations have to be documented. A procedure must be available to ensure that the documents are retained, easily identifiable and retrievable (para 4.5.6).

The organisation may conduct an internal audit to determine whether the organisation complies with the environmental management standard's objectives and targets and whether the environmental management plan is implemented and maintained. The auditor must also establish if the energy management standard improved energy performance (para 4.6.3). On 12 May 2012 it was decided that the Southern African Auditor and Training Certification Association (SAATCA) accreditation processes for lead auditors will apply to energy management system auditors as well.[45] The criteria for SAATCA EnMS start-up auditors were also discussed. Records must be kept of the audit report. The organisation must address all actual and potential non-conformities. These non-conformities may include non-compliance with legal requirements. The preventative steps must also be documented. The effectiveness of the corrective action must also be reviewed. If need be, the energy management standard must be amended.

From time to time, top management must review the energy management standard to determine its 'suitability, adequacy and effectiveness'. The management review must include, for instance, a review of the 'results of the evaluation of compliance with legal requirements and changes in legal requirements and other requirements to which the organisation subscribes' (para 4.7.2). The output of the management review may, for example, include an amendment to the energy policy, objectives and targets or energy performance indicators (para 4.7.3).

Why do companies introduce or not introduce energy management systems? According to Pandolfo[10], organisations will invest money if immediate cost reductions are visible. In the case of energy consumption, the immediate cost reduction cannot be predicted and the benefits cannot be identified. Steele[46] is of the opinion that the benefit of adhering to a management system standard is its voluntary nature and that it was developed by the users themselves, that it provides performance-based solutions, that costs could be reduced, that organisations can participate in markets that were previously closed to them, that it ensures legal compliance, that it reduces risks and ensures continuous improvement, and that it is at least a step taken towards implementing best practice. It also ensures that the organisation is competitive, socially responsible and environmentally friendly by reducing its dependence on natural resources and its carbon footprint.[10] It may be easier for larger companies to effect energy management with the appointment of energy managers. Smaller organisations cannot always afford to attract people with the necessary expertise.[40] Pandolfo[10] found that it is easier for a site with ISO 14001 certification to implement ISO 50001:2011 than for one starting from scratch. In her study she indicated that such a site already complies with 70% of the ISO 50001:2001 requirements. Management must, however, commit to the introduction of an energy-management system to ensure its effective implementation and must be prepared to fund the expenses.[47] The most challenging aspect is to determine the baseline energy consumption, for which determination is not required by ISO 14001:2004. It is important that organisations share information on best practice, energy-efficiency technologies and the results of case studies.[47] Some countries have incentives to stimulate the introduction of energy-efficiency technology and investment.[47] The introduction of a voluntary mechanism such as an ISO standard as an incentive is less well known from a legal perspective.

Conclusion and recommendations

In a recent article, Thopil and Pouris[21] indicated the need for differential pricing of electricity as 'a technique that offers flexibility within the context of the country's economic, social, industrial and environmental policies' and the need to force energy-intensive industries to use energy more wisely. Such a market-based instrument is but one of many instruments that can be employed to drive energy efficiency. In this article it has been established that there is a link between energy-efficiency policy, legislation and the voluntary mechanism SANS/ISO 50001. One regulation already includes ISO 50001 measurement standards into its regulatory procedures, coupling them with tax measures, while the ISO 50001 standard refers to legal requirements. It has also become clear that several laws and policies refer to energy efficiency as a tool to reduce energy use and consumption. The legislation does not explicitly indicate how these measures should be introduced. Policies and laws need to be implemented. The only regulation that provides clear guidelines is the one providing tax incentives for the implementation of energy-efficiency measures. Energy efficiency is, however, not a goal that can be achieved by practitioners schooled in a single discipline. It has become apparent that an interdisciplinary approach will be needed to implement and enforce not only the statutory measures but also voluntary standards. Lawyers will not be able to work in this field without the input of scientists such as engineers, energy specialists, tax specialists, architects, accountants and environmental managers,

among others. Similarly, engineers and other scientists will not be able to implement these measures without legal input. Scientists and lawyers will have to work together to develop norms and standards for energy-efficiency practices.

Climate- and environment-related issues have become an important feature of every person's daily life. As stated above, law is one of the disciplines that is able to integrate natural science, engineering, mathematics, social sciences and other disciplines by providing incentives and disincentives. Science needs to be translated into policy and law. The law cannot ignore the rest of the scientific world. It needs its input, especially in complex fields such as energy and energy efficiency.

The need for improvement of energy efficiency and to reduce the energy intensity of the economy was reiterated in the Draft 2012 Integrated Planning Report that was published in July 2013.[48] Command and control measures (i.e. measures enforced by government) frequently fail to efficiently and effectively drive transitions towards energy efficiency and legal compliance. It is noted that energy efficiency performance by the private sector is in some instances driven rather by international market demands than by command and control measures. It is therefore necessary to move away from a silo-based approach towards science to an integrated approach in which the natural sciences, humanities and social sciences approach issues such as climate change and the environment in a holistic manner.

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Mother tongue as the medium of instruction at developing country universities in a global context

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One of the factors attributed to poor performance of some indigenous students at universities in developing countries is the use of a second language – mainly English and to some extent French – as the language of instruction at the universities. Consequently, policymakers in some developing countries have introduced, or are debating the idea of introducing, local vernacular languages as the official languages of instruction at their respective universities. Indeed, learning the official language of instruction as a second language is an additional hurdle, which to some extent hinders some students from performing well in their university studies. Thus students whose mother tongue is used as the language of instruction at their universities have an advantage over students whose mother tongue is not the language of instruction at their universities. Policies regarding the medium of instruction at universities have a range of short-term and long-term implications, some of which may be easily overlooked yet they may have far reaching repercussions for current and future generations. In this paper, a repertoire of pertinent issues surrounding the use of vernacular languages at universities is explored. These issues include performance of students, quality of graduates produced in terms of employability, university overall productivity, innovation, university competitiveness in the wake of globalisation, preservation of the vernacular languages and contribution towards national as well as global socio-economic development.

Introduction

Many developing countries are grappling with the issue of policy on language of instruction to be used in schools and tertiary colleges. Although English is arguably the most widely used language to the extent that it could be considered to be an international language,[1,2] various developing countries have been debating policy changes regarding the use of vernacular languages or *lingua franca* as the medium of instruction in their educational systems.[2-4] In Africa, the main language of instruction used in most educational systems is English[1,2,4] followed by French. In general, the former colonial language is the one used as the official language of instruction in the educational systems of African countries. It is a widely accepted fact that language was, and may still be, a barrier to access to education of high quality in some developing countries. Proficiency in the language of instruction can affect comprehension of content and hence the performance of students in various subjects such as Mathematics[5-7] and Science. Hence the success of students whose mother tongue is not English or French may be compromised when they embark on university education at universities at which English or French is the language of instruction. Consequently, some universities in developing countries are at different stages of introducing local vernacular languages as official languages of instruction in an effort to address the challenge. Indeed, the importance of the mother tongue has been pointed out even in some developed countries[8]; but developed countries are already economically strong and are generally already more competitive than developing countries in the global village.

However, the language policy of university educational systems should not be considered and developed in isolation from other pertinent factors which affect the overall capability of universities to produce competitive graduates of high quality who can effectively contribute towards national and global socio-economic development of marginalised populations. Thus a holistic approach which takes into account the whole repertoire of relevant issues that affect the entire educational system from kindergarten through primary and secondary schools to universities should be considered. The acquisition of proficiency in any language is a learning process that has to be started as early as possible in the development of students. For instance, it has been reported that starting to learn English as early as primary school helps proficiency in the language.[9] In addition to the issue of early learning, studies have also shown that there is interdependence in the educational development of bilingual proficiency.[10,11]

Although empirical research has shown that the use of mother tongue or *lingua franca* in early literacy and content learning stages is more effective than use of a foreign second language,[12-14] there is a paucity of empirical evidence which shows that the use of a vernacular language at higher levels of learning could lead to educational success and subsequently success in career development in the real world. Although some studies on the effect on performance of the use of a vernacular language as the medium of instruction have been done in Tanzania and South Africa,[15] there is a dearth of empirical data on the long-term impact of using vernacular language until secondary or tertiary levels in terms of the capability of the graduates produced to effectively contribute towards national and global socio-economic development. Thus use of vernacular language as a medium of instruction to the exclusion of an international language such as English could eventually and inadvertently be to the disadvantage of the very people who were meant to benefit from such a policy. In fact, anecdotal evidence shows that graduates from countries that use a local vernacular language as the medium of instruction until tertiary levels eventually face challenges adapting to real-life environments in which English is the official language of communication.

An example of such a country is Tanzania, where Swahili has been used as the official language of instruction and communication for the whole nation. A political decision was made to make Swahili the official national language out of all the vernacular languages and so some tribes in Tanzania have to learn Swahili as their 'second language'. Although Swahili is used to different extents in some countries in the East African region, it cannot be considered to be a widely used international language. Like many other developing countries, Tanzania has to attract and deal

with much needed foreign investment, mainly from developed countries in which English is the language used. Consequently, foreign-owned industrial, mining and tourism businesses depend to a large extent on workers drawn from other countries in the East African region and beyond who are more proficient in English. Whereas the Tanzanian model of language policy is based on one 'local' language being officially made a national language, the model being considered by other developing countries is based on making several specific vernacular languages the languages of instruction in particular localities of the country in which the vernacular languages are predominantly used as the mother tongue. The different models each have pros and cons. Hence the need to objectively consider all pertinent issues in the context of a long-term vision for the individual students, future generations, the universities themselves and the future of the countries concerned. It is critical to ensure that policies – such as those regarding the use of vernacular languages as the medium of instruction at universities – which are meant to enhance academic success of indigenous students do not inadvertently cause or worsen any intellectual and economic marginalisation of indigenous students by restricting their capability to effectively utilise their acquired education and skills to localities in which their vernacular languages are used.

For most African countries, the use of English or French as the language of instruction in educational systems was not by design but was an imposition during the colonial era. Thus language was perceived as a tool for oppression against the disadvantaged indigenous populations. Within that background, policymakers in some formerly colonised developing countries feel obliged to change their national policies so as to make local vernacular languages the official languages of instruction in schools and universities; such a change of policy could be considered to be a demonstration of political independence. However, it is critical to be pragmatic and objectively weigh the potential advantages and disadvantages of any policy change. Whereas some policy changes may be politically plausible, they may not necessarily be advantageous from other points of view. It is critical for policymakers to consider short-term and long-term socio-economic implications as well as the practicability of implementing national policies.

National policies should create micro- and macro-environments that are conducive to better living conditions for citizens through empowerment rather than dependency on some form of aid. A combination of various complementary factors helps to create conducive conditions. Enabling citizens to access good quality education is one of the most effective ways of empowering them, because they can become employed or self-employed. It is in light of the above points that the issue of language of instruction should be considered carefully. This review explores the whole repertoire of pertinent issues that should be considered before making a decision pertaining to use of local vernacular languages in universities. The potential implications of using vernacular languages as official languages of instruction at universities are discussed in terms of (1) the performance of university students, (2) innovation, (3) employability of graduates produced by universities, (4) ability of universities to compete nationally and globally, (5) ability of universities to contribute towards national and global socio-economic development, (6) chances of previously disadvantaged groups to participate in and benefit from the mainstream economy, (7) choice of a vernacular language, (8) use of local vernacular languages at universities as a 'postponement' of rather than a solution to challenges associated with indigenous students learning an international language and (9) efforts to preserve local vernacular languages.

Unpacking pertinent issues

Performance of students

Performance of students is affected by several factors. The level of comprehension of the language of instruction can negatively affect performance because students may experience difficulties in grasping the underlying basic concepts that are taught in various subjects. This difficulty could cause some students to resort to memorising and 'regurgitating' information, which leads to limited success when answering examination questions that require analytical approaches based on comprehension of the basic concepts involved. Performance can also be affected by the quality of teachers in terms of their command of the language of instruction as well as their comprehension of the basic concepts of the subjects they teach. It is critical for teachers and students to interact effectively so that students can express their questions well and teachers can explain explicitly with relevant examples or demonstrations if applicable. Hence subject content teachers may also have to identify and address second language 'barriers' which may be preventing some students from understanding fundamental academic concepts.[16,17] However, if teachers are not fully knowledgeable about the subjects they teach then students will not derive maximum benefits from the student–teacher interactions in class, even if there are no language 'barriers'.

Teachers should therefore have a good command of the language of instruction, be it international or vernacular, plus adequate knowledge of the content of the subject. The language of instruction has no intrinsic value per se – it is merely a medium of communication used to convey subject content. Thus having a teacher who is very proficient in the language of instruction but lacks adequate knowledge of the subject content compromises the performance of students. In order to effectively use vernacular languages for instruction at universities, it would be critical to have teachers who have both a good command of the particular vernacular language (either as their mother tongue or as a learned second language) as well as adequate knowledge of their subjects of specialisation. In addition, enhancement of a student's performance may require implementation of various complementary strategies, such as schema-based word-problem solving instructions[18,19] and peer-assisted inclusive instructions,[20,21] whenever applicable. Thus proficiency in the language of instruction and content knowledge should be complemented with other supportive and appropriate strategies.

The performance of students can also be affected by availability of relevant resources. For instance, availability of textbooks and various reading materials is critical for students to perform well in their subjects, as the students can complement what is taught in class and enhance their comprehension through reading on their own. In addition to textbooks and other reading materials, well-equipped laboratories are critical for students to do well in science subjects. Thus if a specific vernacular language is made the official language of instruction at a particular university, then, ideally, reading materials (textbooks, journals, Internet materials, etc.) written in that vernacular language should be made available. Who would be responsible for such a mammoth task – the university concerned or the national government? The 'learning environment' is also important; a secure environment characterised by a general seriousness of purpose and free of abuse, diseases, delinquency and discrimination enables students to perform to their best abilities. A conducive environment at the place of learning should be complemented with an environment at home characterised by discipline, encouragement and love.

Innovation

Innovation is not restricted by language. One does not have to be proficient in any particular language in order to be able to invent something. Thus an invention can potentially be developed to a stage of application regardless of what language the inventor is proficient in, provided the resources for the development are available without a need to apply for funding which may necessitate use of a particular language preferred by potential funders. If necessary resources are not available, innovative ideas may remain as such with limited chances for development into useful commercialisable products or useful policies.

In other words, language may become a barrier if there is a need to elaborate on an innovation to a stakeholder not proficient in the inventor's mother language. Although language of instruction at universities does not hinder innovation per se, comprehension of basic concepts and existing basic knowledge may form a critical basis for innovation. Thus one may need to have read and understood existing concepts and knowledge to be able to invent something completely new or improve on something already in use. If the reading materials covering the relevant concepts and basic knowledge are written in a language which one does not understand, then one's ability to come up with innovative ideas may

be compromised. For instance, the reading materials may be in English (which is currently the case for most subjects) and not in the language in which an aspiring inventor is proficient.

Employability

Most developing countries are experiencing increasing levels of unemployment. This trend is a result of many factors, which arguably include competition caused by globalisation as well as technological advancements that enable mechanisation of industrial processes, leading to fewer workers being needed even if developing countries are gradually being industrialised. It is therefore critical that graduates who are produced by universities in developing countries are competitive enough to get employment or to create their own employment as entrepreneurs. In addition, the educational systems producing graduates should be demand-driven and responsive to the dynamic needs of the national and global job markets. Some empirical evidence has shown that, controlling for other confounding factors, proficiency in English is significantly associated with increased wage earnings.[22] Thus the question of whether or not graduates will eventually be highly employable anywhere in a particular country, or anywhere in the world, if they obtained their degrees through universities which use particular vernacular languages for instruction purposes should be considered when making such policies. Would the graduates be employable only in the areas in which their respective vernacular languages are used? Would investors from other parts of the country or the world be attracted to such areas or would they prefer areas in which an international language is used? Retrospectively, would graduates themselves appreciate a policy on the use of vernacular languages as the medium of instruction at universities when they are out in the real world fending for themselves and for their families?

University competiveness in the wake of globalisation

Universities are making concerted efforts to attract high calibre students and workforce in order to be competitive nationally and globally. With the best students and workforce, universities can in turn enhance their ability to generate their own funds for research, in addition to attracting research funds from funding organisations. Factors that strengthen university competitiveness include production of high quality and quantities of graduates, high-quality demand-driven research outputs, participation in national and international collaborative programmes, innovative research which results in useful products or policies and publication of research outputs. Generally, these factors to a large extent require use of an international language. For instance, most applications for research grants should be completed in English, which means that graduates who performed well in universities using vernacular local languages may find it difficult to get competitive grants which require applicants to use English. The majority of national governments which offer research grants require applicants to use English (or French in Francophone countries), otherwise the governments would have to offer separate grants to be administered in different local vernacular languages. Widely read academic publications are in international languages. Journals in various vernacular languages may have to be established to enable publications in various local languages. However, the readership would be restricted to specific groups of people who can read and understand the particular local vernacular languages, which would negate the whole purpose of publishing which is mainly to enable widespread dissemination of research outputs.

Contribution towards national or global socio-economic development

Universities in developing countries have a role to play in promoting socio-economic development of people. Through conduction of relevant research, universities should address the needs of their countries primarily and global needs secondarily. The research should also be used as a platform on which students are trained in order to produce graduates with relevant hands-on skills which meet the needs of employers and also form a strong foundation for self-employment. National socio-economic development requires universities which produce nationally and internationally relevant graduates rather than 'provincially' relevant graduates. In addition, universities should contribute towards the creation of micro- and macro-environments which attract investment from across different provinces, countries and continents. Therefore, it could be argued that use of vernacular languages limits the extent to which universities can effectively contribute towards national and global socio-economic development. In addition, the graduates produced by such universities are likely to be derived mainly from previously disadvantaged groups of people, which implies that the groups would be systematically and effectively isolated from the competitive mainstream activities taking place nationally and globally.

Unless the respective governments can create adequate numbers of jobs locally using local resources without need for foreign investment, local people would have limited access to opportunities beyond the areas in which their vernacular languages are used. Their areas may not attract investment from other parts of the country or other parts of the world as much as areas in which an international language is used. To enable research then, the governments would have to provide adequate funding for which applications could be completed in the vernacular languages; otherwise the researchers educated in the vernacular languages would not be competitive enough to get research grants provided by other players who would require applications to be in an international language. The majority of funders are based in developed countries in which English is the main language.

Challenges of choosing one vernacular language out of many

In situations in which there is one vernacular language to consider, the choice of the vernacular language for the medium of instruction at a relevant university or universities would be straightforward. However, in reality, there usually is multiple vernacular languages spoken in particular localities or countries in which a university or universities may be located. In such situations, the issue of criteria to be used to determine which of the many vernacular languages to select as the medium of instruction at the particular local universities becomes a challenge. Would it be based on the 'majority rule', leading to the vernacular language of the majority of people being chosen as the language of instruction? What would happen to the vernacular languages of the 'minorities'?

Risk of ethnic or racial discrimination and 'isolationism'

Use of local vernacular languages as the medium of instruction at specific universities located in particular geographical or political regions of a country or continent could inadvertently increase the risk of discrimination along ethnic or racial lines because vernacular languages are generally specific to particular ethnic or racial groups. Thus the risk of ethnic or racial groups considering certain universities at which their local vernacular languages are used as being exclusively 'their universities' – which primarily should enroll their local children – becomes high if educational policy is amended to introduce vernacular languages as the medium of instruction at universities.

A policy-based system of enrolling university students that leads to the majority of enrolled students being those who speak a particular vernacular language (and hence are from a particular ethnic or racial group) could lead to 'islands' of universities which cater for specific ethnic or racial groups. Such a system could lead to a situation of 'isolationism', which would inadvertently divide nations and continents along ethnic or racial lines. In contrast, use of an international language as a medium of instruction would promote mixing of people from different ethnic or racial groups that would still have their unique cultures and vernacular languages which do not necessarily have to be preserved through use of vernacular languages as medium of instruction at universities. Although English is a former colonial language, its continued widespread use as an international language in the post-colonial era arguably makes it a relatively 'neutral' language which could minimise the potential risk of ethnic or racial discrimination and 'isolationism' that could be caused by localised use of vernacular languages as the medium of instruction at local universities. It should be emphasised that this does not imply that an international language like English is superior to other languages; it is merely a convenient tool or medium to use as it is already widely

used globally. Countries could use English as a tool to their advantage in terms of socio-economic development and upliftment of the quality of life of poverty-stricken populations by maximising economic benefits that could be gained by being competitive self-sustainable players in the global market.

Postponement of challenges associated with second language usage

Use of local vernacular languages as the medium of instruction at university level, to the exclusion of an international language, could in practical terms be only a postponement of the challenges associated with limited proficiency in an international (second) language to the post-university period in the lives of the students concerned. After university, graduates may have no other option but to fit into real-world environments in which an international language is the official language of communication. Thus, although they may have sailed through university educational systems that use their local vernacular languages as the medium of instruction, their career development endeavours may be compromised by their limited proficiency in the international language used in the real world. Even if the graduates were to become self-employed entrepreneurs, their business endeavours may be hampered by the limited proficiency in the international language. For instance, business tenders are generally in English. Business proposals are generally in English. Business clientele may not be restricted to people who speak and understand particular vernacular languages.

Preservation of local vernacular languages

There are many ways of preserving and promoting vernacular languages and there is no single method which could be regarded as the 'magic bullet'. Each method has its own potential advantages and disadvantages, hence the need for a thorough risk–benefit analysis when making policy changes pertaining to the use of vernacular languages as the medium of instruction at universities. Universities have various departments – such as linguistics, arts, theatre and drama – which carry out various activities aimed at enriching and preserving languages and cultures. In recognition of the importance of languages and culture, governments have ministries which focus on promoting and preserving the languages and cultures of their respective countries. In addition, the arts, theatre and media industries are a basis of huge business which not only create wealth and jobs, but also help to preserve and promote different languages and cultures.

In many homes and communities, parents, grandparents, ordinary members of communities, and community leaders could play a role in keeping their cultures and languages alive. For instance, parents could ensure that their children do not neglect and abandon their vernacular language by using the language in their homes instead of using an international language such as English or French at home. However, people are free to use their language of choice in their homes, and parents may consider an international language to be so important that they would rather help their children to master it by using it at home. In addition, some youths may prefer using and developing their own pidgin language to their mother language,[23] regardless of the language of instruction used in the educational systems of their country.

Recommendations and concluding remarks

As policymakers in developing countries consider changing policies in order to make some vernacular languages official languages of instruction at universities, it is critical to take into account a range of pertinent factors and possible long-term implications. A bilingual system that starts with the mother tongue as the main medium of instruction while an international second language is gradually introduced using the mother tongue is recommended. By the time students get to mid-primary school level, they should have mastered the second language to levels that facilitate a transition from the vernacular to the international language as the language of instruction. Thus an international language would be used as a medium of instruction from mid-primary school to university level. Relevant local vernacular languages could be used for instruction purposes from crèche to mid-primary school as a preparatory phase for the introduction of an international language as the medium of instruction all the way to university level. However, if a decision is made to use local vernacular languages as official languages of instruction up to university level, it is recommended that policymakers consider having bilingual systems which include an international language.

Policy changes that will introduce vernacular languages as the medium of instruction at university levels may not lead to the desired results. Such policy changes may inadvertently be to the disadvantage of the very indigenous students for whom they are intended to benefit. There is a risk of being short-sighted and to focus only on university pass rates of 'indigenous' students without considering the possible long-term negative impact on (1) the eventual competitiveness of students in terms of securing employment in the national and international markets after obtaining their university degrees, (2) the productivity of the universities in terms of attracting high-quality students, workforce and research funding, (3) the ability of the universities to significantly contribute towards national and international socio-economic development through production of graduates who can effectively participate in the mainstream economic activities without being restricted to vernacular language-specific localities and (4) national and international cohesion without the risk of ethnic and racial segregation being inadvertently promoted. Because of the heterogeneity of populations and the multiplicity of vernacular languages within and across countries, collaboration between or among developing countries would also be negatively affected if the countries did not use a common international language. For instance, a university in a country in East Africa would have challenges engaging in collaborative research or exchange educational programmes with another university in a country in southern Africa if the universities did not use at least one common language.

Poor performance of university students whose mother tongue is not the language of instruction may not be attributed solely to limited proficiency in the language of instruction because there are other confounding factors such as overall quality of primary and secondary schools attended, quality of teachers, socio-economic status of their families and the type of environment in which the students live and study. In order to enable an evidence-based formulation of policies pertaining to language of instruction in educational systems in developing countries, more empirical research should be conducted, which covers the various pertinent factors – including the views and preferences of stakeholders such as the students themselves, their parents, academics, tertiary education policymakers, politicians, funding organisations, industry and local communities in the vicinity of the universities.

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Realising high-dimensional quantum entanglement with orbital angular momentum

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We report the first quantum entanglement experiment in South Africa. The spatial modes of the entangled photon pair were investigated with their potential for high-dimensional entanglement. The generation, measurement and characterisation of the entangled states were examined in detail and we show high-dimensional entanglement in a Hilbert space of dimension 25. High-dimensional entanglement introduces the possibility for more secure communication and more efficient computations. We highlight the experimental challenges contained within each step and provide practical techniques for future experiments in the quantum regime.

Introduction

One of the most astonishing features of quantum mechanics is that of the entanglement of particles. First introduced as an objection to quantum mechanics by the famous Einstein, Podolsky and Rosen (EPR) thought experiment,[1] entanglement represents the notion of non-local quantum correlations between two or more quantum-mechanical systems. That is, for an entangled pair of particles the measurement of an observable for one particle immediately determines the corresponding value for the other particle, regardless of the distance between the two particles.

This property of entangled systems led to a number of implications that disturbed many scientists and resulted in the emergence of hidden variable theories. Local hidden variable theory assumes that nature can be described by local processes, in which information and correlations propagate at most at the speed of light and in which the observables of a physical system are determined by some unknown (hidden) variables.

It was not until the 1960s when Bell's inequality (and Clauser–Horne–Shimony–Holt (CHSH) Bell's inequality[2]) demonstrated the possibility of practical experiments to test the validity of quantum theory with respect to local hidden variable theories. A slew of experiments followed to test Bell's inequality, each of which violated the inequality and in turn verified quantum mechanical predictions of entanglement.[3-6] These results encouraged the search for a method of producing maximally entangled states. Spontaneous parametric down-conversion (SPDC) has proved to be the most efficient technique in generating two-photon entanglement, in which a single photon is split into a pair of lower frequency photons. Shih and Alley[7] were the first to demonstrate a violation of Bell's inequality using SPDC-generated photon pairs. This demonstration was the start of various polarisation–entanglement experiments; however, in 2001, it was shown that the orbital angular momentum (OAM) of light could also be used as a basis for entanglement. The spatial modes associated with different OAM states also demonstrated a distinct advantage over polarisation with regard to the number of states available.[8] Spatial modes possessing OAM have been studied often in recent years because of the infinite-dimensional alphabets they can possibly provide. In particular, the OAM modes of a photon are a very good avenue for exploring higher dimensions.[9] Quantum mechanics in higher dimensional systems has the potential of revolutionising quantum communication and computation protocols. As an example, quantum cryptography using qudits (systems in which there are *d* orthogonal states) has been shown to be more secure and robust in the presence of noise.[10-12]

Quantum entanglement has sparked an interest in a number of scientific fields, such as quantum information processing[13], quantum cryptography[14] and quantum teleportation[15].

In this paper we report on the first entanglement experiment in South Africa, where quantum correlations were observed for the first time in Africa in 2011. We create a bi-photon pair entangled in their spatial modes, allowing quantum states of high dimension. The paper should serve as a useful guide to encourage further quantum experiments in the region.

Theory

Entangled states

An entangled state can be simply viewed as two states which are inseparable. If the state cannot be separated into a product of the two systems – A and B – it is entangled. For example, the following superposition state is entangled:

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|i\rangle_A|j\rangle_B \pm |j\rangle_A|i\rangle_B\right), \qquad \text{Equation 1}$$

where $\{|i\rangle\}$ and $\{|j\rangle\}$ are orthonormal bases of A and B, respectively. In demonstrating quantum entanglement, a measurement must be made of one of the properties of single photons. It is possible to measure the position, momentum, energy and time of arrival of single photons.[16-18] However, the most well-documented entanglement measurements have been demonstrated using angular momentum: both spin angular momentum (SAM) and OAM.

