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Are Africa's school Biology syllabi decolonised?

South Africa's male homicide epidemic

Probable pangolin fossil trackway on Cape south coast

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Discussion Commentaries

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Research Letter

On the cover

A Temminck's pangolin (*Smutsia temminckii*). Helm and colleagues describe a Pleistocene probable pangolin trackway discovered east of Still Bay in the Western Cape Province of South Africa. All extant pangolin species are threatened with extinction.

Science, truth and power

If ever there was a time when it was clear that scientists, regardless of discipline, cannot ignore politics, it is now. At the moment of writing this piece, it is very unclear what the ultimate impact on science will be of developments in the USA, but clearly what is happening is not good for science.[1] To name but one example, following the transition of presidential leadership, now that Robert F. Kennedy Jr is heading Health and Human Services, and hence the US National Institutes of Health, all those who adhere to scientific methods and principles have reason to be alarmed. We should also be alarmed when social media companies stop fact-checking or actively promote false, and commonly anti-science, views and theories.

In our South African context, we are and should be aware of histories of exclusion from knowledge and science systems on the basis, for example, of race, gender, disability, class, and geographic location. Recognising the realities and challenges of historical and ongoing epistemic exclusion is not the same, as some allege, as saying that all knowledge is equal when it comes to solving problems confronting humanity and our planet. Evidence, contested though it often is and should be, matters. As Hannah Arendt[2] suggested many years ago, totalitarian and authoritarian regimes and actors are involved, not just in the spread of misinformation, but in an attack on the very distinction between truth and lies. Where there is no such distinction, we lose a key hallmark of science, which is the ability to revise beliefs and opinions in light of new evidence and circumstances. The present dangers facing science in our world today are both practical in terms of questions of funding and so on, but also existential. The survival of science itself as a way of understanding and engaging with the world depends on the search for reproducible truths about our reality.

It is not by chance that, amidst the flurry and chaos of crackdowns on science in the USA, the Trump administration reportedly is attempting to exert control on one of the most cited public health journals in the world, the *Mortality and Morbidity Weekly Report.*[3] This is a very serious matter. Some may believe that the *South African Journal of Science*, as the Journal of the Academy of Science of South Africa (ASSAf), funded by the public purse through the Department of Science, Technology and Innovation, is subject to editorial interference of the kind allegedly now being attempted with scholarly outputs in the USA.[4] In my time as Editor-in-Chief of this Journal, there have been no attempts at interference in editorial decisions, nor would these be tolerated.

It is part of the editorial responsibility of the Journal to create and maintain a space in which a range of views of concern to South African science and scientists can be aired in a spirit of open, collegial debate, and subject to the rigour of peer review, or, in the case of commentaries and other pieces in the front section of the Journal, assessment by experts. Though as a journal we are guided by our mission and vision and do not offer a free-for-all as a public square for all opinions, we cannot and do not restrict publication only to those who share our own personal views on science, politics, and the relationship between the two.

Open debate on difficult issues is something we should encourage. It is partly for this reason that periodically we host Discussion Series as fora for science-based discussions on issues affecting scientists and academics in South Africa and further afield – issues which have implications for society. One question which has led to a great deal of debate and discussion in South African higher institutions has been that of how to respond, if at all, to events in Gaza following 7 October 2023. Linked to this question are more general and fundamental questions about academic boycotts and their effects, and about, again, the relationship between science and politics – an issue taken up in many and diverse ways in this Journal throughout its 120 years. We had been planning in 2024 to call for discussions on the Israeli–Palestinian conflict when we received a submission from Nithaya Chetty. We then decided that, were this piece to be accepted after the inputs of expert readers, this would form the basis for a discussion on the issues at hand. Subsequently, we went through a process of soliciting responses to Chetty's Commentary, and we now publish these alongside Chetty's contribution. We approached many more academics with requests to respond than those who elected to submit responses; we also tried our best to approach academics who, we believed, would speak from a range of different perspectives. We are very grateful indeed to all the authors who took the trouble to write responses, and we are gratified by the range of ways in which they engaged. It is also the case, though, that the responses we received cannot be said to be representative in any way of all the views academics hold about the issues at stake. In correspondence we received from people we approached, there were views expressed that it would have been preferable to have made an open call for commentaries rather than soliciting responses specifically to the Chetty Commentary from people we invited. An open call had been our original intention, and we agree that, although there were advantages to our using Chetty's Commentary (which we were grateful to receive) as a point of departure to focus debate, there were also drawbacks to our decision. Given this, though it is always our policy and practice to welcome debate and engagement with anything we publish, and with any of our practices, it is important for us to emphasise that we do not believe the debate we host in these pages is settled or closed. Please do send us your responses, and we will consider these for future publication.

Recently, ASSAf has communicated that it will be organising seminars and debates on issues concerning science and armed conflict. Our publication of the Commentary by Chetty and the responses we received will, we hope, contribute to debate and be helpful in discussions going forward. Finally, we emphasise that none of the decisions made in this regard was at ASSAf's behest or with ASSAf's involvement. As is the case with all articles published in the Journal, neither ASSAf, as the publisher, nor the editors accept responsibility for statements made by the authors.

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Should our universities respond to geopolitical conflicts around the world?

Significance:

The Israeli–Palestinian conflict has given rise to strong campus protests globally, forcing many universities to meander around this difficult political terrain. While some argue this as a human rights issue, more careful consideration reveals a long-standing, controversial political dispute with extremism on both sides. Universities are advised not to take sides in such divisive conflicts that can lead to unintended consequences, particularly when strong opposing views exist on campus. This Commentary urges universities to proceed cautiously, resisting pressure to make official statements on the matter, to preserve academic integrity in the face of polarising global events, and to create an environment where differing viewpoints can be heard.

The Israeli–Palestinian matter is a long-standing, controversial political matter; there are many different political viewpoints in South Africa, and certainly within our universities. In this Commentary, I want to present a view that I believe is in the best interests of our South African universities, not in an authoritative manner, but hopefully in an empathetic way that recognises that there are many different viewpoints on this, and I wish to do this within the framework of good governance principles.

The phrase 'good governance principles' is used a great deal today, but I am not sure that we have a common understanding of what this means in a university setting, and I want to explore this in the context of the conflict in Gaza.

University systems require continual nurturing. Universities are fragile[1] and can break[2] easily. University systems are not perfect, but we are doomed if we stop aspiring to good governance principles.

'Principles' refer to the founding ideas that we hold dear, that guide us, especially in times of difficulty – a compass in our time of need. One of the enduring principles by which all good universities are governed is that they are governed in a principled way.

The principles that I refer to speak less to the legislative and legal framework in which we work, which, in the case of our universities, includes the *Higher Education Act*[3], the university statutes, the national Constitution[4], the Bill of Rights and so on. This is taken as a given, naturally. The principles that I refer to speak more to what we value as our university, and invariably these principles impinge on the policies and procedures that we set for ourselves, and ultimately the decisions that we make as a collective.

A necessary part of good governance is the soundness of our decision-making processes. How decisions are made, through consensus or through voting, how decisions are recorded and how they are implemented and monitored are an important part of our administrative processes at universities. Universities need good administrators, and good administrative systems.

And as universities are principally a place of ideas, principles largely speak to the intellectual culture of the place.

At any one time, the landmark decisions that we make should strive to be precedent-setting, should stand the test of time, and be timeless in a sense. We need to always think about what our key decisions mean for the future, until a new cataclysmic change happens when we might need to revisit the principles that we set for ourselves.

This is how evolution[5] takes place, with periods of stability followed by short bursts of cataclysmic change when the entire ecosystem needs to readjust. At our universities in South Africa, and quite possibly around the world, the Gaza matter could well be one such time when we experience cataclysmic change. With cataclysmic change usually comes fallout, and we need to be cognisant of this at our universities as we meander through this.

At any one time, we can only do as well as we can with who we are collectively. A sculptor can only do as well as the quality of the clay that they have in front of them. We, as an academy, can only make critical decisions that reflect collectively on who we are based on our own integrated values and understandings of where we are now.

If we are a band of racists, then no matter how hard we might try to mask that, our decisions will eventually reflect our racist attitudes. This is why diversity is important at our universities. Universities thrive on a diversity of viewpoints, and so imposing a hegemonic view from the top management often leads to problems in a university setting.

We should avoid making populist decisions or 'jumping on the bandwagon'. Just because some of our competitor universities have made a particular decision should not automatically mean that we at our universities must follow suit. Our leading institutions must be prepared to take the high road, even if it is a lonely road.

It is not about 'the whataboutery'[6], a term that has been used frequently recently, but about taking a principled, long-term approach, about making precedent-setting decisions that stand the test of time, that attempt to address future such situations, both real and hypothetical.

There is no blueprint for what these principles are. They are not in a textbook, nor can they be searched on the Internet. These are established through critical dialogue and debate at our institutions. These principles speak to the very soul of our universities.

I refer to *good* governance principles as this speaks to us as an academic cohort, especially as an academic leadership, always striving for the good of our institutions. We should always think about how we can do good for our universities, for now and for the future. And this is especially important now when we look around and see so many failing institutions around the country.

Universities releasing an official statement on the Israeli–Palestinian matter is not an academic freedom matter. Even though academic freedom[7] is a right accorded to academics, a special group of individuals in society, with important rights, responsibilities and obligations, it is practised on an individual basis. We practice academic freedom as independent critical public voices. It goes against the principles of academic freedom for the university to impose a hegemonic view from the top of an essentially political matter when we have differing views on this amongst staff and students.

By university, I mean the Council, the Senior Executive Committee, the University Forum, the University Senate, the faculties, schools, institutes, the Alumni Association, and so on.

Every citizen has freedom of expression[7] and can speak their minds freely, even with little adherence to the truth, so long as they do not instil hatred or violence. However, academics are obliged to speak critically about their subject and more generally about societal matters and to base their arguments on verifiable evidence. And I encourage academics to speak up on this matter in their individual capacities.

Reputation matters a great deal at universities, and academics pride themselves on their standing in the eyes of their peers. And if an academic becomes known for being less than reliable with the truth, being less critical and more political, they will be denigrated by their peers, and this is harsh enough.

And so, when we bring an essentially political matter into a university discussion and force a decision when there is little consensus, we create unnecessary tensions amongst ourselves, and this in itself is a lesson to be learnt.

At some other university in the world where there is clear bias for one or other position in this decades-long conflict in the Middle East, I can see how it can be straightforward to pass a university-wide resolution that condemns one side or the other.

But at many of our South African universities, we know that there is little consensus on this issue. I do not think that there is anything wrong with airing a geopolitical matter, especially one that is as contentious as this Middle Eastern conflict, but for the university to officially choose sides when there are clearly different political viewpoints across the university is problematic and sets us up for failure as a university. We should strive to be inclusive of differing political viewpoints on this matter at our universities.

Yes, this is, of course, a human rights issue, and a horrific one at that, but if we take only a little step back to ask how this has come about, we enter a slippery political slope that has no end, even if we go back decades if not centuries.

To be clear, I have my own personal political views on this, based on my own understanding of the history, my own conscience, my own prejudices, my own emotions, my own ideas, however untested those might be, and my own hopes and aspirations for that part of the world. However, it would be remiss of me to impose these views on the university, through a vote, for example, when I fully know that there are differing, and probably equally valid, views on this. Making decisions on this goes way beyond the remit of the university.

No matter how hard the university may try to couch this in humanitarian terms, we will invariably be making a political statement one way or another. We should avoid playing into the hands of extremists on both sides.

Declaring upfront that we are not anti-Semitic, or not Islamophobic, or not anti-Israel, or not anti-Palestine is a sign that we know at the outset that we could be interpreted differently. If there is potential for misinterpretation of what we say in an environment that is highly polarised, then you can assume that you will be misinterpreted. So, let us be very careful of what we say officially as a university.

We should be wary of taking sides in what is a known long-standing and controversial political conflict that will clearly exacerbate divisions at our universities, no matter our own personal political convictions. Some individuals are so invested in the political outcome of this conflict that they cannot see the folly of their ways. We should be careful about using the university to fight our own personal political battles.

If we comment on one major human rights issue, then we should make every effort to comment on essentially every other major human rights catastrophe, which is hopelessly untenable to do. I wish to stress that I do not advocate this on practical grounds, but if we want to become a university that speaks up on human rights[8] matters, let us do this consistently and sincerely. That would be taking a principled approach.

Showing but a cursory interest in the conflicts in Sudan and the Democratic Republic of Congo now is a feeble attempt to retrofit our concerns there, when there has previously been no genuine interest at many of our universities. This comes across as being insensitive and insincere, and very much an afterthought.

To the best of my knowledge, many of our South African universities have never previously established a principle of getting involved in such conflicts. But this does not mean that we should not for the future. If this is the university that we want to be, then let us decide how we can do this in a more deliberate way rather than in an *ad hoc* manner where we are selective about which issues we want to take up.

Our aim should not be to maintain unity at our universities over the Israeli–Palestinian matter, but we should not be driving disunity either. Universities are argumentative places, where individuals should engage with each other, hopefully respectfully, on topics on which they have strong disagreement. Our universities should facilitate an environment where this can happen. Our task as a university is to nurture this environment for constructive disagreements to take place, not to take sides in this, or to exacerbate divisions that we know already exist.

The difficulty with having a conversation about this conflict is that no matter what one says, one is often and very quickly put into one camp or another, and so it is hard to have a rational discussion. This environment has become polarised, which makes finding a lasting solution difficult.

We need to be careful about thinking about this in binary form. I am not in favour of our universities releasing any statement, but it should not be concluded that I am in one camp or the other.

The Academy of Science of South Africa[9] (ASSAf) has only recently developed a set of guidelines for putting out statements of this nature in response to the Gaza conflict. ASSAf has recognised different viewpoints amongst its membership and has exercised caution in terms of any perceived entry into the political area, which I think is wise.

It has condemned in strong terms all human rights violations and conflicts around the world without singling any out, so they have issued a general and timeless statement. ASSAf also has appointed a panel of experts to lead a consultative process to advise further. Perhaps our universities can learn from this?

A general and timeless statement that generally condemns all human rights violations and calls for peaceful dialogue in times of conflict would suit our universities well and enable us to focus on our core mission. Or we could develop a set of guidelines that set out clearly under what circumstances our universities can issue a public statement on a geopolitical matter, and then act conscientiously and not preferentially in this regard.

I believe institutions should refrain from making statements of a geopolitical nature if (1) there is little consensus, meaning general agreement, amongst staff and students, or if (2) these are going to cause unnecessary division at the university, or if (3) these are going to bring harm to the university, or if (4) these have little bearing on the operations of the university, or if (5) there is no feasible pathway to impact, not the negative impact that I see internal to many universities around the world. These five guidelines

that I have listed suggest that there is little basis for a university to issue an official statement on the crisis in Gaza.

If all five of these criteria are met, then we should be extremely cautious about going ahead with any public statement. However, for some other geopolitical issue, if it can be established that some but not all these criteria are met, then it becomes potentially possible for the university to put out a statement, but then it will still, in my view, need to proceed cautiously.

When there are extreme challenges at a university, I think that two things need to happen. We should go back to a principled approach, which I always find helpful as a dean of science, and we should not exacerbate divisions. Bringing people together, even those with differing viewpoints, to discuss and debate in a respectful and collegial way is an essential part of what universities are. We should not simply mimic what happens elsewhere. And we should especially be wary of forcing a decision on an essentially political matter. This is not a routine administrative matter where we absolutely must decide. For if we do, this will be interpreted by the outside as our universities taking sides in a decades-long conflict.

Let me close on a somewhat philosophical note. We see this extreme polarisation, not just amongst the chief protagonists in the Middle East, but also around the world. Rather than bludgeon our way through this, could we at our universities perhaps try a new experiment? Could we try to create an environment where the different voices do not just co-exist and grudgingly tolerate each other but where they come together to discuss and debate ways to a more viable future? And maybe that could plant a new seed of hope in that part of the world? Just maybe it will.

Here, the humanities disciplines can play a more constructive role, not just in this conversation but also in many of the challenges facing humanity on a global scale. But to start with, there needs to be a clearer distinction between political discourse and intellectual discourse, between activism and action. More and more now, I see a blurring of these lines in a university setting, often with catastrophic consequences. The principles of academic discourse are very different from those of political discourse, and if we cannot distinguish[10] between these very carefully, it will spell the end of our universities as we know them.

If any university wishes to make a more meaningful contribution to this discussion, then it can, through its proper decision-making processes, perhaps consider establishing a 'Centre for Israel and Palestine'[11] to lead a more rational discourse on how we can imagine a better future there.

Historically, our university Academic Freedom Committees played an important role during the apartheid era, and I would like to see us go back to regular annual lectures on academic freedom at our South African universities. We should not wait for a crisis before we remind ourselves of the role and function of the university and the enduring principles by which all good universities are governed, despite these ever-changing times.

Declarations

I am the Dean of Science at the University of the Witwatersrand. I write in my personal capacity and my views do not necessarily represent the views of my institution or member organisations. The initial draft was submitted to SAJS, which is published by ASSAf, on 5 August 2024, well before I was elected to the ASSAf Council on 7 October 2024. I have no competing interests to declare. I have no AI or LLM use to declare.

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Yes, our universities should take a stand against genocide

Significance:

This article is a response to a perspective that universities should be neutral in the context of genocide. We argue that the academy is not a value-free space and that intellectual pursuits must be informed by a commitment to human rights. As such, universities must be spaces of critical pedagogy and engaged scholarship, where teaching and learning must support the quest for better, egalitarian, and more just societies. It is therefore incumbent on tertiary institutions to take a clear stand against the genocide occurring in Gaza and call for a just peace in Palestine.

It is indisputable that the university is a contested space where epistemologies, ideas, ideologies, cultures and values clash, usually collegially but sometimes conflictually. Nor are science or academia value-neutral. The history of science and knowledge production is replete with examples of how both were and are used to promote specific ideologies of racism, colonialism and apartheid. The university is also a site of the reproduction of ideology and power, as was the case at Stellenbosch University vis a vis the Afrikaaner nationalist agenda. Some dominant and hegemonic trends have been challenged in South African universities through the Fallist movement, the imperative for transformation, and the decolonial turn. It is only those steeped in dominant hegemonic cultures, power structures and narratives who view the university as a neutral space, outside of society and its complex challenges, and uninfluenced by power, both manifest and hidden.

Coming from South Africa – a country that has experienced the brutal power of settler-colonialism, capitalism and apartheid – Professor Chetty's Commentary, entitled 'Should our universities respond to geopolitical conflicts around the world?'[1], should have greater insight into the workings of power in various institutions inside and outside the state, including universities. Prior to 1994, South African universities as sites of state hegemony were challenged by the anti-apartheid movement – faculty, students, staff, community and workers. For example, the University of the Western Cape, under the leadership of Professor Jakes Gerwel, directly challenged the state by branding his institution as the "home of the left", a deeply political and courageous act. Universities and academics across the globe supported the struggle against apartheid, either through participation in the academic boycott or through boycotts and divestments. Tertiary institutions were contested spaces, with faculty holding differing views on boycotts, academic freedom, and the role of education as a tool for liberation. Universities took political positions – some progressive, others deeply reactionary. In the democratic era, the vision and mission statements of many universities extol the virtues of social justice, human rights, and societal benefit. For example, the University of Cape Town, in its 2030 vision statement, bravely proclaims its transformative purpose to "unleash human potential to create a fair and just society". If not given effect to in any meaningful way, such statements ring hollow and are tantamount to virtue signalling, absent of any real commitment to social justice.