Spin angular momentum

Angular momentum associated with circularly polarised light is known as SAM and is quantified by $\hbar$ per photon. The direction of the electric field oscillation of light as it propagates, specifies the type of polarisation. For linearly polarised light, the field oscillates in a single plane, whereas the field rotates about the propagation axis for circularly polarised light. The direction of the rotation specifies the handedness of the circular polarisation: clockwise specifies right-handed, anti-clockwise specifies left-handed. Polarisation has offered an efficient way in which to demonstrate photon entanglement and much has been learnt in terms of optimising the efficiency of

generating and detecting entangled photons.[19,20] However, the limit on the amount of SAM carried per photon has prevented measurements of high-dimensional entanglement.

Orbital angular momentum

The OAM of light is associated with the spatial distribution of the light wave. In 1992, Allen et al.[21] demonstrated that laser beams with OAM have helical phase fronts and possess an azimuthal phase dependence of $\exp(i\ell\theta)$, where ℓ (the azimuthal phase index of integer value) represents the number of azimuthal phase rotations in one full cycle from 0 to 2π. Interestingly, like SAM, the OAM of helically phased beams is in units of $\hbar$; that is $\ell\hbar$ per photon. A light beam propagating along the z-axis with an ℓ-dependent azimuthal phase has a field amplitude described by:

$$\psi(r, \theta, z) = \psi_0(r, z) \exp(i\ell\theta), \qquad \text{Equation 2}$$

where ψ_0 is an amplitude distribution, ℓ is an integer and θ is the azimuthal angle. A common example of such beams is the Laguerre–Gaussian (LG) modes. The intensity distribution of an LG mode with $\ell>0$ consists of a zero on-axis intensity surrounded by $p+1$ concentric rings (p represents the radial modes). This non-zero OAM results from the helical phase front of LG beams. This property is not unique to LG beams and is found in both higher-order Bessel beams[22] and Ince–Gaussian beams[23]. It is therefore possible to study OAM entanglement using modes other than those in the LG basis.[24] Figure 1 shows the intensity distributions for different superpositions of OAM modes in two different bases: the LG basis and the Bessel–Gauss (BG) basis. We can write these superposition states as:

$$\psi_{1,2}(r, \theta, z) = \psi_0(r, z)[\exp(i\ell_1\theta) + \exp(i\ell_2\theta)]. \qquad \text{Equation 3}$$

Here ℓ_1 and ℓ_2 represent two different azimuthal phase indices.

Entangled states in orbital angular momentum

The simplest method of generating entangled photons is via SPDC, where a single photon incident on a non-linear crystal produces two photons of half the original wavelength, which are entangled. Historically, the two entangled photons have been given the names signal and idler. These down-converted photons also possess the property of OAM; and the seminal paper by Mair et al.[8] was the first experiment to demonstrate OAM as a property of single photons produced by SPDC. They showed that OAM is conserved in the SPDC process and consequently showed entanglement involving these modes.[25] That is, the OAM of the entangled photon pair must sum to the OAM of the pump photon. The two-photon state for OAM can be written as

$$|\psi\rangle = \sum_{\ell} a_{\ell_t - \ell} |\ell\rangle - \ell\rangle, \qquad \text{Equation 4}$$

where $|a_{\ell_t - \ell}|^2$ is the probability of finding one photon in state $|\ell\rangle$ and the other in state $|-\ell\rangle$, where the pump beam has zero OAM. As ℓ can assume any integer value, Equation 4 is true for d–dimensional two-photon states, where ℓ ranges over d different values. Here, the radial component of the LG basis is ignored for simplicity; however, there have been studies that examine the effect of the radial modes on entanglement.[26,27]

The conjugate variable of OAM is angular position and the Fourier relationship between them can be written as

$$A_\ell = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \psi(\phi) \exp(-i\ell_1\phi) d\phi, \qquad \text{Equation 5}$$

$$\psi(\phi) = \frac{1}{\sqrt{2\pi}} \sum_{\ell=-\infty}^{\infty} A_\ell \exp(i\ell\phi), \qquad \text{Equation 6}$$

where A_ℓ is the amplitude of the OAM state and $\psi(\phi)$ is the azimuthal dependence of the corresponding complex beam amplitude.[28]

OAM entanglement became a priority for many groups as a result of its potential for increased information capacity per photon. In 2011, high-dimensional entanglement was demonstrated through violations of Bell-type inequalities up to dimension $d=12$.[9] A violation of Bell's inequality is commonly used to test for quantum correlations and is one of many techniques we describe in this paper.

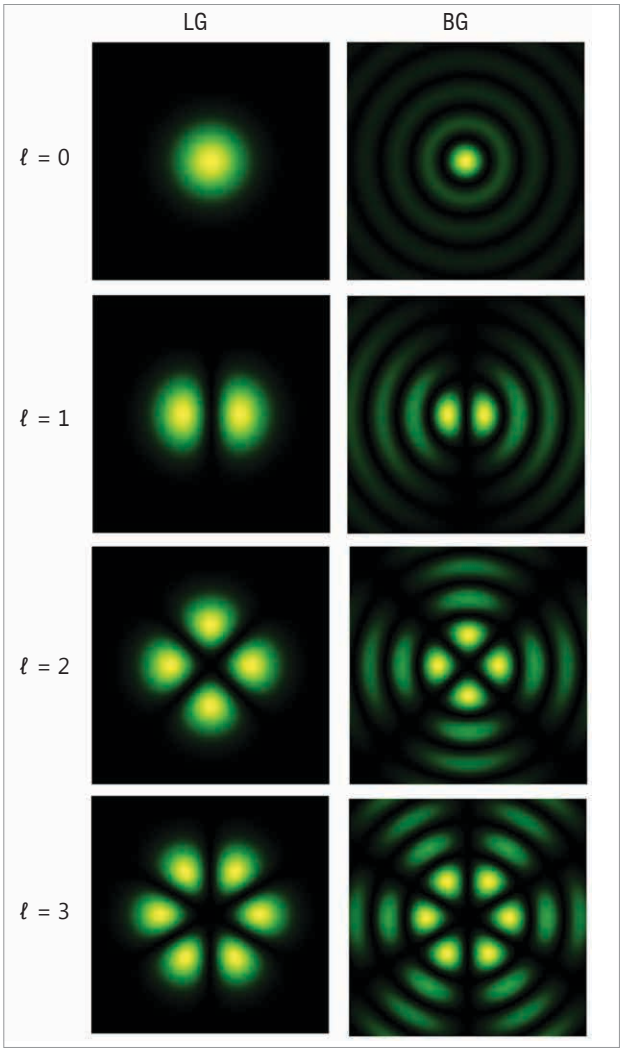


Figure 1: Intensity distributions for superposition modes of orbital angular momentum for different azimuthal indices. For each image, the superposition is between azimuthal phase indices of equal magnitude but opposite sign, ℓ and $-\ell$. Both bases, Laguerre–Gaussian (LG) and Bessel–Gauss (BG), can be used to measure orbital angular momentum. The radial component for the LG basis has been set to zero in each case, while an arbitrary radial component was chosen for the BG basis and kept constant for each case.

Experimental set-up

The most commonly used and most efficient method of producing entangled photon pairs is that of SPDC.[29] This non-linear optical process decays a pump photon into two photons (signal and idler) in a crystal of optical non-linearity, X^2. Both energy and momentum are conserved in this decay process, also known as the phase matching conditions:

$$\omega_p = \omega_s + \omega_i, \qquad \text{Equation 7}$$

$$\vec{k}_p = \vec{k}_s + \vec{k}_i. \qquad \text{Equation 8}$$

Here, ω_p, ω_s, ω_i are the frequencies and $\vec{k}_p$, $\vec{k}_s$, $\vec{k}_i$ the wave vectors of the pump, signal and idler photon, respectively. Because of these

conditions, the measurement of one photon in a particular direction and energy, forces the existence of the other correlated photon pair of definite energy and direction. There are two types of SPDC – type I and type II. In type I, the down-converted photons are produced with the same polarisation, orthogonal to that of the pump. Photons of the same wavelength are emitted on concentric cones centred around the pump axis of propagation. The diameter of the cone depends on the angle between the pump beam and the optical axis of the crystal. Type II SPDC emits one photon with the same polarisation as the pump and the other with orthogonal polarisation. In both cases, the process is said to be degenerate if the down-converted photon pair has the same wavelength (i.e. $\lambda_s = \lambda_i = 2\lambda_p$) and non-degenerate otherwise.

Figure 2 shows our experimental set-up. A mode-locked ultraviolet pump source (fundamental Gaussian mode) with a wavelength of 355 nm and average power of 350 mW was used to pump a 3-mm thick type I barium borate (BBO) crystal to produce collinear, degenerate entangled photon pairs via SPDC. The laser produces pulses at 80 MHz; each pulse is made up of $\sim 10^9$ photons. The SPDC process produces on average 1 photon pair in every $\sim 10^5$ pulses, or 800 per second. This relates to an efficiency of $\sim 10^{-12}$. An interference filter was placed after the crystal to reflect the pump beam and transmit the 710-nm down-converted light.

Depending on the tilt of the crystal, one can transit between non-collinear and collinear down-converted light, as shown in Figure 3.

It has been shown[30] that positioning the crystal to produce near-collinear down-converted photons, potentially allows access to more OAM states. The front plane of the crystal was then imaged ($f_1 = 200$ mm, $f_2 = 400$ mm) onto two separate phase-only spatial light modulators (SLMs). Just as polarisers are used to 'select' a particular polarisation state, the SLMs allow a specific state to be chosen into which the photon will be projected. Initially, the LG basis set was chosen to measure the OAM states; however, any orthogonal basis set can be chosen, such as the BG basis[24]. The SLM planes were then re-imaged ($f_3 = 500$ mm, $f_4 = 2$ mm) and coupled into single-mode fibres (SMFs) (mode-field diameter = 4.6 μm) so as to extract only the Gaussian modal components. Interference filters centred at 710 nm were placed in front of each fibre coupler to prevent any scattered pump light from entering the fibres. Table 1 provides additional details of the equipment used in the experimental set-up.

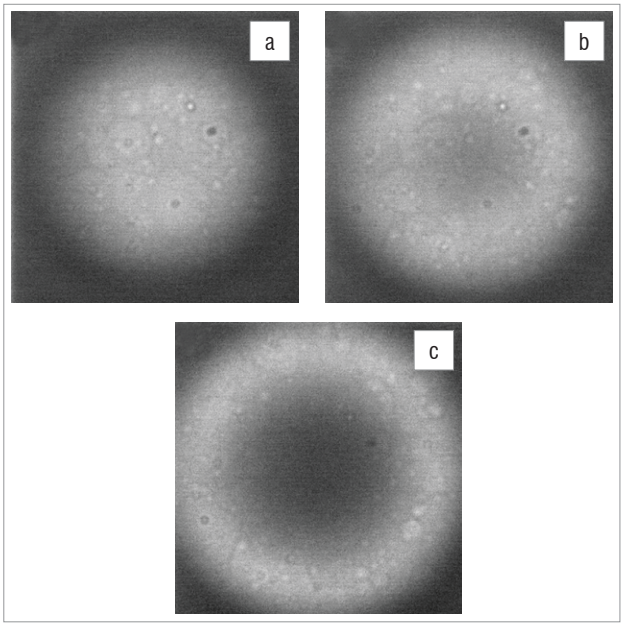
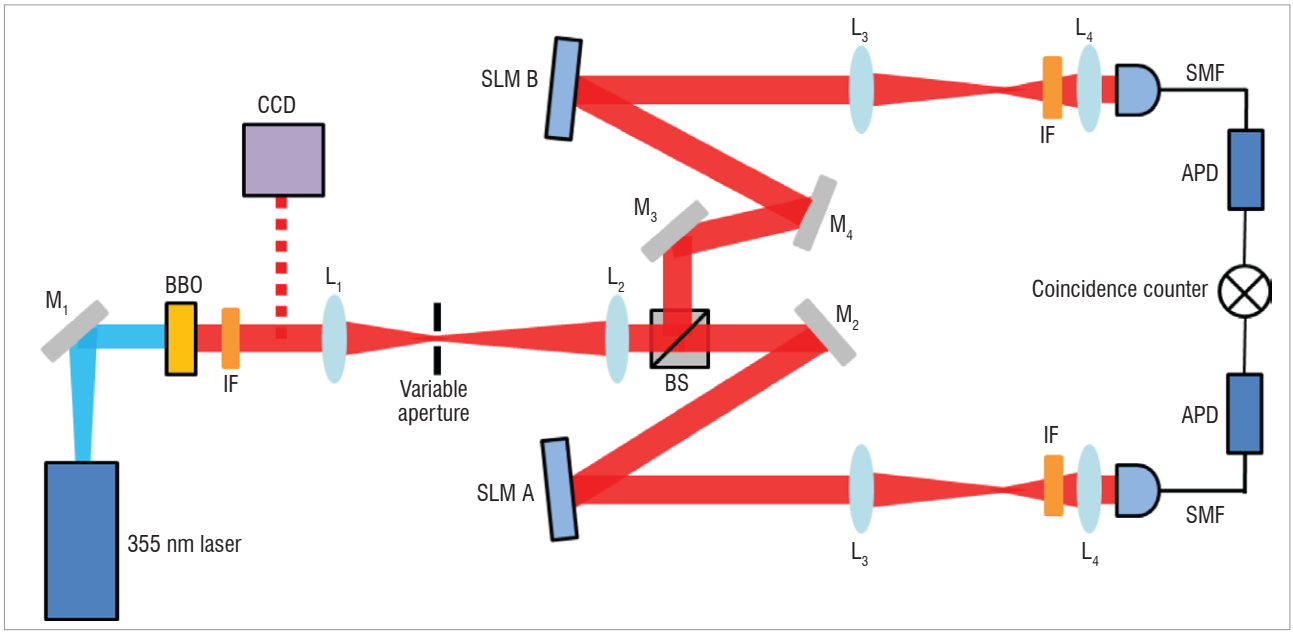


Figure 3: Spontaneous parametric down-conversion is the most efficient method for producing entangled photons; however, the probability of a spontaneous decay into a pair of entangled photons is very low (approximately 1 in every 10^{12} photons are down-converted). Therefore, a very sensitive electron multiplier charge-coupled device (CCD) camera is needed to image the ring of photons. (a) Far-field image of the collinear down-converted light from the barium borate (BBO) crystal. (b) Far-field image of the near-collinear down-converted light from the BBO crystal. (c) Far-field image of the non-collinear down-converted light from the BBO crystal. The change from non-collinear to collinear requires a very small change in tilt.



M, mirror; BBO, barium borate crystal; CCD, charge-coupled device; BS, beam splitter.

Figure 2: Experimental set-up used to detect the orbital angular momentum eigenstates after spontaneous parametric down-conversion. The plane of the crystal was relay imaged onto two separate spatial light modulators (SLMs) using lenses L_1 and L_2 ($f_1 = 200$ mm and $f_2 = 400$ mm), where the Laguerre–Gaussian modes were selected. Lenses L_3 and L_4 ($f_3 = 500$ mm and $f_4 = 2$ mm) were used to relay image the SLM planes through 10-nm bandwidth interference filters (IF) to the inputs of the single-mode fibres (SMFs). Each SMF was connected to an avalanche photodiode (APD) single photon detector, which in turn was connected to a coincidence counter.

Table 1: Specifications of the experimental equipment used to perform quantum entanglement

Equipment	Manufacturer	Specifications
Laser source	Newport	355 nm, 350 mW
Non-linear crystal	Castech	Barium borate, type I, degenerate
Spatial light modulator	HoloEye	Phase-only, near infrared, 1920x1080 pixels
Interference filter	Thorlabs	Central wavelength: 710±10 nm
Single-mode fibre	Thorlabs	630–680 nm
Avalanche photodiode	Perkin Elmer	Dark count ~ 200 counts
Coincidence counter	PicoQuant: HydraHarp400	8 channels

An SLM enables the phase of an incoming beam to be shaped according to the encoded hologram. That is, a Gaussian beam illuminating a phase-only forked hologram of particular azimuthal index, ℓ, produces a helically phased beam in the first diffraction order. This process also operates in reverse, such that a beam with OAM ℓ incident on a forked hologram with an azimuthal index $-\ell$, will produce a Gaussian beam as shown in Figure 4.

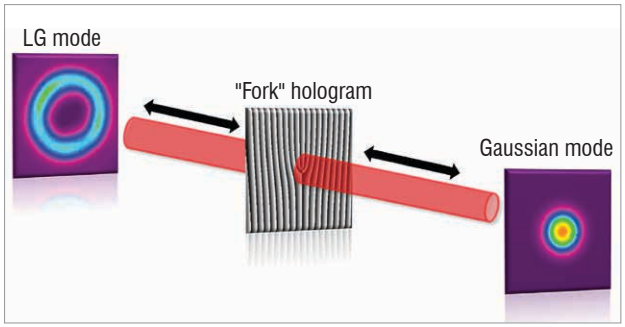


Figure 4: A spatial light modulator encoded with azimuthal phase dependence, $\exp(i\ell\phi)$, shapes a Gaussian beam into a helically phased beam in the first diffraction order. This process also works in reverse, such that an Laguerre–Gaussian (LG) beam can be converted into a Gaussian beam.

Only the fundamental mode (a Gaussian beam) can propagate through SMFs. The hologram on the SLM, together with the SMF, act as a 'match-filter'[31] such that an incoming beam with OAM ℓ will only couple into the SMF if the hologram is encoded with the same azimuthal phase index, ℓ.

The inefficient down-conversion process makes the optical system difficult to align. We therefore used a method of 'back projection' or 'retrodiction', first proposed by Klyshko[32], to align the system, by replacing the two detectors in Figure 2 with light from a 710-nm diode laser beam and passing it through each SMF so as to pass through the system in reverse. When the system is correctly aligned, the pump beam and both back-projected beams overlap at the plane of the crystal. Next, detector B was reconnected to the SMF and a 'pop-up' mirror was placed in the crystal plane. The back-projected light was then directed from fibre A to SLM A, which was imaged to the 'pop-up' mirror, reflected back to SLM B and coupled into detector B. By measuring the single count rate at detector B, the classical back-projection method provides a tool with which to predict the behaviour of the correlated down-converted photons in our entanglement set-up.[33] Back-projection also allows us to view the modes that we generate on the SLMs, which guarantees that we are indeed measuring in the correct basis. We placed a flip-up mirror between the BBO crystal and lens L_1 so as to reflect the back-projected light onto a charge-coupled device (CCD) camera (placed 200 mm from L_1). The alignment of the beam with the centre of the hologram is very important, because a misaligned beam results in an uneven intensity distribution. The measurements of OAM are sensitive to lateral position alignment, while the angular position measurements are sensitive to the axial positions of the image planes. Observing the back-projected beam on the CCD allowed us to ensure both SLMs were placed in the correct image plane. Both lenses – L_1 and L_2 – were placed upon micrometre translation stages to allow for small adjustments along the axis of propagation to find the correct image plane. The size of variable aperture between lenses L_1 and L_2 was decreased until a clear image of the 'slice' was seen.

Quantum measurements

Following the rigorous alignment procedure, a number of fundamental tests were then performed, the first of which was to demonstrate the conservation of OAM. Each SLM was encoded with holograms ranging in ℓ from -20 to 20, one after another. Figure 5 shows the measured coincidence counts known commonly as the spiral bandwidth.

The anti-correlated diagonal is consistent with OAM conservation, that is $\ell_p = \ell_s + \ell_i$, where the OAM of the pump, ℓ_p, must equal the sum of the generated signal, ℓ_s, and idler, ℓ_i, photons. While the coefficients in the OAM spectrum demonstrate a decreasing trend from $\ell = 0$, the size of the mode is another contributing factor as the mode size increases with the azimuthal index, which results in a loss in the detection efficiency, resulting in a decreasing trend from $\ell = 0$. Another important feature obtained from Figure 5f is the values of the off-diagonal elements. Theoretically, these should be zero, but experimentally, this is often impossible to achieve as the spiral bandwidth is highly sensitive to misalignment. We measured the off-diagonal elements to be less than 5% of their corresponding diagonal element. From Figure 5g, we measured the full-width-half-maximum (FWHM) value to be 15.

The spiral bandwidth experiment offers an effective method to test whether the set-up is correctly aligned. Similarly, the angular position (the conjugate variable to OAM) can be used to ensure the optics are positioned in the correct image planes. An angular sector hologram was encoded onto each SLM; one hologram fixed at a particular orientation while the other hologram rotated in small increments through 2π. In a ghost imaging experiment,[34] an aperture is placed in one arm and the detector in the other arm is scanned through its transverse position, resulting in the reconstruction of the aperture shape. Similarly, the width of the angular hologram was determined from the measured coincidence counts. A sharp coincidence peak was recorded when the holograms were both orientated at the same angle, see Figure 6, where the width of the peak gives the width of the angular 'slice'.

Einstein–Podolsky–Rosen paradox

The 1935 EPR thought experiment concluded that quantum mechanics was incomplete by highlighting the uncertainty principle of quantum mechanics, that is, the knowledge of one conjugate quantity precludes the knowledge of the other.[1] In this thought experiment, two assumptions were made – the first being that of locality. This theory implies that measurements made on a subsystem that is spatially separated from another subsystem cannot influence the results of the measurement on the other subsystem. The second assumption of realism stated that a physical quantity has a corresponding element of physical reality if

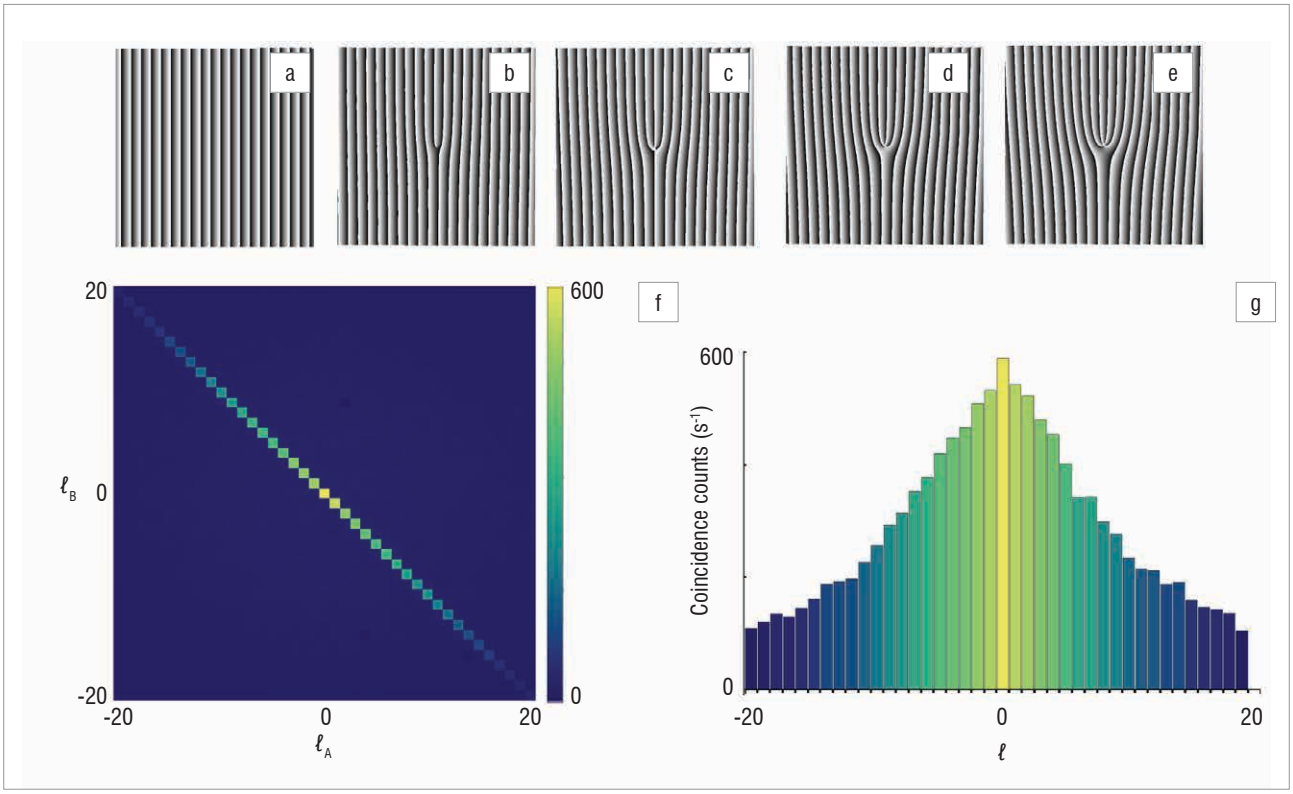


Figure 5: Experimental results of the measured spiral bandwidth. (a – e) Examples of holograms encoded onto each spatial light modulator. (f) Density plot of the measured coincidence counts per second. (g) Non-zero diagonal elements representing a spiral bandwidth plot with a full-width-half-maximum (FWHM) of approximately 15.

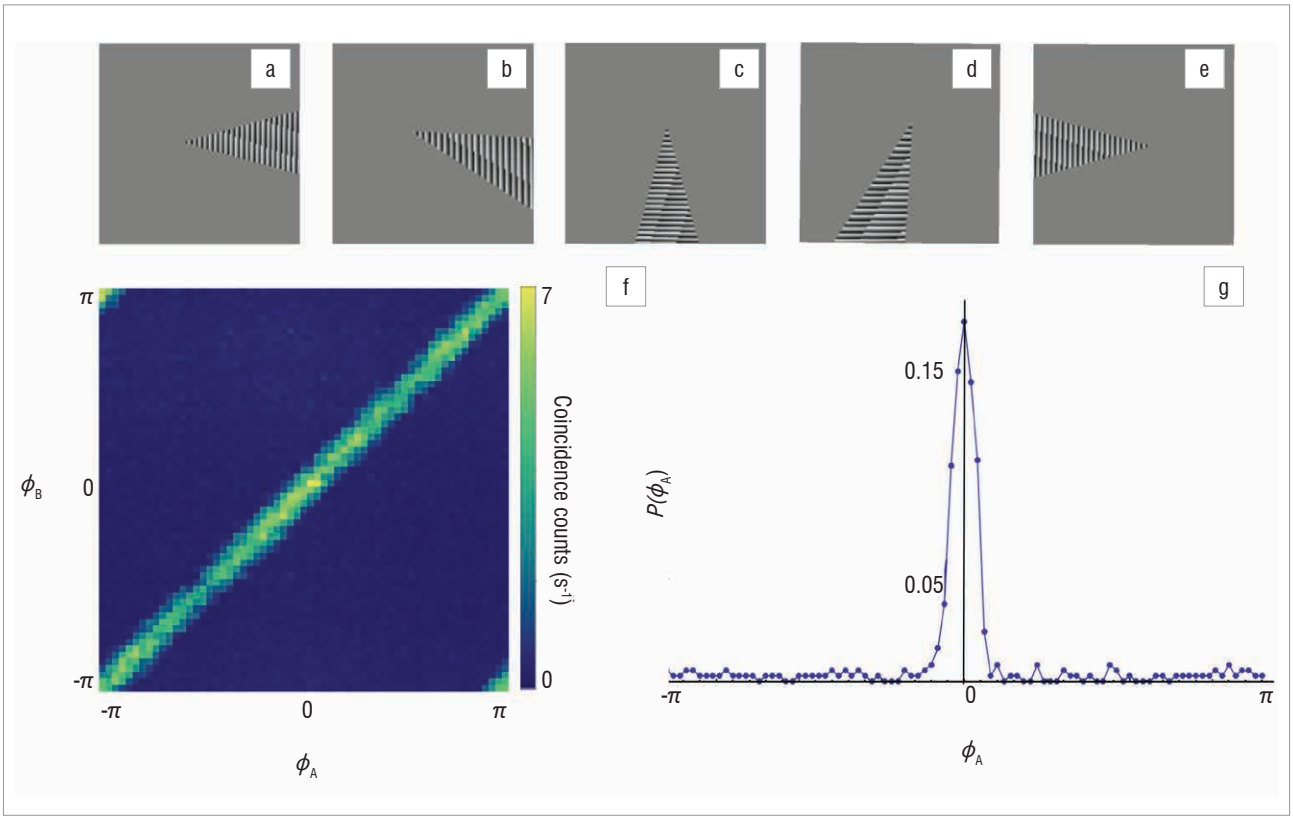


Figure 6: Experimental measurements of the angular position. (a–e) The holograms on each spatial light modulator were rotated through 2π, where the angular width of the 'slice' was set at $\Delta\phi=15°$. Experimental measurements showing (f) a density plot of the coincidence counts per second using the angular holograms and (g) a probability distribution of the angular position ϕ_A for $\phi_B=0$.

the value of that physical quantity can be predicted with certainty without disturbing the system. Howell et al.[35] demonstrated the EPR paradox for position and momentum by measuring the correlations of position and momentum on separate photons. That is, by measuring either the position (x) or momentum (p) of one of the photons, either the position or momentum of the other photon could be inferred with certainty. EPR argued, on the assumption that spatially separated particles do not interact, that the possibility of making such inferences meant that the position and the momentum of the unmeasured particle were simultaneous realities, in violation of Heisenberg's uncertainty relation, $(\Delta x)^2\ (\Delta p)^2 \geq \hbar^2/4$. This paradox can be extended to other conjugate variables such as angular position and OAM. The product of the uncertainty in OAM and in angular position is always larger than a minimum value, expressed as[36]:

$$[\Delta(\ell\hbar)]^2\ [\Delta\phi]^2 \geq \frac{\hbar^2}{4}. \qquad \text{Equation 9}$$

A violation of the inequality in Equation 9 satisfies the EPR–Reid criterion[37], which is analogous to the original EPR paradox, and thus demonstrates an incompatibility with local realism. These correlations demonstrate entanglement, not only for discrete variables such as OAM, but for continuous variables like angular position as well.

From the data recorded for both the spiral and angular bandwidths, we calculated the uncertainty relationship between the two. A profile from the centre of each spectrum was plotted and fitted with a Gaussian distribution (Figure 7), which gave the following widths: $[\Delta\ell]^2 = 0.128 \pm 0.023$ and $[\Delta\phi]^2 = 0.056 \pm 0.006$. Therefore, by taking the product of the two $[\Delta\ell]^2\ [\Delta\phi]^2 = 0.007 \pm 0.001$, the EPR–Reid criterion is satisfied as the product is clearly smaller than the uncertainty relation of 0.25 in Equation 9.

Bell inequalities

The EPR paradox does not eliminate the possibility of hidden variables. To do this, a violation of Bell's inequality must be shown. In 1964, Bell proposed a theorem in which a limit is placed on the correlations achievable by any local hidden-variable theory.[38,39] This theorem provided a means to test for local hidden variables. In a polarisation-based experiment, a polariser is rotated to vary from vertical to horizontal polarisation, allowing access to the superposition states. Similarly, holograms are used to access the superposition states of an OAM subspace and are subsequently rotated. The first demonstration of a violation of a Bell inequality in the OAM basis was shown by Leach et al.[40] in 2009. We follow their methodology in demonstrating a violation of Bell's inequality for our entangled system.

The holograms used to measure the superposition states are described by:

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|\ell\rangle + \exp(i\ell\,\theta)|-\ell\rangle\right). \qquad \text{Equation 10}$$

Here θ denotes the degree of rotation of the hologram around its centre in the plane of the SLM. By choosing a particular value for ℓ, we generated superposition holograms for a range of angles θ. The holograms were varied on both SLMs, by fixing one at orientation θ_A and rotating the other θ_B, and the coincidence count rates were measured. Bell showed that the sinusoidal behaviour seen in Figure 8 cannot be simulated by classical correlations and the deviation from classical theory can be calculated using Bell's inequality or a variation thereof derived by Clauser et al.[2]

The Bell parameter S can be defined as[40]:

$$S = E(\theta_A, \theta_B) - E(\theta_A, \theta'_B) + E(\theta'_A, \theta_B) + E(\theta'_A, \theta'_B). \qquad \text{Equation 11}$$

Where θ' is a different orientation from θ. $E(\theta_A, \theta_B)$ is calculated directly from the measured coincidence counts $C(\theta_A, \theta_B)$ at particular orientations. The inequality is violated when $|S|>2$. For the CHSH inequality, the upper limit for an entangled system is $|S|\leq 2\sqrt{2}$.

For $|\ell|=2$, we observed a violation of the inequality by 26 standard deviations, $S = 2.78 \pm 0.03$, indicating an entangled system.

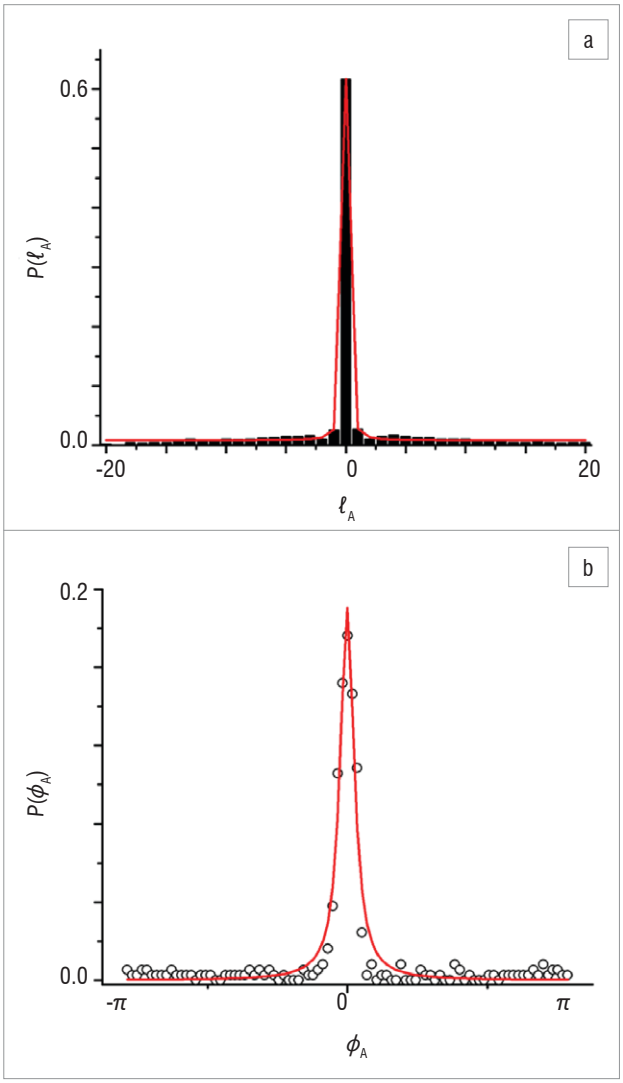


Figure 7: Probability distributions for (a) the orbital angular momentum ℓ_A for $\ell_B = 0$ and (b) the angular position ϕ_A for $\phi_B = 0$. A Gaussian distribution has been fitted to both to determine the widths of each plot, which were used to demonstrate the EPR–Reid criterion.

State tomography

Lastly, it is important to form a characterisation of the entangled states by measuring the degree of entanglement. This characterisation is attained by performing a state tomography[41] on the system. We chose to study OAM entanglement with the objective of measuring entanglement in higher dimensions. The density matrix, $\rho = |\psi\rangle\langle\psi|$, was reconstructed using two bits of information per photon, that is $|\ell\rangle = \pm 1$ and its superpositions. However, in high-dimensional entanglement we encode multiple bits of information per photon. For example, for dimension $d=3$, we could use $|\ell\rangle = 0, \pm 1$ and for dimension $d=5$, we could use $|\ell\rangle = -2, -1, 0, 1, 2$ (other combinations of OAM modes are also acceptable). We therefore reconstructed the density matrix for dimensions from $d=2$ to $d=5$. A detailed description on the tomography measurements can be found in Agnew et al.[42] The linear entropy,[43] S_L, defines the purity of the system, where the linear entropy of a pure entangled state is zero. The fidelity, F, is a measure of how close our reconstructed state is to the target state, which is the (pure) maximally entangled state with fidelity of 1. Figure 9 shows the measured values for both the fidelity and linear entropy.

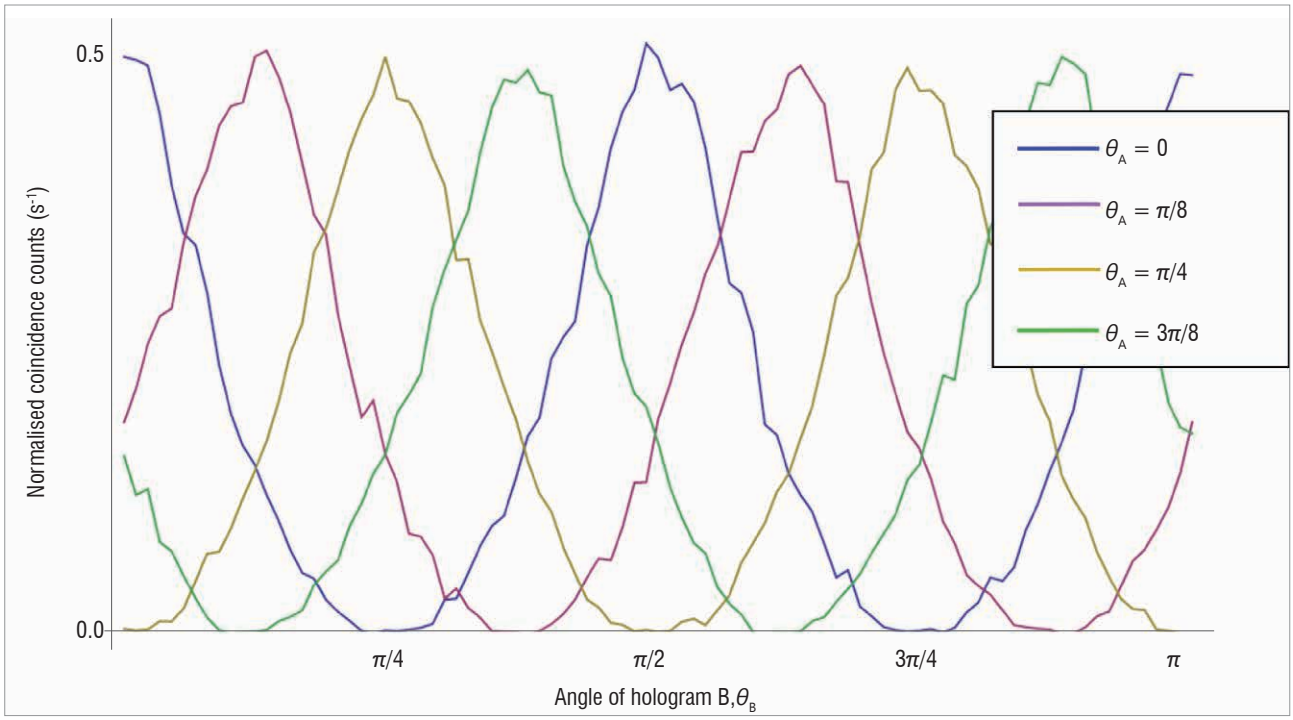


Figure 8: The normalised coincidence counts as a function of the orientation of the holograms on each spatial light modulator (SLM). The orientation of the hologram on SLM A was fixed while those on SLM B were rotated from 0 to π. The photons were projected into the $|\ell|=2$ subspace.

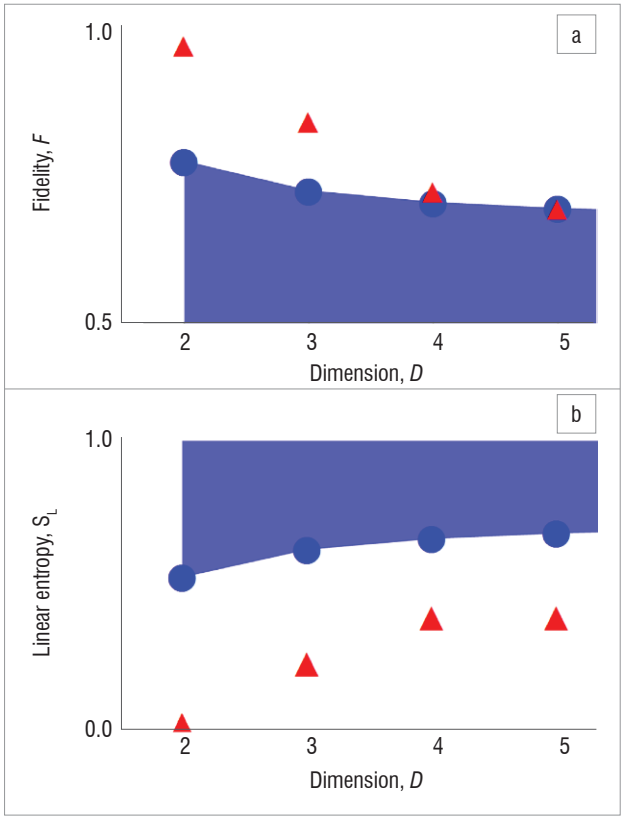


Figure 9: (a) Fidelity and (b) linear entropy as a function of dimension. The red triangles represent the experimental measurements, while the blue shaded area represents the states that will not violate the appropriate high-dimensional Bell inequality.

The results indicate that the degree of entanglement decreases as the dimensionality increases; however, the results do not fall below the threshold states, which lie on the threshold of the high-dimensional Bell inequality.[44] The generalised Bell inequalities test whether or not the observed correlations, which are predicted by quantum mechanics, can be explained by local hidden variable theories. The quantum state at the threshold of the high-dimensional Bell inequality can be denoted as[44]:

$$\rho_B = p_d^{\min} |\psi\rangle\langle\psi| + (1 - p_d^{\min}) \frac{I}{d^2}, \qquad \text{Equation 12}$$

where $p_d^{\min}$ is the probability above which the Bell inequality is violated, $|\psi\rangle$ is the maximally entangled state of two d-dimensional systems and I is the identity matrix of dimension d^2. A state with a linear entropy below that of ρ_B or a fidelity above that of ρ_B will violate the high-dimensional Bell inequality, and all of our measured states satisfy these conditions.

Discussion

We have introduced the techniques and equipment required to demonstrate quantum entanglement in the OAM basis. We have presented a set-up together with procedures to measure and quantify the entangled system (a more detailed description is presented in McLaren et al.[45]). We used SLMs encoded with specific 'forked' holograms together with SMFs to measure the OAM states of each photon and found that OAM is conserved in the down-conversion process. The alignment of single photons is made easier using the method of back-projection, such that classical light is passed through the set-up from one fibre to the other. By using the OAM basis we can choose to perform measurements of two-dimensional entangled states, or extend the set-up to higher dimensions by altering the phase holograms used in the measurement scheme.[42] We first satisfied the EPR–Reid criterion by measuring both the angular position and OAM correlations. This result confirms the idea that local realism is incorrect; a measurement made on one entangled particle does in fact affect the properties of the other particle. We then built upon this idea of non-locality by demonstrating a violation of Bell's inequality. This result clarifies that the coincidence measurements are quantum in nature as Bell's theorem shows that the predictions of quantum mechanics and local hidden variable theories are inconsistent. For example, we have shown a violation of a Bell-type inequality for dimension two within the OAM subspace $|\ell=2\rangle$. Any subspace could be chosen to demonstrate a violation of Bell's inequality – we simply

chose one in which we had a sufficient count rate. We then quantified our entangled states by showing high fidelity states up to dimension five, which equates to a Hilbert space of dimension 25 for a two-particle system ($D_{Hilbert} = (d_{particle})^{No.\ of\ particles} = 5^2$). It is possible to measure the fidelity of even higher dimensions; however, the number of measurements required to perform a full-state tomography increases significantly as the dimension increases, thus becoming highly time consuming. Nonetheless, the high fidelity results indicate that our quantum states up to dimension 5 are very close to being maximally entangled, while the low linear entropy values confirm that we have very pure high-dimensional quantum states. Our results are consistent with those found in the literature; that is, as we increase the dimensionality of our entangled state, both the fidelity and linear entropy are affected negatively, suggesting that there is an upper bound on the dimensionality in which we can measure. In order to access higher dimensions, we require access to higher-order OAM modes. Theoretically, these modes are attainable; however, there are many experimental elements which have a considerable effect on the number of accessible OAM modes. These include both the length[46] and orientation[30] of the non-linear crystal, as well as the mode sizes of the pump, signal and idler photons[47]. Alternative methods to increase the number of measurable OAM modes include altering the pump beam incident on the non-linear crystal from a Gaussian to a Hermite–Gaussian mode,[48] as well as changing the projective measurement basis from the LG to the BG basis. The latter technique not only demonstrated a wider OAM spectrum but also showed that entanglement lost as a result of an obstruction in the path, can be recovered but only if measured in the BG basis.[49] High-dimensional entanglement is a requirement for a number of quantum processes. One such application is quantum key distribution, which establishes a secure key between two parties, allowing secret messages to be encoded. By implementing high-dimensional entangled states, higher generation rates of the secure key bits, as well as increased information capacity, were demonstrated.[50]

Authors' contributions

All authors contributed equally to this manuscript.

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Understanding of the farmers' privilege concept by smallholder farmers in South Africa

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Legislation on plant breeders' rights – the *Plant Breeders' Rights Act, 1976 (Act No. 15 of 1976)* – currently is being reviewed by the Department of Agriculture, Forestry and Fisheries. This legislation provides for farmers' privilege, which is one of the exceptions to plant breeders' rights. It allows farmers to save seed of protected varieties for their own use. Farmers' privilege, and particularly its impact on smallholder farmers in developing countries, is a widely debated issue. During the public consultation process, several comments proposing amendments to the farmers' privilege provision were received from various stakeholders. However, no comments were received from the smallholder farmers who may be directly impacted by this provision. This pilot study was undertaken to assess the understanding of the farmers' privilege concept by smallholder farmers from the historically disadvantaged communities and their current practices with regard to seed saving. The results showed that the majority of the smallholder farmers were not aware of the existence of the legislation on plant breeders' rights and therefore do not understand the farmers' privilege concept and its implications. They also did not know whether the varieties they were using were protected by plant breeders' rights or not. Little information has been published on the impact of plant breeders' rights in South Africa in general. We hope that this study might inform policy decisions on matters related to plant breeders' rights and the farmers' privilege.

Introduction

The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) requires that all countries that are members of the World Trade Organization provide a minimum level of intellectual property protection in their national laws.[1] Botanical innovation resulting in the creation of new plant varieties is afforded legal protection through intellectual property rights (IPRs) – specifically, plant breeder's rights and patents.[2] Article 27(3)(b) of the TRIPS agreement provides that members shall provide for the protection of plant varieties either by patents or by an effective *sui generis* system ('of its own kind' meaning 'unique in its characteristics') or by any combination thereof. The major parameters of most common *sui generis* protection systems involve the so-called 'farmers' privilege'. The farmers' privilege provides the farmer with some exemptions to IPRs, ranging from the right to save seed for his or her own use to the right to exchange or sell seed, depending on the national law.[3]

Plant variety protection, also called 'a plant breeder's right', is an exclusive right, granted to the breeder of a new plant variety, to exploit their variety. It is a form of IPR; other examples of such rights are patents, copyrights, trademarks and industrial designs.[4] The plant breeders' rights model developed in The International Union of the Protection of New Varieties (UPOV) Convention has been seen as an acceptable *sui generis* system that fulfils the requirements of the TRIPS agreement in this field.[5] The mission of UPOV is to provide and promote an effective system of plant variety protection, with the aim of encouraging the development of new varieties of plants, for the benefit of society.[6] The UPOV Convention was adopted in Paris in 1961 and it was revised in 1972, 1978 and 1991.

The farmers' privilege describes the agricultural tradition of farmers saving part of their harvest for the seeding or propagation of the next crop.[7] There is no reference in the 1978 UPOV Convention to the right of farmers to re-sow seed harvested from protected varieties for their own use. The Convention establishes minimum standards such that the breeder's prior authorisation is required for at least three acts: the production for purposes of commercial marketing, the offering for sale and the marketing of the reproductive or vegetative propagating material, as such, of the variety. Thus, countries that are members of the 1978 Convention are free to either uphold farmers' privilege or eliminate it. All UPOV member countries implemented the exemption for 'private and non-commercial use' under the *UPOV Act of 1978* to include the re-sowing and, in some cases, the local exchange or sales of seed,[8] at least for some crops.

With the UPOV Convention of 1991, the provision on 'farmers' privilege' is an optional benefit-sharing mechanism provided by the UPOV Convention, under which UPOV members may permit farmers, on their own farms, to use part of their harvest of a protected variety for the planting of a further crop. Under this provision, members of UPOV are able to adopt solutions, which are specifically adapted to their agricultural circumstances. However, this provision is subject to reasonable limits and requires that the legitimate interests of the breeder are safeguarded to ensure there is a continued incentive for the development of new varieties of plants, for the benefit of society. For example, certain members of UPOV apply the provision on farm-saved seed only to certain species or limit its application using criteria such as the size of the farmer's holding or the level of production[9] or in such a way that only farmers with large farms have to pay royalties on the reuse of farm-saved seed.

South Africa has been a member of the UPOV Convention since 1977 and is bound by the 1978 UPOV Convention. Intellectual property protection for new plant varieties is afforded through the *Plant Breeders' Rights Act, 1976 (Act No.15 of 1976)* which is administered by the Department of Agriculture, Forestry and Fisheries (DAFF). DAFF is currently reviewing the *Plant Breeders' Rights Act* and one of the provisions that attracted interest from various stakeholders is the provision on farmers' privilege. This contribution investigates the understanding of the farmers'

privilege concept by smallholder farmers from previously disadvantaged communities as well as their current practices with regard to seed saving.

Farmers' privilege provision in South Africa

Farmers' privilege is provided for in Section 23 of the *Plant Breeders' Right Act, 1976*. This section stipulates that farmers' privilege is provided to

> *a farmer who on land occupied by him or her uses harvested material obtained on such land from that propagating material for purposes of propagation: Provided that harvested material obtained from replanted propagating material shall not be used for purposes of propagation by any other person other than that farmer.*

The provision excludes exchange of protected varieties among farmers. This section was inserted in the *Plant Breeders Rights Amendment Act, 1996* and is modelled around Article 15 of UPOV 1991.

A major reason that plant variety protection does not elicit greater investment in commercial seed production for open-pollinated varieties is the difficulty of limiting farmers' seed saving and exchange.[1] UPOV 1991 offers a solution to this problem, by prohibiting seed saving of the protected seed (except for specifically designated crops) and eliminating the possibility of seed exchange. However, for most farming systems in most developing countries, such restrictions would be politically explosive and impossible to enforce among farmers who are used to saving seed or obtaining it from their neighbours.

It is against this background that we decided that, as part of the reviewing process of the current legislation on plant breeders' rights, inputs should be solicited from various stakeholders, particularly on the farmers' privilege provision. Inputs were received from several stakeholders, including breeders, commodity groups, patent attorneys and commercial farmer representatives. However, no inputs were received from smallholder farmers. Smallholder farmers numbered approximately 225 000 as of 2010, belonging to about 150 000 households, and are predominantly black.[10]

Methodology

In the absence of inputs from the smallholder farmers, we decided that workshops be held for historically disadvantaged smallholder farmers or their representatives. Workshops for this pilot study were held in the Eastern Cape, the Free State, Limpopo and Western Cape Provinces. Participants for the workshops were mainly invited through the extension officers working for Provincial Departments of Agriculture, except for the Western Cape where the participants were organised by civil society organisations that work in the interests of smallholder and subsistence farmers.

During these workshops:

- A presentation on the plant breeders' rights system and farmers' privilege was given. Discussions on the practice of saving seed were conducted.
- Questionnaires with basic questions on the *Plant Breeders' Rights Act* and the farmers' practices on saving seed were distributed to all participants. Questions most relevant to this study are depicted in Appendix 1. The participants were assisted to complete the questionnaires by the extension officers who explained the questions in the participants' languages.

Results

Discussions on saving seed

During the discussions with the participants, it was evident that farmers' opinions differed with regard to the practice of saving seed. Some farmers were in favour of seed saving while others were against the practice. The following arguments were put forward:

For saving seed:

- Saving, sharing and exchange of seeds are ancient practices within communities and must be allowed in the legislation.
- Selling of protected seed by smallholder farmers should be allowed (for surplus seed).

Against saving seed:

- Saving of seed should not be allowed as it compromises the quality of seed.

Results from questionnaires

The number of participants

A total of 187 farmers/farmer representatives participated in this study, with 40% from the Free State Province, 26% from Limpopo Province, 23% from the Western Cape Province and 11% from the Eastern Cape Province.

Size of land under cultivation

The area under cultivation ranged between 1 ha and 5 ha, with the tenure ranging from communal to leased or self-owned land.

Familiarity with the *Plant Breeders' Rights Act*

The respondents differed in their familiarity with the *Plant Breeders' Rights Act* (Figure 1). Overall, and in all provinces except the Western Cape, most participants were not familiar with the Act.

Practice of saving seed

There were major differences in the percentage of respondents from different provinces who indicated that they do save seed compared with respondents who indicated that they do not save seed. These differences are shown in Figure 2.

Types of crops from which seed is saved

Respondents listed the following crops from which they saved seed: maize, sorghum, soya beans, wheat, potato, apricot, beans, beetroot, butternut, cabbage, carrot, chillies, green pepper, onion, peas, plum, pumpkin, spinach, strawberry, tomato and watermelon. We note that not only seed-propagated crops were listed, but that vegetatively propagated crops were also listed by some respondents.

Discussion and conclusions

It is estimated that African farmers depend on seeds cultivated within their communities for as much as 90% of their seed needs. According to IPR expert Andrew Mushita:

> *All resources belong to everyone and they are regulated by the community's cultural and local knowledge systems and practices. In this sense, farmers have exchanged seeds among themselves since time immemorial, passing from neighbour to neighbour, mother to daughter, mother-in-law to daughter-in-law, or even across villages and communities.*[11]

Farmer seed saving is one of the most contentious issues related to plant variety protection[4], is very sensitive and has political implications[12]. In both Europe and the USA, seed saving has become one of the most hotly disputed aspects of IPR in agriculture.[13] The issue of seed saving is a good example of how IPRs in plant breeding must be tailored to the conditions of national seed systems.[4]

In South Africa, little is recorded on the understanding of the impact on IPR, particularly plant breeders' rights on smallholder farmers mainly from historically disadvantaged groups.

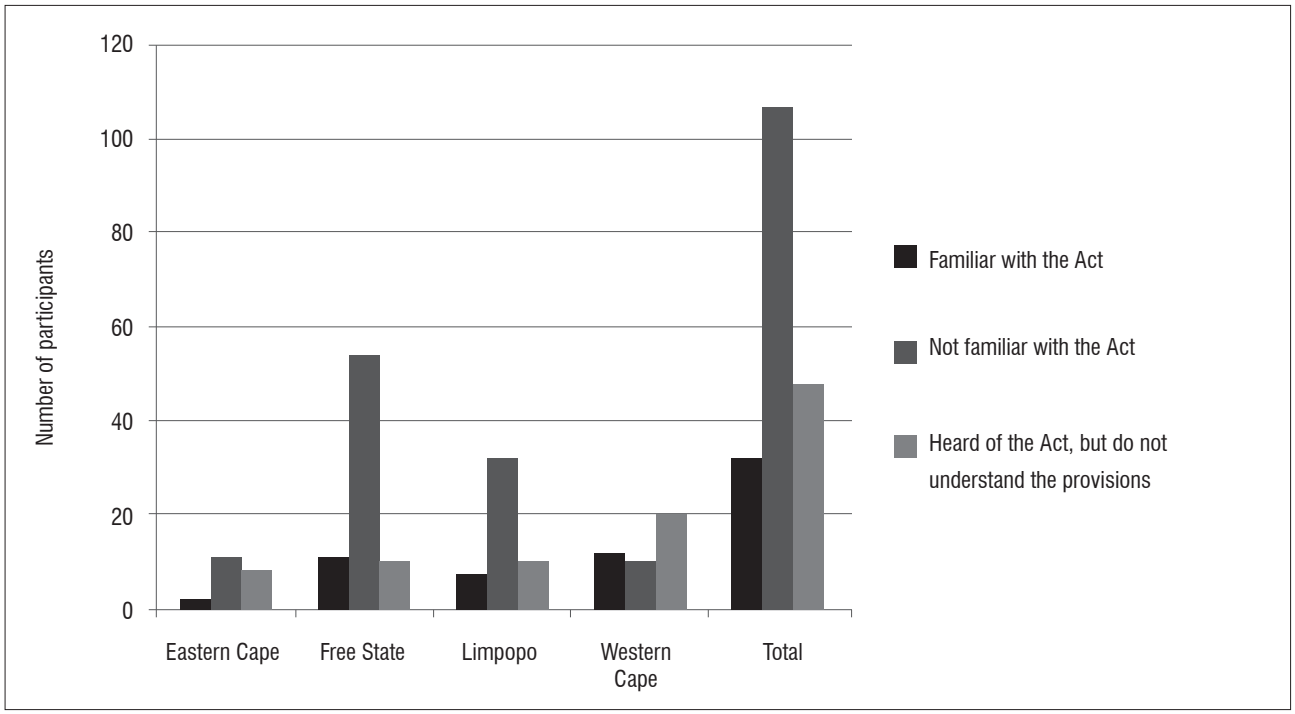

Figure 1: Familiarity with the *Plant Breeders' Rights Act* among participants from different provinces.