As Professor Saleem Badat has argued, the academy is not a value-free space and intellectual pursuits should be informed by a commitment to human rights.[2] Rather than places of neutrality, universities in all places should be front and centre in support of human rights and academic freedom, and consequently should stand in solidarity with Palestinian universities, scholars and students. They should be spaces of critical pedagogy where power structures are challenged rather than reinforced and where teaching, learning, and research, all core functions of the university, support the struggle for non-racialism, non-sexism and social justice.

Aside from personal political choices, our experiences are rooted in political circumstances, systems of power and experiences of discrimination. The privilege of being 'apolitical' is only afforded to some. Black people's experiences have been shaped by their position as an underclass, while white people's experiences are shaped by their position as an overclass. This positionality grants the latter power to say that politics is not important because they have been its constant beneficiaries, but not the former who have been its victims – victims of science, medicine, sociology, politics and demography, and victims of access and language, all of which were designed and used to exclude and oppress them.

Genocide as a human rights matter

Professor Chetty's position is betrayed when he states that the Gaza genocide is a "political matter" being brought into a university discussion, "bringing unnecessary tension amongst ourselves". It is surely incontrovertible that mass murder, including the deliberate annihilation of children and adult non-combatants, scholasticide, epistemicide, the destruction of homes, hospitals, schools, universities, and cemeteries, denial of medical care, and starvation, are war crimes. In terms of international humanitarian law, these crimes are far beyond what Professor Chetty refers to as a "political conflict". Francesca Albanese, the United Nations Special Rapporteur on the Occupied Palestinian Territories, stated in March 2024 that "there are reasonable grounds to believe that the threshold indicating the commission of the crime of genocide…has been met"[3]. American-Israeli historian and genocide expert Omer Bartov, himself a former Israeli military commander, has stated that Israel's actions in Gaza are "a combination of genocidal action, ethnic cleansing and annexation of the Gaza Strip"[4]. The International Court of Justice has ruled that Israel should take steps to prevent genocide from occurring in Gaza and should prevent and punish incitement to commit genocide.[5] By all accounts, the events that we have witnessed in Gaza for over a year now should be called for what they are – beyond war crimes, it is a genocide.

Genocide is a human rights matter on which universities as institutions of learning must take a clear stand. This is particularly important as every university, institution of learning, and cultural centre has been deliberately destroyed

in Gaza by Israel and professors and teachers have been murdered en masse. It is incumbent on scholars around the world to stand in solidarity with those colleagues who have either been killed or are at risk of annihilation.

Whataboutism

Professor Chetty raises the usual trope of whataboutism – Sudan, Congo, etc. Whataboutism is a rhetorical technique that deflects attention away from the genocide being perpetrated in Gaza. Yet, implicit in this objection is an acceptance, rather than a denial, of the fact that Israel is committing crimes against humanity. He states that "if we comment on one major human rights issue, then we should make every effort to comment on essentially every other major human rights catastrophe"[1]. This is a false assertion that, unless we take a position on every issue, we cannot take a position on any issue, however egregious it may be. Further, neither Professor Chetty nor supporters of Israel have any abiding interest in supporting the people of the Congo or Sudan, whom they simply instrumentalise as useful black bodies to justify genocide. By the logic of whataboutism, no university should have made a statement against apartheid because there were other injustices taking place around the world.

In a political context, one does not surrender because there is complexity, or because a minefield of complexity has been manufactured to confuse, obfuscate, and create despair and thus apathy, so that the truth can never be determined. While it is incumbent on academics to seek the truth, it is not possible to attend to all war crimes occurring around the globe. The Gaza genocide is front and centre on our screens every day, aided and abetted by Western nations, most prominently the USA, UK and Germany, and by Israeli universities.

For public institutions to be silent or neutral on the matter of genocide amounts to complicity. Similarly, for Professor Chetty to suggest that a public stand against crimes against humanity is "populist" or "jumping on the bandwagon" is obscene and morally unconscionable. He seems to suggest that the "high road" is silence and apathy. Further, condemning genocide has nothing to do with "competitor universities". It has everything to do with the institutional culture of our tertiary institutions – a culture of standing firm against war crimes and genocide and in support of human rights, and upholding the values of freedom, dignity, and the right to life. Imagine if this were Germany in 1935, with a holocaust being inflicted on victims, or the British concentration camps in South Africa in 1900, or the German genocide of the Herero and Nama people in 1904. It is doubtful that Professor Chetty would be making the same point about silence. Whataboutism can cut both ways.

There are bound to be differing views at any university, but if there are indeed "differing views" about whether genocide or mass starvation of a population as an instrument of war are morally acceptable practices, as Professor Chetty seems to suggest, then we require a very deep rethink about our values, our morality and our ethics. In fact, to say that "we need to be careful about thinking about this in binary form" or there can be "little consensus" on this matter is outrageous. This is very much a binary matter – no excuse or apologist can find a suitable morality for the deliberate murder of 17 000 children in Gaza. There is a simple binary choice: either silence and thus complicity with genocide, or condemnation.

Any honest historical text will expose the current genocide as part of a continuing ethnic cleansing campaign against the Palestinian people, perpetrated by the ethnoreligious supremacist Israeli state since 1948.[6] To suggest that activists against the genocide are using the university to "fight our own personal political battles" amounts to ignorance of history and betrays a deep right-wing personal predilection. Activist scholars are guided by the lodestars of human rights, freedom and justice.

The loud silence from the Academy of Science of South Africa

Professor Chetty suggests that we learn from the stance taken by the Academy of Science of South Africa (ASSAf). However, a year and a half into the genocide, ASSAf has not yet issued a statement on the matter. In its silence, ASSAf has failed the test of moral clarity.

The Gaza genocide is not a human drama in which two opposing sides represented by standing armies are engaged in a conflict. The Palestinian people are defenceless against the military might of the Israeli state, a nuclear power that is intent on mass murder. This is not simply a matter of two sides in conflict, but a question of enduring state-sanctioned violence and the erasure of Palestinian society in Gaza, the West Bank and East Jerusalem and in parts of Israel. What is going on is the destruction of Palestinian life, society, history, knowledge, culture, and infrastructure at the hands of Israel, the most powerful military force in the region.

As the highest academic decision-making body of the university, and one central in its moral and ethical position, it is critical for the senate at each university to adopt a motion condemning genocide and to call, at a minimum, for a ceasefire in Gaza. Such an act is far more meaningful than for individual members of the senate to sign a statement in their individual capacity.

Funding: The lifeblood of universities

Universities frequently invoke the risk of donor flight should they take a position against the genocide, risking funding for research and students in need. While this may be a legitimate concern, the critical question is: what is the price of a university's values? If the moral and ethical values of donors do not align with the values of the university, demanding that the university complies with their beliefs, it poses a serious threat to institutional autonomy and academic freedom. It is deeply concerning how accepted the choice of silencing has become in the face of a loss of funding. This is not an abstraction, as we have in recent months witnessed how power and the powerful have bullied universities across the world, including in South Africa.

The case of Gaza will have special resonance when history is written about our period. It will be described as the most televised genocide in human history, with active complicity by major Western powers, consent manufactured by the media, and a situation where perpetrators are cast as victims and victims as deserving of death. Academics too will be held to account. Nowhere in history was there such a perversion of reality – Baudrillard's hyper-reality played out in real time. We actually agree with Professor Chetty that we need to constantly think about what our key decisions mean for the future, but for a different reason. Future generations will judge our institutions for their silence when people are being murdered in their tens of thousands in real time.

Declarations

Our views are our own and do not necessarily represent the views of our institutions or member organisations. We have no competing interests to declare. We have no AI or LLM use to declare. Both authors read and approved the final version.

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Is silence in the face of global injustice in the "best interests" of South African universities?

Significance:

Invited to respond, we write here not to rebut every argument advanced in the provocation piece 'Should our universities respond to geopolitical conflicts around the world?'. This would presuppose alignment with the issues raised as the only ones germane to questions of academic neutrality in the face of injustice of genocidal proportions. Rather, we probe assumptions we consider central to the ethical responsibilities of South African universities when faced with immense human suffering. Rather, we ask: what is the cost of silence to our society and academic communities if, as once beneficiaries of global outrage and action against apartheid, we now comfortably look on so as not to be seen as taking sides?

In a recent Daily Maverick piece, University of Cape Town (UCT) Law Professor Pierre de Vos warned against turning discussions about "the appropriate role and function of a university in a neoliberal society, into disputes about procedures or the purpose of the decision (in the form of rationality reviews)"[1]. De Vos was responding to litigation lodged by his UCT colleague against that University Council's decision in June 2024 to endorse two Senate resolutions on the Gaza conflict, challenging that institution's moral position about the role of the university in society. To us, this warning can equally apply to the short-sighted and avoidant stance outlined in the Commentary 'Should our universities respond to geopolitical conflicts around the world?'[2]

Public universities in South Africa have an "obligation to serve the public good"[3-5]. Although the "public good" can and should be debated, whatever that constitutes surely includes an obligation by academics to align with the human rights framework contained in our Constitution's Bill of Rights[5] and, similarly, to be guided by the aspirations of the 1948 Universal Declaration of Human Rights[6]. Within our South African context, commitment to universal human values has never been axiomatic; democracy and its attendant values of equality, freedom and dignity were hard won. Emerging from decades of a racialised educational system, former 'white' universities had direct roots in South Africa's colonial history and were at the forefront of the civilising mission that perceived and treated Indigenous inhabitants of South Africa as less than human and unworthy of the dignity endowed on white European settlers.[7] These legacies endure. Many black colleagues within the academy actively remember what it was like to apply for ministerial permission to study at these universities; when educational exposure and opportunities for black students were separate and unequal; when differential wages for the same work were legislated based on race; and when social spaces were segregated. Further, and most egregiously, they remember when engaging with the politics of liberation was perceived as state treason, leading to the deaths of inter alia Steve Biko, Victoria and Griffiths Mxkenge, Abu Baker Asvat, Fabian and Florence Ribeiro, David Webster, Neil Aggett and others[8-11], as well as to the detention and banning of thousands of students and some university academics.

This history and ongoing struggle to restore humanity to the victims of coloniality within higher education must be borne in mind when we examine events in Palestine. In April 2024, the United Nations Office of the High Commissioner for Human Rights (OHCHR) warned about the "scholasticide" in Gaza, the "systemic obliteration of education through the arrest, detention or killing of teachers, students and staff, and the destruction of educational infrastructure" including the organised destruction of universities, libraries (including the Central Archive of Gaza), heritage sites, hospitals and scientific facilities by Israeli Defence Forces[12], as well as the killing of 119 university academics since October 2023[13]. The West Bank has also not escaped incursions with damage to seven universities and colleges.[13] The United Nations Educational, Scientific and Cultural Organization (UNESCO) has expressed "deep concern" following its damage assessment of 64 cultural properties (historical buildings, religious sites and museums).[14]

In early 2023, the Academy of Science of South Africa (ASSAf) released a *Guideline* to consider the "impact [of conflict] on scientific infrastructure, including scientific collections, laboratories, libraries, digital resources, or communications" before issuing a position statement.[15] Despite a recent ASSAf Council decision not to release any statement about the scientific impact of war in Gaza, we argue that the bombardment of academic, cultural, medical and educational infrastructure in Palestine indeed meets the organisation's own criteria for action.

To be clear, other ongoing global conflicts are equally deserving of condemnation. Rather than avoidance on the grounds of potential divisiveness, institutional and organisational failure to respond appropriately to other scholasticides such as those in Afghanistan, Sudan, Ukraine and elsewhere[16-19] necessitates institutional introspection and conscious self-study. What should be questioned is not the position taken by some South African higher educational institutions denouncing the ongoing scholasticide in Gaza but rather the insistence and defence of silence by others on the grounds of "academic neutrality". To do so is to claim that public institutions of higher education in South Africa can afford to be non-committal in matters of life and death.

Furthermore, the practice of science is never apolitical, although the myth of empiricism would have us believe otherwise. All our endeavours are embedded in a much larger social context, forcing us to balance our freedoms to teach, research and pursue avenues of scholarly enquiry, with our ethical responsibilities. Accordingly, it becomes our moral duty to call out all attacks on the academy and the pursuit of knowledge itself, wherever this may occur, and most certainly in the context of the "plausible genocide"[20] taking place in Gaza. All people's cultural

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and historical memories are sacrosanct, and the erasure of the means to educate, research and preserve historical records is as grievous as other war crimes.

At the time of writing this, 6 of the 26 South African public universities (Nelson Mandela University, University of Fort Hare, University of the Western Cape, University of South Africa, University of Venda and University of Cape Town), have, in various ways, resolved at the institutional level to sever ties with Israeli institutions, either in line with the Palestinian Campaign for the Academic and Cultural Boycott of Israel (PACBI) guidelines[21] or other criteria. Such resolutions are not without precedent; and we must recall that South African institutions were on the receiving end of similar isolation during apartheid, when the United Nations, pursuant to declaring apartheid a crime against humanity, issued its resolution to "cease any cultural and academic collaboration with South Africa"[22].

To oppose intolerable human rights violations is not to jump on some "bandwagon", but rather to recognise that academic institutions in Israel operate in direct service[23] to a state and/or its military whose policies and actions are 'beyond the pale', as has been found by the International Court of Justice (ICJ)[24]. Furthermore, scholars at Israeli universities have themselves called for solidarity against the censorship and assault on freedom of thought and expression at the hands of the Israeli state.[25-27]

We acknowledge that taking a position on conflict is not without consequence. Internationally, particularly in the USA, Europe and Canada, university presidents endured severe scrutiny and at times forced resignations when previously issued statements and/or unending student protests did not align with powerful interests. The subsequent chilling effects on freedom of expression have been well documented.[28] Israeli scholars are speaking out about the isolation their universities are facing, with fewer foreign students and exchanges with the outside world; and, as one Israeli academic put it, "If your science is not connected to international science, if you're not in dialogue and collaboration with scholars and students around the world, then science cannot happen"[29].

The costs and consequences of taking a principled stand on Israel's relentless war in Palestine must moreover be weighed against the cost of inaction. What is the price of South Africa's higher education institutional conscience? What happens if the academy loses its critical stance, shies away from controversy and dances to the tune of the powerful who wield immense financial and cultural capital?

In the case of a South African boycott and/or selective severing of institutional and individual ties with Israel, there most certainly will be local and international backlash. This is the inevitable 'cost' of exercising academic freedom. Notwithstanding its recent submission to the ICJ, South African institutions have long-established and productive relationships with the higher education sector in Israel. Alumni and donors are threatening to and, in some instances, have already withdrawn funding and other forms of support because of such positions. Confronting this requires robust and nuanced debate rather than mere capitulation to economic manipulation.

The question then turns pragmatic. Debates on institutional values, rights and responsibilities are often polarising; however, rather than failing to engage, we must develop the skills to contain these while remaining true to our core mandate. With universities under relentless pressures of the fiscus and creeping managerialism[30], space to connect with the myriad wicked problems of our times is limited, especially as this requires transdisciplinary approaches that fit poorly with our disciplinary silos. Nevertheless, the nettle must be grasped, not just for the sake of academic integrity but for the continued relevance of universities as sites of critical inquiry in South African society.

Declarations

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The illusion of university neutrality in the face of global conflicts

Significance:

Our universities can play a critical role in demonstrating *how* we can respond to global conflicts. Universities are, by their very nature, political and not neutral. Academic freedom is an *institutional* commitment to the defence of the principle in the public arena. A university that stays silent in the face of a staggering loss of human life would have to revisit their commitment to social justice.

I appreciate the reasoned approach offered by Professor Chetty, a dean of science, in the Commentary entitled 'Should our universities respond to geopolitical conflicts around the world?'[1], as his position invites engagement on an explosive issue on campuses: the horrendous conflict in the Middle East. Though admittedly difficult, I will respond on the terms of the invitation and start with what we can agree on.

Agreed, the university is principally a place of ideas. Our responses to the tragedy of Gaza and surrounds should be thought through rather than impulsive. A principled approach is vital, and this should come through critical dialogue and reasoned debate in this special kind of institution – the university. And yes, the academic community has been relatively silent on other conflicts, such as those unfolding in the Sudan and the DRC, but less so on the conflict in the Palestinian territories.

That said, there are some foundational weaknesses in the arguments tabled. First, to call responses to Gaza "an essentially political matter [brought] into a university discussion" in ways that "force a decision when there is little consensus" is disingenuous. Universities are, by their very nature, political. We decide who comes in and who is left out. We choose the content of curricula, and, from a universe of knowledge, we select what counts as official knowledge and what does not. We decide every year in our institutional budgets what is worth funding and what will be overlooked for financial support; there are core and ancillary budgets. In their essence, universities at home and abroad are inescapably political institutions; ask historians like Paul Maylam[2], who has gifted us a brilliant account of the historiography of South African universities.

Furthermore, the argument that "academic freedom is practised on an individual basis" is conceptually flawed. As the foremost South African scholar on the subject remarked, such a position "[confuses] the individual right to free speech with the institutional practice of academic freedom" (Higgins J, personal communication, 21 November 2024). Academic freedom lectures, birthed in the furnace of apartheid, remain an *institutional* commitment to the defence of the principle in the public arena.

Which brings me to the elephant in the room. If one applied, straightforwardly, Chetty's principles of good governance to the evil of apartheid, they would sound rather hollow. Imagine taking positions on what the United Nations called "a crime against humanity" by seeking "equally valid views" or straining ourselves "not to be driving disunity" among our academic colleagues, or that making a political statement would amount to "playing into the hands of extremists on both sides". Of course those would be ridiculous standpoints given the nature of the crime in question.

I would make a counterargument, which is that a university that says nothing in the face of genocide played out right before our eyes has lost all credibility in the face of its students, staff and communities. The prestigious medical journal *Lancet* estimates that more than 186 000 people have been killed – a figure that includes indirect deaths through starvation. More than 12 000 children have been blown to death, with more than 25 000 of them having lost a parent or being orphaned, apart from thousands more without limbs. A university that stays silent in the face of such a staggering loss of human life would have to revisit their mission statements that often include commitments to social justice.

Institutional neutrality, as some have argued, is a moot point precisely because the modern university has never been neutral on the most significant moral issues of the day, whether it is the protection of a supposed meritocracy in admissions or the US investment of federal government dollars in engineering departments for military purposes; we make political choices all the time.

Commenting on the neutrality principle, John Higgins is again persuasive:

> *The neutrality principle seeks to make the university a space outside of politics.*
>
> Yet,
>
> *In practice, as the politics of academic freedom in apartheid South Africa showed … all too often this principle can be the cover for a vehemently partial and politicized response. Neutrality can be action with consequences.* (Personal communication, 21 November 2024)

Of course, there are conflicts the world over. Yet even if institutional restraint prevents a university from being sucked into every global crisis, I agree with Janet Halley of Harvard Law School that "…there will be times when a commitment to neutrality will have to be overridden in the interests of making a statement on an issue of contemporary controversy"[3].

Surely the scale of the genocide in Gaza, with its norm-shifting consequences for the conduct of war and how we value human life on the planet, is one such time.

There is, parenthetically, a deeper crisis at play here and that is our inability to cry twice. When 7 October 2023 happened, my Muslim academic friends were largely silent in the face of the Hamas attacks which led to the deaths and hostage taking of mainly Jewish people. When Israel retaliated with months of bombings of Palestinian people, my Jewish friends (not all of them) took up defensive postures or said nothing at all. The reason is simple: we take sides and we dig into positions for historical reasons.

Those who remember the Holocaust and the enormous loss carry within themselves and across generations the sense of an existential crisis which lingers in the mind and is triggered by every anti-Semitic act or utterance, one that never quite goes away.

Those who remember the incessant attacks of successive governments of Isreal on the very existence of Palestinians over decades mark 7 October, not as a single act of resistance, but a long and inconclusive struggle for self-determination.