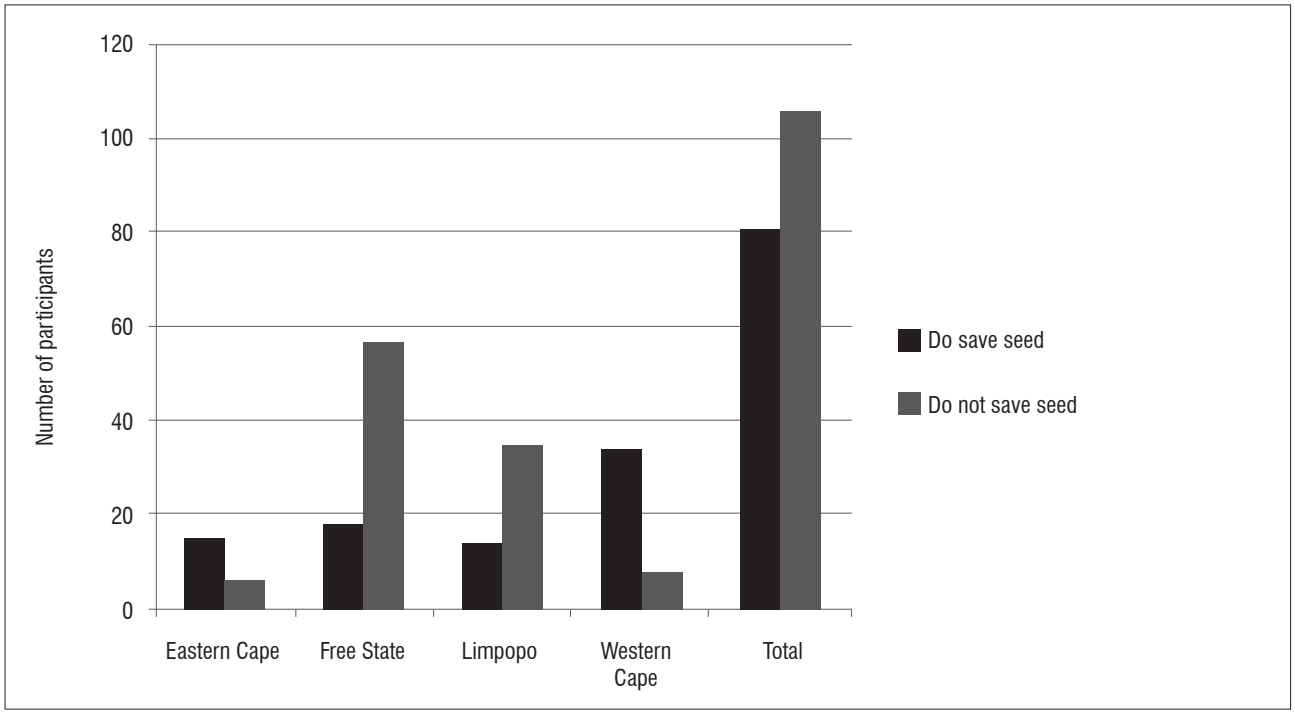

Figure 2: Practice of saving seed among participants from different provinces.

Of the total number of respondents, 57% indicated that they had never heard of the *Plant Breeders' Rights Act* before, 18% were familiar with the Act and 25% had heard of the Act but did not quite understand the provisions of the Act and how it impacted on them and their farming practices.

A majority of the respondents (57%) indicated that they do not save seed, citing two main reasons:

1. They were advised by the extension officers to not save seed but rather to buy seed annually to ensure a good yield as they mostly used hybrid seed.
2. From their own experiences, saved seed did not produce good quality product. They preferred to buy seed annually and practice crop rotation.

During the discussions it was discovered that this group of respondents mainly used hybrid seed and hence the practice of saving seed was not encouraged.

Nearly half (43%) of the respondents indicated that they do save seed. Respondents from Limpopo indicated that they save seed from both hybrids and open-pollinated varieties. They mostly use harvest from hybrid seed for feed in the following year. Respondents from the Eastern

Cape indicated that they mostly save seed from their traditional crops and not from the hybrids sold by the commercial companies. Respondents indicated that seed is mainly saved for their own use but that they do exchange and sometimes sell seed to neighbours when they have a surplus. The main crops from which seed is saved are maize, sorghum, soya beans and wheat. It is interesting to note that respondents from the Western Cape also listed vegetable crops such as cabbage, butternut, carrot and spinach, but not fruit crops such as apricot.

There are smallholder farmers from previously disadvantaged communities who still practice the tradition of saving seed, and, in some cases, do exchange and sell this seed to their neighbours. These farmers are, however, neither familiar with the legislation on plant breeders' rights nor aware of the farmers' privilege concept. They indicated, however, that the seed they save is from their traditional varieties, and that they were not aware of any varieties that were protected by plant breeders' rights.

We conclude from this survey that:

1. Awareness of the *Plant Breeders' Rights Act* and the farmers' privilege concept is very low among smallholder farmers.
2. Some of the smallholder farmers interviewed considered that a future Plant Breeders' Rights legislation in South Africa should create some freedom for smallholders to continue their traditional practice of saving and exchanging seed. Further study may be useful to identify whether such exemption could be consistent with the *UPOV Act of 1991*.

This pilot study may assist policymakers in understanding the importance of engaging the smallholder farmers in discussions pertaining to legislation that has an impact on them. The participants appreciated the effort made by DAFF to engage with them as it was the first time they were involved in such discussions. This study highlights the need for further studies to establish the extent of seed-saving practices, particularly those using protected varieties, among smallholder farmers. This study also highlights the importance of ongoing dialogue between policymakers and non-governmental organisations representing the interests of smallholder farmers.

The participants also indicated that they do their own selection of some crops but were not aware that they could develop varieties that can be protected in terms of the *Plant Breeders' Rights Act* – they were under the impression that these pieces of legislation are meant for big companies which use modern breeding techniques.

This pilot study will contribute in assisting DAFF in developing norms and standards that may ultimately inform regulations pertaining to the application of farmers' privilege in South Africa.

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Authors' contributions

N.C.N-N., J.B.J. and M.A.D. contributed to the conceptual development of the paper and facilitation of the workshops. N.C.N-N. analysed the data and led the writing. J.E. provided guidance and valuable comments on the first draft of the manuscript.

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Appendix 1: Questionnaire distributed to participants

1. FARM DETAILS:

   1.1 Farm name: .....

   1.2 Province: .....

   1.3 District municipality: .....

   1.4 Local municipality: .....

   1.5 Village/town: .....

   1.6 No. of hectares: .....

2. *PLANT BREEDERS' RIGHTS ACT, 1976 (ACT NO. 15 OF 1976)*:

   2.1 Are you familiar with the *Plant Breeders' Rights Act* which aims to protect the rights of breeders of new plant varieties? (Please tick the most appropriate)

   Yes ☐

   No ☐

   Heard of it, but I do not understand it ☐

3. FARM-SAVED SEED

   3.1 Do you save seed from your harvest to use the following year?

   Yes ☐

   No ☐

   3.2 If yes, please complete the table below:

Crop type (maize, wheat, etc.) and variety names (if known)	No. of hectares under cultivation	Do you save seed of varieties protected by plant breeders' rights? [yes (Y), no (N), do not know (D)]

   3.4 Why do you save seed? (Please tick the most appropriate)

Reason	**Most important**	**Important**	**Least important**
i) To save money			
ii) To sell to other farmers			
iii) To exchange with other farmers			
iv) For own use (in my own farm)			
v) To use in creating improved varieties (e.g. selection)			
vi) To take it to cooperatives for further processing (e.g. milling)			
vii) Other: please specify ……..			

Development of pesticide use maps for South Africa

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Over 3000 pesticides are registered for use in South Africa. Many studies have highlighted the movement of pesticides to agricultural crops from the point of application into non-target environments, particularly surface and groundwater resources. Exposure to pesticides can lead to serious human health and environmental effects. It is therefore important to identify critical areas where specific pesticides may result in a high risk of exposure to humans or the environment. Crop specific pesticide use data were obtained from a market research company and integrated into a geographical information system detailing the distribution of agricultural crops in South Africa as determined by an agricultural census performed in 2002. By estimating the total application of a specific pesticide to all crops produced in a magisterial district, it was possible to generate maps which provide an estimate of the application rate of over 200 pesticides per magisterial district. These maps were intersected with an agricultural land-cover map to provide a refined map giving details of the spatial distribution of pesticide use across the country. These maps are the first of their kind in South Africa and provide a spatial overview of the likely distribution of specific active ingredients based on the distribution of crops throughout the country. While there are a number of limitations and uncertainties associated with the data used to produce these maps, these are not unique to South Africa, and similar methodologies have been applied in more developed countries.

Introduction

According to the South African Department of Agriculture, Forestry and Fisheries (DAFF) there are in excess of 3000 pesticide products approved for use in South Africa.[1] Pesticides are important to crop management because they contribute to increased crop yields and improve the quality of crops. However, pesticides tend to move from the point of application into non-target environments, which can result in serious acute and chronic human health and environmental effects. A number of studies, located throughout the country, have detected a variety of current-use pesticides in surface and groundwater.[2-5] In South Africa, studies have linked pesticide exposure to acute poisoning[6], acetylcholine esterase inhibition[7], possible occurrence of Guillain–Barré syndrome in a rural farming community[8], birth defects[9] and endocrine disruption[10,11] in human communities. Additionally, studies performed in South Africa have linked pesticide contamination with toxic effects in aquatic and terrestrial ecosystems.[12-14] These effects are concerning from an environmental and human health point of view, particularly in the latter case, considering that many communities in South Africa use groundwater for drinking purposes or do not have access to, or reliable access to, treated water and often drink untreated water.

The risk a pesticide poses to human health or the environment is dependent on a number of factors, including the quantity of the pesticide applied, the toxic mode of action and the physico-chemical properties of the pesticide, such as half-life and solubility (which influence their mobility and thus the potential to move from the point of application into non-target environments).[15-17] These factors vary considerably among pesticides. However, considering the number of different pesticides used in agriculture, it is important to identify and prioritise those most likely to be of human health and environmental concern. Yet, despite the risks posed by pesticides, to date, freely available public information on the quantities used in South Africa is unavailable and is generally the factor that limits our ability to prioritise, manage and predict environmental health risks posed by pesticides. As a result thereof, there are a limited number of studies that have prioritised pesticide risks to human and environmental health in South Africa. Dabrowski and Balderacchi[18] prioritised pesticides in terms of their mobility and risk to the aquatic ecosystem in the Lourens River catchment, Western Cape. Their study relied on pesticide use data provided directly by farmers in the catchment. In larger, national-scale studies, pesticide sales data are often used as a proxy for pesticide use data. In South Africa, Dalvie et al.[19] published information on national pesticide use for the years 1994 and 1999 which was used to prioritise acute health risks of pesticides. A more recent study has been published in which the relative human health risks of pesticides used in South Africa were prioritised based on factors such as quantity of usage, evidence of toxic effects (e.g. carcinogenicity, neurotoxicity, mutagenicity, teratogenicity and endocrine disruption) and their mobility in the environment.[20]

Prioritisation studies are an important initial step with respect to identifying those pesticides most likely to pose the greatest risk to human and environmental health. This step is particularly useful in a country where resources and expertise for pesticide monitoring are limited. The next step is to identify where these priority pesticides are applied. This identification is vital in terms of designing monitoring programmes and identifying hotspot areas (e.g. where access to treated water is limited or ecologically sensitive areas) for more detailed risk assessment studies. While the estimate of pesticides applied only provides an idea of where pesticides might be washed off into the environment, few practical alternatives for risk assessment exist. Measuring pesticides in water and sediments is possible but requires advanced analytical instruments, specialised personnel and sample collection in remote areas in different seasons and flow regimes. Furthermore, spatially explicit pesticide use information is essential for the development of environmental fate and transport models that relate pesticide use to concentrations in surface and groundwater.[21] The aim of this study was to present a methodology that provides a spatial assessment of the use and likely sources of pesticides across the country through the development of pesticide use maps. This study

forms part of a larger integrated project examining the risks to human and animal health of current agricultural pesticide use.[22]

Methods

Crop distribution

Knowledge on the spatial distribution of pesticide use is dependent on the spatial distribution of the crops to which they are applied. The Census of Agriculture Provincial Statistics performed by Statistics South Africa (Stats SA) in 2002[23] was used to estimate the spatial distribution of crop production in South Africa. The census collected data on crop area (ha) and production (tonnes) for commercial crops at a magisterial district level, which was used to estimate the percentage agricultural area covered by a specific crop type within a magisterial district. Each magisterial district falls within one of South Africa's nine provinces and summarised data of percentage crop area per province have been included as supplementary material online (Supplementary table 1). These data have allowed for the production of maps that provide a spatial overview of important production areas for specific crops (Figure 1). For the purposes of this study, the magisterial district boundaries as demarcated in 2002 were used for the spatial mapping of crop coverage and pesticide use. The census provides data only for farmers that responded. Consequently, the census underestimates total area and production at a magisterial district and national level, but does provide as accurate an estimate of the relative distribution of crop coverage and production as is possible at this level of spatial detail. The census data were therefore normalised to take this underestimation into account, as well as to account for changes in area and production over time, so as to provide an estimate of total crop coverage per magisterial district in 2009. The normalisation procedure compared total crop coverage estimated by the 2002 Stats SA census data (i.e. the sum of the area of each crop type for all nine provinces) with total crop area statistics collected by DAFF[24] and the Food and Agriculture Organization of the United Nations (FAO)[25] for 2009. DAFF only publishes crop area for a limited number of crops, whereas the FAO publishes data for a larger number of crop types. Therefore DAFF data were compared to FAO data to determine whether the two sources of data corresponded. As can be seen from Table 1, the DAFF data were almost identical to those published by the FAO and so the FAO data set, with a greater crop representation, was considered reliable for the data normalisation procedure. The crop normalisation quotient was calculated as the ratio of FAO to Stats SA crop coverage. The crop coverage reported by Stats SA for each magisterial district in South Africa was multiplied by the respective crop normalisation quotient to derive a normalised crop coverage for each crop type in each magisterial district. The normalised area of each crop in each magisterial district was expressed as a percentage of the national crop area for the crop.

National pesticide use data

Pesticide use data for South Africa were obtained from the Sigma™ program, a proprietary database maintained by the market research company GfK Kynetec (this database is now referred to as the AgroTrak™ database). The company provides quantified data on the use of agricultural active ingredients (collected from, amongst other sources, agrochemical manufacturers, distributors, trade associations and importers) on a country-by-country and crop-by-crop basis. Data purchased from GfK Kynetec were for the year 2009 and were the latest data available at the time of the study. These data were used to prioritise pesticides at a national level for South Africa.[20] The US Geological Survey has sufficient confidence in the data provided by GfK Kynetec to use the data for estimating pesticide use in the USA as part of their National Water Quality Assessment Programme.[26]

Pesticide use per magisterial district

The amount of each pesticide applied to a crop was expressed as a percentage of the total national application. For example, approximately

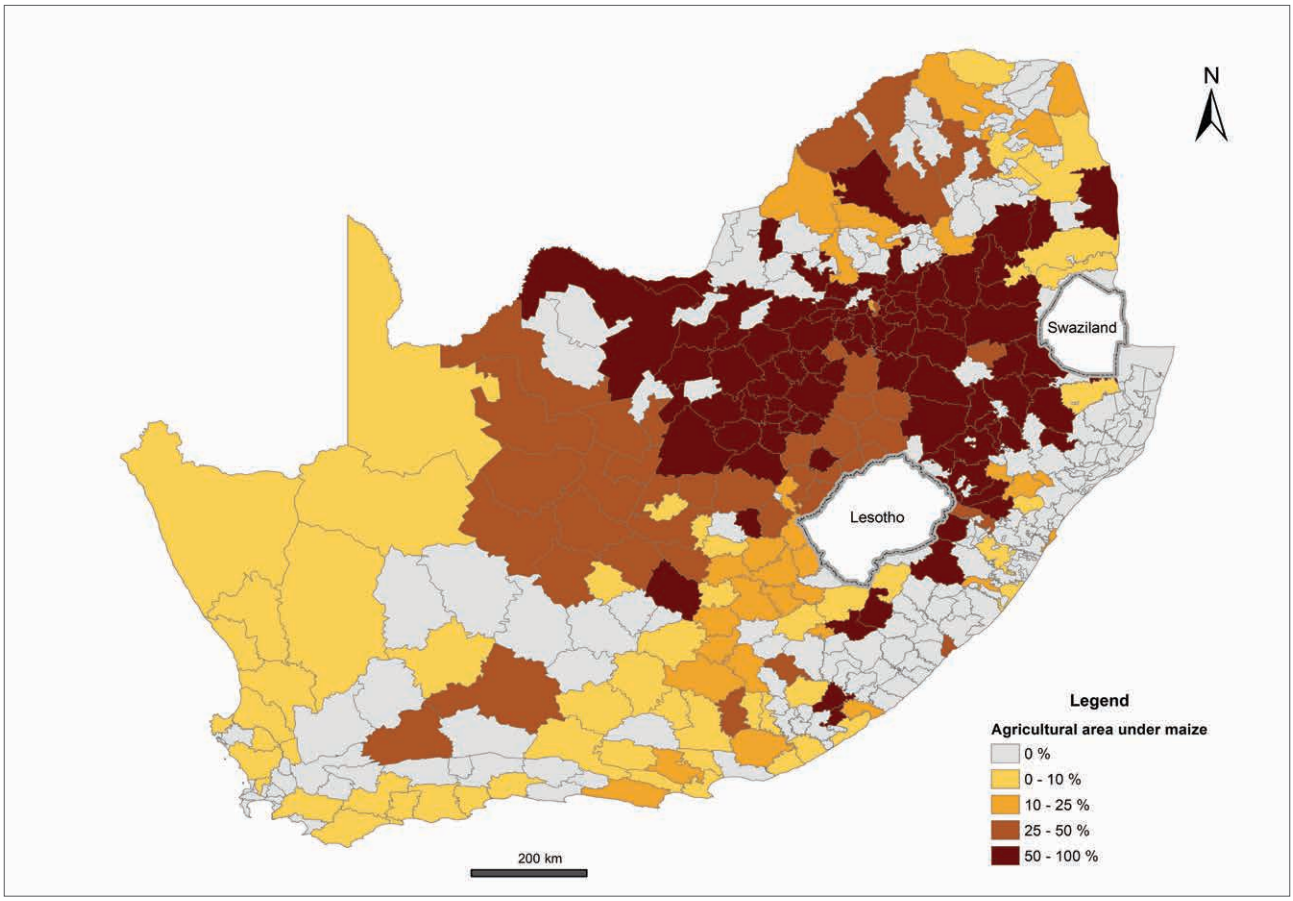

Figure 1: Proportion of national agricultural area under maize per magisterial district in South Africa.

Table 1: National crop area statistics reported by Stats SA[23], the Food and Agriculture Organization of the United Nations (FAO)[25] and the Department of Agriculture, Forestry and Fisheries (DAFF)[24] for the year 2009. The ratio of FAO to Stats SA statistics was used to normalise crop area data for each magisterial district in South Africa.

Crop	Area (ha)			Ratio
	Stats SA	FAO	DAFF	FAO/Stats SA
Maize	184 1887	2 427 500	2 896 000	1.32
Wheat	591 008	642 500	648 000	1.09
Sunflowers	298 548	635 800	636 000	2.13
Sugar cane	224 167	391 000	391 000	1.74
Lucerne	128 640	128 640		1.00
Grapes (wine)	65 592	89 448		1.36
Citrus	64 596	69 480		1.08
Soybeans	58 991	237 750	238 000	4.03
Sorghum	56 487	85 500	86 000	1.51
Groundnuts	53 152	54 550	53 000	1.03
Barley	45 433	74 760	75 000	1.65
Potatoes	41 667	55 000		1.32
Dry beans	35 782	43 800	44 000	1.22
Cotton	22 099	11 500	7000	0.52
Grapes (table)	18 737	25 551		1.36
Apples	16 685	21 000		1.26
Bananas	15 904	7500		0.47
Peaches	11 149	10 000		0.90
Pears	9694	10 500		1.08
Avocadoes	9264	14 500		1.57
Mangoes	8708	3500		0.40
Tomatoes	7938	7700		0.97
Pumpkins	7776	7776		1.00
Pineapples	6352	11 500		1.81
Onions	6082	20 500		3.37
Cabbages	5583	2400		0.43
Carrots	3671	5300		1.44
Green beans	3559	4000		1.12
Plums	2996	6500		2.17
Sweet potatoes	963	21 000		21.81
Green peas	612	5500		8.99

88% of the total national use of atrazine is for maize (Table 2). These percentages were used to estimate the percentage of the total amount of each pesticide applied to each crop in each magisterial district *(P%)*:

$$P\%_{x,y,z} = \frac{Area_{y,z}}{100} \times CApp_x \qquad \text{Equation 1}$$

where *Area* is the proportion of crop type *(y)* in a magisterial district *(z)* expressed as a percentage of the total national coverage of the crop and *CApp* is the proportion of the pesticide *(x)* applied to the crop, expressed as a percentage of the total application of the pesticide. The assumption in this equation is that a specific pesticide was applied equally (or at an identical application rate) to a specific crop regardless of the magisterial district in which the crop was produced.

The total estimated quantity (*Pq*, in kg) of each applied pesticide *(x)* to each crop type *(y)* in each magisterial district *(z)* was calculated as follows:

$$Pq_{x,y,z} = \frac{P\%_{x,y,z}}{100} \times TApp_x \qquad \text{Equation 2}$$

where *TApp* is the total quantity of pesticide *x* applied to all crops in the country. From these data it was possible to estimate the total quantity

(*Ptot*, in kg) of pesticide *(x)* applied within a magisterial district *(z)* regardless of crop type *(y)*:

$$Ptot_{x,z} = \sum_{y=1}^{n} Pq_{x,y} \qquad \text{Equation 3}$$

Table 2: Example of a summary of the application of atrazine to crops produced in South Africa for the year 2009

Crop	Total application (kg)	Application (% of national use)
Maize	890 981	87.83
Sorghum	43 015	4.24
Sugar cane	75 924	7.48
Other	4500	0.44
Total	1 014 420	100

Summarised estimates of total pesticide application per province are available as supplementary material online (Supplementary table 2). In order to estimate the application rate of a pesticide per magisterial district it was first necessary to calculate the total area (*Atot*) of all crop types *(y)* within each magisterial district *(z)*:

$$Atot_z = \sum_{y=1}^{n} Area_{y,z} \qquad \text{Equation 4}$$

The pesticide application rate (*Pr*, in kg/ha) of each pesticide *(x)* in each magisterial district *(z)* was estimated by:

$$Pr_{x,z} = \frac{Ptot_{x,z}}{Atot_z} \qquad \text{Equation 5}$$

Map displays of pesticide use data

Estimation of the application rate of different pesticides within all magisterial districts in the country enabled the production of maps displaying the estimated distribution of applied pesticides as well as their estimated application rate. The derived pesticide use database, containing estimated pesticide application rates of 217 pesticides per magisterial district, was imported into ArcGIS (Esri) as a table and joined to corresponding magisterial districts in a shapefile demarcating their location as they appeared in 2002.[27] This process produced a shapefile containing information on the estimated application of pesticides per unit area of all agricultural land per magisterial district and allowed for the production of maps providing a spatial estimation of pesticide use per magisterial district across the country (Figure 2).

Each map displays, in six intervals, the amount of active ingredient applied over a magisterial district. The first interval depicts areas where no application (No Estimated Use) is expected to occur. The other five class

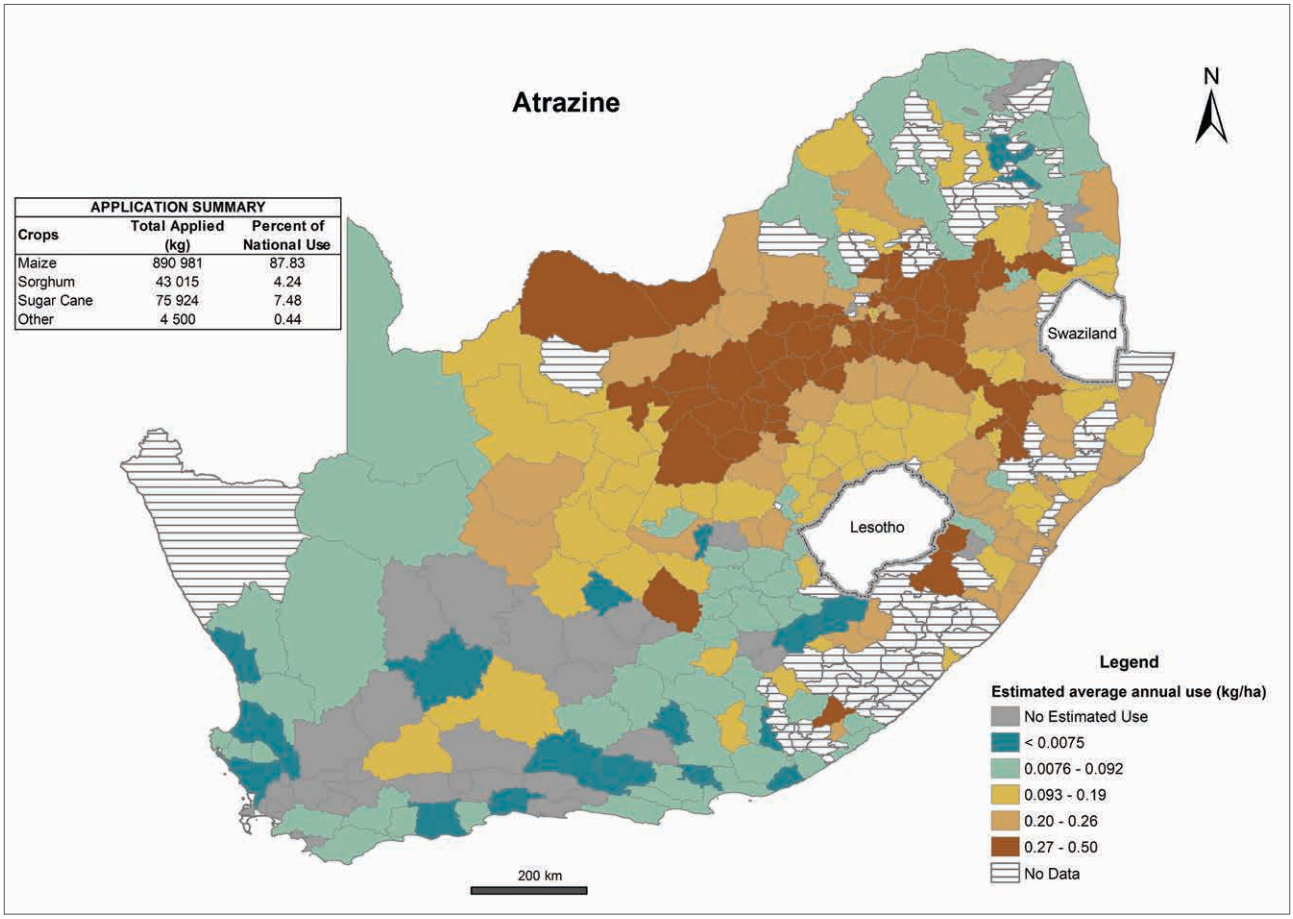

Figure 2: An example of a map showing the average annual use of atrazine per hectare of agricultural land in magisterial districts of South Africa for the year 2009, estimated from pesticide sales and agricultural crop census data.

intervals were established independently for each of the compounds for which the magisterial districts had an associated pesticide application data point (greater than zero kilograms applied per hectare). Each of the five class intervals represents an equal number of data values from the distribution of the pesticide data, with upper boundaries representing the 20th, 40th, 60th, 80th and 100th percentiles, respectively. The Stats SA census did not provide agricultural statistics for some magisterial districts, particularly those that fall within the former homeland areas, so no pesticide use estimates could be calculated for these areas. For these areas, data were displayed as 'No Data' instead of displaying data as 'No Estimated Use'. As part of each map, a table lists, in order of use, the crop treated with the compound, the total amount (in kilograms) of the active ingredient applied to the crop, and the percentage of national use. Because the percentages are rounded, they do not always total 100%.

Display of the pesticide use information was improved by using additional data. The spatial distribution of agricultural land cover was extracted from the 2009 national land cover map.[28] Using ArcGIS, the agricultural land cover was intersected with the shapefile displaying pesticide use per magisterial district so as to create an improved graphical display of the distribution of agricultural land within each magisterial district (Figure 3). These maps provide a more refined estimate of where in each magisterial district pesticides are most likely to be applied. The boundaries depicting 2004 water management areas and coverage of major rivers in South Africa were also added.[29] The class intervals in Figure 2 are based on magisterial districts while those in Figure 3 are based on the number of agricultural land-cover polygons.