There is a way out of these staked-out positions if we recognise that there is a humanity that precedes politics. Our ability to be moved by the oppression of others, regardless of who is suffering or dying, is what makes us essentially human. The doctor on the battlefield is unlikely to ask who the combatant is fighting for in order to decide whether to treat the wounded person or not. The car hijacker, seriously wounded in a shoot-out with police, is kept alive until the ambulance arrives.

"I am Jewish", reads one poster, "and that is why I care about the killings in Gaza". More than one Arab diplomat in the United Nations asked questions like, "Are we not also human?" Or, "Do our lives also count?" To say that there is a humanity that precedes politics is not to argue for moral equivalence in this Middle East conflict. Here we might depart from each other in the understanding of political and historical facts. I, for one, believe that the Palestinians are on the receiving end of a brutal oppression by the Israeli government – something that has continued for decades.

But my argument for crying twice is to bring the recognition of the ongoing suffering of the Israelis and the Palestinians into the foreground, both as a matter of shared humanity and also one of strategic importance. By the latter, I mean that, unless we recognise the essential humanity of those on both sides of the conflict, there are no grounds (or very little) to begin a conversation that resolves such a deep and emotional problem. Put differently, to wipe out the other side requires that they be demonised and presented as less human, deprived of all human value. Think about ethnic stereotyping in the run-up to the Rwandan genocide, or racial stereotyping in the hands of the apartheid masters.

This is where our universities can play a critical role in demonstrating *how* we can respond to global conflicts. There are some simple public positions which university leaderships could take that risk minimal backlash. *Call for a ceasefire in Gaza*. Believe it or not, even such a simple, humanitarian statement had difficulty passing the decency test in some university senates.

A more complete statement would condemn the killings and kidnappings of 7 October initiated by Hamas and at the same time condemn the ongoing genocide that seems to have no other purpose than murdering and maiming Palestinians by the tens of thousands. Even in this hopelessly asymmetrical war, a recognition of the violence from both sides of the conflict would be an honest assessment of the situation on the ground. Going further, the statement would include the fact that the oppression of the Palestinians did not start on 7 October. Such a balanced announcement that recognises historical facts is what the original UN statement got right.

The intriguing question that follows is this: Can a university make a statement that does not speak for all its stakeholders or constituents of the academy? Of course it can. Admittedly, there are antisemites on our campuses as there are Islamophobes. No official university statement, whether it is on racial justice or transgender rights, will ever carry the consent of all campus citizens. That is where the quality and morality of the university leadership matters, led by the vice-chancellor and their team. Make a statement based on humanitarian values, such as contained in university mission statements and threaded through our constitution, and take the flack.

I will not pretend that doing so is easy. In the United States of America, even private universities are being hounded by Congress, that performative arena of Trumpian politics, with presidents losing their jobs, including Claudine Gay of Harvard, for being less than clear about what they would do to defend conservative interests. The mechanism for dislodging leaders is a powerful one – rightwing donors threaten and actually deliver on their threats to withdraw hundreds of millions of dollars in donations which, in the case of private universities, would sink an institution within three or four budget cycles. Retrenchments follow, institutional reputations take a hammering, and public confidence in a university begins to wane.

Donor money has come to play an outsized role in tempering any kind of politics in which university leadership takes a public stand on injustice. Having sat in that hot seat through multiple crises, I know the strain on leadership when faced with difficult choices in the public domain. But I also understand, that in the face of one of the greatest human tragedies of the century, not to take a leadership stand is to side with injustice. Or in the words of the acclaimed Palestinian scholar Edward Said: "To enter into the public sphere means not being afraid of controversy or taking positions."[4]

Such a stance would certainly apply to South Africa's 26 public universities.

Declarations

I have no competing interests to declare. I have no AI or LLM use to declare.

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Neoliberalism constrains academic freedom

Significance:

Positioning the university as a public good that serves people and the planet was a central concern for those responsible for shaping post-apartheid education. Unfortunately, the current neoliberal environment has led to institutional risk aversion. This means that universities are loathe to speak out on issues of social injustice and environmental degradation. And academics often forfeit their freedoms by assuming that top management can speak on behalf of the university.

In the Commentary 'Should our universities respond to geopolitical conflicts around the world?'[1], Chetty questions when and why a university should speak out on global issues. In particular, Chetty refers to the Israeli–Palestinian war. I leave it to other respondents to tackle the substantive issue of South African higher education's silence on this issue. Instead, I home in on what I see as a common problem in the post-apartheid university.

Chetty explains that:

> *By university, I mean the Council, the Senior Executive Committee, the University Forum, the University Senate, the faculties, schools, institutes, the Alumni Association, and so on.*[1]

He thus understands the university as a complex organisation, as indeed it is. But he repeatedly reveals an understanding of the university as one which is controlled by management. For me, one of the most troubling sentences in the article is this:

> *Universities thrive on a diversity of viewpoints, and so imposing a hegemonic view from the top management often leads to problems in a university setting.*[1]

Chetty has reduced a call for universities to take a collective position on this issue to the imposition of a hegemonic view from top management. The suggestion that a statement on the genocide would come from "top management" is reiterated in this later sentence:

> *It goes against the principles of academic freedom for the university to impose a hegemonic view from the top, of an essentially political matter, when we have differing views on this amongst staff and students.*[1]

There is an assumption that "top management" can impose a view on the university, which I would argue is at odds with the notion of academic freedom. This view is perhaps unsurprising, given how widespread managerialism is in the system. Jansen[2], in his book *Corrupted*, suggests that much of the rot in many of our institutions emerges from the overreach of Councils and top management, which lack an understanding of the academic project.

Chetty later specifies that:

> *How decisions are made, through consensus or through voting, how decisions are recorded and how they are implemented and monitored are an important part of our administrative processes at universities. Universities need good administrators, and good administrative systems.*[1]

At face value, this is difficult to argue against, but the issue is one of emphasis, particularly when read in relation to the previously quoted sentences. Administrative processes at universities are meant to serve the academic project; they have no other role. In common with many others, Chetty at times seems to understand the purpose of administrative processes as driving academic activities rather than facilitating them.

Alongside the assumption that a statement on international events could take the form of a "hegemonic view from top management", he acknowledges that institutional decisions should be guided by principles:

> *There is no blueprint for what these principles are. They are not in some textbook or to be searched on the Internet. These are established through critical dialogue and debate at our institutions. These principles speak to the very soul of our universities.*[1]

All who care about the sector need to reflect deeply on the extent to which universities are indeed such spaces of critical dialogue. When staff are precariously employed[3], performance management focuses on metrics over matter, and managerialism allows the flourishing of subterfuge, bullying and blame-games[4,5,6], it is very difficult for critical dialogue to thrive. Arguably, there is little soul in a university that is at the mercy of managerialism. It is not only fear of retribution that makes it less likely for academics to engage in critical dialogue and debate, but also that instrumental rationality foments onerous administrative loads[7] for those who might otherwise contribute to the nurturing of the academic project.

> *Universities are argumentative places, where individuals should engage, hopefully respectfully, with each other on topics on which they have strong disagreements. Our universities should facilitate an environment where this can happen.*[1]

Here Chetty gets to the nub of the matter. But, unfortunately, the neoliberal university is increasingly not a space for argument.[8] Within the neoliberal university, compliance is more valued than critique of the status quo within or beyond the academy.

Chetty includes reference to two texts, one by Benatar and the other by Chetty and Merrett, about specific South African universities. These books both tackle examples of the suppression of academic freedom and the incursion of managerialism. But their focus on personality politics arguably reduces their consideration of how the actions of specific people are enabled by the neoliberal conditioning of post-apartheid higher education.

And even if the university was a space for critical dialogue, what would be the point of us debating amongst ourselves? Far too much energy is spent in the neoliberal university on publishing articles that make little contribution and even less impact in the interests of promotion, financial incentives, ratings and rankings, and far too little is spent on knowledge building, science communication and participating in social dialogue. If the university was a public good, it would focus as much on sharing views with the public as it does on publishing 'accredited outputs'. This would include sharing research-based insights on all issues of interest and importance.

It is worth reflecting on this idea of the university as a public good[9,10,11] – good for all people, including those who never step foot on a campus. In the years leading up to democracy, a great deal of energy was spent discussing the need for universities in South Africa to be positioned as a public good, given that, during apartheid, universities had been "creatures of the state"[12].

Under apartheid, Afrikaans-medium institutions provided pseudo-scientific justifications for apartheid, educated apartheid's most notorious leaders and entrenched white supremacy. Their ideological positioning also enabled support from the Broederbond.

While historically white, English-medium institutions outwardly generally rejected the racist premise of apartheid, they complied with the state at almost every level. The extremely low number of applications by these institutions for permission to enrol black students[13], their kowtowing to the apartheid state's petty interferences, and their own suppression of 'troublemakers', all indicate the extent to which these institutions capitulated to the apartheid state.

Universities designated for black population groups were formed largely to provide the labour needed by the 'homelands' and to ensure the provision of the massive bureaucracy required by the apartheid machinery.[14] While these institutions were often spaces of defiance and protest, they were kept under control through the withholding of funds, limitations on the programmes they could offer, restrictions on undertaking research, and state oversight of key appointments.

And then there were the racially differentiated technikons. Almost all education in South Africa was premised on fundamental pedagogics, but technikons bore the brunt of this narrow understanding of education. Fundamental pedagogics, as it was applied in South Africa, was closely entwined with Christian National Education, and positioned the education process as one of input-process-output, failing to take structural and cultural contexts into account.[15] Knowledge was pragmatically understood as neutral rather than inherently political, and it was directed only towards practical implementation. Technikons were thus positioned as training centres, rather than higher education institutions. Like the universities designated for black population groups, they also battled suffocating control by the state, including national oversight of all syllabi and textbooks via the convenorship system.

It was thus unsurprising that those planning a post-apartheid higher education system were determined that universities shake off this heritage. The inclusion of the phrase 'academic freedom' in the Bill of Rights, Chapter Two of the Constitution, was not without debate, but given the need for the new university system to play a very different role to that played during apartheid, this inclusion was eventually deemed necessary. The potential for universities to speak truth to power has been codified in various ways, such as the 1997 White Paper making clear that universities bear the task of nurturing critical citizens and must have a "commitment to the common good".

Sadly, since the vision for post-apartheid universities to become a public good emerged, the sector has tumbled into a neoliberal ideology that reduces all human activity to an economic endeavour. Instead of being a creature of the state, as it was under apartheid, the South African university has become a creature of the market. And in so doing, it has neglected its responsibilities as a public good. It has consistently failed to speak out on issues related to the well-being of people and the planet.

Chetty states that:

> *If we want to become a university that speaks up on human rights matters, let us do this consistently and sincerely.*[1]

I would argue that this is not a matter of what we *want* or *do not want* to do. Universities have a responsibility to be spaces that make contributions to public discourse. While it is true that

> *many of our South African universities have never previously established a principle of getting involved in such conflicts…*[1],

this is a dereliction of duty. In succumbing to neoliberal interpretations of the role of higher education in society, universities have become risk averse, chasing rankings and focusing on credentialling for industry at the cost of contributing to social equity and environmental sustainability.

Academic freedom is not only something to be exercised by individuals; our history demonstrates the need for the university to be a place of collective action. If we only exercised this responsibility as "independent critical public voices", as Chetty suggests we should, then we would be avoiding our responsibility as a structure serving the common good. The university should always be a place of dissent; any collective statement by the Senate should allow for those who disagree. And we should collectively protect the rights of dissenters, even as we belatedly take up our responsibilities as a public good.

Declarations

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Evasive tactics

Significance:

This response to the Commentary entitled 'Should our universities respond to geopolitical conflicts around the world?' analyses some of the evasive tactics adopted by Chetty. It demonstrates how these tactics weave an associative web that inhibits the reader from the work of deliberation necessary to forming an opinion. It further argues that (in terms of philosophical grammar) proper deliberation is a necessarily prior step to the holding or maintaining of something as a principle (including, as here, the neutrality principle).

I understand the Commentary[1] as putting forward or drawing upon what is generally referred to in academic freedom debates as the 'neutrality principle'. This is usually identified with the University of Chicago's Kalven Committee Report, published in 1967, but, more lately, accorded an authoritative status by university administrators as these responded to pressure from Republican politicians in the USA. I leave aside direct engagement with the history of this principle for now, only noting that the current Commentary seems to repeat much of its internal and contextual complexity.[2] I intend to provide necessary extension on this matter and will submit a contribution to the *South African Journal of Science* discussing the neutrality principle in practice.

The current response offers a prior step in that necessarily more detailed argument. It seeks to demonstrate a pattern of evasiveness in the Commentary, one which proves to be particularly important in preparing the reader for its eventual conclusion, the adoption of the neutrality principle. The cumulative effect of this text's evasive tactics is to prepare the reader to support the adoption of a principle without engaging in the due deliberation necessary to actively *choose* whether to adopt something as a principle.

As a teacher of critical and attentive reading, I always say to my students that the beginnings of texts are important. They repay the most careful attention.

Beginnings necessarily work to establish the framework for the argument or analysis to come. Carefully read, they can be seen to *embody* (and not simply anticipate, in the manner recommended by composition manuals) the focus of what is to follow. Any choice of focus sets in place the necessary, but perhaps barely conscious, selection of what an argument is to include, what it is willing to consign to its blurry margins, or what it even prefers to keep entirely out of sight.

The current Commentary is no exception. From the very first clause of its very first sentence, it embodies the evasiveness which governs the argument to follow. (It may be worth noting, though I will not elaborate here, that the first 'sentence' is not, strictly speaking, a sentence: it lacks the formally necessary markers of grammatical co-ordination.)

How does this work as a matter of textual practice?

Consider how the Commentary establishes the ground for the argument to follow by first stating that the "Israeli–Palestinian matter" is a "long-standing, controversial political matter".

Let us begin with the choice of the word "matter" as the noun to refer to the real-world events to which this text is responding. It is worth noting that, somewhat paradoxically, the noun 'matter' is the most *abstract* way of referring to something concrete. The whole point of the noun is its capacity to refer abstractly to *any* kind of matter, but always with the proviso that the matter in question will then require further specification if it is to make any particular sense.

What is the particular sense that is offered here by the adjectival specification? The qualifying and restrictive adjectives are "Israeli–Palestinian": the particular matter in question is the "Israeli–Palestinian matter".

Many implications are put into play through this formulation; but these implications all work to *obscure* rather than to throw light on the "matter" at hand. To choose to refer to the events in Gaza (the reality which Chetty does his level best to avoid) as the "Israeli–Palestinian matter" is immediately to choose to evade – rather than to try and come to meaningful terms with, as is essential to any practice of deliberation – those events.

Let us detail just a few of these. In the first instance, stating that the "matter" is an "Israeli–Palestinian" one strongly suggests that *no one else should be (or has the right to be)* involved in it. As an *Israeli-Palestinian* matter, the implication is that *only* Israelis and Palestinians are entitled to speak about it, importantly establishing one thread in the associative web that helps to support the central assertion that universities in general *should just keep quiet*.

At the same time, it is worth noting how the formulation creates a false and misleading characterisation of the actors *actually involved* in this "matter". First, the formulation distorts reality in a politically unhelpful way, suggesting that Palestinians and Israelis (from their respective sides) are *all of one mind* with regard to this "matter", the "Israeli–Palestinian matter". This is unhelpful because it is the fact of internal divisions within the two sides that yields a potential opening to the possibility of the dialogue and deliberation which seem necessary (if not sufficient) for reaching any truly sustainable political solution.

The real range of Palestinian opinion is never sounded, nor is there any recognition of the major opposition within Israel itself to the government's conduct, nor to the divisions in the Jewish community worldwide, both in terms of public statement and alignment, but going all the way down into the most private and bitter disputes within individual families.

Second, it ignores the reality that many other national actors are already engaged, whether as more or less direct political allies or antagonists (such as the USA, Egypt, Iran, and Lebanon) or as international reporting bodies such as the United Nations, the International Criminal Court, Amnesty International and many others. That this initial specification does not really work is confirmed by the attempt at the immediate further clarification of the "matter" as a "long-standing, controversial political matter".

Does this help?

Unfortunately (in terms of what a real clarification, apt for furthering deliberation, would involve), each of these descriptors is evasive in its own way. "Long-standing" works to bracket off from consideration the specifics of any punctual moment: the now retreats from view as merely an instance of what has *always* been happening; second, and in so doing, it *refuses the possibility of historical (and consequently of political) understanding*. This possibility is further removed by the category of the "controversial", here invoking the idea of the "matter" as essentially irresolvable, akin to the paper-thin Scholastic controversies now considered meaningless.[3]

The most crucial adjective here, though, is "political". As the third and final qualifying adjective, it necessarily contains the accumulating force of what has gone before, as well as working to anticipate the signifying force of much that is to come. What are we to make of the use of "political" in the Commentary?

The adjective "political" is used some seventeen times in the Commentary (the related "geopolitical" five). Suffice it to say that the "political" is always invoked in a negative and often trivialising way, so that cumulatively, it comes to assume the force of what we might call a 'dirty word': something that should never be mentioned in polite (or academic) company.

I suggest that this insistent return to the *adjective* "political" can be read as the sign of the word and concept that the essay wishes to keep at bay and keep out of sight. This is the substantive noun, *politics*: never once used in the Commentary, it is always spectrally present as what stands behind or somehow within the adjective political. Politics is there (but not there) as an insistent pressure from a reality that the writing does not wish to acknowledge.

Does not wish to acknowledge but cannot entirely evade.

For politics insists on coming through even as it is being denied and evaded. We can see this perhaps most clearly in a sentence which stands at the very centre (the Derridean in me wants to say the 'absent centre') of the Commentary.

Let us read how the pressure of politics comes through, even (or perhaps especially) as it is resisted and denied.

"Yes," the text acknowledges, as if responding to a querying interlocutor, "this is, of course, a human rights issue [*yes, politics*] and a horrific one [*yes, in the real world*] at that". But, as everyone knows, an apparently casual "of course" in a formulation only prepares the ground for a firm (and perhaps even scathing) rebuttal of the interlocutor's views, a turn away from them.

So, despite the admission that the "issue" (another abstracting noun) is "a horrific one" (or would be if you took the trouble to look at it), a "but" immediately introduces a swerve in thinking away from that momentary intrusion of a horrific reality ("but if you take only a little step back"). The rebuttal openly warns the interlocutor to stay away from *any attempt to think historically* (that is, taking a "little step back to ask how this has come about"). This warning seeks to justify itself on the grounds that properly understood (and as we have already been primed, by the web of implication, to accept) the issue is a *timeless* one, one that "has no end even if we go back decades if not centuries".

At this point, the interlocutor (or this interlocutor at least) might refuse to follow and accept this syntactical swerve. They might insist that politics – understood as the effort at political understanding that historical analysis is needed to inform – is the name of the necessary attempt to find some footing on a slippery slope. In this case, finding a footing means, at the very minimum, trying to face the reality of events, rather than turning your back on it.

It involves the effort of thinking things through and, as a key component in such an effort, the struggle to find an adequate language to use as the basis for public deliberation. Not that finding such an adequate language is likely to be an easy matter. Specification would involve an account of the events themselves, including the actions of both the Netanyahu government and of Hamas, the informed consideration of questions such as: Are Palestinians in Gaza best understood as citizens or refugees? Is Gaza a state, a proto-state or a ghetto-state, or, as some have suggested, just 'an open-air prison camp'? Is best considered a war (between opposing armies) or something more akin to counterinsurgency, with all its deliberately barbarous tactics?[4-6]

These, and many other fundamental questions, are effectively cordoned off by the Commentary when they are, in fact, essential to the thinking that should go into *making a decision* about the question of public statement.