Application of maps

These pesticide maps are the first of their kind for South Africa and provide a spatial overview of the likely distribution of specific active ingredients based on their application to crops and the distribution of those crops throughout the country. While a number of geographical and physico-chemical factors influence the movement of pesticides into surface waters, the quantity and rate of application of pesticides used (and by implication the relative application rate) in an area is the most important indicator of the potential for contamination of non-target environments.[30] In this respect, the maps provide important information, not only in terms of estimated application rates, but also in terms of identifying where in the country specific pesticides are most likely being applied. Integrating these data together with geographical data of slope, soil and climate in a GIS platform can significantly improve our ability to identify ground- and surface water resources at risk of pesticide exposure through leaching and run-off. Considering the large number of active ingredients used in South Africa, as well as the expense of monitoring these chemicals, the use of these maps in combination with existing information on the relative risks of pesticides to human health and the aquatic ecosystem[18-20] provide guidance on which pesticides should be monitored and where they should be monitored. By combining the maps with information on community access to water, we can identify those communities that may be at risk of pesticide exposure through use of river or groundwater for drinking purposes. Additionally, use of the Blue Drop Report on Drinking Water Quality Performance Management[31] could potentially be used to flag communities at risk of exposure through poor drinking water quality management. A similar approach could be adopted with respect to identifying potential pesticide risks to sensitive aquatic environments. For example, use of pesticide maps produced in this study in combination with maps of Freshwater Ecosystem Priority Areas[32] could identify hotspot areas where specific pesticides may pose a risk to aquatic ecosystems with a high conservation status.

Constraints of spatial analysis

The pesticide maps are intended to provide a qualitative distribution of the likelihood of pesticide use in South Africa, directing more costly

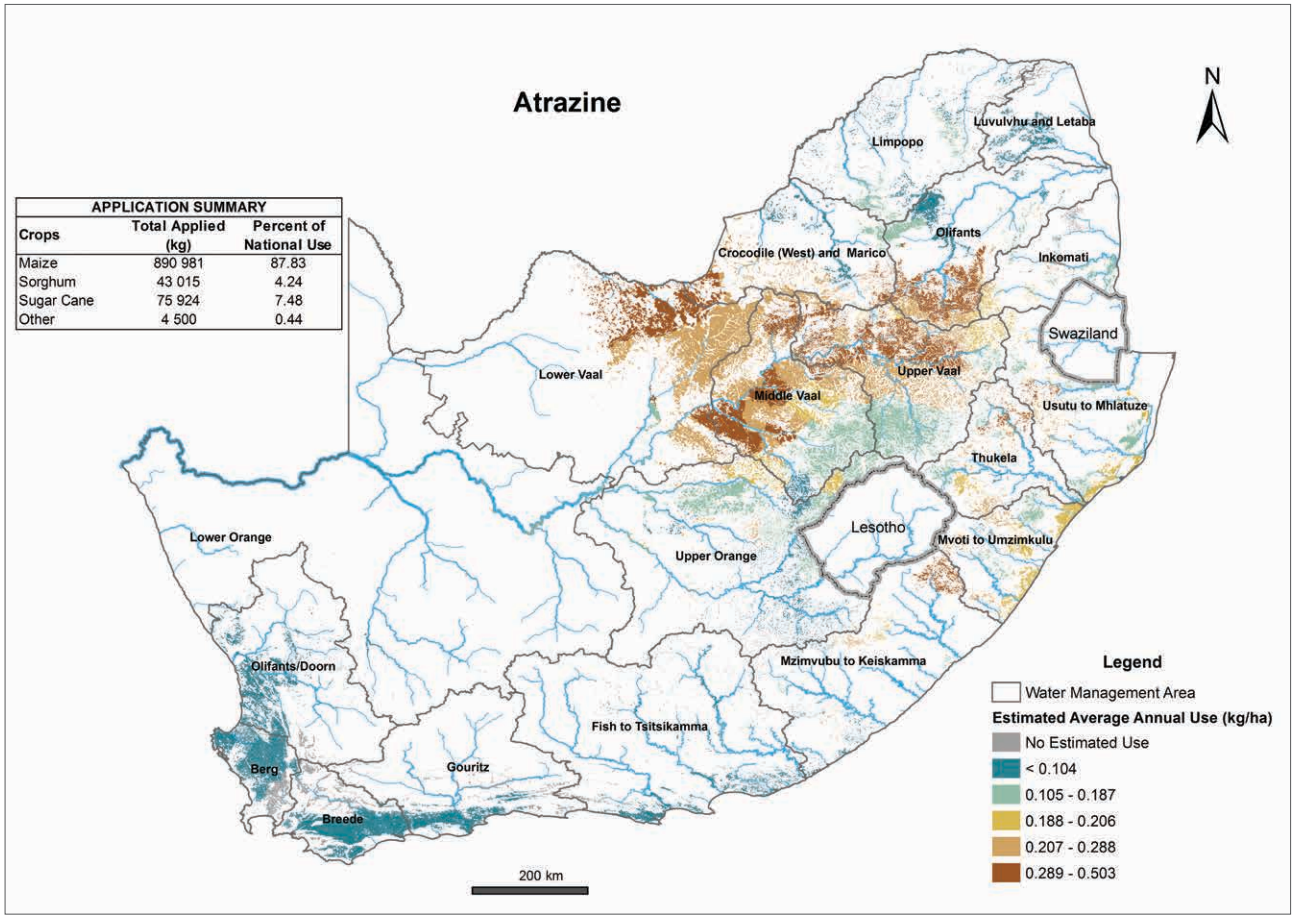

Figure 3: An example of a map showing the average annual use of atrazine per hectare of agricultural land in South Africa for the year 2009, estimated from pesticide sales, agricultural crop census and land-cover data.

quantitative monitoring efforts to those regions where they will be most cost effective. Known uncertainties exist in the agricultural census and pesticide usage data, as discussed in more detail here.

Agricultural census data

The distribution of crops across the country formed a critical component of the final pesticide use estimation. These data were obtained from the Stats SA census performed in 2002. While the data provide a good estimate of the relative distribution of crops across magisterial districts in 2002, agricultural patterns may have changed since then and current pesticide use patterns may also have changed as a result. Additionally, as described in the normalisation procedure, not all farmers within a magisterial district may have responded to the census. As a result, total crop area estimates were underestimated in comparison to national estimates and data had to be normalised accordingly. This normalisation procedure applied a normalisation factor to each crop type equally across all magisterial districts and therefore increased the crop production area by an equal proportion across all magisterial districts. This procedure may have built inaccuracies into the estimates as the ratio of Stats SA estimates to FAO statistics may vary from one magisterial district to another.

The agricultural census did not collect crop production statistics from magisterial districts in former homeland areas. This omission is most likely because agriculture in these areas is largely restricted to subsistence agriculture and therefore is not important for the country's national food production. However, this does not mean that pesticides are not being applied in these areas. Given the subsistence nature of crop production and the relative expense of plant protection products, it is assumed that pesticide application in these areas is relatively low.

Pesticide use data

Currently there is no publicly accessible source of information on pesticide use in South Africa. Market-related sales data thus provide the best available indication of pesticide usage in the country. A major limitation of the data is that the use of different pesticides is aggregated and quantified at a national level. The data therefore do not necessarily reflect an accurate assessment of actual use or regional differences in the use of a chemical as a result of variations in climate (and associated pest problems) or farm-management practices. Furthermore, farmers may stock up on specific agro-chemical products in anticipation of forecasted weather events or pest outbreaks. These may not materialise and the product may therefore not actually be used. There is thus a large amount of uncertainty related to the use of these data and results or outputs should be interpreted accordingly. However, this type of surrogate data is often all that is available, even in more developed countries such as the USA and member states of the European Union.[33-35]

Methodology

The methodology assumes that the total quantity of pesticide applied to a specific crop is evenly distributed across the whole country. The estimates therefore do not take into account the local variability in pesticide application and management practices found within a magisterial district or across a regional landscape. As outlined in the Methods section, the relative quantity of a pesticide applied to a crop was expressed as the total application of the pesticide to a specific crop (kg) type per unit area of all agricultural land within a magisterial district. The main variable in differentiating pesticide use among magisterial districts is therefore the percentage composition of all agricultural land in a magisterial district covered by the specific crop to which the pesticide is applied.

Integration with land-cover maps

The agricultural land area displayed in the maps does not correspond with the area used in the estimation of the calculation of pesticide use statistics. The agricultural land cover is used to indicate where pesticide application is most likely and calculations of total pesticide use based on area calculations using the land-cover map will not necessarily correspond with those used in the calculation of pesticide use. The agricultural land-cover layer does not indicate the location of specific crops, so pesticide use was aggregated up to a magisterial district level and assumed to be distributed across all agricultural land within a magisterial district. All agricultural land cover that fell within a magisterial district was therefore assigned a pesticide use category for the pesticide in question. In reality, a section of agricultural land may not necessarily have an application of the pesticide if that specific land-cover area is not covered by a crop to which the pesticide is applied. The land-cover maps should therefore be used as a guide to indicate where agricultural land is located and the likelihood of application as represented by the application categories.

Conclusions

The pesticide use maps and supplementary data developed in this study provide the most detailed overview of pesticide use in South Africa produced to date. This information can be used to make national, provincial and catchment-based assessments of pesticide use which are essential for performing spatial assessments of human and environmental risk associated with pesticide use. Considering the large number of pesticides used in the country, the maps are particularly useful in identifying where specific pesticides are most likely to be applied, thereby prioritising those that are likely to be of greatest concern; the maps can therefore make useful contributions to the design of water quality monitoring programmes and interpretation of data. This activity is particularly important considering the high cost associated with the analysis of pesticides in environmental samples.

The maps display average annual pesticide use intensity expressed as average weight (kilograms) of a pesticide applied to each hectare of agricultural land in a magisterial district. Use estimates are based on (1) the spatial distribution of crops at a magisterial district level as reported by Stats SA in the Census of Agricultural Provincial Statistics (2002) and (2) national estimates of pesticide use rates for individual crops as compiled by the market research company GfK Kynetec. The area of mapped agricultural land for each magisterial district was obtained from the 2009 national land-cover map (NLC 2009) produced by the South African National Biodiversity Institute. The areas of uncertainty in these maps are:

1. The magisterial district coverage is based on the 2002 Census of Agricultural Provincial Statistics and did not represent all total coverage as accurate statistics were dependent on farmers that responded to the census. Data were therefore normalised to reflect actual crop coverage as reported by the FAO (i.e. the area of each crop type in a magisterial district was multiplied by the ratio of total national area reported by Stats SA to total national area reported by the FAO).
2. In the methodology, we assumed that a specific pesticide was evenly distributed to a specific crop regardless of the magisterial district in which the crop was produced. Pesticide use data as displayed in the maps may therefore not reflect the local variability of pesticide management practices found within a magisterial district.
3. Because the agricultural land cover does not discriminate between different crop types, pesticide use was aggregated up to a magisterial district level and assumed to be distributed across all agricultural land within a magisterial district. All agricultural land cover that fell within a magisterial district was therefore assigned a pesticide use category for the pesticide in question.
4. Crop production statistics may not have been available for all magisterial districts in which a pesticide may have been applied to agricultural land, and if so, are not displayed on the maps.
5. Pesticide use estimates are based on market research data for the year 2009.
6. Agricultural land cover used to display pesticide use rates is for the purpose of providing an indication of the spatial distribution of pesticide application and is not representative of actual agricultural land area used in the calculation of pesticide use rates.

Despite the limitations listed above, the data used in this study represent the best information currently available and therefore provide the best possible estimate of crop distribution and pesticide use in the country

at present. Furthermore the limitations discussed here are not unique to South Africa. The uncertainty can be reduced by performing this type of assessment annually in order to obtain a range of pesticide use patterns and evaluate variation over time. Freely available, annual data on pesticide use are essential to meeting these objectives. Furthermore, the reliability of the maps could be improved through an updated census of crop production statistics in magisterial districts of South Africa.

Acknowledgements

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Assessing the quality of food served under a South African school feeding scheme: A nutritional analysis

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School feeding schemes have been implemented in various schools across the globe to improve the nutritional welfare of learners. The purpose of this study was to identify possible nutritional benefits or deficiencies of the foodstuffs served in the South African National School Nutrition Programme in the Free State Province (South Africa). Representative meal samples were collected from randomly selected schools and the nutrient content of meals was determined. The results were measured against nutrient-based standards for an average school lunch for individuals aged 7–10 and 11–18 years. The meals did not meet the nutrient standards for carbohydrate and energy contents for either age group. Protein standards were met by 90% of meals for individuals aged 7–10 years and by 40% for those aged 11–18 years. Only 10% of meals met the standards for calcium and zinc, while 80% and 30% met the iron standards for those aged 7–10 years and 11–18 years, respectively. The lipid and vitamin C contents were within standards. The implementation of proper storage and food preparation procedures may assist in preserving the quality of nutrients.

Introduction

Approximately one-third of young children globally experience stunted growth; causes of their growth failure may be traced to poverty.[1] Malnutrition and hunger account for nearly half of the death rate of preschool children worldwide, with approximately 26% of undernourished children residing in Africa.[2,3] An estimated one-fifth of the total population comprises those of school age. Approximately 25% of all children in developing countries are vitamin A deficient, whilst other nutrients most likely to be deficient in school-aged children are reportedly iron and iodine, with prevalence rates of the latter between 35% and 70%.[3-7] Although data regarding the nutritional status of school-attending children in South Africa were not established during the current study, Iversen et al.[5] report that undernutrition particularly affects young children residing in rural areas of the country. Furthermore, during a national food consumption and anthropometric survey among South African children, it was revealed that the Free State Province has a high prevalence of nutritional disorders.[8]

Nutrients are not only essential for growth and development, but also provide young children with fuel to perform physical and metabolic functions. Nutrition also influences the efficiency of educational programmes.[9] Adequate nutrition is therefore vital during the school-age years because nutrition and health influence a child's cognitive development.[3,10] Children lacking certain nutrients in their diet and who suffer from protein-energy malnutrition, persistent hunger, parasitic infections or other food-related diseases, are likely to have a reduced potential for learning compared with healthy, well-nourished children.[8] Difficulty in concentrating and performing complex tasks in hungry learners can be attributed to poor or inadequate nutrition.[10] Nutrient deficiencies account for the inability of a child to achieve their full mental and physical potential because of stunted growth, low physical work capacity, reduced IQ and a lower resistance to infection.[4] In a report compiled by Usfar et al.[1], a study conducted in rural villages of Guatemala indicated a more rapid growth in children who received supplementation (with a vegetable protein mixture) while children who did not take supplements were stunted and at risk of chronic infections even during adulthood.

Schools are uniquely positioned to promote healthy eating behaviours and attitudes among children, which may be the foundation for future dietary preferences and eating behaviour in their adult lives.[11,12] Furthermore, school feeding schemes such as the National School Nutrition Programme (NSNP), a South African school feeding scheme, provide access to various nutritious foodstuffs that promote learners' health and their capacity to perform academic tasks.[13] The NSNP was initiated in 1994 and, as an integral component of the Department of Basic Education (DBE), serves meals to schools located in communities with low socio-economic status nationwide in South Africa.[14,15] The programme is funded through a provisional grant that is transferred to provinces according to the *Division of Revenue Act* and directives from the DBE and National Treasury (Grant Framework 2010/11).[16] The provincial/district office and/or schools are allocated funds for the procurement of foodstuffs.[17] Food items are then delivered to schools by private contractors and further prepared on the school premises.[18] The NSNP aims to improve class attendance and participation among learners by alleviating short-term hunger.[14] The UK government established food-based standards (to increase intake of healthier foods such as fruit, vegetables and oily fish) and nutrient-based standards (to promote an increased provision of foodstuffs containing essential nutrients) as guidelines for school lunches. The standards are aimed to address concerns regarding the poor quality of school meals and to improve the quality and nutritional balance of meals served to schoolchildren.[19-21] In this study, we used chemical analyses to determine the nutrient contents of the meals served during the administration of the NSNP in Bloemfontein, South Africa. The study aimed to cast light on the possible nutritional benefits or deficiencies of the school meals.

Materials and methods

Sampling procedure

Representative food samples were collected from 10 randomly selected schools that were beneficiaries of the NSNP in Bloemfontein, South Africa. The school sample included primary, intermediate, combined and special schools, categorised under the three quintiles – Q1, Q2 and Q3. This sample also represented an even distribution of schools in the urban and rural areas of the region. The NSNP representative or school principal was notified prior to the visit and arrangements were made to collect food samples which were collected during serving times (between 10:30 and 12:00) during the summer season. This notification was necessary because schools were found to not always adhere to the serving time stipulated by the DBE as they operate differently in terms of the duration of classes and general attendance. The samples consisted of representative portions of food that were served to children under normal serving practices. In an attempt to collect a variety of food and obtain a wider perspective on the nutritional benefits of the meals, the samples were collected on specific days with guidance regarding menus provided by the schools. Schools used the menu provided by the DBE,[13] which gave detailed descriptions of meals to be served each day, as a guideline.

Meal samples of between 267 g and 477 g were collected using latex gloves and placed in sterile polythene bags. Schools were alphabetically coded to maintain confidentiality. Samples consisted of the following from each of the schools: A – maize porridge and cabbage with potatoes; B – maize porridge and soup with beans and cabbage; C – maize rice and soya mince stew with potatoes and carrots; D – maize rice and beef stew with carrots and potatoes; E – rice and cabbage with potatoes and carrots; F – maize porridge and cabbage with tinned fish; G – samp (a South African staple food made from broken, dried corn kernels) and soya mince stew with potatoes and pumpkin; H – maize porridge and milk; I – maize rice and soya mince stew with potatoes and carrots; and J – rice and tinned fish (pilchards in tomato sauce) stew. Onions, cooking oil, salt and spices were included during the preparation of all meals except for the meal served by school H. The food handlers followed recommendations of the DBE in preparing the meals with some modifications according to availability of ingredients.[15] All meals had been prepared on the day they were sampled. The samples were transported to the laboratory on ice and homogenised upon arrival at the laboratory. Sampling and analyses were performed in triplicate.

Gravimetric determination of moisture content

Samples were dried in an oven at 105±5 °C for 24 h and the moisture content was expressed as the percentage of moisture in the fresh sample upon determining the difference in mass between the fresh sample and dry matter.[22]

Analysis of soluble sugars

High-performance liquid chromatography analysis

A high-performance liquid chromatography (HPLC) system consisting of a Shimadzu Prominence HPLC apparatus (Shimadzu Corporation, Nakagyo-ku, Kyoto, Japan) equipped with a pump (LC-20AD), a solvent degasser (DGU-20A3), an autosampler (SIL-20AC, 230V), a refractive index detector, a CBM-20A controller and an integrator running DataApex Clarity Chromatography software was used in the determination of soluble sugars. For separation, a Phenomenex Luna NH_2 250×4.60 mm reverse-phase column (5 μm particle size) (Phenomenex, Torrance, CA, USA) was used with an oven temperature of 40 °C. An isocratic elution was employed with 75% acetonitrile (HPLC grade from Merck, Johannesburg, South Africa) in nanopure water at a flow rate of 1.25 mL/min and the injection volume was 10 μL. A carbohydrate kit (Sigma-Aldrich, Johannesburg, South Africa) was used to identify and quantify individual sugars by comparing the relative retention times of sample peaks with standards using calibration curves. The calibration was carried out using the external standard method and four sets of calibration standards at concentrations of 0.4 g/L, 0.8 g/L, 1.8 g/L and 3.2 g/L were prepared for each reference sugar. The standard material was weighed, the appropriate volume of nanopure water was added and the mixture was vortexed for 30 s. The resultant solutions were filtered using syringe filters and analysed using HPLC.

Extraction of soluble sugars

The sugars were extracted from the various food samples using a modified method as proposed by Barreira et al.[23]. Approximately 10 g of the homogenised samples was extracted using 40 mL of 80% aqueous ethanol (Merck) at 70 °C for 30 min. After cooling to room temperature, the samples were centrifuged at 3000 rpm for 15 min. The ethanol in the supernatant was evaporated and the extract was diluted to a final volume of 10 mL in nanopure water, filtered at 0.45 μm and injected for HPLC analysis.

Total carbohydrate determination

Total carbohydrate content of food samples was determined by difference,[24] that is: 100 g minus the sum of grams of water, protein, fat and ash.

Total lipid content and fatty acid analyses

Quantification of total lipid content

With minor adaptation, the method proposed by Gressler[25] was applied for the identification and quantification of lipids and fatty acids. To each homogenised food sample (5 g), 250 mg of pyrogalic acid (Sigma-Aldrich) (to minimise fatty acid degradation) and 5 mL of ethanol were added. For acid hydrolysis, 25 mL of 32% HCl (Merck) was added and the solution was shaken for 40 min at 70–80 °C, followed by vortexing for approximately 10 min. The lipids were extracted (at room temperature) with ethyl ether (60 mL mixed in vortex for 1 min) and petroleum ether (60 mL mixed in vortex for 1 min) (both were purchased from Merck). The samples were centrifuged (4000 rpm × 5 min) and the ether phase was evaporated to dryness under nitrogen gas. The residue was gravimetrically determined as total lipid content.

Identification of fatty acids

The fatty acids in the extracted lipid were methylated to fatty acid methyl esters (FAMEs) with boron trifluoride/methanol complex (5 mL of 20% BF_3/MeOH reagent) (Merck) followed by heating in 2.5 mL toluene (Merck) at 100 °C for 45 min under gentle mix. At room temperature, nanopure water (12.5 mL) was added and the FAMEs were extracted with 5 mL hexane (Merck). The hexane fraction was dried in nitrogen gas, suspended in 500 μL hexane and the solution was filtered prior to analysis. The fatty acids were analysed using a Finnigan Focus gas chromatograph (Thermo Fisher Scientific, Waltham, MA, USA) with a flame ionisation detector and a 25 mm x 0.32 mm ID SGE capillary column BPX70 and 0.25-μm film (SGE, Melbourne, Victoria, Australia). The temperature conditions were 100 °C for 5 min, 100–240 °C (at a rate of 3 °C/min) and at 240 °C for 20 min. The samples were injected at 225 °C and detected at 285 °C with helium (linear flow of 200 mm/s) as the carrier gas and a split ratio of 1:50. A 37-Component FAME mixture (Sigma-Aldrich) was used to identify the fatty acids.

Protein content determination

The Dumas combustion method as described by Jung et al.[26] was used to determine the nitrogen content of food samples. The protein content was determined by means of a nitrogen conversion factor of 6.25.

Analysis of vitamins A and E

High-performance liquid chromatography–ultraviolet conditions

The HPLC system used for the analysis of vitamins was the same as that described earlier for carbohydrate analysis, with minor variations. For vitamin separation, a Phenomenex Luna C18 (2) 5-μm 150×4.60 mm

reverse-phase column (Phenomenex) was used and the analyses were performed under isocratic mode (mobile phase of acetonitrile) at a flow rate of 2 mL/min with the oven temperature at 40 °C. The injection volume was 10 μL and a UV detector was set at 325 nm for vitamin A (retinyl acetate purchased from Sigma-Aldrich) and 290 nm for vitamin E (δ-tocopherol, α-tocopherol and α-tocopherol acetate purchased from Sigma-Aldrich) to monitor column effluents. The retention times, peak areas/heights and the spectra of the standard compounds were used for vitamin identification. For standard solutions, a stock solution of each vitamin was prepared by dissolving 3 mg of the vitamin standard in 100 mL ethanol containing 3 mg of antioxidant butylated hydroxytoluene (BHT) (Sigma-Aldrich) as a protection reagent.

Saponification and extraction of vitamins

With minor adaptations, the method proposed by Salo-Väänänen[27] was applied to identify vitamin A and E contents of the homogenised samples. For saponification, samples of approximately 2 g were weighed into flasks after which 20 mL pyrogallol (15 g/L, dissolved in absolute ethanol, Sigma-Aldrich) and 10 mL KOH saponification solution (which consisted of 100 g of KOH pellets – purchased from NT Laboratory Suppliers Excom, Johannesburg, SA – dissolved in 100 mL of nanopure water) were added. Taka diastase (0.01 g) (Sigma-Aldrich) was added to digest starch and prevent formation of lumps. The flasks were heated at 60 °C for 30 min and cooled to room temperature for about 15 min. To avoid emulsion formation, 10 mL of 10% NaCl (Merck) was added.

After saponification, the vitamins were extracted using three portions of 20 mL *n*-hexane-petroleum ether (80:20) (*n*-hexane was obtained from Merck). With each portion, the flask was vortexed for about 30 s and centrifuged (4200 rpm × 5 min). The phases were allowed to separate, and the organic layers were washed with 20 mL of 5% NaCl and evaporated. Then 5 mL ethanol and 5 mL *n*-hexane were added to the flask and the solution was evaporated to dryness with nitrogen gas. The residue was dissolved in 1 mL *n*-hexane (containing 5 mg of BHT) and filtered (Whatman, 0.45 μm) prior to HPLC analyses. Exposure to high temperature and bright light were eliminated throughout the process to prevent the loss of vitamins.

Vitamin C analysis

Total vitamin C content was determined according to AOAC Method 984.26 as proposed by Moses et al.[28]

Determination of total ash and mineral content

The total mineral content was determined by a dry ashing method during which the dried food samples were ashed at 525 °C overnight in a muffle furnace.[29] The resultant ash was determined gravimetrically while individual minerals (calcium, iron and zinc) were identified and quantified using inductively coupled plasma-optical emission spectrometry (ICP-OES) as per the method proposed by Zhou et al.[30].

Energy calculation

Energy was determined using the following formula as described by Charrondiere et al.[24]: energy (kJ) = (total carbohydrate grams ×17 kJ) + (protein grams ×17 kJ) + (lipids grams × 37 kJ).

Analyses of data

The results of this study were analysed according to the United Kingdom's nutrient-based standards (NBS), which are derived from the Dietary Reference Values, for an average school lunch.[19] The NBS were used as they articulated well with the units and best described assumptions used in this study. It was deemed necessary to compare schools that served the same meal in order to explore the possible impact of the preparation methods on the nutritional quality. The results were expressed as grams/day and milligrams/day for macro- and micronutrients, respectively, and as kilojoules/day for energy. All descriptive and inferential statistical analyses were performed using SigmaPlot 10.0.1, Systat software. In the cases of determination of significance, the *t*-test was used with a significance level of 0.05. Means of triplicate values ± standard deviations and percentages are used to present the results.

Results and discussion

According to the menus received from the schools and the one which had been designed by the DBE, balanced and wholesome meals should alternately include a green and yellow vegetable along with the starch and protein portions. However, the only measurable vegetables served during sampling were cabbage (served by schools A, B, C, E and F) and pumpkin (served by schools G and J) (data not shown). In addition, the cabbage was served as a replacement for or in combination with the protein portion of the meals. To further supplement the nutrient intake, it was expected that a fruit would be provided to each child per week; however, it was observed that only one school adhered to this regulation during the course of this study.

Carbohydrates

The soluble sugars (glucose, fructose and sucrose) were quantified and the mono- and disaccharide contents are listed in Table 1. Low sugar contents were also reflected in the results of a study by Menezes et al.[31], who found that the contents were below 0.5% of fresh weight for all foods and ranged between 3.07 mg/100 g and 38.42 mg/100 g for glucose, 3.77 mg/100 g and 55.90 mg/100 g for fructose and 9.39 mg/100 g and 368.27 mg/100 g for sucrose. These results were attributed to the high starch content of the foodstuffs. Carbohydrates (in the form of glucose) are the main source of energy in the human diet and consist of a diverse family of compounds, namely mono-, oligo- and polysaccharides.[9] Further illustrated in Table 1 are the total carbohydrate contents of meals which ranged between 20.29±0.76 g/day and 59.41±0.10 g/day. These data were significantly ($p \leq 0.05$) below the NBS minima of 70.6 g and 86.1 g for pupils aged 7–10 and 11–18 years, respectively (Figure 1). Similar results were observed from a study by Nicholas et al.[32] in which school meals were below the standard (≥86.1 g) required for carbohydrates at a content of 73.2±35.6 g. However, Pearce et al.[33] found that school lunches yielded a carbohydrate content which was above the standard at 89.2±38.9 g.