You can now see, I hope, the importance of the web of associative logic that has been briefly traced here. It is important because it primes the reader for an *unconsidered* acceptance of the 'content' of the argument: the advocacy of the 'neutrality principle'.

Indeed, it is worth noting (as a closing point) that such unconsidered acceptance is aided and abetted by the semantic ambivalence present in the very term "principle".

In the natural sciences, and particularly in Newtonian physics, a principle is a fundamental truth or proposition on which others depend, and so can serve as the *unexamined starting point* of an inquiry.

This is far from the case in moral and political discourse, where a principle is more properly understood as a stance that is (more or less consciously) adopted by an agent as the result of (more or less conscious) deliberation.[7,8]

In moral and political argument, the correct grammar is always to speak of *adopting* a principle, with the implication that this can only properly be done *after* a process of deliberation has been engaged and concluded. It seems to me that the Commentary works precisely to try and obviate such a necessary process.

Indeed, I read the Commentary (with its associative web carefully woven to support what I have argued is a grammatically mistaken appeal to the 'neutrality principle') as seeking, above all, to spare the academic community from what, in another context, the philosopher David Wiggins described as the "agony of thinking and all the torment of feeling that is actually involved in reasoned deliberation"[9].

I do not think, that in the case of Gaza, such agony and torment can properly be avoided or should be avoided.

It should also be added that adopting the neutrality principle as something like a principle in the scientific, axiomatic sense also incurs the real danger of making anyone who refuses to accept or follow it as an unquestionable principle into what Carl Schmitt referred to as 'an internal enemy', to be dealt with accordingly (and as we now see happening in Germany and the USA), and in ways that obviate the very possibility of deliberation from the start.[10]

Declarations

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Chabani Manganyi (1940–2024): An intellectual, man of letters, and black psychologist

We may well have lost one of the most impressive and scholarly thinkers of the last 50 years with the recent death of Noel Chabani Manganyi on 31 October 2024 at the age of 84. While we obviously had no control over the life and death of Manganyi, we certainly do have control over the legacy of his work and ideas. His prodigious output is a treasure trove for critical intellectuals who wish to make sense of the human condition in these troubled times of our lives, our country, and the world.

Professor Manganyi's work ranged over what can be identified as four distinct areas. Firstly, the field of psychology, and his concern to account for black subjectivity under the conditions of apartheid racism. Ironically, Chabani Manganyi always wanted to be recognised as a psychologist and psychological researcher, although the discipline of psychology, until fairly recently, was extremely remiss in acknowledging his important contributions.

It is worth highlighting some of his analysis and thinking about black subjectivity under the conditions of black oppression and subjugation. For instance, in an essay called 'Us and them'[1], published in his first book, *Being-Black-in-the-World* (1973)[2], he explores what could be called the material conditions of black experience, and the resultant psychology of the existential position of oppression. Manganyi discusses the interaction and dialectic of an 'us/them' opposition on the identity and lived experience of black people under apartheid. What is striking about this essay, then and now, is how mild mannered and considered it is given the backdrop of a vicious apartheid regime's control and degradation of black lives. And yet the essay is assertive and affirming of being black in the world, thus appropriating a moral position – one might even say a moral high ground – by refusing the demeaning terms of existential reference set by apartheid.

Furthermore, during his time as a postdoctoral researcher at Yale University in the early and mid-1970s, working with the renowned psychobiographer Daniel Levinson, Manganyi wrote *Mashangu's Reverie and Other Essays* (1977)[3] "as a frivolous kind of 'self-analysis' and in this way started to rid myself of disturbing impulses." The "disturbing impulses" refer to what happens to the self "under conditions of subordinacy, the self that is projected in everyday life is false and unauthentic since it remains a mask protecting its double – an unnatural division which does violence to the integrity of the self."

We find Mashangu talking to his psychotherapist, Dr Davies, about his anguish, pain and anger about what it means to be black in a dehumanising world of white domination. Mashangu/Manganyi says to Dr Davies:

> *I…I was thinking of repudiation. You know what I mean? Repudiation. I was looking at my life since the days at the Mission School. It has been one big battle repudiating, negating something or other – myself, my culture, even my people. You see, we're forced to speak English on certain days at school. Mind you, not only to enable us to read Milton or Shakespeare at a later stage but to prepare us…to create a readiness to repudiate everything which was native to us. Can you visualise that…each one of us carries a double…a kind of replica of self that is always in conflict with the mask that faces the world. To protect this mask from its double, one cherished an illusion and nourished it – the illusion that the future and prosperity of the mask depends upon a negation of the past, both individual and collective…*[3(p.20)]

The beauty, pathos and agony of this paragraph captures Manganyi as a great writer and a profoundly incisive analyst of the deformations of black subjectivity. It is also alive to the possibilities and difficulties of liberating black subjectivity from the yoke of subjugation and racial domination. He was a de-colonial thinker in the mould of Frantz Fanon long before the currency of de-colonial thought took hold.

The second distinct area is Manganyi's work on memory, biography and exile. The biographies that he wrote explore the unfolding and dialectical intertwining of individual, social and historical consciousness. His first biography, published in 1983, was on Es'kia Mphahlele (1919–2008)[4], the novelist and literary theorist. It is not insignificant that his three biographies are about black men. Except for Es'kia Mphahlele, who was a giant of (African) literature and recognised during his lifetime, the other two are artists – Gerard Sekoto and Dumile Feni. And not just artists, but artists living in exile, with Gerard Sekoto (1913–1993)[5] mostly at peace with "becoming" a Frenchman, and Feni troubled by being away from home. Sadly, Dumile Feni (1939–1991)[6] died suddenly just before he was planning to return to South Africa. Mphahlele was also an exile as an academic in the USA, but this was to some extent "voluntary". The exile experience is an experience of disruption and dislocation and has profound effects on psychological well-being. Manganyi's biographies show us the personal costs of (political) exile, and the struggle against being away from home, and how these memories both sustain and "torture" the exiles.

Thirdly, one can say that, from his first writings, there is an abiding interest in political violence. In Manganyi's early writings he is concerned with the effects of the violence of apartheid and racism on black subjectivity, and, in his later work, with the violence of the state in trials against people accused of "terrorism". Manganyi's expert witness testimonies are some of the most complex and sophisticated psycho-legal defences against the repressive political and legal apparatus of the apartheid state.

His work, in my view, also has a strong *moral* dimension to it, and this is particularly evident in his work on political violence (see the edited collection with André du Toit published in 1990)[7], and his appearance as an expert witness

in political trials (see Chapters 5–7 of his memoir[8]). In his expert witness testimony, he was concerned to explain the complexities of the political acts (so-called political violence, or "terrorism") in terms of the meaning of the lived experience of black subjectivity under apartheid, and the understandable (if not justifiable, for the state and its agents) resistance to oppression and exploitation.

Fourthly, besides his contribution to the life of ideas, he also unselfishly gave his expertise and wisdom to public institutions in South Africa, and, especially since 1994, held some highly prestigious appointments in educational and academic spheres: firstly as the Director-General of the national Department of Education (under Minister Sibusiso Bhengu in Mandela's government); as a vice-chancellor of the University of the North; as both a vice-chancellor (1999–2003) and vice-principal (2003–2006) of the University of Pretoria; and as a chairperson of the Council on Higher Education.

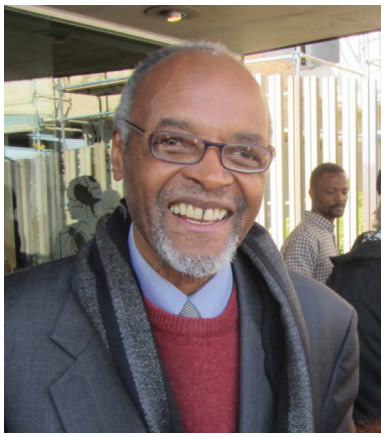
I would now like to make a few remarks about my personal relationship with Chabani, not out of any vain attempt to insinuate myself into the life of this remarkable South African intellectual and 'man of letters', but rather to show a side of him that not many people who have only read his work would have any inkling of. I also think Chabani would have approved of my reminiscences of our friendship.

My first encounter with Chabani Manganyi was with his first book, *Being-Black-in-the-World* published in 1973[2] and re-issued in 2019[9]. I did not read this book as part of any course in Psychology, but rather as a young academic and someone who had come through "white student politics" in NUSAS. *Being-Black-in-the-World*[2], a collection of essays on the "black experience" as Manganyi framed it back then, had a huge influence on a young generation of left-leaning, anti-apartheid, mostly white, aspiring academics and intellectuals. Saths Cooper, in his PsySSA video tribute to Manganyi, reminds us that he and other black student radicals were also significantly influenced by this book.

My next encounter with Manganyi was through my association as Editor of the journal *Psychology in Society* (PINS). PINS first introduced its readers to Manganyi in 1985 through a long critical essay by Cyril Couve[10] (then at the University of Cape Town, and, at the time, an editor of PINS), entitled, 'Psychology and politics in Manganyi's work: A materialist critique'. This was followed by a review of Manganyi and du Toit's 1990 edited collection, *Political violence and the struggle in South Africa*[11], by Etienne Marais (1992)[12]. The last review of Manganyi's work was by Leslie Swartz (1994)[13] of *Treachery and Innocence* (1991)[14]. Other notable works of Manganyi's were *Alienation and the Body in Racist Society: A Study of the Society that Invented Soweto* (1977)[15]; *Looking through the Keyhole: Dissenting Essays on the Black Experience* (1981)[16]; *A Black Man called Sekoto* (1996)[17]; *On Becoming a Democracy: Transition and Transformation in South African Society* (2004)[18]; and *Making Strange: Race Science and Ethnopsychiatric Discourse* (2018)[19].

A 17-year gap transpired before PINS published anything on Manganyi again. Through the suggestion of Derek Hook (a PINS editor at the time), PINS published Manganyi's brilliant essay 'The violent reverie'. This essay had been published in Manganyi's (1977)[20] collection entitled *Mashangu's Reverie and Other Essays* by Ravan Press. I got permission from Ravan Press to re-publish this essay in PINS, but thought that it would be appropriate to contact the author himself. I emailed Chabani in 2010 asking for permission to re-publish his violent reverie essay, which he unhesitatingly gave to PINS. In his reply email, he asked that I phone him so that we could talk about this and mentioned that he preferred a *personal* touch in these matters! And so started a wonderful and rewarding intellectual and personal friendship with Chabani.

During 2011, Chabani contacted me about the memoir he was writing, the book that became *Apartheid and the Making of a Black Psychologist*[8], published in 2016. He asked whether I would read what he had written thus far, and I gave him some comments and thoughts on the manuscript. Chabani clearly liked what I had said about his manuscript in its early stages, as he arranged for Wits University Press to appoint me as the academic editor of his book, which we then worked on for the next couple of years. From that time on until the lockdown of the COVID-19 pandemic, we would see each other every couple of months, either because he was holidaying in the Durban area or because I was in Johannesburg. We would meet for lunch and Chabani liked not to be rushed. He ate slowly, spoke thoughtfully, and always wanted to linger and talk about ideas and politics.



Source: Wits University Press (reproduced with permission)

Professor Manganyi at the launch of his memoir, June 2016.

The last time we met in Johannesburg he mentioned feeling old, he was then about to turn 80, and said that he probably had written his last book, meaning his memoir *Apartheid and the Making of a Black Psychologist*[8]. I wondered then whether he was ill and not wanting to be part of public life anymore. After our lunch we said goodbye and I watched as he walked away slowly from the restaurant – that was the last time I saw him.

Chabani Manganyi was a man who throughout his life pursued an independence of thought, and had a profound respect and love for the life of the mind. It was a privilege and a joy to know this gentle, principled man of letters as both an intellectual inspiration and a friend. I hope we keep alive the legacy of Chabani Manganyi's work and ideas in the challenges that lie ahead as we consider what it means to live as free and compassionate human beings.

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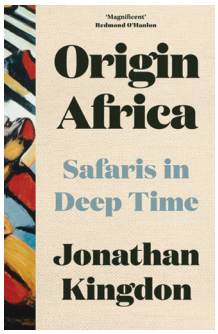

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Jonathan Kingdon treats nature lovers to the varied beauty of Africa's fauna

What an absolute delight to read someone with a most curious mind and to share his joy for the variety of plant and animal life on his own continent, "the sense-igniting mother-continent" and "the birthplace of all humanity", Africa. How very fortunate Jonathan Kingdon was told early in life that "questions are more important than answers". His infectious ecstasy is revealed by the statement that life, "even within a single hectare of African forest", is beyond the imaginings of a science-fiction writer! Kingdon aimed at helping those with outdated and primitive mindsets who view Africa negatively and to assuage his own despair at humanity's disinterest and rejection of the science of our shared origins in Africa.[1-4] My long-held view that biology should and must be taught outside the classroom is affirmed on every page of this unputdownable book, with its beautiful sketches and illustrations, several by the author's mother. And when it comes to the birth of primates, this work aptly complements many previous works.[3,4]

Africa ('the dark continent') hardly ever receives good press in socio-economic and political spheres; but proud Africans would share Kingdon's view that ours is a misrepresented, dehumanised and abused continent. Kingdon has written a paean to the theory of evolution and natural selection[5] – the understanding of which helps us make sense of the diversity of life. However, whilst it is written in a manner for both the specialist and general reader, the latter may become overwhelmed by the volume of material, describing hundreds of species on our continent. The book is a celebration of the biodiversity in the song of the birds, the sonic boom of the whale, the vibration of every insect, feather or vocal cord, the smell of birth and death and of the flowers, which are flung at Kingdon's every sense, for his and the reader's delight. And then there is the sadness of the humiliation of Africans caused by colonisation and the slave trade, the exploitation of our plant, animal and human resources, the threat to and extinction of many species, together with droughts, poverty, poaching and post-colonial governmental corruption. African dictatorships are vulnerable to exploitation by huge powers in the Global North.

For some context, we are taken to Pangaea, the 'supercraton mother' of continents, its fracture 300 million years ago, the continual movement of land masses from each other (Wegener's drift), and, for our interest, the birth of the African continent.

Interestingly, lungfish, killifish and frogs are older than the earth's continents. The earth is 4.5 billion years old, and the first unicellular bacteria and archaea appeared 4 billion years ago, whilst the ancestor of the human cell is approximately 2 billion years old.[6] Of significance for humans and their ancestors was the crash to earth of a 10-km-wide, iridium-loaded meteor (Chicxulub), in the region of the Yucatan Peninsula and the Caribbean Sea. This was the period of the C(K)retaceous-Tertiary (K-T) boundary, 66 million years ago, that caused the extinction of the dinosaurs and left the smaller and hardy animals, 'shrew-like lineages', and hibernating genera to evolve into carnivores and primates.[7] In Africa, following this crash, all surviving mammals are labelled 'afrotheres'. This is our ancestry and, rather than it being a moment of creation, Kingdon sees it as a moment of release for these "holocaust's survivors".

Kingdon has a message for those who claim that the world is determined[8,9] and we humans have no free will. The appearance of primates on our planet is a consequence of the meteor strike during the K-T boundary period, and scientists and philosophers need to appreciate evolution as a response to both chance accidents and regular predictabilities of existence, including migrations of people, cultures and epidemics. Our very existence depends on plants, and yet, we humans, in this age of the Anthropocene, care little about our warming planet. We ignore oral histories and knowledge to our peril. We have a golden opportunity to save our planet[10], having the aptitude and the tools to understand the processes that generate the biodiversity around us. In this light, there is an urgent need for systemic research such as the 'Frontier Tanzania' programme, Africa's most significant multi-partner scientific enterprise and a wonderful model of what is needed in the rest of Africa and the world.

Kingdon brings us closer to our hominid and hominin family members with a description of *Proconsul africanus*, an 18-million-year-old dental ape, a complete skeleton of which was unearthed by Mary Leakey on the Lake Victoria Island of Rusinga. The very same Mary Leakey gave us the 3.6-million-year-old Laetoli footprints of *Australopithecus afarensis* (near Tanzania's Olduvai Gorge), preserved in the hardened ash of volcanic material.[11] Kingdon has nailed his colours to the mast by declaring that the "grand spectacle of evolution hangs on the emancipation of hands", rather than the advent of bipedalism or uprightness.[7] However, the birth of bipedalism is covered (with descriptions of a skull in Chad, *Sahelantrophus*, 10.5 million years ago) and so is our divergence from our ape ancestors 6 million years ago (with the finding of *Orrorin tugenensis* and *Ardipithecus ramidus* (5.8 million years old), in the Afar region of Ethiopia. Speciation happened in shifting major vegetation zones with oscillating climates and genetic drift. Adaptation to different climes by primates has been amazing. The history of our evolution has been characterised by so many competing species amongst the *Australopithecus* and *Homo* genera, leaving scientists to grapple with our direct line of ancestry.[2,4,12] Suffice to say that *Homo sapiens* is 300 000 years old, and, approximately 70 000 years ago, our ancestors migrated out of Africa and colonised the world.[7]

What has been disappointing in this otherwise brilliant history, is the absence of the significant discovery of the skull of Taung Child (*Australopithecus africanus*) in 1924 (the 'missing link') and Raymond Dart's battles to have it acknowledged by European scientists (how can humans have originated in Africa?).[4] Then there was the insult of the Piltdown forgery[13] and, while mention is made of one of our most exciting finds of 'Little Foot' (*Australopithecus prometheus*), the contributions of Phillip Tobias, Ron Clarke, Stephen Motsumi and Nkwane Molefe are not covered[3]. In Ethiopia, the discovery of Lucy (*Australopithecus afarensis*) shook the world, and the implications of her discovery are mentioned by Johanson[14].

Origin Africa should be distributed to every biology teacher in our schools. The question the reader is left with is whether we have lost our connection with nature in our modern way of living? Kingdon offers us (especially the youth) the possibility of shifting our attention from the modern celebrity culture to the awe and wonders of this world.

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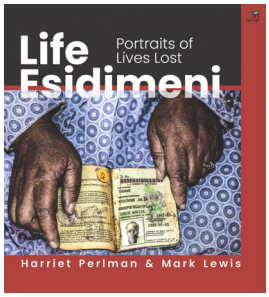
BOOK TITLE:
Life Esidimeni: Portraits of Lives Lost



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The missing voices of the Life Esidimeni tragedy

Life Esidimeni: Portraits of Lives Lost is a moving tribute to the 144 mental health patients who lost their lives from 2016 due to systemic neglect, abuse, and the failure of the Gauteng public health system. Harriet Perlman and Mark Lewis recount the tragedy that goes beyond being just a record of one of South Africa's darkest moments in mental health care; it is an urgent call for justice, accountability, and the reform of a system that has failed not only its most vulnerable citizens but also the families and caregivers who love them.

The tragedy of Life Esidimeni was not just about the 144 lives lost. It affected over 1700 patients and their families – human beings who were treated as mere numbers, shuffled from a place many called home to unregistered and ill-equipped NGOs with no regard for basic human life. The authors open the book by immediately confronting the reader with the grim reality of these events. In a country where mental health care is already underfunded and often misunderstood, the Life Esidimeni disaster was the culmination of years of mismanagement, corruption, and indifference towards mental healthcare users and ultimately, the community as a whole.

Perlman sheds light on the mammoth efforts made by various organisations, such as the South African Depression and Anxiety Group (SADAG), SECTION 27, and the South African Society of Psychiatrists (SASOP), to prevent this catastrophe. These groups, along with the Life Esidimeni Family Committee, fought tirelessly to raise alarms about the closure of the Life Esidimeni facility in Randfontein as early as June 2015. They warned of the devastating consequences of this decision, yet their pleas were ignored. The book painstakingly details the systemic failures that led to this mass tragedy, including failed litigation processes and the sheer disregard for human life by key players in positions of power.

As someone with lived experience of mental illness and who has been involuntarily institutionalised multiple times in South Africa, this tragedy resonates deeply with me. The Life Esidimeni tragedy exposes not just cracks, but wide, gaping chasms in the South African mental health care system. It highlights how easily those who are most vulnerable – those who are silenced by stigma or incapacitated by illness – can be mistreated and ultimately forgotten. It is difficult to move beyond the story of the first life lost, the story of Deborah Phetla, a well-loved daughter found with plastic and brown paper in her stomach after her death. Deborah's suffering is a brutal reminder of how dehumanising the mental healthcare system can be.

This book stands as a testimony to the families and loved ones of those who lost their lives in this tragedy. It honours the emotional and psychological toll that families continue to bear. These individuals were not just numbers; they were loved and cherished by their families. The photographs that fill the pages of this book give back a semblance of dignity to the lives lost. The beauty of these portraits lies in the humanity they capture – a stark contrast to the inhumanity they endured in their final days.

The Life Esidimeni tragedy also illuminates glaring deficiencies in South Africa's mental healthcare policies and legal frameworks. The *Mental Health Care Act of 2002* (MHCA) has long been criticised as outdated. Although South Africa ratified the Convention on the Rights of Persons with Disabilities (CRPD) in 2007, there has been little progress in fully integrating these principles into national legislation and practice. The CRPD emphasises the right to health care, freedom from torture, and the right to dignity for persons with disabilities, including those with mental health conditions. This convention aligns with our Constitutional rights, but too often these are simply just words on a page.

This failure is systemic, but it is also deeply personal. It is about the everyday people – families, caregivers, and mental healthcare users – who are desperate for care, but it often ends in tragedy. And it is also about the imbalance of power, where a small group of decision-makers can have such devastating control over the lives of so many. In July 2024, nearly a decade after the tragedy began, Judge Teffo ruled that nine of the deaths were unnatural and attributed the responsibility to key figures such as the former MEC for Health Qedani Mahlangu and Dr Makgabo Manamela. However, for the families, and for those of us who are part of the mental health community, this is not enough. The compensation provided in June 2018 to some families who participated in the arbitration process does not equate to justice. True justice will only be realised when there are criminal convictions and when the entire mental healthcare system is reformed to ensure that this never happens again.

For those of us who have lived through mental illness and who continue to fight for the rights of mental healthcare users, this book is a sombre reminder that we cannot be voiceless. The brokenness of the system is not inevitable. There are people within the system – care workers, nurses, doctors, community workers, civil society, mental health advocates – who do their jobs with care and empathy, despite the challenges that are faced. But without systemic reform, these individual efforts are not enough to protect mental healthcare users from harm.

In its essence, *Life Esidimeni: Portraits of Lives Lost* is not just a memorial to those who lost their lives, but a manifesto for change. It calls upon every one of us to demand better. It reminds us that mental health care is not a medical issue but in fact a human rights issue.

We owe it to the victims of Life Esidimeni, their families, and future generations of mental healthcare users to ensure that their suffering was not in vain. We must demand the careful implementation of the CRPD, reforms to the MHCA, and a complete overhaul of the current mental healthcare system. Only then can we begin to restore dignity to those who have been stripped of it and ensure that such a tragedy never happens again.

To the authors and all who fought for these patients' rights, you inspire hope that, through unity and dedication, we can create transformative change and protect the dignity and lives of the vulnerable. We are deeply grateful for your courage.

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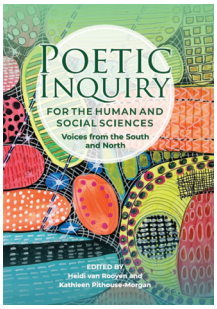
Poetic Inquiry for the Humanities and Social Sciences: Voices from the South and the North



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Beyond prose: Review of 'Poetic Inquiry for the Humanities and Social Sciences: Voices from the South and the North'

The 54 authors of this book reflect on the use of poetic inquiry at a time when feminist, decolonial, and post-humanist researchers are raising concerns about the ways in which qualitative data collection and dissemination can silence some and reduce the experiences of others by adhering to the often-arbitrary restrictions of academic texts.

Poetic inquiry, the authors of this book argue, should be welcoming, invite new perspectives, and make possible alternative interpretations of the social world. Sadly, as Pithouse-Morgan indicates, poetry is often associated with negative rather than positive educational experiences (p.201). For many of us, poetry is about mysterious meanings that our schoolteachers berated us for being too dense to access.

While my own interest in poetic inquiry is in how we can use it to create and disseminate research, many authors in this book, such as Hough, Peté and Ndlovu, suggest that poetry can also be used "to teach complex topics from different points of view, make people more self-aware, encourage dialogue and empathy, grow social awareness, and raise ethical questions" (p.169).

Badenhorst and McLeod point out that this can be challenging when working in neoliberal universities that turn us into human capital in service of competition and efficiency over social justice and equity. They suggest that poetry can help us to shift to a world "of senses and feeling [that] can provide a way to resist the tendrils of neoliberalism" (p.126). Indeed, many of the authors argue that poetry can be a means of disturbing dominant patterns by enabling stronger relationships with others and the world around us. Van der Walt and Meskin argue that art-based methods "offer a space within which to explore the intersections between thinking, doing, and writing in ways that move beyond the linear rationality of conventional research methods" (p.229). They go on to say that "[a]rts based research arose as a productive counter narrative to the idea of an omniscient, authoritative researcher as the sole arbiter of unambiguous knowledge and the holder of power and voice in research" (p.257).

A central argument running through the text is that reflection on our own thoughts, views, and motivations nurtures an awareness that our well-being rests on the well-being of others. By placing empathy, vulnerability and care at the centre of the research endeavour, poetic inquiry can offer us a means of foregrounding social justice and equity in our research. In my view, however, this is only possible when we explicitly understand society as interconnected; an understanding that is at odds with the late-capitalist individualism underpinning some notions of self-care and self-reflection.

Certainly, the valuing of objectivity in research often rests on the idea that we can observe all that which is meaningful through our senses, especially with increasingly complex technological instruments. Poetic inquiry, on the other hand, suggests that empirical observations will always be partial and unable to fully represent the complex nature of being human.

While many scientists may feel uncomfortable with the idea of poetry as a means of data collection, analysis, or research representation, many of the chapters in this book argue that being able to understand and represent the human condition more fully and inclusively is central to answering intractable questions about society. Sliep and d"Abdon suggest that researchers have a duty to investigate that which is less obvious and to consider understandings that may be hidden in a whisper (p.12). In these ways, several of the authors argue that poetry can challenge the epistemic silencing inherent in many academic practices.

As Dark argues, some people's experiences "are rendered invisible via a kind of disrespect so normalised that there seems to be no possibility for wisdom emanating from them" (p.153). It is these kinds of challenges that we need to take seriously, regardless of the field of science with which we are engaged. Science takes place within society and the prejudices and biases of society inevitably leak into the science. Dark suggests that poetry might be "one way to restage, re-language, reframe and reclaim humanity" (p.155).

The multiple authors of Chapter Two argue for the power of poetry to challenge, subvert, and resist epistemic silencing. In this way, poetry and other non-traditional forms of knowledge-making and -sharing can open our understandings of the social world beyond the constraints imposed by more traditional forms of research. These authors argue that the use of poetry in many ways constitutes a culture of resistance to the dominant Eurocentric norms of knowledge creation and transmission.

There is frequent reference in the book to the relationship between poetic inquiry and indigenous knowledges and a suggestion that "traditional" scientific knowing is not entirely the rational activity we may wish it to be. While including poetry in our teaching, research, and community engagement may seem strange to many of us, what if, as Hough and Van Rooyen argue, "seeking the unfamiliar is the key to a brighter future personally and for society?" (p.27).

The authors of this book thus use poetry to find, create, interpret and represent data. They also reflect on how they use it to teach, and to share and connect with community in all its richness. My particular interest is in poetic representation of data, and I would have liked a deeper exploration of when it is that poetry constitutes research. I was convinced by the arguments made by many of the authors that poetry can be an enormously powerful

means of capturing the essence of participants' words in more nuanced ways than linear transcriptions. And I was convinced by the argument that poetry can be a highly participatory data creation method that can be more inclusive and socially just than traditional (often extractive) research methods. But I wanted to engage more with discussions about when poetry is research and when is it (simply, only, powerfully) poetry. There are dangers in relativist positions whereby all representations of the social world are deemed to constitute research. To be fair, though, as the title of the book makes clear, this is a book about poetic inquiry in all its forms, and not just poetic research. And perhaps my desire to pin down definitions of 'poetry as research' reveals my own narrow thinking. But that is a reflection to be undertaken after reading this engaging book.

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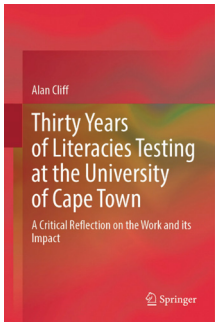

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Review of 'Thirty Years of Literacies Testing at the University of Cape Town: A Critical Reflection on the Work and its Impact'

Work on testing for admissions and placement conducted at the University of Cape Town (UCT) will be familiar to anyone who has worked with student recruitment and enrolment in South African higher education. A new book, Alan Cliff's *Thirty Years of Literacy Testing at the University of Cape Town,* chronicles the work of what began as the 'Alternative Admissions Testing Project' and, in doing so, provides an important record of what is arguably the most sustained piece of work in the history of the field known, in South Africa, as 'Academic Development'.

As Cliff points out, the 'testing project', which began in the 1980s, was rooted in activism and observations that students' results on the school-leaving examinations, in the context of the poor quality of schooling provided to black learners, did not always predict their ability to succeed in higher education. The desire to widen access as the country moved towards democracy and, at the same time, ensure that students were properly supported once they entered university, led to work that developed tests of academic and mathematical and scientific literacy.

Although a great deal of Academic Development work draws on activist intentions, the nature of knowledge produced in the field often lacks the power to 'reconceptualise' problems in teaching and learning in ways that will contribute to transformation.[1-3] The 'testing project' has been different in this respect because of the body of theory that backs it and the rigorous research that has been used to inform it. In spite of this, attempts to use tests alternative to the school-leaving examinations to admit and place students have often been met with resistance, and questions about why this is the case are interesting to consider.

In many respects, the answer to such questions lies in the power of common sense. As Brumfitt[4(p.1)] points out, "[l]anguage and education share two disadvantages that many other areas of study avoid – they are both too familiar". Familiarity with schooling and school-leaving examinations can result in the uninterrogated assumption that schooling prepares for higher education and school-leaving examinations are an indication of an individual's ability to engage with it. This is in spite of the fact that, in South Africa, only about 20% of 18-year-olds enter universities, and schools therefore need to prepare for, and test, a wide range of abilities.

The tests developed by the UCT project were never intended to replace school-leaving examinations but were rather intended to provide additional information – information that, importantly, would allow additional support to students to be designed and provided. Testing was also largely free thanks to support from donors. Nonetheless, the number of universities drawing on an important source of information that will allow them to better serve their students has dwindled, not only because of ignorance but also because of political reasons. Questioning school-leaving examinations on the basis of their power to predict the readiness of young people to engage with higher education is not an easy task, as the history of the project has shown.

In the light of the observations made above, Cliff's book not only provides a record of the testing initiative but, also, a means of challenging many of the commonsense assumptions that inform thinking about access to higher education in South Africa and elsewhere by providing an account of the reasoning behind the tests and their analysis. In doing this, the book is a powerful reminder of what we do not know, and are often blinded from knowing, by the power of common sense.

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Pan-African indicators for creative cities

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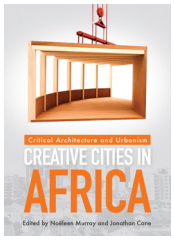
Creative Cities in Africa: Critical Architecture and Urbanism



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Cities in Africa are increasingly in the spotlight as the realisation dawns that contemporary urbanisation in the Global South is rocketing ahead, at an accelerated rate and scale that Euro-America has not known. But it is not all about "the economy, stupid" – as the expression goes. This well-known catchphrase is attributed to James Carville, who coined it in 1992 while campaigning for Bill Clinton, advising that the political race was largely an economic one.

Cities are growth drivers but also incubators of social imagination, without which societies struggle to reinvent themselves for a future in which urbanisation is a global mega-trend. Africa and Asia are at the sharp end; it follows that southern cities are indicators of entangled polycrises that others have yet to see, and their creative responses are all the more beguiling.

Cue a newly published book from HSRC Press on the 'creative cities' concept, from the vantage point of Africa. It makes a valuable contribution, from a multicity perspective. Its editorial approach draws upon Walter Benjamin's *The Arcades Project* and his methodology of the convolute – assemblages of research, sketches, collections, notes and cuttings, as the Introduction sets out. *Creative Cities in Africa*, as an assemblage in itself, invites a less instrumentalist notion of the subject matter, as productive responses to the nested complexities that accelerated urbanisation brings.

The first chapter sets the tone. It is about a fantasy city – Ville Fantôme created by Bodys Isek Kingelez. This large-scale art installation of plastics, paper and recycled materials is a bold and playful imagined megacity, "making a noisy claim for its own cityness, for cityness in Congo, and African cities in general", writes Jonathan Cane – also the book's co-editor with Noëleen Murray. Cane follows the cue of Filip de Boeck and Sammy Baloji, that Ville Fantôme is a "prolegomenon" – that is, a preliminary to a work of complexity. His chapter operates this way too. The book grapples with less tangible aspects of what a creative city might be while forging a plausible set of indicators through a pan-African prism.

Each chapter cuts into the topic in a distinctive way, the authors using varied methodologies that range from ambulatory thinking to everyday urbanism, a single building as lens, an unreal city, 'ruins', short stories, artworks, and a public park. The case studies move the reader from city to city, with the African continent as shared referent and conceptual anchor. The volume as a whole, in its urban juxtapositions, manages the tricky balancing act of respecting contextual difference while seeking commonalities.

After Villa Fantôme, a hopscotch through the continent begins in Johannesburg. Chapter 2 is about an iconic bridge that has arguably come to represent the interests of the elite and narratives around nation-building rather than the collective democratic values of the person whose name it bears – Nelson Mandela. Chapter 3 moves to Lubumbashi in a considered reflection of urban design, using walking as a research tool. It's about learning to read the city's signs and back routes or pathways invisible to an outsider – *katricher*, as it is known. Chapter 4 makes parallels between Dakar and Cape Town by referencing both the rise and fall of respective monuments and memorials, paying particular attention to literal and figurative scaffolding – or "not-yet" space. Chapter 5, on Nairobi, is about the hold planning still has on imaginaries about the African city.

Next up is Douala, with Chapter 6 apprehending creativity as embedded in the quotidian. Chapter 7 looks at singer Miriam Makeba's home in Dalaba, and Ângela Ferreira's artistic rendering thereof. It uses sounding as a methodology – as related to the sonic, but referencing critical architecture and urbanism to posit a hybrid, messy modernity. Chapter 8 also takes a single building as a lens – this time the former Durban home of a Hindu association, to offer a spatial biography of socio-cultural connections and how it expanded incrementally to become a significant urban actant. Chapter 9 on Maputo is a lyrical contribution that begins with buildings, critiques the discourse of ruin via short stories, and ends with an artist turning buildings into stories. Chapter 10 returns to Johannesburg, offering a notion of the "empathic" city in Paterson Park on the Louis Botha "corridor of freedom" – a placemaking initiative by the City of Joburg to infrastructurally restitch what spatial apartheid has fragmented.

Creative Cities in Africa demonstrates a rich variety of approaches to rethinking the topic, from the empirical to the more poetic, and what it might mean from a pan-African perspective. Its multidimensionality celebrates a complexity that is often elided for more singular narratives, countering in the process rising exceptionalism. It should have crossover appeal, not only to scholars and researchers in urban studies and creative fields, but also to practitioners, policymakers and anyone invested in re-imagining city futures.

A critical review of 'African Philosophy of Religion and Western Monotheism'

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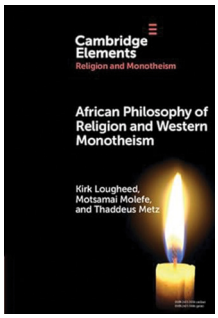
African Philosophy of Religion and Western Monotheism



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This small book does its job of spotlighting/providing a critical summary of some ideas in African traditional religion(s) and a comparative analysis of those ideas with ideas from some monotheistic religions that are popular in Europe and America. Following some preliminary clarifications in Section 1, the reader is introduced to various key concepts in ATR in Section 2. These include a description of God as "the most powerful, good, and knowing person" and also as an eternal, distant and imperceptible being that is responsible for creating and sustaining the universe. This view is later contrasted with the limited God view, which rejects the argument that God possesses certain absolute/maximal properties of omni-benevolence, omnipotence, omniscience, etc. There is also the idea of the interconnectedness of things, which the authors cash out in terms of vitality. This idea of vitality flows through to statements about the hierarchy of being, where a thing's place in the world is dependent on the type of vitality that is imbued in it by God. Now, I must remark here that relationality/interconnectedness in African thought is not only cashed out in terms of vitality. For some, like Asouzu[1] and Attoe[2], relationality is a necessary feature of the world, as existent things are necessarily missing links of a complementary whole. This focus on vitality ought not to be misinterpreted as establishing vitality as the primary conceptual model for understanding relationality in African traditional religion (ATR).

Sections 3 and 4 focus largely on questions about God's existence/non-existence. On the cosmological view, the authors argue that the view is "lost on ATR". This argument is hinged on the rejection of creation *ex nihilo* in favour of creation *ex materia*. However, one wonders whether creation *ex nihilo* is necessary for an account of the cosmological argument to be considered as such. I do not think so. If a crucial aspect of most cosmological arguments is the existence of a necessary being or beings from which contingent beings emanate, then the cosmological view is consistent with most traditional African viewpoints as such a necessary/eternal first cause is thought to exist.[2,3] Another important point to note is that God's necessity does not imply aseity. While God's necessity comes from the rejection of absolute nothingness in ATR, this rejection is still consistent with the idea that God (a condition that constitutes all regressively eternal entities), in some ATR, is not self-sufficient. The condition of relationality (in *ex materia* arguments), and the presence and sustenance of the universe, as a way of avoiding the unattractive state of *being-alone*, all point to this non-aseity.[2] In Section 4, the book explores arguments about God's hiddenness (which seems odd for a section focused on arguments about God's non-existence). First explaining God's hiddenness through the framework of J.L. Schellenberg's views (although the African views can be examined on their own merit), the authors conclude that, in some versions of ATR, God is concealed and distant from the human being and that relationships with other mediating agents (such as ancestors) are often sufficient alternative options that are available to the practitioner of ATR. This may be true for some views, but this hiddenness, I must say, does not imply atheism (or the non-existence of God) in the strict sense. Furthermore, a treatment of Okot p'Bitek's views on the non-existence of a Supreme Being in ATR would have been important for this section, rather than arguments about God's hiddenness.[4] Concerning the best possible world argument – where God is either unfree (if God has no choice than to create the best possible world) or morally surpassable (if God can only create a less-than-perfect world) – the authors conclude that, for ATR, God does create the best possible world, but there is little discussion about whether God can be free in a libertarian sense. This best possible world is, however, not a world bereft of evil, because good cannot exist without evil.

In addressing the problem of evil, the authors discuss the appeal to fate (whether good or bad) as a reflection of a grand plan for one's life as envisioned by God. In this way, the experience of evil is not gratuitous. While one might wonder about the type of God that metes out bad destinies to certain beings, the authors also consider the idea of a limited God that is capable of evil and/or limited in knowledge or power.[5,6] While the book argues that the problem of evil still applies to the limited God, as suggested by Ada Agada, I dispute this point because a God capable of evil or lacking some powers might fail at preventing gratuitous evil as (1) a morally limited God might showcase evil or (2) a limited God cannot prevent all evil at all times. The insistence that the problem of evil persists for the limited God is, for me, problematic.