Lipids and fatty acids

The values for the total lipid content (Table 1) were within the NBS of below 20.6 g and 25.1 g for individuals aged between 7–10 and 11–18 years, respectively, as illustrated in Figure 1. A study by Haroun et al.[20] indicated that the majority of the school lunches also met the standard for total fat content. Lipids, particularly fats, are dense sources of energy and facilitate the absorption of fat-soluble dietary components such as vitamins. Lipids also aid in regulating blood pressure and nerve transmissions.[34-37] While fat intakes should be kept minimal, intakes below 25% of total energy have been associated with low vitamin levels in young children.[35] Lipid intake further depends on the composition of fatty acids and the health effects of various lipid components (saturated, unsaturated and trans-fatty acids).[34] Table 2 lists the fatty acids identified in the various samples analysed in this study. It is apparent that saturated fatty acids were dominant in the majority of the meals. A high content of saturated fatty acids in school lunches was also observed in the study by Pearce et al.[33] Saturated and monounsaturated fatty acids are synthesised by the human body and are thus not required in the diet, whereas polyunsaturated fatty acids, such as omega-3 and -6, are essential fats which should be obtained from the diet.[35] School B's meal contained omega-3 (C18:3n3) fatty acids while meals from schools C, H and I contained omega-6 (C18:3n6) fatty acids. Meals which excluded foodstuffs of animal origin (schools D, E and G) were deficient of essential fats, whereas the meal from school F had the highest fatty acid composition and, along with that of school J, had both omega-3 and omega-6 essential fatty acids (Table 2). Schools F and J served tinned fish (pilchards) and it is a recognised fact that essential fats are abundant in fish oil.[38] Prior et al.[39] elaborate that these essential fats occupy one-third of the central nervous system while approximately 20% of the human brain consists of omega-3 fatty acids. This occupation of essential fatty acids in the brain was found to reduce attention deficit

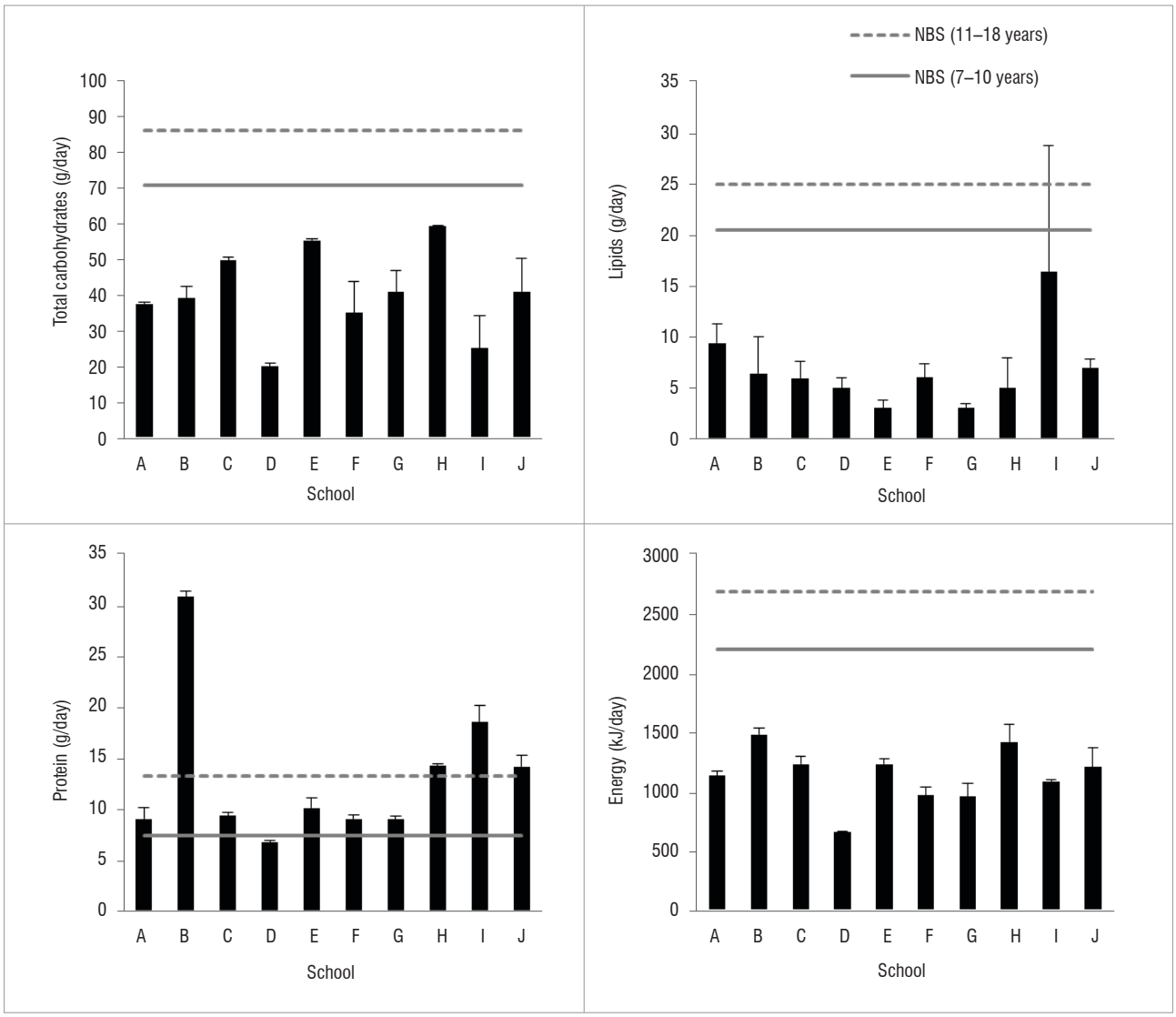
hyperactivity disorder symptoms in children during a study by Johnson et al.[40]

Protein

One meal (School D) did not contain the protein required in a school lunch (minimum of 7.5 g) for children aged 7–10 years. For pupils aged from 11 to 18 years, only four school meals (B, H, I and J) met the nutrient standard of a minimum of 13.3 g, whereas the remaining six schools were significantly ($p \leq 0.05$) below the standard as indicated in Figure 1. School meals analysed for nutritional quality during the studies by Nicholas et al.[32] and Pearce et al.[33] met the standards for protein requirements. As indicated in Table 1 and Figure 1, the meal served by School B had noticeably higher protein content than those sampled from the other schools. This difference was because School B's meal was the only one that included meat (beef), which is a primary source of protein. Proteins mainly provide structure for the body and are major components of bone, muscle, blood, cell membranes, enzymes and immune factors.[41] Additionally, proteins may be a source of energy; however, the body does not rely on protein for daily energy requirements.[37] The quality of protein in food is dependent on the composition of amino acids, which bind together to form proteins such as in hormone formation.[35,41] The human body is unable to synthesise the eight (or nine in the case of infants) essential amino acids – lysine, tryptophan, methionine, valine, phenylalanine, leucine, isoleucine, threonine and, for infants, histidine – and these should be obtained from the diet.[36]

Energy

The energy values indicated in Table 1 were significantly ($p \leq 0.05$) below the minimum required values for an average school lunch ($\geq$ 2215 kJ for individuals aged 7–10 years and $\geq$2700 kJ for those aged 11–18 years) as illustrated in Figure 1. According to the School Food Trust[19], a minimum of 50% of energy from food should be obtained from carbohydrates, less than 35% should be from fats, and a portion (quantity not specified) should be supplied by proteins. Data obtained from the current study indicated that meals from the majority of the schools contributed the



Each data point represents triplicate values. The standard deviation is represented by the error bar.

NBS, nutrient-based standards.

Meals sampled from Schools A to J: A – maize porridge and cabbage with potatoes; B – maize porridge and soup with beans and cabbage; C – maize rice and soya mince stew with potatoes and carrots; D – maize rice and beef stew with carrots and potatoes; E – rice and cabbage with potatoes and carrots; F – maize porridge and cabbage with tinned fish; G – samp and soya mince stew with potatoes and pumpkin; H - maize porridge and milk; I – maize rice and soya mince stew with potatoes and carrots; and J – rice and tinned fish (pilchards in tomato sauce) stew. Onions, cooking oil, salt and spices were included during the preparation of all protein portions of meals, except at School H.

Figure 1: Mean macronutrient values of meals sampled at various schools participating in the National School Nutrition Programme.

required amount of total carbohydrates to the energy values and did not exceed the standard for lipids. This finding is similar to those of a study by Charrondiere et al.[24], regarding numerous food items from various countries, during which the total carbohydrate content supplied 50–80% of energy and 7–11% of energy was from protein. However, the meal from School B supplied approximately 47%, 17% and 37% of energy from carbohydrates, lipids and protein, respectively, and therefore relied on protein for energy, and the meal from School I contributed approximately 31%, 45% and 23% to the energy value from carbohydrates, lipids and protein, respectively (data not shown), indicating fats as the main source of energy. In an ideal diet, carbohydrates should be the main source of energy and the body should avoid reliance on protein for energy.[37,42] Similar results of low energy provided by school meals were observed during a study by Nicholas et al.[32]; however, the meals generally met the standards for percentage of energy from carbohydrates and fats, but not from non-milk extrinsic sugars (sugars that are not contained within the cellular structure of food). Burgess and Bunker[43] found that the energy values of school meals in their study were above the minimum standard, although none of the percentages of energy from carbohydrates, fats and non-milk extrinsic sugars were within the standards. Energy intake of children should be sufficient to ensure growth, and meals consumed by children should provide all the required nutrients without additional excessive energy sources to the diet.[44]

Vitamins A and E

The analysis for vitamins A and E in the present study yielded undetectable results for both vitamins. Depending on the cooking method and composition of food, variable losses of vitamins may occur as a result of processing and cooking conditions.[45] Kuyper[46] reported an average loss of 53% of vitamin A during the preparation of maize meal. The results obtained from a study by Pretorius and Schönfeldt[47] indicated that fortification contributed to the improvement of the overall vitamin A status of children aged 1–9 years, whereas foodstuffs that

Table 1: Macronutrient content and energy values of various school meals

School†	Glucose (g/day)	Fructose (g/day)	Sucrose (g/day)	Total carbohydrate (g/day)	Lipid (g/day)	Protein (g/day)	Energy (kJ/day)
A	0.61 ± 0.24	0.57 ± 0.14	0.24 ± 0.03	37.75 ± 0.40	9.42 ± 1.88	9.12 ± 1.12	1142.71 ± 43.54
B	0.26 ± 0.29	0.23 ± 0.26	0.19 ± 0.06	39.12 ± 3.25	6.42 ± 3.59	30.86 ± 0.62	1488.76 ± 52.66
C	0.54 ± 0.47	1.11 ± 0.20	0.23 ± 0.17	49.93 ± 0.87	5.96 ± 1.71	9.38 ± 0.40	1242.12 ± 62.76
D	0.36 ± 0.00	0.52 ± 0.29	0.16 ± 0.16	20.29 ± 0.76	4.97 ± 1.00	6.83 ± 0.18	663.86 ± 7.79
E	1.01 ± 0.40	1.20 ± 0.72	0.61 ± 0.40	55.33 ± 0.52	2.99 ± 0.81	10.15 ± 1.00	1240.33 ± 40.41
F	0.07 ± 0.05	0.23 ± 0.14	0.07 ± 0.00	35.09 ± 8.67	6.03 ± 1.38	9.12 ± 0.31	974.63 ± 69.78
G	0.32 ± 0.07	0.11 ± 0.00	0.07 ± 0.07	40.92 ± 5.94	3.01 ± 0.42	9.10 ± 0.22	964.63 ± 115.50
H	0.81 ± 0.26	0.19 ± 0.05	0.43 ± 0.19	59.41 ± 0.10	5.05 ± 2.88	14.32 ± 0.20	1430.16 ± 149.80
I	0.46 ± 0.07	0.39 ± 0.07	1.02 ± 0.26	25.30 ± 8.91	16.49 ± 12.42	18.67 ± 1.55	1097.47 ± 8.27
J	0.06 ± 0.03	ND	0.03 ± 0.00	41.12 ± 9.22	6.98 ± 0.84	14.23 ± 1.09	1213.61 ± 167.81

Values shown are the mean±s.d. (n=3).

ND, not detected using the current method.

†Meals sampled from Schools A to J: A – maize porridge and cabbage with potatoes; B – maize porridge and soup with beans and cabbage; C – maize rice and soya mince stew with potatoes and carrots; D – maize rice and beef stew with carrots and potatoes; E – rice and cabbage with potatoes and carrots; F – maize porridge and cabbage with tinned fish; G – samp and soya mince stew with potatoes and pumpkin; H - maize porridge and milk; I – maize rice and soya mince stew with potatoes and carrots; and J – rice and tinned fish (pilchards in tomato sauce) stew. Onions, cooking oil, salt and spices were included during the preparation of all protein portions of meals, except at School H.

Table 2: Fatty acid compositions of meals served in schools in the National School Nutrition Programme

School†									
A	B	C	D	E	F	G	H	I	J
C4:0 C6:0 C8:0 C10:0 C12:0 C14:0 C16:1 C18:0 C18:1n9c C20:0 C21:0 C20:2 C22:2 C24:0 C20:5n3	C4:0 C8:0 C10:0 C13:0 C15:0 C17:0 C17:1 C18:3n3 C21:0 C20:3n6 C22:1n9 C20:3n3 C23:0 C22:2 C22:6n3	C4:0 C8:0 C10:0 C14:0 C16:1 C18:0 C18:1n9 C18:3n6 C21:0 C20:2 C22:0 C24:0 C20:5n3	C4:0 C16:0 C18:0 C18:1n6c C20:2 C22:2 C24:0	C4:0 C8:0 C10:0 C11:1 C12:0 C13:0 C15:0 C17:0 C21:0 C22:1n9 C20:3n3 C22:2 C20:5n3 C22:6n3	C4:0 C6:0 C10:0 C12:0 C13:0 C14:0 C15:0 C16:0 C16:1 C17:0 C18:0 C18:1n9t C18:2n6t C18:1n6c C20:0 C18:3n6 C20:1 C18:3n3 C20:2 C22:0 C20:3n3 C22:2 C24:0 C20:5n3 C24:1 C22:6n3	C4:0 C10:0 C14:0 C16:0 C18:0 C18:1n9t C18:1n9c C18:1n6c C21:0 C20:2 C24:0 C20:5n3	C4:0 C8:0 C10:0 C12:0 C14:0 C15:0 C16:0 C16:1 C17:0 C18:0 C18:1n9c C18:2n6t C18:1n6c C18:3n6 C20:1 C21:0 C20:2 C20:3n3 C23:0 C24:0	C4:0 C8:0 C16:0 C18:1n9t C18:1n9c C18:2n6t C18:1n6c C18:3n6 C20:2 C22:0 C24:0 C20:5n3	C4:0 C6:0 C10:0 C12:0 C14:0 C15:0 C16:1 C17:1 C18:1n9t C18:1n9c C20:0 C18:3n6 C20:1 C18:3n3 C21:0 C20:2 C20:3n6 C20:3n3 C24:0 C24:1 C22:6n3

†Meals sampled from Schools A to J: A – maize porridge and cabbage with potatoes; B – maize porridge and soup with beans and cabbage; C – maize rice and soya mince stew with potatoes and carrots; D – maize rice and beef stew with carrots and potatoes; E – rice and cabbage with potatoes and carrots; F – maize porridge and cabbage with tinned fish; G – samp and soya mince stew with potatoes and pumpkin; H - maize porridge and milk; I – maize rice and soya mince stew with potatoes and carrots; and J – rice and tinned fish (pilchards in tomato sauce) stew. Onions, cooking oil, salt and spices were included during the preparation of all protein portions of meals, except at School H.

were not fortified did not yield results. Vitamins enable numerous chemical reactions to occur in the body, which may aid with the release of energy from carbohydrates, lipids and proteins.[37] The important roles that fat-soluble vitamins play in several functions of the human body include vision (vitamin A), calcium absorption (vitamin D) and antioxidative protection in cell membranes (vitamin E).[48]

Vitamin C

Vitamin C contents of meals are indicated in Table 3 and meals from all the schools met the requirements for pupils of all ages as stipulated for an average school lunch (Figure 2). Similar results were observed in the studies by Nicholas et al.[32] and Pearce et al.[33]. Both groups of researchers reported that the vitamin C contents of the school meals they analysed met the required standards. A study by Fontannaz et al.[49] revealed that soya-based food contained higher vitamin C levels than meat-based food. This trend was also observed in the meals analysed in the current study as the food provided by Schools D and G, which included soya mince, contained higher vitamin C levels than the meals of School B (which included beef) and School H (which included milk). Vitamin C is essential for growth and repair of tissues in the body.[50] In addition, ascorbic acid acts as a cellular antioxidant and facilitates intestinal absorption of iron and maintenance of plasma iron.[51] Interestingly, meals collected from Schools D and I were prepared using similar ingredients, but the meal from School I contained higher counts of all quantified nutrients, except for vitamin C. The *t*-test indicated that the meal from School D had a significantly higher ($p \leq 0.05$) vitamin C content than that of School I. This finding may be because vitamin C is water soluble and School D's meal had a higher moisture content (86%) than that of School I (78%). Furthermore, a moderate positive correlation between moisture and vitamin C was observed (Figure 3).

Mineral content

As illustrated in Figure 2, only two school meals did not comply with the nutrient standard (≥3.0 mg) for iron content, for pupils aged 7–10 years, while seven schools did not comply with the standard (≥5.2 mg) for those aged 11–18 years. In addition, meals of Schools C, H and I had iron levels that were above the NBS for both age groups and the standard for the zinc content of school lunches was met by one meal (School B) for both age groups (Figure 2). Furthermore, for the 11–18 years age group, the calcium standard (≥350 mg) was not met by any of the meals analysed while only one sample (School J) met the standard for individuals aged 7–10 years (≥193 mg). Llorent-Martínez et al.[52] observed significantly higher levels of minor nutritional elements (copper, iron and manganese) in soya products than in products of animal origin; however, the authors found that zinc levels were higher in foodstuffs of animal origin than of soya. A similar observation was made during the present study with the meal from School B containing the highest level of zinc (which may be attributed to the inclusion of beef) and lower levels of the other micronutrients. The results of the studies by Nicholas et al.[32] and Pearce et al.[33] indicated school meal values that were below standards for calcium, iron and zinc. A below standard calcium content and an above standard iron content were reported in the results of a study by Burgess and Bunker[43]. Iron is critical for the transportation and storage of oxygen in the body and children are at risk of developing iron deficiency anaemia should iron be deficient in their diet.[42] Children require calcium for mineralisation and to maintain their growing bones. The primary sources of calcium are milk and dairy products,[37] hence a calcium content above the NBS was expected from School H's meal (which consisted of milk). Zinc is essential for growth and healing of wounds in children, with the major sources of zinc being meat and seafood.

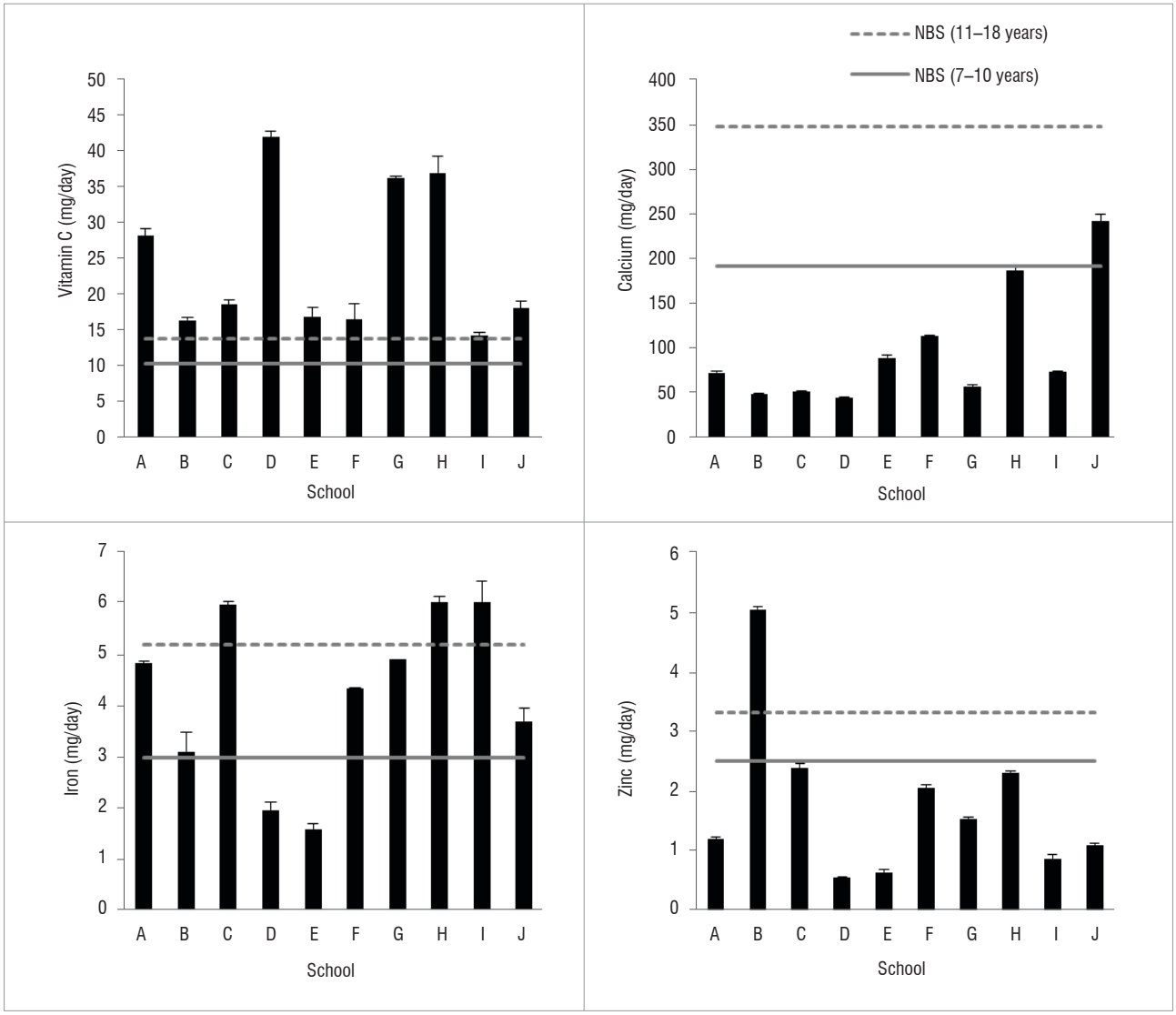
The effect of storage conditions and preparation methods on the different nutritional categories was notable in this study. According to Yuan et al.[53], food preparation methods induce significant changes in the chemical composition of foodstuffs. In addition, the literature suggests that high temperatures used in cooking have an effect on the contents of nutrient and health-promoting food constituents such as vitamins.[54,55] Yuan et al.[53] reported that various cooking treatments caused major losses of total soluble proteins, soluble sugars and vitamin C in broccoli as a result of the application of heat for prolonged periods. The authors also identified the use of excessive liquid as reducing the nutritional content of foods via leaching of water-soluble components into the liquid. Components of the meals sampled in the present study were prepared using high volumes of liquid with the possible aim of supplementing the foodstuffs. However, this practice may compromise the nutrient content of food as water-soluble nutrients (such as vitamin C and soluble proteins and sugars) may be lost through leaching into the surrounding liquid medium.[56] Further deterioration and loss of nutrients (particularly vitamins) may occur from excessive exposure of foodstuffs to UV light and oxygen, the pH of the solvent or combinations of various conditions.[56,57] Moreover, a study by Vinha et al.[58] revealed that

Table 3: Micronutrient content of meals sampled from various schools

School†	Vitamin C (mg/day)	Iron (mg/day)	Zinc (mg/day)	Calcium (mg/day)	% Ash (dry weight)
A	28.38 ± 0.96	4.83 ± 0.05	1.20 ± 0.04	73.65 ± 1.42	3.87
B	16.57 ± 0.46	3.11 ± 0.39	5.04 ± 0.05	50.36 ± 0.92	3.47
C	18.76 ± 0.71	5.96 ± 0.07	2.38 ± 0.08	52.25 ± 1.66	5.5
D	42.30 ± 0.69	1.98 ± 0.15	0.54 ± 0.02	45.88 ± 0.00	4.18
E	17.09 ± 1.32	1.60 ± 0.10	0.64 ± 0.06	90.78 ± 2.64	2.5
F	16.61 ± 2.32	4.35 ± 0.00	2.04 ± 0.06	115.08 ± 1.16	4.73
G	36.40 ± 0.25	4.90 ± 0.00	1.52 ± 0.04	58.80 ± 0.99	4.05
H	37.24 ± 2.36	6.02 ± 0.11	2.30 ± 0.04	189.07 ± 3.71	3.45
I	14.41 ± 0.46	6.03 ± 0.39	0.87 ± 0.06	75.33 ± 0.46	6.22
J	18.22 ± 1.01	3.70 ± 0.26	1.08 ± 0.05	243.63 ± 7.45	3.72

Values shown are the mean±s.d. (n=3).

†Meals sampled from Schools A to J: A – maize porridge and cabbage with potatoes; B – maize porridge and soup with beans and cabbage; C – maize rice and soya mince stew with potatoes and carrots; D – maize rice and beef stew with carrots and potatoes; E – rice and cabbage with potatoes and carrots; F – maize porridge and cabbage with tinned fish; G – samp and soya mince stew with potatoes and pumpkin; H - maize porridge and milk; I – maize rice and soya mince stew with potatoes and carrots; and J – rice and tinned fish (pilchards in tomato sauce) stew. Onions, cooking oil, salt and spices were included during the preparation of all protein portions of meals, except at School H.



Each data point represents triplicate values. The standard deviation is represented by the error bar.

NBS, nutrient-based standards.

Meals sampled from Schools A to J: A – maize porridge and cabbage with potatoes; B – maize porridge and soup with beans and cabbage; C – maize rice and soya mince stew with potatoes and carrots; D – maize rice and beef stew with carrots and potatoes; E – rice and cabbage with potatoes and carrots; F – maize porridge and cabbage with tinned fish; G – samp and soya mince stew with potatoes and pumpkin; H - maize porridge and milk; I – maize rice and soya mince stew with potatoes and carrots; and J – rice and tinned fish (pilchards in tomato sauce) stew. Onions, cooking oil, salt and spices were included during the preparation of all protein portions of meals, except at School H.

Figure 2: Mean micronutrient values of meals sampled at various schools participating in the National School Nutrition Programme.

in all the studied parameters, temperature and storage duration caused statistically significant differences in the nutritional values of each food sample analysed. Macronutrients are relatively stable under various storage conditions; however, the length of storage considerably affects the retention of micronutrients with high losses observed as a result of prolonged periods of storage.[56,57] It is therefore essential that NSNP-benefitting schools adhere to the first-in-first-out principle for storage.

Conclusions

The small variety of ingredients in the meals served may be why the content of some nutrients are lower than the standards. In this regard, a study by Snelling and Yezek[59] indicated that using nutrient standards to guide the selection of foods offered in schools may positively affect the intake of energy and nutrients. Therefore, to improve the macro- and micronutrient quantities of meals, NSNP-participating schools should serve meals that include a variety of whole grains, meat/meat alternatives, fruits, vegetables and dairy options.[13] Food-handling methods, especially during storage and preparation, may also have a significant influence on the nutritional quality of foods. This influence was observed in the present study, in which there was a wide variation in nutrient levels in meals that contained similar components. Moreover, it may have been possible that vitamin C leached into surrounding media because meals with a high moisture content yielded higher values for this vitamin. It is further postulated that the undetected contents of vitamins A and E may be attributed to deterioration of these vitamins during handling of foodstuffs. Therefore, proper storage practices should be maintained to minimise loss of nutrients caused by exposing foodstuffs to surrounding elements and meals should be prepared in a manner that preserves the quality of nutrients.