The final parts of the book deal with religious ethics and the afterlife in ATR. The book, again, draws on the idea of vitality, monism and holism in African thought. The authors, however, fail to describe the sort of logic that undergirds these viewpoints. To argue against dualism and yet bifurcate reality into the natural and supernatural; and to argue for the interdependence/inter-relationality of all things, which are also opposed to each other, requires a logic that is not strict on contradictions. For the reader to understand the underlying worldview (monism and holism), the reader must also be exposed to the logic that grounds such a view.

In any case, the authors attempt to develop a meta-ethical and normative account of vitality ethics (the latter focusing on accounts of dignity). Meta-ethically speaking, though, one is not quite clear about the actual meta-ethical concerns discussed or resolved. One would expect discussions on how vitality stands as a moral property, and/or how the vitalist account successfully bridges the is/ought gap. Similarly, while the book makes some interesting arguments about how the vitalist view escapes the Euthyphro dilemma, questions remain about how the vital force, in itself, constitutes God's will.

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The essential role of interdisciplinary approaches in addressing hunger and social justice: The 2024 International Social Justice Conference and Summit in Cape Town

Significance:

- Food insecurity in South Africa represents a critical social justice issue in which hunger has become 'normalised' along racial lines due to historical inequities, demonstrating how food access intersects with systemic racism and inequality.
- Legal frameworks and rights-based approaches, like the Equal Education legal case during COVID-19, show how social justice interventions can protect vulnerable populations' right to food, particularly for marginalised children and communities.
- Evidence from successful cases like Brazil's Zero Hunger Campaign and South Africa's Equal Education case shows that interdisciplinary interventions – combining legal, educational, health, and social protection measures – are more effective than single-domain approaches in addressing food insecurity.

The 2024 International Social Justice Conference[1] and Summit[2] in Cape Town highlighted a critical issue in addressing food insecurity: the need to move beyond traditional disciplinary boundaries and adopt interdisciplinary approaches. Adopting approaches that combine rigorous interdisciplinary research with effective research-policy linkages and social learning is essential for tackling the complex challenges of food insecurity in South Africa and beyond.

Overview

The Conference revealed how hunger intersects with multiple systems and social issues, exemplifying the "knot of multiple stressors" that characterise food insecurity. Despite South Africa being an upper-middle-income country with national food self-sufficiency and comprehensive social protection systems, it has made limited progress in addressing various dimensions of food insecurity at household and individual levels over the past three decades. This 'paradox' suggests that technical solutions within individual domains – whether legal, agricultural or economic – are insufficient when operating in isolation.[3]

The Conference highlighted that this paradox stems from hunger being a multidimensional systems issue with economic, social and environmental determinants that transcend the mere availability or production of food. As Chris Nisson, Chairperson of the South African Human Rights Commission, emphasised, the right to food has six components built into it in both international and domestic law, including:

> *availability (of food at national level); access (at household level); in a sustainable way (accessibility and availability extend to present and future generations); of quantity and quality; free from adverse substances; and possess adequate amount of requisite nutrients for human dietary needs; and culturally adequate food.*[4]

Single-sector interventions have consistently proven inadequate in addressing the multifaceted challenge of food security. Historical efforts have often been hampered by three limited approaches: the vertically sectoral approach, which operates in isolation through singular departmental lenses; the technological treatment approach, which favours technocratic solutions that address symptoms rather than root causes; and the short-view approach, predominantly favoured by donors in recent decades, which includes measures like food aid that, whilst providing immediate relief, may fail to create sustainable change and can even produce unintended negative consequences.[5] These single-issue solutions have fallen well short of addressing what is, fundamentally, a complex social challenge.

The Conference and Summit reiterated repeatedly: food security challenges cannot be addressed through disciplinary or single-sector approaches alone.

An ongoing research study presented at the Conference by Stephen Devereux suggests that one explanation for this failure might be the 'normalisation' of hunger – a social process by which conditions that should be considered abnormal and unacceptable become accepted and tolerated as normal.[6] In South Africa, this normalisation has taken on a distinctly racial character, with hunger being closely correlated with poverty and race due to the country's history of colonialism, slavery and apartheid. This complex social process cannot be addressed through single-discipline approaches, as it involves historical, psychological, sociological, economic, and political dimensions that must be considered together. Hunger, while biologically universal, is socially determined through race, class, and status intersections.[7]

Evidence for interdisciplinary success

The Conference and Summit showcased successful examples of cross-boundary interventions, notably Judge Sulet Potterill's discussion of the Equal Education case, which demonstrated how legal intervention, in conjunction with educational and public health perspectives, successfully protected children's nutritional rights during the

COVID-19 pandemic.[8] This case exemplified how cross-disciplinary approaches can achieve what single-domain interventions cannot.

Brazil's Zero Hunger Campaign was another powerful example. By integrating political commitment, social protection, agricultural support, and public health measures, Brazil reduced child stunting from 20% to 7% between 1989 and 2019.[9] This aligns with the need for approaches that span disciplines and sectors while engaging stakeholders in joint learning processes.

The role of academic institutions in fostering interdisciplinarity

The proceedings highlighted academic institutions' unique position in facilitating inter- and transdisciplinary approaches. This resonates with a vision of academic institutions serving as bridges between different knowledge domains and sectors.

The Conference itself modelled this approach by bringing together academic institutions, government departments, international organisations, civil society organisations, private sector representatives, legal professionals, public health experts, and environmental scientists.[10] This diverse participation enabled what Nomakwezi Mzilikazi of Rhodes University advocated for: moving beyond "becoming experts at admiring the problem" toward developing integrated solutions.[11]

The importance of translating academic research into practical solutions was exemplified by the Department of Science and Innovation–National Research Foundation Centre of Excellence in Food Security (CoE-FS) held at the University of Western Cape[12], which works closely with a range of other academic institutions and partners across sectors. Another was Stellenbosch University's Food Lab, which was discussed in a paper by Kennedy Dzama[13].

These demonstrate how academic institutions can serve as bridges between different knowledge domains and sectors.

Moving forward: Implementing interdisciplinary action

The Conference produced a framework for strengthening interdisciplinary approaches through institutionalised cross-sector collaboration, integrated monitoring systems, and regular stakeholder dialogue.[4] These recommendations acknowledge that addressing hunger requires more than the sum of individual disciplinary contributions. This reflects a need for systemic approaches that combine rigorous disciplinary and interdisciplinary research with effective approaches to research-policy linkages and social learning.

Just as Brazil's success in reducing hunger required a coordinated suite of interventions that declared hunger socially unacceptable while simultaneously implementing practical solutions, South Africa's challenge requires a similar multi-faceted approach. Hunger and social injustice can only be effectively challenged through combinations of interventions that address both material conditions and social perceptions, including legal frameworks that enforce the right to food; economic measures that ensure adequate social grants; public health initiatives that monitor and address nutritional outcomes; educational programmes that challenge accepted narratives about hunger; and social justice frameworks that address historical inequities.

Conclusion

The 2024 International Social Justice Conference and Summit demonstrated that addressing hunger requires more than the sum of individual disciplinary contributions. The evidence presented suggests that effective solutions emerge from the synthesis of multiple perspectives and approaches. This interdisciplinary imperative is not merely theoretical but practical and urgent. The Conference's resolution, which will inform the 2025 United Nations World Summit for Social Development, reflects this understanding by calling for integrated approaches to food security that combine sustainable agriculture, social protection and economic development within a comprehensive framework of social justice.

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Declarations

I have no competing interests to declare. I have no AI or LLM use to declare.

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Titanoniscus, a replacement name for the South African woodlouse, *Titana* Budde-Lund, 1909 (Isopoda: Oniscidea)

Significance:

In any area of scientific study, it is important to be able to identify the objects being discussed. Within zoology, this applies to the identity of the species. This process is controlled by the Code of the International Commission for Zoological Nomenclature, which requires each animal to have a unique name (genus and species). When the same name is inadvertently given to a second animal, a new name must be given to the second described animal in order to retain clarity within the scientific literature. This article provides the required replacement name for a South African isopod. Isopods are an order of about 10 000 species of crustaceans, about half of which are terrestrial. These are commonly referred to as woodlice and form the suborder Oniscidea.

Walker (1864)[1(p.813)] named a genus of lepidopteran from Sarawak, Borneo *Titana* Walker, 1864. He included only a single species, *Titana adelella* Walker, 1864, which is therefore the type species. Meyrick (1925)[2(p.237)] synonymised *Titana* under *Lecithocera* Herrich-Schäffer, 1853. Subsequently, *Titana* was moved to *Thubana* Walker, 1864, where it remains in the most recent works.[3] Despite these synonymies, the name *Titana* Walker, 1864 remains an available lepidopteran name.

Budde-lund (1909)[4(p.65)] named a genus of ligiid isopteran from Southwest Africa *Titana* Budde-Lund, 1909. He placed only one species in the genus, *Titana mirabilis* Budde-Lund, 1909, which is therefore the type species. Barnard (1932)[5(p.208)] transferred this genus to the family Trichoniscidae. Verhoeff (1938)[6(p.253)] created a new family Titanidae (the name was spelt incorrectly on p.256) for the genus *Titana*. In the latest world catalog of terrestrial isopods (Schmalfuss, 2003)[7(p.294)], this genus name is still in use. It is also shown as "accepted" in Boyko et al., 2024[8].

Titana Budde-Lund, 1909 is a junior homonym of *Titana* Walker, 1864 and a replacement name is required. *Titanoniscus* (Zoobank registration: urn:lsid:zoobank.org:act:702EE5B9-3DDA-4F5A-9B35-7D61375D30EF) is hereby proposed for *Titana* Budde-Lund, 1909, preoccupied by *Titana* Walker, 1864. The name is derived by adding a suffix derived from the suborder name (-oniscus) to the original genus name. The gender is masculine and the only species is *Titanoniscus mirabilis* **comb. n.**, which is therefore the type species.

When Verhoeff[6] created the family Titanidae to hold this genus, *Titana* (as the only genus) was automatically the type genus. In accordance with Article 39 of the International Code for Zoological Nomenclature, the replacement name for the type genus of this family makes it necessary to amend the name of the family to Titanoniscidae **nom. n.** (Zoobank registration: urn:lsid:zoobank.org:act:46C42787-EAA5-4DF8-9EA7-3481166DC733). There are four other genera in this family[7(p.24,82,134,211)]: *Antidorcasia* Kensley, 1971 (3 species), *Coatonia* Kensley, 1971 (1 species), *Kogmania* Barnard, 1932 (1 species) and *Phylloniscus* Purcell, 1903 (2 species).

These changes mean that the potential confusion arising from the name *Titana* being given to two different animals is resolved, with minimal disruption to nomenclatural stability.

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Infectious diseases in a warming world: A call for action

Significance:

Climate change risks triggering epidemics of emerging and re-emerging diseases across the world with disastrous consequences. Climate change impacts are typically discussed with long-term consequences in mind, but when it comes to climate effects on infectious diseases, the future is already here. Combatting the complex effects of climate change on infectious diseases requires a collaborative effort from governments, scientists, public health officials, and the private sector. We should view the response to climate change as an opportunity to invest in robust health care and outbreak response systems. However, we must act now to mitigate the impending global public health crisis for a healthier future for all.

Introduction

As the world begins to recover from the COVID-19 pandemic, it is crucial to recognise that another looming crisis demands our immediate attention. Human-induced climate change is frequently discussed in terms of its impact in the mid- to long-term future with gradual long-term shifts in global climate patterns. However, current events show the devastating consequences of climate change from extreme weather events. A recent example being the compounding effects of heat waves and long-term drought driving wildfires in the Brazilian Pantanal[1], damaging up to 9% of the world's largest wetland[2]. Closer to home, several regions of South Africa have been battered by floods over recent years, resulting in thousands of people injured and displaced and several fatalities.[3] The physical damage caused by these climate events burdens healthcare systems, but, regrettably, amidst these challenges, there is another impending threat to our health that requires urgent attention – the intricate interaction between climate change and infectious diseases.[4]

Climate-triggered disease outbreaks

We are facing a new era of global health with outbreaks of endemic, emerging and re-emerging pathogens triggered by climate and global change, and swiftly spread by global connectivity.[5] A recent review has revealed that climate change has the potential to aggravate almost 60% of known human pathogens.[6] Warming effects, changes in precipitation levels and floods are the most prominent climate hazards that predominantly stimulate vector-borne, waterborne, and airborne diseases. For example, West Nile virus, a vector-borne virus of African origin[7] spread by mosquitoes, has taken on an almost global distribution within the last two decades, facilitated by climate effects[8], with devastating outbreaks in Europe and the USA. The incidence of diarrhoea, particularly among children in low- and middle-income countries of Africa, South America and South Asia, increases during floods and floods preceded by drought[9] as these events reduce the quality of drinking water sources and contaminate them with pathogenic agents[10]. Additionally, changes in temperature and rainfall have been shown to affect human social behaviour, as people favour indoor activities over outdoor activities during unfavourable weather conditions, and, depending on indoor ventilation rates, this may facilitate the transmission of airborne diseases like COVID-19.[11]

Mechanisms of disease aggravation

There are three main mechanisms by which climate hazards stimulate infectious disease transmission:

Gradual environmental change

The slow but consistent increase in global temperatures is enabling climate-sensitive disease vectors, such as mosquitoes and ticks, to expand their geographical ranges into new territories and reproduce at a faster rate, consequently increasing their ability to transmit diseases.[12] Altered rainfall patterns can create breeding grounds for mosquitoes, which escalates the incidence of vector-borne diseases. Such increases in these diseases have been noticed around the world. For example, in 2023, there was a large outbreak of chikungunya virus (CHIKV) in South America with over 120 000 confirmed cases and 51 deaths.[13] Of those deaths, 46 occurred in Paraguay, causing substantial health disruptions as the virus spread to all corners of the country. This was the largest outbreak of CHIKV ever recorded in Paraguay and coincided with the highest average reported temperatures in the country's history.[14] In 2023, there was an extremely high global risk of contracting dengue virus, with an estimated 40% of the population at risk, partly attributed to the El Niño phenomenon and humanitarian crises.[15] At this time, 15 countries within the World Health Organization's (WHO) African region had reported cases of dengue with the number of infections in the region nine-fold higher than in 2019.[15]

Additionally, in the face of climate change and land-use change, in order to survive, many animal species will need to move their home ranges along with the environment as it changes. Such local and large-scale movements of animals will cause new species to interact with one another, potentially stimulating novel pathogen-sharing events and disease emergence in wildlife.[16] These pathogen-sharing events have the potential to be globally devastating, just as the SARS-CoV virus jumped from bats into civets which enabled infections of humans and caused a mini-pandemic in 2002–2003.[17]

Extreme climate disasters

Extreme climate events are sudden and severe weather conditions such as floods, cyclones and wildfires that devastate communities, agriculture and natural ecosystems. These events are increasingly causing or amplifying

disease outbreaks by contaminating drinking water[18], displacing people and animals from their homes[19], disrupting social services, destroying crops and creating conditions of malnourishment such that affected communities are less capable of naturally fighting off disease[20]. These disasters often unfold quickly, catching countries off guard with limited time to prepare treatment facilities or interrupt disease transmission. Arguably, one of the most devastating infectious diseases triggered by extreme climate events is cholera. According to the WHO, as of mid-2021, we are in the midst of an acute upsurge of the seventh global cholera pandemic.[21] This pandemic has been characterised by multiple large outbreaks, spread of the bacteria to previously cholera-free areas, and alarmingly high mortality rates. Two such epidemics are worth noting. In 2022, Pakistan experienced extreme flooding, resulting in hundreds of thousands of infections (https://who-global-cholera-and-awd-dashboard-1-who.hub.arcgis.com/). The strain responsible for the outbreak in Pakistan was also associated with the deadliest cholera epidemic in Malawi's history, with over 57 000 confirmed cases and 1733 deaths during the 2022/2023 outbreak.[22]

Climate-induced migration

The above-mentioned gradual changes in temperature and rainfall also have indirect effects on disease transmission via their impacts on food production and water availability. Long-term droughts are causing crop failures and raising issues of food insecurity[23], while desertification fosters conflict over water access[24]. Disrupted access to food and water prompts both people and animals to migrate in search of these basic resources as well as new economic opportunities.[25] Regional and international movement of people may stimulate outbreaks by the introduction of pathogens into non-endemic areas to naive populations, through susceptible migrants being exposed to new pathogens, or from overcrowding in informal settlements.[26] For example, there have been 12 recorded outbreaks of acute viral hepatitis in forcibly displaced peoples in sub-Saharan Africa since 2010, with at least 30 000 cases and over 600 deaths.[27] These outbreaks have been attributed to poor sanitation and overcrowding conditions[26], which are a consequence of climate-induced migration and displacement of people.

Call to action

Unfortunately, while countries in the Global South contribute less than 10% of greenhouse gas emissions (https://ourworldindata.org/co2-emissions-metrics), they are more at risk of climate-related health threats (https://ourworldindata.org/health-meta#burden-of-disease) and have less adaptive capacity to respond to these threats. As such, low- and middle-income countries are highly vulnerable to climate-induced hazards. In response to the Global South climate-health crisis, the Climate Amplified Diseases and Epidemics (CLIMADE) consortium has banded together leading scientists working to close knowledge gaps, improve disease surveillance tools and develop disease transmission interventions to decrease the impact of climate-amplified diseases (https://climade.health/). The CLIMADE consortium has highlighted five action points for governments, academic institutions, scientists, public health officials, private sector industries and health organisations to consider in order to collectively address the climate-health crisis.[28] Firstly, CLIMADE urges governments and health organisations to **report outbreaks timeously** and transparently, as it is crucial for global preparedness and outbreak response efforts. Secondly, relevant stakeholders, such as governments, academic institutions, and health organisations, must expand and **strengthen disease and genomic surveillance** capacity. Strong genomic surveillance programmes will equip nations to detect emerging pathogens and instate response strategies early on in outbreaks. Thirdly, globally, we need to **prioritise** the development of adequate health care, infrastructure, and disaster preparedness systems for **vulnerable populations,** as they are most affected by the crisis. Also, academic institutions and private sector industries should **promote climate resilience** within healthcare systems by developing solutions to prevent damage from extreme weather events and ensure the supply of essential medical supplies during crises. Lastly, CLIMADE calls on governments, private sector industries, and health organisations to **commit sustainable funding** for research, capacity-building, and community engagement in the fight against climate change related infectious diseases.

With the world already grappling with climate-induced disease outbreaks, we need immediate and concerted action to address the complex challenges posed by the intersection of climate and health. Building global capacity, improving surveillance, and developing climate-resilient healthcare systems are critical steps in safeguarding communities from further harm. The window to act is narrowing; we need to work collectively to mitigate potential public health losses and build a more resilient, equitable future for all.

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Is there enough space for Africa in outer space?

Significance:

Access to outer space is crucial for African nations, for enhancing agricultural efficiency, disaster management, bridging the digital divide, strengthening national security, promoting scientific research, innovation, and fostering international collaboration. Furthermore, gaining access to outer space would empower African nations to actively participate in and benefit from the global space economy. However, the challenge of space debris from spacefaring nations threatens this progress, potentially leading to conflicts. To safeguard their interests, African nations must increase involvement in space activities, promote collaborations, adhere to sustainability principles, and advocate fair debris responsibility. These steps are vital for the future of space exploration.

Introduction

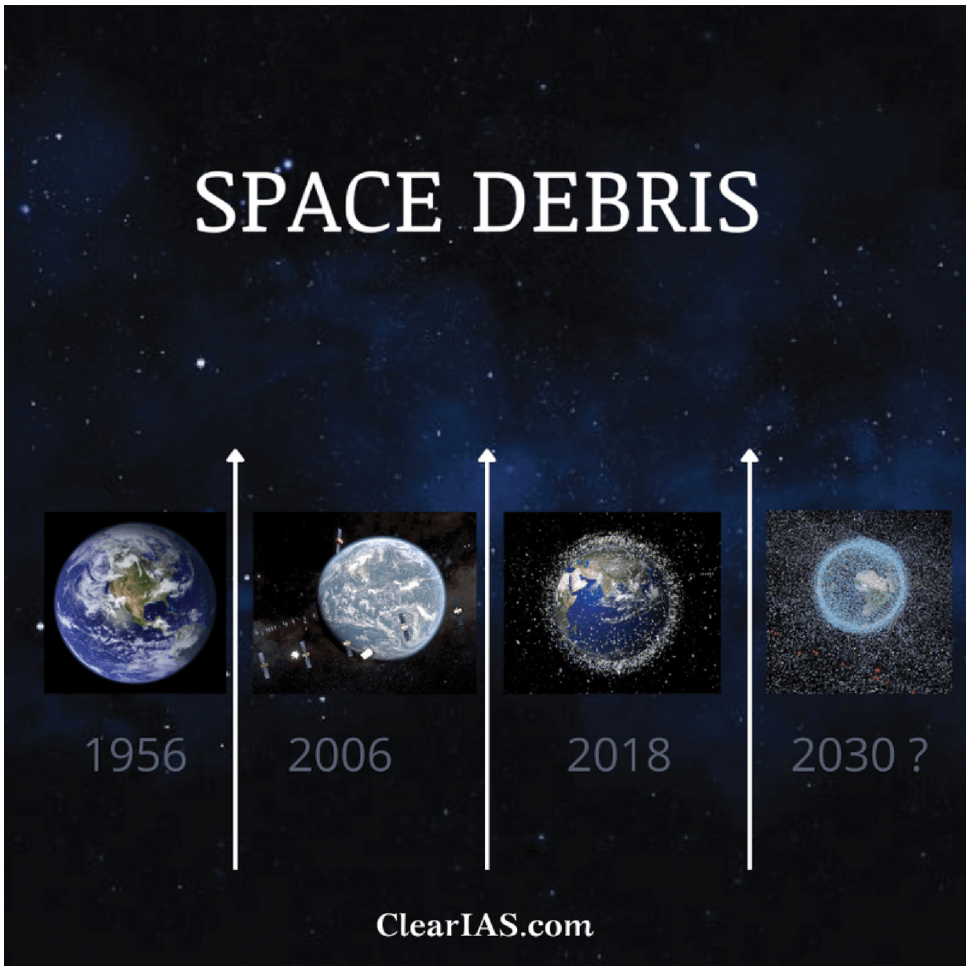
Earth observation satellites (EOS) have significantly improved environmental monitoring and communication accessibility, thus contributing to addressing various challenges faced by humanity. Investing in EOS activities yields numerous long-term benefits, including providing reliable data for informed decision-making in urban planning, agriculture, and biodiversity conservation, to mention only a few. This also entails ensuring consistent communication services, even in regions with challenging terrain or infrastructure limitations. Space-based projects are essential for promoting sustainable development on a global scale. Their varied technologies and wide-ranging applications enable them to effectively address all 17 Sustainable Development Goals (SDGs) and numerous Targets outlined in the 2030 Agenda.[1] However, although some SDGs benefit more from space-based projects than others, this Commentary does not aim to differentiate between these varying levels of support. Despite Africa's limited involvement in EOS and space exploration, recent literature indicates a growing interest and participation in this field.[2,3] However, inconsistent funding is a significant barrier to African space technology development.[4,5]

Outer space availability

The high cost of launching EOS into space – in competition with other essential expenditures such as food, water, and infrastructure development – limits Africa's space exploration endeavours. However, the primary threat facing space exploration is the generation of space debris, which poses a significant risk to EOS and manned missions. Space debris, which consists of defunct satellites and fragments from previous missions, has increased substantially since the inception of space missions, leading to congestion in Earth's orbit.[6,7] Collisions at orbital velocity can cause catastrophic damage to operational satellites and pose risks to future space exploration missions. The Kessler Syndrome predicts that, as the number of debris objects increases, collisions will become more frequent, creating a self-perpetuating cycle of debris.[7] Despite the vastness of space, most EOS are concentrated in low Earth orbit, which is regarded to be particularly vulnerable to debris accumulation.[7] Accidental satellite collisions have occurred in previous instances, resulting in further debris generation. Computer simulations predict an increase in collisions in the coming decades, potentially rendering low Earth orbit inaccessible due to debris density.[7] Currently, out of the 34310 objects under observation in orbit, about 25% are operational satellites, with the rest being debris [6,7] (Figure 1). Furthermore, there are an estimated 130 million debris fragments, too small to be monitored, ranging from 1 mm to 1 cm in size.[7] Travelling at speeds exceeding 25 000 kilometres per hour, even these tiny fragments pose a substantial risk of inflicting damage to operational satellites.[8,9]

The vulnerability of space to interference and disruption has led the USA security space community to perceive space as a contested domain, acknowledging its potential for significant social, economic, and military advantages.[11] The advancement of microsatellite technology and the establishment of multiple satellite constellations have enhanced space exploration initiatives for both the private and government sectors. This has generated greater interest in Africa's activities in space exploration, with ambitious projects such as the 'Africa to the Moon' initiative.[12] Meanwhile, concerns about space debris and the availability of space resources persist, prompting international efforts to promote space sustainability through treaties like the Outer Space Treaty of 1967. This treaty encourages international cooperation in space exploration and utilisation, while prohibiting the deployment of nuclear weapons or any form of mass destruction weapon in space. It explicitly states that no state can assert sovereignty over or occupy outer space, the moon, or any other celestial body. Additionally, the treaty addresses liability and mandates states to inform the United Nations (UN) Secretary-General and the international scientific community about the nature, conduct, location, and outcomes of their activities in outer space. The 1972 Liability Convention establishes international liability for damage caused by space objects. The convention imposes an international and absolute liability on a launching state, or states, and on states that are members of inter-governmental organisations, for any damage caused by their objects. The state that launches or procures the launch of a space object, or from whose territory or facility the launch occurs, is defined as the launch state, regardless of the launch's success or failure. Damage encompasses the loss of life, personal injury, or any other health impairment, as well as damage to a state's property or the property of individuals, whether natural or juridical, or the property of international or intergovernmental organisations. This also applies to any damage caused by a space object on the surface of the Earth or to an aircraft flight.

Despite these treaties' existence, leading spacefaring nations have demonstrated non-compliance. Since the 1960s, both the USA and Russia have conducted numerous anti-satellite test missions in space, resulting in a significant portion of the orbital debris present today. China executed an anti-satellite mission on 11 January 2007, targeting its outdated FY-1C meteorological satellite positioned at an altitude of 855 km. The satellite was destroyed



Source: ClearIAS[10] (reproduced with permission)

Figure 1: The status and future prediction of outer space debris.

by a missile, resulting in the creation of more than 3000 pieces of debris larger than 10 cm.[13,14] The USA conducted a similar mission on 21 February 2008, destroying a military satellite at an altitude of about 250 km. Then-President George W. Bush dismissed concerns about the negative impact of such operations.[15] On 15 November 2021, Russia conducted an anti-satellite missile test that destroyed the defunct Soviet satellite Cosmos 1408. The resulting debris came extremely close to the International Space Station, forcing its crew to take shelter.[16] Australia's Defence Minister Peter Dutton and Foreign Minister Marise Payne condemned the test as provocative and dangerous, questioning Russia's commitment to the peaceful use of space. These events highlight the dominance of advanced spacefaring nations and raise concerns about potential bullying in space.

Navigating outer space accessibility

The intentional destruction of satellites[15,16] has exacerbated the hazardous space debris environment, significantly increasing the risk of collisions with operational satellites. Thus, the threat of satellite loss due to space debris is no longer a theoretical concern but a harsh reality that is likely to intensify in the future.[7,17] The deliberate generation of space debris could also ignite conflict between nations with a vested interest in space exploration, potentially escalating into war. Therefore, it is essential to maintain a stable outer space environment that is free of conflict, with minimum creation of new debris, and effectively manage the existing debris. This will ensure space remains accessible for all those who wish to explore and utilise it. Consequently, it is crucial for all states – whether established, emerging, or future space actors – to engage in multilateral dialogues aimed at developing cooperative international solutions to address and mitigate these shared challenges.[18,19]

With its growing endeavours in outer space, Africa must actively and constructively engage in these discussions. However, the continent's participation in space affairs has been hindered by the absence of formal governance frameworks for collaboration, resulting in countries operating independently. This is set to change with the establishment of the African Space Agency (AfSA), headquartered in Egypt. Supported by a comprehensive space strategy and policy, the agency aims to align with the African Union's Agenda 2063[9], which underscores the critical role of space in Africa's development. The African Union's space policy and strategy are recognised as one of 15 key programmes within this agenda, providing a framework for Africa's space priorities, programmes, and partnerships.[19] The African Space Strategy, grounded in the African Space Policy, outlines fundamental principles for the use of outer space. It emphasises key actions and objectives necessary to leverage space science and technology to address political, economic, social, and environmental challenges. The space policy and strategy were endorsed by African heads of state to foster continental growth by enhancing capabilities in Earth observation, navigation, positioning systems, satellite communication, and space exploration.[19] The African Union Agenda 2063 is also aligned with the UN Sustainable Development Goals (SDGs) 2030.

Currently, 17 African countries have collectively launched 61 satellites, with Egypt and South Africa leading the way through the launches of EgyptSat-1 in 2007 and SUNSAT-1 in 1999, respectively.[20] Senegal recently joined this initiative with the launch of GAINDESAT-1A on 16 August 2024.[18] Despite being latecomers to space activities, African leaders are urged to act to safeguard outer space and promote development and prosperity. Smith et al.[21] argue that addressing the challenge of space debris will enable the African continent to enhance its

national and regional legal frameworks, aligning them with international standards. This engagement will also allow Africa to play a proactive role in the global initiative for the long-term sustainability of outer space.[21] Additionally, African nations must actively participate in establishing international best practices for responsible behaviour, which includes engaging in discussions regarding the draft International Code of Conduct for Outer Space Activities.[22] Active participation in these consultations is crucial for African states to ensure that any resulting agreements reflect their specific interests, particularly those of emerging space actors.

International guidelines have been created to promote responsible space activities, but compliance varies among nations and is not enforced by any global authority.[21] Gaps in international law and national policies contribute to uncertainty in addressing outer space issues.[23] Atkins et al.[23] argue that the current political and legal frameworks for space security are inadequate for the needs of today's spacefaring and space-dependent communities. They also highlight the absence of a clear global regulatory framework to address key issues such as ownership rights in space, liability for collisions, dispute resolution, licensing, or the registration of security interests. In this regulatory vacuum, individual nations have developed their own space legislation and policies, leading to inconsistent and potentially conflicting regulations across countries. This lack of coordination risks disputes and creates an unpredictable environment for space investments and activities.[17] Furthermore, progress on legally binding agreements in traditional forums has been limited, despite the growing urgency to address space stability and sustainability.[17,23] Therefore, it is crucial for African nations to engage in the creation of legislation that balances national interests with the collective goals of space agencies.

Collaborative efforts among different nations to implement a space debris remediation programme are limited. Therefore, to ensure the long-term sustainability of space operations, coordinated efforts are essential to mitigate the risks of operating in a debris-congested environment.[23] This involves both preventing the creation of new space debris and effectively managing existing debris. Support from external organisations, such as the US National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and the China National Space Administration (CNSA), would be invaluable to the emerging African Space Agency (ASA).

The UN Committee on the Peaceful Uses of Outer Space (COPUOS) Scientific and Technical Subcommittee adopted non-binding space debris mitigation guidelines based on the Inter-Agency Space Debris Coordination Committee (IADC) standards, which were endorsed by the UN General Assembly in 2007. These space debris mitigation guidelines provide seven key principles to guide the mission planning, design, manufacture, and operations of spacecraft and launch vehicles. The principles are: limiting debris release during normal operations, minimising the risk of break-ups, reducing the probability of accidental collisions, avoiding intentional destruction, minimising post-mission break-ups, restricting the long-term presence of objects in outer space, and promoting international compliance with space debris mitigation measures.[22] Through its African Union policy, Africa is committed to supporting the space regulatory principles to ensure that outer space remains accessible to all. Additionally, the continent seeks to promote the long-term sustainability of outer space by adopting responsible practices in its continental space programmes.[18]

Conclusion

Protection against space debris as well as space debris mitigation impose significant costs on space actors, including potential loss of satellites during collisions with space debris. Mitigation efforts involve measures such as impact avoidance (e.g. shielding and debris avoidance manoeuvres), orbit clearance, and venting residual fuel, all of which can affect spacecraft design. Additionally, there are considerable expenses associated with debris surveillance, tracking, and reporting, with little known about the impact of non-tracked debris objects.[24]

It is believed that the current costs associated with space debris are minimal compared to what lies ahead. In a worst-case scenario, certain orbits could become unusable due to the ongoing and self-perpetuating generation of space debris.[7,25] This situation would significantly hinder the delivery of vital government services and likely impede economic growth, particularly for developing continents like Africa.

Africa should expand its space situational awareness to include tracking space debris and assessing collision risks. African members of the COPUOS should advocate for historical space powers to bear financial responsibility for debris removal, with costs proportional to their cumulative payloads. Additionally, Africa should conduct technological research and develop methods for space debris removal. Promoting international collaborations, adhering to principles of space sustainability, and advocating for equitable responsibility in debris removal are crucial for the future of space exploration.[26] Recent developments, such as the 2023 collaboration between South Africa and the Russian government to establish a space debris monitoring facility in South Africa, should be encouraged. Moreover, the African Space Agency's efforts to advance outer space research should encompass studies on space debris, acknowledging that the benefits of space exploration go beyond mere discovery. By addressing the threats posed by space debris and promoting the sustainable use of outer space, Africa can help ensure the long-term availability and accessibility of space for future generations.

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Capitalising on 'the missing middle' dilemma to strengthen South Africa's research pipeline

Significance:

Mid-career researchers are at risk of falling into a critical gap in which they are no longer eligible for early-career support, but not yet fully prominent enough for established grants. This lack of strategic funding creates a precarious position that threatens to stall their innovative potential and curb the progress of South Africa's research ecosystem. Are funders, institutions, and society unintentionally sidelining this crucial talent pool? The future of research and groundbreaking innovation hinges on intentional investment in mid-career researchers. By creating targeted funding opportunities and developing a more inclusive environment, funders can bridge this gap, turning the untapped potential of these researchers into the driving force behind long-term academic and scientific excellence. Now, more than ever, we must ask ourselves: can we afford not to invest in the researchers who will shape tomorrow's breakthroughs?

Introduction

In South Africa's academic landscape, the path from PhD graduate to established researcher is often segmented into three key stages: early career, mid-career, and established researcher. Early-career researchers, typically defined as those who earned their PhD within the past 5 years and are generally between 30 and 40 years old, benefit from an array of targeted funding opportunities specifically designed to cultivate their potential.[1] Funding opportunities, including those from the National Research Foundation (NRF), often prioritise investment into the innovative capacity of early-career researchers, focusing on their proposed research rather than a long track record, while also incorporating mentorship and professional development to foster growth.[1,2] At the opposite end of the spectrum, established researchers, with extensive publication history, significant grants, and leadership experience, have access to prestigious funding. This enables them to lead large-scale research projects, influence national and international research agendas, and further cement their standing within the academic community.

However, between these well-supported stages of early-career researcher and established researcher, mid-career researchers are left stranded, overlooked, and underfunded. In the literature, mid-career researchers are defined in various ways, each emphasising different aspects of academic growth. Some definitions include scientists who have held the rank of associate professor (or equivalent) for at least 3 years and are balancing teaching and service with limited resources[3]; researchers with about 5–10 years of post-PhD experience, moving into mentorship and leadership roles[4]; and those in the early stages of independent research after completing one or two major projects[5]. For this article, we define mid-career researchers as individuals with approximately 5–10 years of post-PhD experience, assuming increased academic and leadership responsibilities. They are no longer eligible for grants specifically for early-career researchers but still lack the esteemed portfolio required for established funding. Despite their proven potential to drive innovative, transdisciplinary work, the lack of strategic funding and support often stalls their progress, impeding not only their own career trajectories but also the advancement of the research landscape.

Barriers to progress – challenges faced by mid-career researchers in South Africa

Mid-career researchers in South Africa face a unique set of challenges that severely hinder their progress toward becoming established academics. Unlike early-career researchers who benefit from strategic funding and mentorship programmes, mid-career professionals find themselves in a 'funding limbo'. They are caught in a gap that could stall their academic trajectory and diminish their contribution to innovative research. One of the most significant barriers is the scarcity of tailored funding for mid-career researchers. While various programmes are designed to encourage the innovative potential of early-career researchers or support established academics, the middle ground is woefully underfunded. This gap forces mid-career researchers into fierce competition for limited opportunities, threatening the continuity and momentum of their research. Previous studies have reported that insufficient financial support directly affects the quality of research, as mid-career researchers often lack access to essential resources such as equipment and materials, which can lead to stagnation in research projects, reduced publication output, and missed opportunities for potentially groundbreaking work.[6] This challenge is not confined to individual researchers – it also impacts sustainable development by limiting the capacity of research to address societal challenges. For universities, the shortage of funding exacerbates supervisory capacity issues, with increasing PhD enrolments not matched by enough qualified faculty, which affects mentorship quality and training.[7] Securing adequate resources is undeniably essential for advancing research and boosting publication output. A study found that funded researchers produce significantly more publications than those without financial support, with their output being 22 times higher.[6] However, for mid-career researchers, this funding gap risks becoming a blocking point, reducing both their potential and the overall research ecosystem.

Mid-career researchers also grapple with increasing responsibilities, such as leading research teams, mentoring junior colleagues, and managing higher administrative burdens, alongside personal obligations, including family commitments and other life responsibilities.[7] However, these demands are often not supported by the necessary institutional backing, adding to the strain. Many mid-career researchers do not have the infrastructure to conduct independent research, often relying on established researchers to act as principal investigators. This dependency limits their ability to show leadership and explore bold and innovative ideas that could shape their fields. Moreover, it reduces their opportunities to secure funding. Adding to the challenge is the relentless 'churn' of mid-career

research, where the pressure to secure funding and churn out papers overshadows opportunities to engage in deep, transdisciplinary work. Instead of pushing the boundaries of knowledge, many researchers are left chasing short-term goals. Compounding this is the rising administrative and teaching responsibilities that mid-career researchers face, leaving even less time for their primary pursuit, research.

Real-life examples illustrate these barriers. Consider a promising scientist who secures early-career funding, using it to initiate impactful research, but after the grant ends, they are plunged into uncertainty, unable to secure new funding due to a lack of an extensive publication record. Their career, along with their research, is stalled. Without access to innovative, transdisciplinary collaborations or the financial backing to expand their networks, these researchers are left in a precarious position, highlighting the severity of the 'funding limbo'. To address these critical challenges, some institutions have introduced mid-career awards, such as the South African Medical Research Council and the US National Science Foundation's Mid-Career Advancement programme. These initiatives, although promising, are still too few. Strategic and targeted funding for mid-career researchers must become the norm, not the exception, if we are serious about fostering innovation and ensuring sustained growth of South Africa's research capacity.