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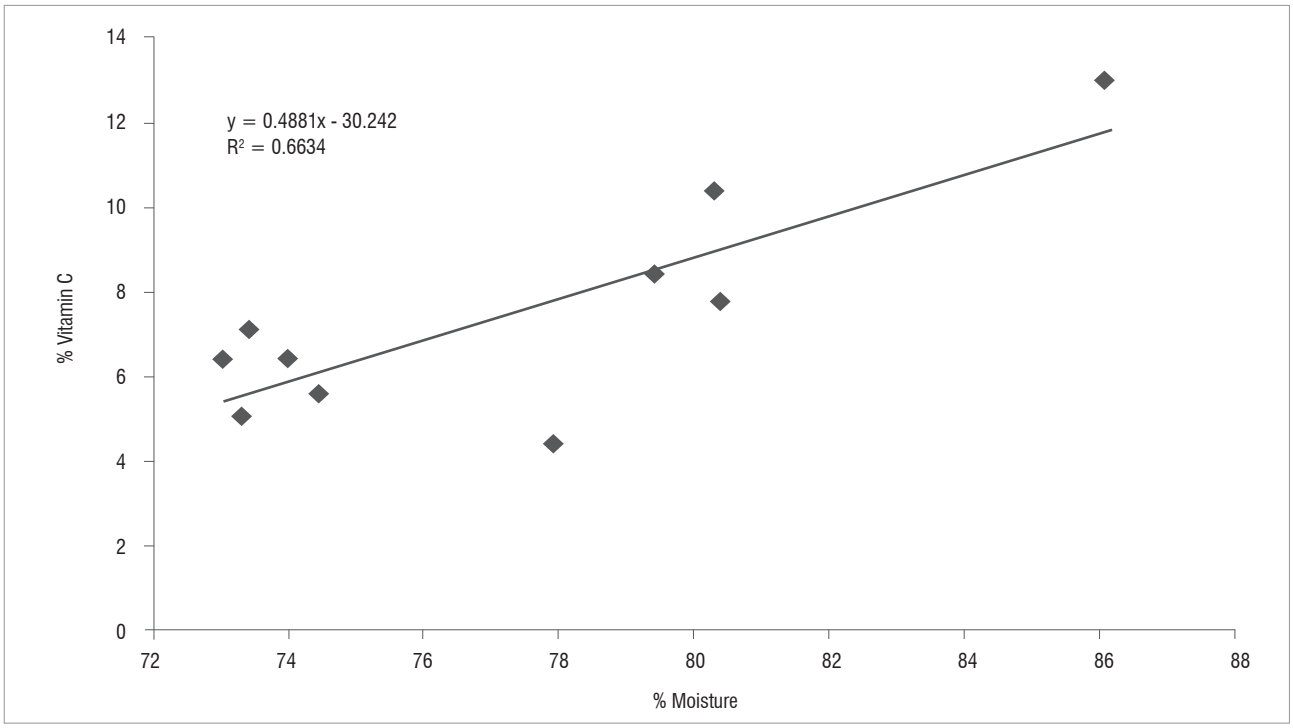

Figure 3: Relationship between moisture and vitamin C contents of meals served at various schools.

Authors' contributions

This work formed part of N.N.'s master's degree. N.N. performed all of the experiments and wrote the manuscript. W.H.G. was the project supervisor and made conceptual contributions. R.J.F.L. made conceptual contributions and was responsible for the experimental and project design. E.K. assisted with the project design, made conceptual contributions and supervised the experimental analyses.

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Recognition of materials and damage on historical buildings using digital image classification

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Nowadays, techniques in digital image processing make it possible to detect damage, such as moisture or biological changes, on the surfaces of historical buildings. Digital classification techniques can be used to identify damages in construction materials in a non-destructive way. In this study, we evaluate the application of the object-oriented classification technique using photographs taken with a Fujifilm IS-Pro digital single lens reflex camera and the integration of the classified images in a three-dimensional model obtained through terrestrial laser scanning data in order to detect and locate damage affecting biocalcarenite stone employed in the construction of the Santa Marina Church (Córdoba, Spain). The Fujifilm IS-Pro camera captures spectral information in an extra-visible range, generating a wide spectral image with wavelengths ranging from ultraviolet to infrared. Techniques of object-oriented classification were applied, taking into account the shapes, textures, background information and spectral information in the image. This type of classification requires prior segmentation, defined as the search for homogeneous regions in an image. The second step is the classification process of these regions based on examples. The output data were classified according to the kind of damage that affects the biocalcarenite stone, reaching an overall classification accuracy of 92% and an excellent kappa statistic (85.7%). We have shown that multispectral classification with visible and near-infrared bands increased the degree of recognition among different damages. Post-analysis of these data integrated in a three-dimensional model allows us to obtain thematic maps with the size and position of the damage.

Introduction

We present a case study combining three-dimensional measuring techniques, such as terrestrial laser scanning, and advanced digital classification techniques using multispectral images to yield thematic maps with the size and positions of damage that affects the biocalcarenite stone of the Santa Marina de Aguas Church located in the city of Córdoba (Spain). We introduce the techniques used, review the benefits and drawbacks of spectral classification methods and discuss how object-oriented classification can improve the analysis of complex surfaces.

Throughout time, humans have built many unique landmark buildings of great historical, cultural and monetary value. But with time, the stone used to build them deteriorates as a result of natural processes, which are exacerbated and accelerated by conditions and circumstances attributable to human activity.[1] Today there is notable concern regarding the need to conserve this heritage given its enormous value to humankind. Therefore, multidisciplinary studies are necessary to learn about the deterioration that affects the different materials from which monuments and historical buildings are composed.[2, 3]

The documentation, preservation and restoration of historical buildings requires, first and foremost, knowledge of the state of their degradation before the appropriate reconstruction techniques can be applied to correct the problems detected.[4] When determining the state of degradation of a unique building, samples must be taken from both the deteriorated area and another part of the building in good condition in order to compare the two degenerative states. It is precisely during sampling, traditionally performed using invasive techniques, that the most damage is caused to the building; hence, there is great interest in finding fast and economical non-invasive techniques to detect alterations in building materials.[5]

Scientists have long used multispectral images for building diagnosis, especially in cultural heritage tasks.[6] Strackenbrock et al.[7] and Godding et al.[8] used multispectral image classification for the analysis of different stones and damage types in architectural applications. The effect of atmospheric phenomena such as rainfall, cloud temperature and cloud water content is determined using false-colour photographs, i.e. photographs with an observation range greater than the visible spectrum (normally the infrared spectrum). Recently, image interpretation has been applied to characterise the façades of architectural buildings. The methodology of the spectral classification is based on the fact that those specific materials have wavelengths which are dependent on the reflection characteristics. By transferring the value of a pixel of an image into a feature space, a cluster for each object class is formed. Finally, classification techniques reduce the range of values of the image (digital number) to another level (classes) through a system of allocation statistics.[9] Spectral classification methods can be differentiated into two groups: supervised and unsupervised classifications. Lerma[10] studied the application of photogrammetry and remote sensing using cameras sensitive to the visible and infrared spectra, obtaining rectified images classified by automated methods and thus determining the structural elements and pathologies detected on the façades of different buildings. In the aforementioned study, Lerma applied supervised multispectral classifications on multiband images, which were within the visible and infrared range.

However, in spectral classifications, problems arise when the pixels which comprise individual objects are spectrally heterogeneous and when identical spectral features have got different image texture.[11] There have been several studies with statistical supervised pattern classification on different monument façades under differing situations and external conditions. The overall accuracy of classification for mortars and paintings (among others)

was 83.6%[12]; for limestones was 94.5%; for mortars was 90.8%[13]; and for mixed mortars, limestones, wood and glass was 90.1%[14].

New possibilities are given by the application of the object-oriented analysis of images, which takes into account, inter alia, the shapes, textures, background information and spectral information in the image.[15]

Neusch and Grussenmeyer[16] compared spectral classifications and the oriented-based classification in order to extract the elements comprising the half-timbered façades. The best results were achieved using the oriented-based classification.

On the other hand, terrestrial laser scanning has been successfully applied in a number of different fields, such as architectural heritage, civil engineering, geology and documentation of heritage sites. It provides geometrical information used for the creation of realistic virtual three-dimensional models.[17-21] One of the most important applications is the preservation and restoration of historical buildings.[22-25]

Our case study applies to the Santa Marina de Aguas Santas Church in Córdoba (Spain). This church is a historical building dating back to the 13th century and is of great cultural heritage value. The monitoring of its conservation state is thus necessary.

We proposed a new method to assess damage on the concrete surfaces of the church using multispectral images analysis. The main objectives of this study were:

- To evaluate the use of the object-oriented based classification using images taken with a single lens reflex camera recording non-visible light (ultraviolet and infrared), in order to detect damage affecting biocalcarenite stone employed in the construction of historical buildings, and other materials used in the restoration and its quantification.
- To integrate the results in a three-dimensional model obtained through terrestrial laser scanning data in order to yield thematic maps with the size and the position of damages that affect the biocalcarenite stone.

Experimental section

Study site

The study site was the Santa Marina Church, located in the city of Córdoba (Andalusia, Spain). The church is located in the city centre. The materials used in the construction of this building were Tortonian biocalcarenite with micritic carbonated cement (fine grain) and limestone fossils.[26] Built in the 13th century, together with the Magdalena Church, Santa Marina de Aguas Santas is one of the oldest churches in Córdoba, and both buildings can be considered to be models for the other 'Fernandina' churches, built after Ferdinand's reconquest of the city.[27] The Santa Marina Church was declared a Historic-Artistic Monument on 3 June 1931. It is exposed to a large number of air contaminants.

Equipment

The realistic virtual three-dimensional model of the monument was obtained using a Leica HDS 6600 laser scanner based on terrestrial LiDAR technology and manufactured by Leica Geosystems AG (St. Gallen, Switzerland). This equipment has a maximum instantaneous scan speed of 50 000 points/s. Data post-processing following the site survey was performed using Leica Cyclone 7.1 software.

The image analysis study to identify the construction materials and pathologies affecting these materials was performed using the Fujifilm IS-Pro digital single lens reflex camera (Fujifilm, Tokyo, Japan). This camera – designed for law enforcement, scientific, medical and fine art communities – was used in the study with a selection of filters for limiting the spectrum of certain wavelengths to the image. This 12.3-megapixel camera captured spectral information for the areas studied in an extra-visible range, generating a wide spectral image with wavelengths ranging from 300 nm (ultraviolet) to 1000 nm (near infrared). Thus, in addition to this camera, a specific visual target was used, an AF Nikkor 24mm f/2.8D (Nikon, Tokyo, Japan), with the characteristics required for coupling different filters, in order to screen the spectral information required.

The choice of the filters to use in this study was based on previous results obtained by the working group.[28] These filters, whose transmittance curves are shown in Figure 1, were characterised using a calibration sphere Li-Cor 1800-12.[29] The filters were obtained from B+W (Berlin, Germany).

B+W 099 filter, infracolour orange

Figure 1 shows that the filter absorbs almost all light until a wavelength of approximately 550 nm and consequently filters all the spectral information corresponding to ultraviolet and the visible portion composed of blue and green. Part of red is also reflected; hence, the light passing through the filter will be formed by infrared and the orange area.

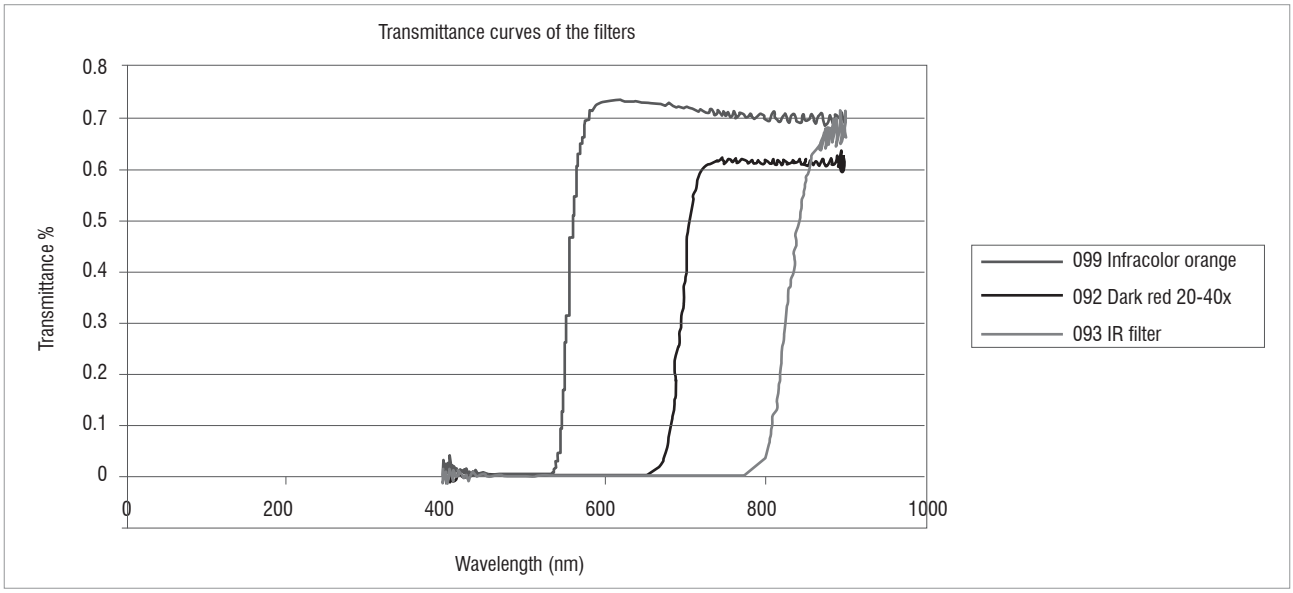

Figure 1: Transmittance curves of the B+W 099, 093 and 092 filters.

B+W 092 filter, dark red 20–40X

This filter has a transmittance curve characterised by an inflection point in the wavelength region of 690 nm. This curve indicates that the filter eliminates the ultraviolet response and practically the entire visible portion, except for dark red. As a result, the light beam will be characterised by an infrared and partly dark red spectrum.

B+W 093 filter, infrared

This filter eliminates ultraviolet and the entire visible portion as it screens the beam of light up to the area close to 830 nm, which is already in near infrared.

Data gathering and processing

Characterisation of materials and alterations in the stone

Figure 2 shows the four study areas selected for the characterisation of the materials and their alterations. These areas have important damage and they need to be restored. Four false colour photographs were taken of each area, using the camera with: (1) no filters, (2) a B+W 099 filter, (3) a B+W 092 filter and (4) a B+W 093 filter.

Figure 2: The Santa Marina Church, Córdoba. Insets: Areas of the building that were studied.

Image analysis techniques were applied to the captured images in order to obtain thematic information on the state of degradation of the building. These techniques require prior confirmation in situ regarding the existence of pathologies on the building's façade. This information was taken from previous studies carried out on the church, in which the pathologies affecting the façade were plotted using traditional techniques.[26] In Figure 3, a diagram shows the characterisation of materials and alterations in the stone obtained in the aforementioned research.

Figure 4 shows a diagram of the methodology followed in this study to identify the pathologies from the classification of hyperspectral images taken. The object-oriented classification technique applied is described below.

Object-oriented classification of images

Traditional remote sensing studies the level of response of each photographic pixel in the electromagnetic spectrum, completely ignoring the spatial structure of the image. In contrast, the new object-oriented classification technique takes into account shapes, textures and spectral information present in the image, among other aspects. Recent studies[30-32] have demonstrated the superiority of the new concept with respect to traditional classifiers. Its basic principle is the use of information (shape, texture, contextual information, etc.), which is only present in significant objects in the image and in the relationships between them. The strategy is based on the spatial structure of images and consists of generating partitions of these images in which each region may be considered relatively homogeneous and different from the neighbouring regions. Each region corresponds to a segment, which, after classification, is added together with other neighbouring segments to form a larger region and thus to form an area with similar spectral characteristics. This process is called segmentation.

In short, the division of the images into a variety of objects is a key procedure for successfully analysing images or for their automatic interpretation. In this sense, image segmentation is a critical step for subsequent image analysis and even for understanding these images in the future.

Given the specific nature of the study, ENVI 4.7 software was selected. This software is used to process and analyse geospatial images.

The process consisted of an initial composition of the four photographs taken on the same wall. The multispectral digital camera gives three bands of information for each of these photographs (with and without a filter); however, some of these bands contribute little information. Thus, a *.vsk file was then created consisting of four overlapping pictures, each with three RGB bands.

The object-oriented classification was performed according to the steps below:

- Information segmentation stage
- Compute attributes
- Legend selection stage
- Training stage
- Classification or assignation stage
- Classification evaluation stage

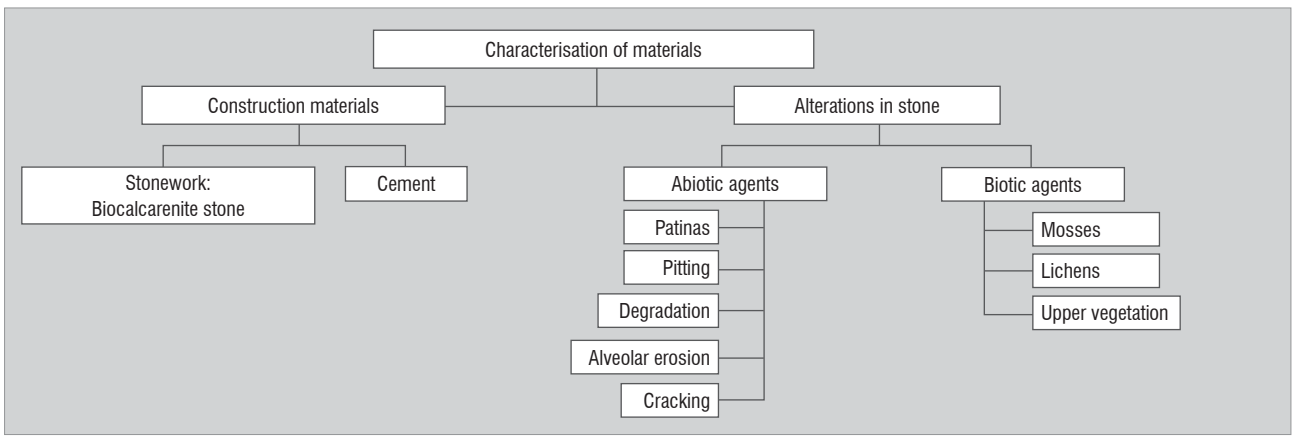

Figure 3: Characterisation of materials on the church façade.

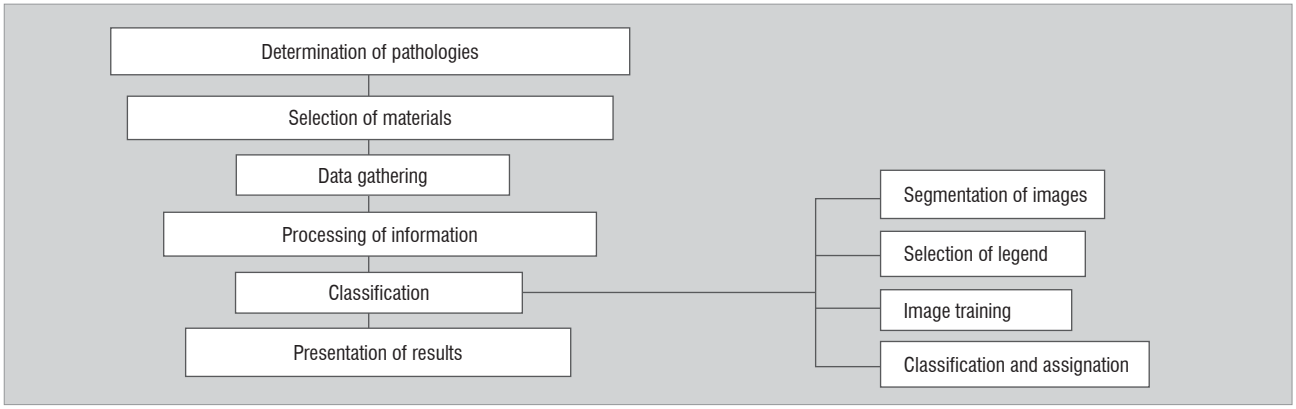

Figure 4: Phases for the identification of stone pathologies.

Information segmentation stage

Segmentation is the process of partitioning an image into segments by grouping neighbouring pixels with similar feature values (brightness, texture, colour, etc.). These segments ideally correspond to real-world objects.[33] Segmentation may be carried out using different procedures:

- Detection of grey levels: this consists of comparing the grey levels of the pixels and grouping them based on a gradient of variation in the grey level. When the grey-level variation gradient is substantially modified, it is stipulated as a boundary of the region.
- Edge detection: the composition of each pixel is studied and the images are grouped on that basis. When there is an abrupt change in the spectral response of the pixels, an edge is defined; thus, areas in which pixels have a similar spectral response are determined.
- Feature extraction: binarisation is performed based on thresholds of membership to textural and colour classes, whereby pixels with similar responses are gradually added.
- Multiresolution segmentation: this segmentation takes into account variability in both colour and shape, calculating a function of global variation. This parameter is compared with the homogeneity pre-established by the user, which will be the variability threshold for the formation of the object.

In this study, the segmentation method based on Feature Extraction was applied using ENVI zoom 4.7 software with Feature Extraction module. This system is based on the watershed by immersion algorithm. The watershed transform is based on the concept of hydrological watersheds. Basins fill up with water starting at the lowest points, and dams are built where water coming from different basins meets. When the water level has reached the highest peak in the landscape, the process stops. The landscape is thus divided into regions separated by dams, called watersheds.[34]

A similar process occurs in digital imagery. The darker a pixel, the lower its 'elevation'; this type of pixel is called a minimum. The Vincent and Soille watershed algorithm sorts pixels by increasing greyscale value, then begins with the minimum pixels and 'floods' the image, partitioning the image into basins (regions with similar pixel intensities) based on the computed watersheds. The result is a segmentation image, in which each region is assigned the mean spectral value of all the pixels that belong to that region.[35]

The Watershed algorithm requires the user to determine a series of parameters:

- Scale level (%): Determination of the level of homogeneity to be established when generating the different objects. During this step, the software starts image segmentation with the Feature Extraction module and requires a scale parameter. This parameter is a numerical value between 0 and 100 that controls the size and the complexity of the resulting segments. Values close to 0 produce fewer and bigger segments. In order to choose the right value, the software gives you the option of previewing the result.
- Merge (%): The next step is to merge the current segmentation for the determination of the restrictions when merging different objects with similar characteristics. This step eliminates errors produced during segmentation. The merge is also controlled by a numerical value between 0 and 100, where 0 means no merge at all and 100 means merge all.
- Thresholding: Union of adjacent groups, based on a comparison of pixel brightness.

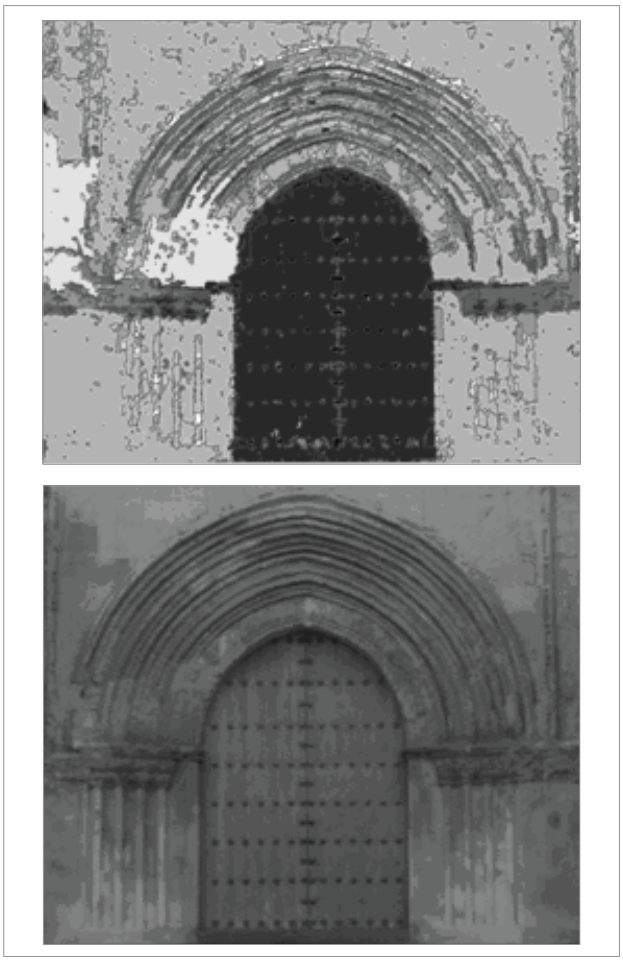

Figure 5: Comparison between the segmented composition (upper) and the original composition (lower) of the main door of the Santa Marina Church, Córdoba.

Table 1: Configuration parameters for segmentation in ENVI 4.7 software

Areas of study	Segment	Merge	Thresholding
Main door	50%	72%	7
Rose window	43%	68%	7
North side of the left wall pillar	40%	76%	7
Left side of the façade, left small wall	40%	76%	7

Image segmentation requires the performance of numerous tests to obtain a result that provides the best fit with reality. To obtain adequate results, various segmentation tests were carried out on each wall analysed using different configuration parameters until the appropriate segmentation was found. Figure 5 shows a good segmentation of the main door of the Santa Marina Church. The settings chosen for each wall are outlined in Table 1.

Compute attributes

In this step, attributes are computed for each segment. These attributes are:

- Spectral: minimum, maximum, mean and standard deviation for each channel
- Spatial: area, length and shape of the segment
- Textural: range, mean, variance and entropy of the segment
- Custom: band ratio, hue, saturation and intensity

Legend selection stage

Based on the characterisation of materials and changes in the stone shown in Figure 3, the legend defining the classes to be automatically differentiated was obtained. The different uses of the legend are listed in Table 2.

Table 2: General legend

General legend
Plaster and cement
Patinas
Cracks
Stone degradation
Pitting and alveolar erosion
Upper vegetation
Lichens
Mosses
Biocalcarenites (non-degraded stony material)

Training stage

Training fields characteristic of each sample class were selected to correlate the statistical values of the spectral responses of the pixels corresponding to the selected object with the representative class to which it was assigned. Existing cartography of alterations was used to determine which areas were characteristic of each class type.[26]

Classification or assignation stage

The main goal of classification is to differentiate groups (informational classes) whose members have certain characteristics in common. The object-oriented classification is based on the fact that the semantic information, fundamental to interpreting an image, is not represented in pixels individually, but in representative objects of an image and their relationships. In this study, classifications were established using a class hierarchy procedure in which images are classified based on a list of available classes.

The k–nearest neighbour algorithm was used for the classification. The k–nearest neighbour classification method considers the Euclidean distance in *n*-dimensional space of the target to the elements in the training data, where *n* is defined by the number of object attributes used during classification. This method is generally more robust than a traditional nearest-neighbour classifier, as the k–nearest distances are used as a majority vote to determine to which class the target belongs. The k–nearest neighbour method is much less sensitive to outliers and noise in the data set and generally produces a more accurate classification result compared with traditional nearest-neighbour methods.[30] This method also takes into account different parameters related to the objects (area, length, mean colour, brightness and texture).

Classification evaluation stage

For this classification, the overall accuracy, the kappa statistic and the producer's and user's accuracy were calculated. Kappa quantifies how superior a particular classification is in comparison to a random classification; the producer's accuracy is a measure of omission error and indicates the percentage of pixels of a given land-cover type that is correctly classified; and the user's accuracy is a measure of the commission error and indicates the probability that a pixel classified into a given class actually represents that class on the ground.[15]

Obtaining a realistic virtual three-dimensional model of the façade

Scanning positions were selected according to technical specifications and by searching the front and the proximity of the studied area in order to minimise the influence of geometry during data acquisition, for example, by minimising hidden areas.

After obtaining the three-dimensional model from the points cloud, the following metric information on the façade was extracted:

- CAD format plan
- orthophotographs
- virtual models of triangle meshes and solid surfaces.

Figure 5 shows a virtual model of the principal façade.

Figure 6 shows an orthophotograph of the façade based on a real colour photograph. This photograph was a high-resolution orthophotograph (3735 x 2610 pixels) in which measurements and annotations could be made, showing the three-dimensional structure of the morphological details found on the façade of the building.

Finally, a map was prepared which summarised the pathologies affecting the monument. The map was obtained by combining the metric information obtained in the LiDAR survey and the thematic information prepared.

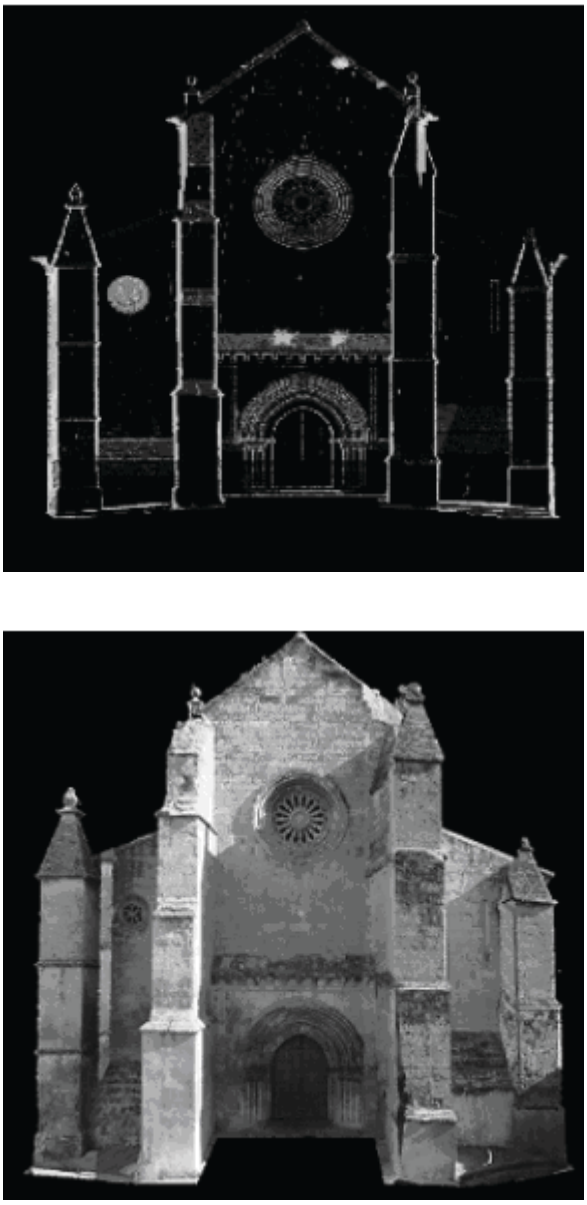

Figure 6: Virtual model of the façade (upper) and orthophotograph of the façade (lower) of the Santa Marina Church.

Results and discussion

After segmentation of the composite images, the assignation of legends to each image and the next stage of training, the composites were classified.

As expected in an object-oriented classification, the images obtained consisted of groups of homogeneous segments, characterised by their smooth texture, which did not allow us to appreciate any morphological forms. This aspect forced us to use the original image to analyse the components in this area. After a thorough analysis of the façade, the different pathologies in specific areas were observed.

The 'plaster and cement' class was present almost entirely in the lower parts of the church. This distribution was because of remediation work carried out on the outside of the church to restore degraded areas.

'Patinas' were located in areas in which, for morphological reasons, small deposits had gradually accumulated, forming a thin layer that gives original monuments a lighter colour.

The cracks that appear between the ashlar blocks are because the bonding material between the ashlar blocks is less resistant to degradation than the stone of the blocks used to build the church. Therefore, the entire monument shows cracking, the largest proportion of which was found in the most severely degraded areas.

Stone degradation, pitting and alveolar erosion are the most common pathologies on the outer surface of the building. Because these pathologies affecting the stone are caused by atmospheric weathering, degradation, pitting and alveolar erosion are more frequent in the areas in which wind and rain have a stronger impact. These areas are located on the northwest façade and the left side of the main façade.

With regard to the pathologies resulting from the presence of living organisms, a distinction must be made between mosses and lichens. At first glance they may look similar. However, closer examination of their distribution shows that lichens prefer higher parts of the building where oxygenation and radiation are more abundant, and where adjacent buildings do not inhibit ventilation or lighting of their habitat. In contrast, mosses prefer moist and shady areas, which explains why these bryophytes were located in the lower parts of the monument and preferred more humid north-facing parts of the building.

To conclude our findings on living organisms, upper vegetation usually is in areas with larger accumulations of sediment because they need more substrate for their roots to anchor and find support. The classification showed that upper vegetation was found on the edges of the roof, the small roof above the main door and the different projections on the outside of the building; there were no errors in the classification of this legend item.

A confusion matrix was prepared to evaluate the reliability of the classification made based on the compositions of images taken of the monument (Table 3). The confusion matrix was prepared from the manual analysis of 1000 sample regions distributed homogeneously on the four photographic compositions. The matrix was constructed by determining whether each sample region actually belonged to the category in which it had been classified, and if not, in which of the other categories it had been classified erroneously.

As can be seen, most of the regions studied (65%) were classified as stone material in good condition. Of these 650 samples, 610 were classified correctly and 40 belonged to the plaster and cement, patinas, degradation and bryophytes categories. The analysis of the samples classified as plaster and cement (10% of the total) revealed that 20% of the samples classified in this class belonged to the stonework and patinas categories. When evaluating the categories belonging to degradation by atmospheric agents (13% of the total areas studied), most belonged to the stone degradation category (6% of the sample regions classified in this category) and all had been classified correctly (100% user accuracy). When studying the biological agents, it was observed that overall these accounted for 6% of the regions studied and all were correctly classified, i.e. 100% reliable detection (producer accuracy).

Based on the data obtained in the confusion matrix, a statistical analysis was performed that yielded a total accuracy of 0.92 and a kappa statistic of 0.857. The total accuracy obtained showed that 92% of the regions generated had been classified correctly, with only 8% assigned to the wrong classes. The generation of a kappa statistic of 0.857 indicated that 85.7% of the errors that would have been committed with a random classification had been avoided. Considering a minimum kappa statistic value of 0.80 for the classification to be considered valid, it may be concluded that the classification obtained was acceptable.

Finally, the corresponding orthophotographs were obtained based on the classified images and using the three-dimensional model of the façade obtained with the terrestrial LiDAR. These orthophotographs already had metric characteristics in which measurements could be taken, allowing the exact position of the detected pathologies to be determined and the exact surface area affected by these pathologies to be quantified (Figure 7).

Table 3: Confusion matrix

Confusion matrix											
Legend	**Biocalcarenites**	**Plaster and cement**	**Patinas**	**Cracks**	**Stone degradation**	**Pitting and alveolar erosion**	**Upper vegetation**	**Lichens**	**Mosses**	**Total**	**User accuracy**
Biocalcarenites	610	10	10	0	10	10	0	0	0	650	0.94
Plaster and cement	10	80	10	0	0	0	0	0	0	100	0.80
Patinas	10	0	40	0	0	0	0	0	0	50	0.80
Cracks	0	0	0	20	0	0	0	0	0	20	1.00
Stone degradation	0	0	0	0	60	0	0	0	0	60	1.00
Pitting and alveolar erosion	0	0	0	0	0	50	0	0	0	50	1.00
Upper vegetation	0	0	0	0	0	0	20	0	0	20	1.00
Lichens	10	0	0	0	0	0	0	20	0	30	0.67
Mosses	0	0	0	0	0	0	0	0	20	20	1.00
Total	640	90	60	20	70	60	20	20	20	100	
Producer accuracy	0.95	0.89	0.67	1.00	0.86	0.83	1.00	1.00	1.00		

Figure 7: Object-oriented classifications of the rosette (left) and of the main door (right) of the Santa Marina Church.

Conclusions

This study is a first approach to evaluate the applicability of the methodology to map and measure pathology on concrete surfaces. The evaluation of the proposed methodology for the detection of alterations in the construction material of unique buildings based on the application of advanced object-oriented classification techniques on multispectral images proved to be very successful, with a total accuracy of 92%.

Through the combination of these classified images and the virtual three-dimensional model obtained with terrestrial LiDAR technology, a thematic map of the areas studied was obtained with a level of detail and accuracy that no other technology can provide. Additionally, the combined use of both technologies is useful for appreciating the relief and physiognomy of the monument, thus making it easier to determine the parts of the church affected by each pathology. This system for detecting alterations can therefore be used to lower the costs of restoring unique buildings and provides accurate results for surface areas affected by the different types of damage detected.

Authors' contributions

J.E.M. was the project leader; A.J.P. was responsible for the experimental and project design and M.J.A. and A.M.L. performed some of the experiments.

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Plagiarism in South African management journals

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Plagiarism by academics has been relatively unexplored thus far. However, there has been a growing awareness of this problem in recent years. We submitted 371 published academic articles appearing in 19 South African management journals in 2011 through the plagiarism detection software program Turnitin™. High and excessive levels of plagiarism were detected. The cost to government of subsidising unoriginal work in these journals was calculated to approximate ZAR7 million for the period under review. As academics are expected to role model ethical behaviour to students, such a finding is disturbing and has implications for the reputations of the institutions to which the authors are affiliated as well as that of the journals that publish articles that contain plagiarised material.

Introduction

In 2003, an editorial[1] in this journal alerted readers to the developing concern about misconduct in the sciences, and acknowledged that the extent of such misconduct and its various manifestations were largely unknown. In 2012, Honig and Bedi[2] published the findings of a study in the prestigious *Academy of Management Learning and Education* journal in which they examined 279 papers submitted for the 2009 Academy of Management conference. They found that 25% of papers contained some degree of plagiarism, with over 13% evidencing significant plagiarism (defined as comprising 5% or more of the content). In addition, they reported that a greater amount of plagiarism appeared to emanate from countries outside North America. Against the background of these studies, and given the paucity of research relating to this problem, in the present study, located in a country outside North America, we have attempted to contribute to deliberations in this area.

The objective of the study was to investigate the degree of plagiarism evident in articles published in 2011 in South African management journals that attract subsidy from the Department of Higher Education and Training (DHET). As a subcategory of research dishonesty, plagiarism is the representation of the work of another, or one's own work, without acknowledgement of such work and can include careless paraphrasing, the copying of identical text or providing incomplete references that mislead the reader into believing that the ideas expressed belong to the author of the text.[2,3]

Over the past years student plagiarism has commanded much research attention[4-8], with increasing focus on the detection of plagiarism[9] and ways of addressing it[4]. However, relatively little has been published about plagiarism committed by academics[10-13], with research thus far regarded as largely anecdotal and speculative[2]. In this regard, Honig and Bedi note:

> *Although many in our professions appear to be suspicious of students cutting corners in an effort to marginally improve their grades, we seem to have full confidence in our colleagues, whose incentives to skirt rules and policies are limited to less significant issues such as tenure, reputation and six-figure salaries.*[2(p.105)]

Plagiarism is intellectual theft[14] and transgresses the fundamental values of the academy[15], preventing learning, the dissemination of new knowledge, and the integrity of the scientific record[16]. Schminke[13] notes how plagiarism is sometimes committed by experienced and established authors for whom the blame is apportioned to junior co-authors.

The DHET remits approximately ZAR120 000 to higher education institutions for each peer-reviewed academic article published by a member of the institution in any of the local or international journals that appear on a list compiled by the DHET each year; this funding is an essential income stream for universities.[17] Accordingly, increasing pressure has been placed on academics to publish in these accredited journals; and such publication is usually linked to financial and promotional rewards.[1,18] This pressure can contribute to a research culture in which output is promoted at the expense of research quality, which can manifest as plagiarism by those who attempt to achieve the greatest publication output in the shortest time.[19] In this regard, self-plagiarism – which portrays previous work as new – also contributes to this problem.[20]

Academics have a role to play in developing student moral literacy[21] and a link has been shown to exist between the dishonesty of academics and student cheating behaviour[22]. Furthermore, academics have been found to be reluctant to report and take action on student academic dishonesty.[23] Accordingly, it is important to understand research integrity or the lack thereof amongst academics themselves.

Methods

We submitted 371 peer-reviewed articles that were published in 2011 in 19 South African management journals (spanning the major fields of management) through the Turnitin™ software program to identify similarities between the articles and other published material, i.e. to identify plagiarism. Once a manuscript is submitted to the program, it is compared against billions of Internet pages, online publications, journal articles and student assignments, dissertations and theses, and a report is generated that highlights the actual text that has been copied and indicates the percentage of similarity between that manuscript and those documents that appear on the Turnitin™ database. In the remainder of this article, this percentage is referred to as the similarity index.

Only South African journals that appeared on the Thomson Reuters Web of Science (WoS, previously ISI) or the International Bibliography of the Social Sciences (IBSS) lists or on the local list of journals compiled by the DHET, thereby qualifying for subsidy, were included in the study. Two journals (not included in the 19), containing 17 articles, could not be accessed. The results for each article were checked twice and a conservative approach was adopted in the interpretation of the similarity indices, in which the benefit of doubt was in favour of the authors. For each article, the following content was not included in the assessment of similarity: bibliography/list of references, quotations, strings of words of less than 10, student write-ups on which the article was based, conference proceedings and abstracts detailing the main features of the article. In addition, during the second inspection of the data, specific methodological terms and statistical or mathematical formulae were excluded in the analysis of similarity. The Turnitin™ software program has been used in other studies to detect plagiarism.[2,24] It has been reported that the Turnitin™ program itself is conservative in the generation of the results.[25]

Results

Across the 371 submissions, the similarity index (i.e. the percentage of similarity between an article and the documents in the Turnitin™ database) ranged from 1 (indicating almost no similarity) to 91 (indicating almost complete similarity). The latter pertained to a single article that was published in two journals under two different titles. Figure 1 shows that the distribution of the similarity index across the 371 submissions was positively skewed. In addition, several outliers were detected, which called for the use of robust statistics in subsequent analyses.[26] The mean similarity index across the 371 submissions was 17.10 (SD=12.15), the mode was 9, the median was 14 and the 20% trimmed mean was 14.70 (95% confidence intervals: 13.61 and 15.89, Winsorised SD=6.67).

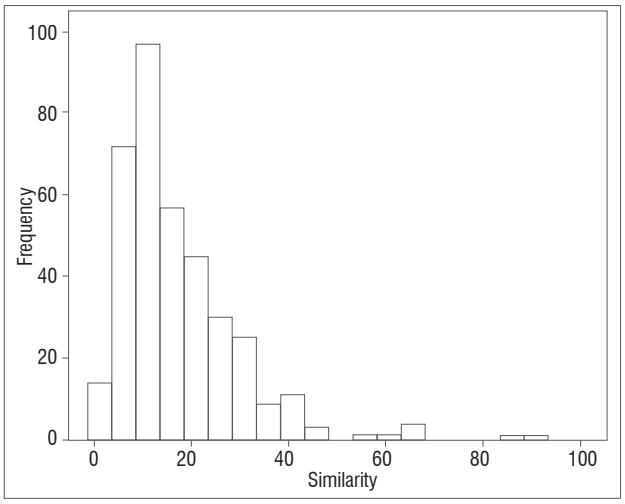

Figure 1: Distribution of the similarity index across 371 submissions.

To gain an overview of the relative frequency of plagiarism we categorised the similarity indices as follows: 1 to 9 as low; 10 to 14 as moderate; 15 to 24 as high and >24 as excessive. Table 1 summarises the frequencies in these categories.

Table 1: Similarity according to extent in categories

Category	*n*	%	Cumulative %
Low: 1 to 9	118	31.8	31.8
Moderate: 10 to 14	73	19.7	51.5
High: 15 to 24	101	27.2	78.7
Excessive: 25+	79	21.3	100.0
Total	371	100.0	

The most striking aspect of Table 1 is the proportion of submissions that fell into the high (27.2% of the submissions) and excessive (21.3% of the submissions) categories. Whereas one might have expected the bulk of the submissions to fall into the low to moderate categories, the results show that high levels of plagiarism are relatively common in these journals. If we use a cut-off point of 9% for the similarity index, then it is evident that 68.2% of the submissions were above the cut-off point. It is noteworthy that 21.3% of the submissions contained an excessive amount of similarity.

We compared the 20% trimmed means of the similarity indices among the types of submissions. For submissions to journals in the DHET list (n=201), the trimmed mean=13.69 and Winsorised SD=6.15; for submissions to journals indexed in WoS (n=62), the trimmed mean=14.84 and the Winsorised SD=5.65; and for submissions to journals on the IBSS list (n=108), the trimmed mean=16.71 and the Winsorised SD=7.90. Robust ANOVA[26] showed that there were no statistically significant differences in the trimmed means across the different journal categories (F=2.2, df1=2, df2=96, p=0.11).

We also isolated the 10 journals with at least 20 submissions during the period under review (n=270 submissions). Across these journals the trimmed means of the similarity index ranged from 11.67 to 27.24. Robust ANOVA[26] revealed statistically significant differences in the trimmed means (F=2.6, df1=9, df2=62, p=0.012), with a medium effect size (ξ =0.40). Robust post-hoc tests[26] revealed that the differences could be traced to excessively high levels of similarity in one journal only (i.e. the journal with a trimmed mean similarity index of 27).

We also examined whether single versus multiple authorship played a role in the similarity index of an article. The difference in trimmed means between three categories of authorship – single (n=169, trimmed mean=15.75, Winsorised SD=6.76), dual (n=148, trimmed mean=15.42, Winsorised SD=7.08) and three or more authors (n=54, trimmed mean=10.65, Winsorised SD=4.28) – was statistically significant (F=9.6, df1=2, df2=115, p=0.0001) with a medium effect size (ξ =0.32). Robust post-hoc tests revealed that the similarity index of articles with three or more authors was significantly smaller than that of a single or dual authored article. No significant difference between single and dual authored articles was observed.

We complemented the three robust analyses of variance reported above with standard analyses of variance and non-parametric Kruskal-Wallis tests, both of which yielded a similar pattern of results as the robust tests.

Discussion

Our results indicate that there was extensive plagiarism in 19 South African management journals during the period under review, confirming the findings of other studies.[2,10-13] The findings also indicate that although one journal appeared to contain more plagiarised articles than the others, the problem of plagiarism existed across the board. The type of journal (i.e. whether it appears on the DHET, WoS or IBSS lists) was not a factor in the level of plagiarism. However, the findings indicated that articles submitted by three or more authors contained significantly less plagiarised material than did those articles submitted by a single or by dual authors. A possible explanation for this finding is that potential plagiarism can be more readily detected and corrected when several authors are involved. Conversely, a single author may more easily be able to hide plagiarised work.

We suggest that the intense pressure on universities and their academics to increase their research output within short time periods, plays a role in this problem. In addition, academics are rewarded in a variety of ways for such output[1,19], which can contribute to a culture of expedience and opportunism[18].

An additional problem of governance also emerges when one considers the payment of government subsidy to universities based on research output. If at least one author of an article is affiliated to a South African higher education institution, government will pay a research subsidy of ZAR120 000 per article, which may be proportionally split according to

the institutional affiliation of authors. Excluding those articles submitted by authors not affiliated to a South African higher education institution ($n=47$), it was estimated that government paid ZAR32 400 000 in subsidies for articles published in these 19 journals during the period under review. Given that 21.3% of these articles contained excessive plagiarism, a government subsidy of almost ZAR7 000 000 was paid for questionable publications.

The problem of human error in data coding always exists in studies such as this one, but we tried to minimise this risk by checking the data twice. The findings indicate the existence of plagiarism in the published articles we submitted for study. This finding has implications for government, for the universities to which the authors are affiliated and for the journals themselves.

The culture of research expediency that may be developing in academic institutions in order to increase subsidised research output can have long-term implications for the reputation of universities. Their contribution to society can also be compromised in terms of both the dissemination of new knowledge and the upholding of moral values transmitted through the students who graduate from these institutions and who can be expected to be influenced by unethical role models.[22] It is critical that the DHET engages with universities to devise measures to subsidise research output without inadvertently promoting the sacrificing of the quality of such research and inadvertently encouraging shortcuts, such as plagiarism. In a similar vein, internal rewards to academics should not be based on the quantity of research output without considering that a greater contribution could be made by researchers who publish fewer articles but in highly cited journals with greater stringency in requirements pertaining to quality. It is also recommended that, in order to preserve the reputation of journals, editors subject manuscripts to plagiarism detection through software programs and that the penalties for detected plagiarism be severe for authors.

It is recommended that future studies of this nature explore the extent of plagiarism (if any) in journals related to other disciplines in order to ascertain whether this problem is pervasive in other fields as well. In addition, a qualitative study of the experiences of journal editors in addressing plagiarism may throw some light on how the extent of plagiarism, noted in this study, managed to appear in articles that are deemed to contain original material for which the DHET remits subsidy to academic institutions.

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Authors' contributions

A.T. was the project leader and was responsible for the literature review and the data collection. G.P.d.B. conducted the data analysis. Both authors were involved in the interpretation of the data and the writing of the manuscript.

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The prevalence of free-living amoebae in a South African hospital water distribution system

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The purpose of this study was to investigate the occurrence of free-living amoebae in the water system of a teaching hospital in Johannesburg (South Africa). Water and biofilm samples were collected from the theatres, theatre sterilisation service unit, central sterilisation service unit and endoscopy/bronchoscopy unit. The samples were filtered and seeded on non-nutrient agar spread with heat-killed *Escherichia coli*. Of the 71 samples collected, 63 (88.7%) were positive for free-living amoeba. *Acanthamoeba* spp., *Balamuthia* spp. and *Hartmanella* spp. were identified by morphology. The presence of free-living amoeba in the hospital water network may be a potential health risk.

Introduction

Free-living amoebae (FLA) are unicellular protozoans that are widely distributed in aquatic environments, including constructed water systems such as hospital water systems and swimming pools.[1,2] Although FLA are useful as predators of bacteria, algae, viruses and fungi in the environment, some species – *Naegleria fowleri, Balamuthia mandrillaris, Sappinia pedata* and *Acanthamoeba* species – have been implicated in infections of the central nervous system, eye and skin.[3,4] Some FLA also allow the survival and growth of bacterial pathogens linked to nosocomial infections such as *Legionella pneumophila, Mycobacteria, Pseudomonas aerugionosa* and *Acinetobacter baumannii*. These bacteria are able to infect, resist the digestive process of FLA, survive, multiply and exit FLA. Intracellular bacteria within FLA cysts are protected from hostile environmental conditions such as the presence of biocides used in water treatment.[5,6] FLA may also serve as vehicles for transmission of waterborne bacterial pathogens, enabling them to spread and colonise hospital water systems. Furthermore, bacteria that infect FLA can undergo morphological modifications within FLA and become more resistant to antibiotics and better adapted to survival in macrophages.[7] Therefore the presence of FLA in hospital water supplies may present a potential health concern for medical personnel and immunocompromised patients.

Methods

From February to April 2014, 71 samples were collected from a teaching hospital in Johannesburg, South Africa. A total of 35 tap water samples, 30 tap swab samples and 6 showerhead swab samples were collected. The samples were collected from theatres ($n=41$), the theatre sterilisation service unit ($n=4$), the central sterilisation service unit ($n=8$) and the endoscopy/bronchoscopy unit ($n=18$). Temperature, pH, residual chlorine and total dissolved solids were measured at the site of collection.

Samples (500 mL) were concentrated by filtration using a 0.45-μm pore size cellulose nitrate membrane. Swabs were vortexed for 30 s in 10 mL of Page's amoeba saline in individual sterile tubes and the suspensions were concentrated by filtration. The filter membrane was placed upside down onto a non-nutrient agar overlaid with heat-killed *Escherichia coli*. The plate was then incubated aerobically at 32 °C and examined daily under a light microscope for the appearance of amoebal trophozoites and cysts. Amoebae were sub-cultured on fresh non-nutrient agar–*E. coli* plates three to four times and harvested by scraping the agar surface and re-suspending in 2 mL of Page's amoeba saline. The suspensions were inoculated in microtitre wells before being observed under an inverted microscope for the presence of amoebae species.

Results

Water temperatures ranged between 19.0 °C and 27.0 °C (mean=23.1 °C), pH ranged between 7.5 and 8.0 (mean=7.9), total dissolved solids ranged from 110 mg/L to 187 mg/L (mean=109 mg/L) and residual chlorine ranged from 0.04 mg/L to 0.17 mg/L (mean=0.08 mg/L). Free-living amoebae were observed in 63 (88.7%) of the water and biofilm samples that were analysed using amoebal culture techniques. Of the samples collected, amoebae were recovered from 31 (43.7%) of the water and 32 (45.1%) of the swab samples taken from taps and showerheads. Typical *Acanthamoeba* spp., *Balamuthia* spp. and *Hartmanella* spp. were observed in samples that were positive based on their morphology (Figure 1). Of the positive samples, 7 (11.3%) were *Acanthamoeba* species, 20 (32.3%) were *Hartmanella* species and 12 (19.4%) were *Balamuthia* species. The other 24 (38.7%) were not morphologically classified as belonging to any species (Table 1). Negative samples were from the theatre sterilisation service unit (2), the central sterilisation service unit (2), the endoscopy/bronchoscopy unit (2) and theatres (3).

Discussion

To our knowledge, this is the first report on the occurrence of FLA in a South African hospital water system. All physico-chemical parameters analysed in this study were within prescribed South African guidelines for drinking water.[8] Using amoebal enrichment, the prevalence of amoebae in this study – 88.7% – is higher than the prevalence found in previous studies done by Rohr et al.[9] and Lasheras et al.[10], in which 50% and 68.9% of samples, respectively, were positive for amoebae. In a study by Thomas et al.[11], amoebae were detected in 11.5% of water samples and 5.7% of taps and showerheads in a Swiss hospital, compared with the 43.7% of water and 43.7% of swab samples that were positive in this study. A more recent study by Ovrutsky et al.[1] recovered amoebae, mainly from biofilm, in 14.8% of hospital samples analysed. The higher prevalence of amoebae observed

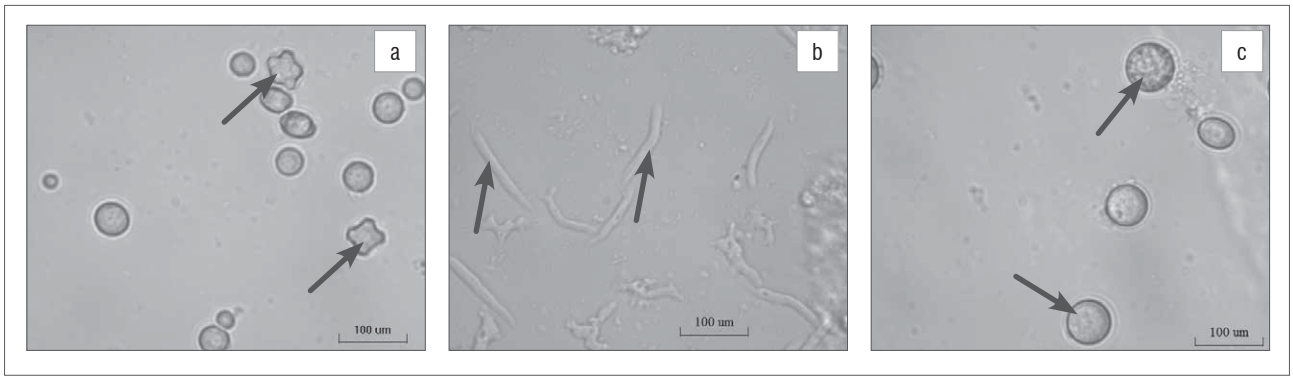

Figure 1: (a) *Acanthamoeba* cysts, (b) *Hartmanella* trophozoites and (c) *Balamuthia* cysts (all indicated by arrows) in water and biofilm samples from a hospital water system.

Table 1: Biodiversity of free-living amoeba from different sampling sites in a hospital water system

Sampling site	*Acanthamoeba* spp. (+) (%)	*Hartmanella* spp. (+) (%)	*Balamuthia* spp. (+) (%)	Other free-living amoeba† (+) (%)
Theatre and central sterilisation service units	3 (37.5)	3 (37.5)	0 (0)	2 (25.0)
Endoscopy/bronchoscopy unit	0 (0)	7 (43.8)	6 (37.5)	5 (31.3)
Theatre complex	4 (10.8)	10 (27.0)	6 (16.2)	17 (45.9)
Total	7 (11.3)	20 (32.3)	12 (19.4)	24 (38.7)

†*Not identified morphologically*

in our study could be a result of the relatively lower temperatures of cold water samples compared with the relatively high temperatures of hot water samples analysed in other studies. FLA with a low temperature tolerance would not survive the temperatures applicable in the other studies, which were above 45 °C.[1,9,10] High amoebae recovery rates may also be caused by increased water age in the distribution system, which encourages microbial re-growth.[12] Coşkun et al.[13] reports that 24 out of 33 detected FLA from 150 drinking water samples were of the genus *Hartmanella.* These data are consistent with our findings that 20 out of 63 detected FLA were *Hartmanella* spp., 7 were *Acanthamoeba* spp. and 12 were *Balamuthia* spp. (Table 1). The detection of FLA in this study indicates that the large population of immunocompromised individuals in this health-care setting might be exposed to these organisms. The pathogenic potential of *Acanthamoeba* spp. and *Balamuthia* spp. isolated in this study may play a significant role in hospital-acquired (nosocomial) infections in patients exposed through water systems. The presence of FLA may also present an added risk for a health-care setting, as FLA have been described as reservoirs and disseminators of opportunistic bacterial pathogens associated with water-related diseases. These pathogens have been implicated in nosocomial infections such as *Legionella pneumophila,* non-tuberculous mycobacteria, *Pseudomonas aeruginosa* and *Acinetobacter baumannii*.[14]

Information on the prevalence of FLA in hospital networks may help identify connections between environment and patient infections. This identification will assist physicians to diagnose and treat amoebae-related infections in immunocompromised individuals. In addition, infection control staff can take precautions to prevent exposure to patients based on reported FLA data. Future work will focus on the molecular analysis of FLA using the polymerase chain reaction and sequencing to confirm FLA identified by morphology and to detect the other 24 isolates not identified in this study. The association between FLA and potential nosocomial bacterial pathogens will also be determined.

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Authors' contributions

P.M. performed the experiments and wrote the manuscript. C.D. was the project leader, made conceptual contributions and assisted in the data analysis. T.G.B. made conceptual contributions and assisted in project design.

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