Another glaring issue is the lack of mentorship for mid-career researchers. In contrast to the mentorship-rich environment of early-career stages, this phase often lacks guidance, leaving researchers without the critical advice needed to navigate this complex period. Without mentorship, mid-career researchers often focus narrowly on immediate outputs, sacrificing the opportunity to explore ambitious research questions that could distinguish them in their fields. Established researchers, with their wealth of experience, can play a pivotal role here. By mentoring mid-career researchers, sharing insights, and helping them understand the evolving expectations of academic leadership, they can ensure that this cohort is better equipped to thrive.[8] Without this support, mid-career researchers are at risk of burnout, diminished productivity, and, ultimately, career stagnation. Addressing these barriers through strategic investment, targeted funding, and tailored mentorship – ideally involving field-specific mentors – is not just a solution for mid-career researchers, it is essential for sustaining a vibrant, innovative research ecosystem in South Africa. This approach ensures that mentorship is not generic but rather responsive to the specific challenges faced in different fields. In doing so, we ensure that promising academics at this critical career stage have the resources and guidance they need to continue making groundbreaking contributions to their fields.

How can funding bodies support 'the missing middle'?

To combat the challenges faced by mid-career researchers, funding bodies and industry partners must take a far more proactive stance. This impacts succession planning due to the ageing established researcher community. One critical intervention is the establishment of targeted funding opportunities, specifically designed for researchers who have outgrown early-career support but have not yet gained access to established funding. This approach should lead to policy interventions that directly address the unique needs of mid-career researchers, ensuring that they receive the support necessary to continue their progression. These grants should empower mid-career researchers to strengthen their track record, scale up their projects, and secure stable academic positions – key steps in advancing their careers and ensuring they contribute meaningfully to the research landscape.

In addition, mentorship has proven invaluable in shaping early-career researchers, so why should mid-career researchers be left out? Funding bodies should make mentorship a requirement in established researchers' funding proposals. A structured mentorship programme for mid-career researchers would ensure that they get essential guidance on building networks, improving research impact, and positioning themselves for leadership roles. While the current capacity for such programmes may be limited, South Africa, for example, has 130 A-rated and 768 B-rated researchers, providing a strong foundation for mentorship initiatives. These mentors do not necessarily need to be subject experts but can focus on offering career progression mentorship. Collaborative efforts between the DSTI/NRF and academic institutions could further expand capacity to support these initiatives. Such an approach would not only assist mid-career researchers in navigating the complexities of research funding but would also expose them to innovative, transdisciplinary projects, helping them push the boundaries of their fields. Therefore, policy recommendations that advocate for structured, tiered funding and sponsored and funded mentorship programmes designed to address the distinct needs within the mid-career category would ensure that mid-career researchers are able to transition into established roles with adequate infrastructure, leadership skills, and guidance.

Another key intervention lies in rethinking the evaluation criteria for mid-career grants. Far too often, funding is awarded based on extensive publication records or past leadership in large-scale projects.[9] This narrow focus sidelines promising mid-career researchers who may not yet boast these credentials but possess groundbreaking ideas. Instead, funders should prioritise the potential for innovation, the quality of preliminary work, and the strategic relevance of the research area. This shift would create space for mid-career researchers on the brink of major breakthroughs, those who need just one more strategic push to realise their potential and make significant contributions to South Africa's research landscape.

Equally important is the need for continuity between early-career and mid-career funding. Funders must design programmes that allow for seamless transitions for researchers to build on their previous work without interruption. Such continuity would not only preserve research momentum but would also prevent the erosion of talent that occurs when promising mid-career researchers are forced to step back due to financial constraints. By adopting these strategic interventions, targeted funding, mentorship programmes, and continuity in funding, the gap that mid-career researchers currently fall into can be curbed. These researchers are not only the future of innovation; they are the critical link between early promise and established success. Supporting them through this critical career stage is vital to creating a dynamic and resilient research ecosystem that drives long-term scientific and academic excellence in South Africa.

Paving the way for a sustainable research pipeline

The sustainability and vivacity of South Africa's research landscape hinge on addressing the overlooked challenges faced by mid-career researchers. If there is no intervention, the current gap in support threatens not only to derail individual careers but also to erode the overall impact of the nation's research output, an essential pillar of South Africa's National System of Innovation.[10] Ensuring that mid-career researchers are adequately supported is essential for maintaining a steady pipeline of innovation, retaining top talent, and cultivating the next generation of academic leaders. The challenges faced by mid-career researchers are not confined to specific types of institutions, such as historically disadvantaged ones – they affect researchers across all higher education sectors. From historically advantaged to historically disadvantaged institutions, the plight of mid-career researchers is universal. Resolution would result in improved research output and succession planning. Sustained support would allow researchers to develop long-term projects with the potential to make significant contributions to both knowledge and societal impact. In addition, South Africa would be more competitive on the global stage, making it an attractive destination for top research talent.

Moving forward requires a collective, coordinated effort from all stakeholders: funding bodies, academic institutions, government agencies, and the researchers themselves. Funding bodies must lead the way by adopting more innovative and flexible approaches and designing programmes that address the specific needs of mid-career researchers. The one-size-fits-all model is no longer sufficient. Tailored inclusive funding that bridges the gaps in the current system is urgently needed. Academic institutions must also play a pivotal role in fostering environments that support research across all stages of a scholar's career. This includes offering internal funding streams, mentorship opportunities, and professional development resources that target mid-career academics. Institutions must also adopt transdisciplinary approaches that promote collaboration across sectors and research fields,

thus maximising the innovative potential of mid-career researchers. Taking this into consideration, funding bodies could partner with institutions to create co-sponsored grants that include both financial support and institutional resources. This dual approach could alleviate some of the administrative and teaching burdens on mid-career researchers, allowing them to focus more on their research contributions.

Furthermore, government agencies and policymakers cannot afford to remain passive. National strategies and policies must be developed that acknowledge and address the funding gaps for mid-career researchers. This could include the establishment of national benchmarks for funding allocations, ensuring that no researcher falls through the cracks of the research pipeline. Additionally, incentives could be introduced to reward institutions that successfully support the progression of mid-career researchers, recognising them as key drivers of innovation. For researchers themselves, it is crucial to take an active role in navigating this challenging phase of their career. Career planning, seeking collaboration opportunities, and building diverse research portfolios are vital strategies to improve competitiveness. Active participation in professional networks and seeking mentorship are equally important in maximising visibility and access to new funding avenues.

Ultimately, the creation of sustainable support systems for mid-career researchers requires a collective effort from all spheres of the research ecosystem. By addressing its unique needs, South Africa can foster a more inclusive, dynamic, and innovative research landscape. This will ensure that excellence and groundbreaking innovation are nurtured at every stage of a researcher's career, driving the country toward sustained academic and societal progress.

Conclusions

Navigating the complexities of academic funding and career development reveals that both researchers and funding bodies have vital roles to play in overcoming the challenges faced by mid-career researchers. Although funding gaps and transitional obstacles create significant barriers, these can be addressed through collaborative efforts centred on open communication and mutual understanding. By aligning expectations and clearly defining roles, both parties can build a more supportive and effective structure, ensuring that no researcher is left behind. Funding bodies should take the lead by designing tailored programmes that bridge the gap between early career and established researchers' support, enabling mid-career researchers to build strong track records and establish themselves as leaders. Strategic partnerships, including public–private partnerships, can enrich the research environment, while targeted investments in capacity-building – such as workshops on grant writing, data analysis, and research methodologies – equip researchers to manage career transitions effectively. Mentorship programmes further support mid-career researchers by guiding them in funding opportunities, career strategies, and research advancement. At the same time, researchers must actively engage with available opportunities, seek mentorship, expand their networks, and strategically plan their career paths. This cooperative approach will address current challenges and strengthen the entire research ecosystem, fostering a more inclusive environment that promotes research culture, innovation, and sustained growth. With the right support, South Africa can create a resilient and thriving future for its research landscape and enable mid-career researchers to reach their full potential and make meaningful contributions to the advancement of knowledge.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. Both authors read and approved the final manuscript.

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Engaging the Anthropocene beyond disciplinary boundaries: Biosemiotics and ecosemiotic perspectives

Significance:

In this Commentary, we discuss biosemiotics and ecosemiotics as two interrelated fields of thought that, in our view, create a platform for natural, social and humanities scientists to join hands in exploring issues relating to the environment and ecology. The insight that ecological systems are also semiotic systems and not only physical-chemical-biological systems means that the ecological debate cannot be reduced to the interests of natural scientists.

Introduction

Humans have always pondered the meaning of their existence and their relationship to the world around them. The 21st century is no exception; scholars from all over the academic spectrum are currently engaged in various questions regarding human existence and its ecological implications. While neuroscientists are trying to explain the workings of the human brain and how it gives rise to complex phenomena such as language and art[1], philosophers and humanities scholars generally are trying to understand what it means to be human in this century. One of the factors that is central to questions around human life in the 21st century is the ecological crisis.

One could argue that humanity is, on the one hand, trying to figure out how far it *can* go with its technical abilities, exploring advances such as space travel and artificial intelligence. On the other hand, it is trying to figure out how far it *should* go, in other words, what the ethical and ecological implications of its technological 'progress' are. The question of how far humans *should* go is currently closely linked to the impact that technological advances might have on the more-than-human environment. One of the core problems in this ecological debate is what Timo Maran[2] calls 'symbolocentrism', i.e. the idea that humans are under the illusion that they exist in a symbolic universe only, with little contact with, and therefore little consideration for, the material world. Hence, the rise of a plethora of approaches broadly known under the term 'new materialism'.[3-7]

Biosemiotics and the concomitant ecosemiotics offer, in our view, transdisciplinary perspectives for engaging with this complex debate that are promising for both biological and semiotic reasons. We use this Commentary to explain the two approaches and consider their implications for scholarly work on the ecological crisis in South Africa.

Biosemiotics

Biosemiotics is a fairly recent addition to the smorgasbord of scholarly interests. It entails an interdisciplinary collaboration between biologists and semioticians, emerging from the insight that semiosis and life are probably co-emergent. The development of this field in the 20th century has been documented in detail[8,9], so we do not repeat it here. Rather, we focus on some of the foundational concepts and research opportunities that the field provides.

As indicated above, the basic tenet in biosemiotics is that life and semiosis are co-emergent. From the molecular level upwards, life requires semiosis, i.e. meaning-making and meaning-taking, both internally and externally to the organism.[10] Internally, information is shared between the cell and molecules such as DNA. This process is called endosemiotics.[10] In multicellular organisms, at a next level, information also needs to be shared between the cells, and between organs in the organism, to maintain the whole organism. Equally, externally to the organism, all living organisms need the biological ability to perceive information in their environment, judge its relevance and act on that judgement, which is a semiotic activity.[11] In the biosemiotic view, life cannot be reduced to either biophysics or semiotics, but must entail a biosemiotic component because living organisms are semiotically active.

One of the implications of a biosemiotic approach is that semiosis does not require a brain and is not limited to lingual action. Recall that semiosis happens even at a cellular level. Semiotic processes take place both within and between the bodies of living organisms and their environment, irrespective of whether that organism has a brain. A good example is the ability of bacteria to sense a higher gradient of glucose in a Petri dish and then move in the direction of this higher solution. This means, per implication, that there are levels of semiosis. The argument is that semiosis at a cellular level and semiosis between human organisms and their environment are not at the same level. Emergent levels of semiosis are, according to this view, increasingly complex[12], starting as chemical interaction and evolving into ideational interaction. Generally speaking, biosemioticians distinguish between biosemiotics, which covers semiosis in all non-human living organisms, and eusemiotics, which deals with human organisms only. Biosemiotics itself is usually divided into zoosemiotics and phytosemiotics to distinguish between semiosis in animals and plants. We need to point out that there is debate about these (categorial) distinctions, not only about whether they are valuable in the first place, but also about the boundaries between them, should one argue for the need to make them. An implication of this emergent view of semiosis is that one could also describe the translation processes at the various levels, starting from making protein on the basis of messenger RNA[13] and moving on to the ideational translation processes involved in the creation of human culture. Describing these levels of translation has only just begun[14], and poses fascinating research possibilities.

Another key consideration in biosemiotics is Umwelt, a concept developed by the Estonian biologist of Baltic German origin, Jakob von Uexküll.[15,16] Despite criticism that can be brought against Von Uexküll's political agenda

and some of the philosophical implications of his work[17], Umwelt remains a useful concept. The notion is used to capture the idea that every species is endowed with a particular set of perceptual apparatus, which means that every species perceives reality in the way allowed for by their perceptual apparatus. This means that every species constructs its Umwelt, its phenomenal world, in a unique way.

More recent work in Umwelt theory has linked it to phenomenology and questions of interspecies communication.[18-21] This question of interspecies communication has moved the biosemiotic debate into the larger debate about ecology, giving rise to the field of ecosemiotics[22-25] that will be discussed in the next section. This interest covers communication between different species and also communication between humans and other species.[26,27]

Ecosemiotics

As a discipline, ecosemiotics is relatively young. It emerged in the mid-1990s as a branch of biosemiotics to explore the semiotic interactions between organisms and their environments. More succinctly, it aims to connect semiotics to ecology.[28] It thereby offers a novel lens through which the relationship between the signs intrinsic to all life (which, as explained above, can be both verbal and non-verbal) and the environments in which they are sent and received, can be explored. As a point of departure, ecosemiotics takes a sign, which is often regarded as belonging to the domains of language and culture only, to be "not as a fully conventional and arbitrary means of human culture, but as partly rooted in the natural world and in our corporality"[28]. In other words, signs are as much a part of nature as they are of culture, and furthermore, human culture is fully part of nature, and not separate from it.[22]

Kalevi Kull argues that semiotics is about knowledge and knowing[29], and as such, through an ecosemiotic lens, we can start to understand how physical objects and their meanings influence ecological systems and human understanding of – and interaction with – these systems. By physical objects he means here both animate and inanimate objects, and both individual objects, such as a particular animal, and collective objects such as ecosystems. Important to note here is that ecosemiotics does not only consider intentional signs as contributing to meaning making, but non-intentional signs as well.[30] In this light, we can argue "that meaning is always rooted in the material processes of life"[31], hence the need to combine biology and semiotics without reducing the argument to either.

Semiotic processes in ecosemiotics involve the continuous interaction between signs, their objects and the meaning ascribed to them by a particular meaning maker (human or more-than-human). These processes are seen as fundamental to the functioning of ecosystems, as well as to the way in which these ecosystems are regarded by observers (in other words, humans). An ecosemiotic approach allows for an analysis of these processes to uncover their meaning within an ecological system as well as their cultural implications in a particular space and time. This can involve studies of landscapes[32], studies of human–animal relations and human ecology[33], exploration into ecosystems[34], and even agricultural activities[35], amongst many others.

Like biosemiotics, ecosemiotics allows for cross- and transdisciplinarity between human and social sciences and natural sciences. Moreover, one of the distinguishing features of semiotics, and, by extension, ecosemiotics, is its propensity to stimulate self-reflexivity in the researcher.[34] It also allows the researcher to identify the ways in which human activities impact more-than-human spaces and lives, and at the same time how more-than-human spaces and lives impact human activity. In other words, studying closely the interaction between humans and the more-than-human, or the perception of the more-than-human by the human, can be done through a critical lens. For example, a researcher can observe the impact that human action has on a particular environment, and place it in relation to the production of the human perception of that environment. For instance, expanding an urban space into a once non-urban space (an open field) replaces the trees and grasslands with buildings, which signifies habitat loss and ecological disruption. Alternatively, nature can also influence human perceptions and actions – natural phenomena such as droughts can introduce new signs, such as dry natural water sources and dying flora, that signify environmental change. These examples of interactions point to the reciprocal nature of human–more-than-human relations in the environment, where material signs (such as dry dams or buildings) mediate the dynamic interplay between nature and culture.

In our view, biosemiotics and ecosemiotics create a platform for natural, social and humanities scientists to join hands in exploring issues relating to the environment and ecology. The insight that ecological systems are also semiotic systems and not only physical-chemical-biological systems means that the ecological debate cannot be reduced to the interests of natural scientists. Rather, what seems to be emerging is a transdisciplinary debate mediated through translations between species, languages, and disciplines. Having recently hosted the 24th Gatherings in Biosemiotics in Bloemfontein, the first time ever that these Gatherings have been held south of the equator and in the Global South, we call on southern African scholars interested in aspects of the ecology to consider participating in a bio-ecosemiotic debate about the Anthropocene.

Interestingly enough, South Africa has a rich history of thought in biosemiotics and ecosemiotics through the work of philosopher John Collier from the University of KwaZulu-Natal, theoretical biologist Jannie Hofmeyr from Stellenbosch University and evolutionary biologist Hugh Paterson from the University of the Witwatersrand. Currently, we are working in bio- and ecosemiotics and translation. It is perhaps time to formalise these scattered interests in structured discussions amongst South(ern) African scholars.

Conclusion

Given the current ecological crisis and the focus on ecology and the more-than-human, biosemiotic and ecosemiotic approaches to studying the relations between humans and the material (and, by extension, the natural) world are not only significant for those working in ecology and other relevant biological fields, but also for humanities scholars who work in the broader environmental humanities. The integration of ecosemiotic and biosemiotic approaches in our understanding of the environment and the world is not just a scholarly endeavour. Rather, we believe that it is a critical shift in how we perceive and engage with the environment in an era of profound ecological and existential crisis. By recognising that all life forms – from the simplest cells, to plants, to animal communities, to complex human societies – are engaged in continuous meaning-making processes, we break free from the outdated notions that humanity is isolated in a symbolic world and that the material issues of the world are not related to humanity. Instead, we see that our actions, perceptions, and cultural practices are deeply embedded in, reflective of, and determined by, the natural world.

This realisation can be transformative, as it calls for a new ethic of understanding the interrelations between humans and the natural world. In this transformed understanding, human progress cannot be measured only by technological advances but must crucially also be measured by our ability to understand and reflect on the semiotic relationships that sustain all life on earth. Ecosemiotics and biosemiotics offer conceptual tools to navigate this complex terrain, bridging the gap between formerly disparate disciplines and fostering a more holistic, reflective and responsible approach to research about our shared environment. In doing so, these fields provide a pathway toward an interconnected future of scholarly engagement in which human culture, the environment and all of its inhabitants (from bacteria, to plants, to all animals – including humans) are inextricably linked and interdependent.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. Both authors read and approved the final manuscript.

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Utrecht University; exploration, colonial knowledge: A 'Civilizing Mission'. Interview with Henk van Rinsum

Significance:

This piece relays an interview with Henk van Rinsum (retired from Utrecht University). In the interview, the idea of the university as a detached space connected with the notion of the alleged objectivity of science is challenged by an "older white Dutchman attempting to offer insights on colonialism". The interview explores the colonial historical development of a university in Western Europe as it finds its place within the entanglements of Christianity, capitalism, commerce, colonialism, and civilisation. The interview calls for a sensitive dialogue on issues of decolonisation. Are we prepared to address the ills of colonialism, given that we still seem to live under the influence of coloniality, including in higher education?

Henk van Rinsum (retired from Utrecht University and 2021–2024 Research Fellow at CREST, Stellenbosch University) is a curious creature in the world of universities. For one thing, his professional career was primarily in academic administration, not in the academy. In addition, his educational training in history and anthropology interested him in the world of institutions of higher education and research. And thirdly, early dabbling in theology gave Dr van Rinsum an understanding of the (near) spiritual place of the university in changing times and different spaces.

While on a study visit to Stellenbosch University recently, Van Rinsum spoke to Jan Botha, Emeritus Professor at CREST and Peter Vale, Emeritus Professor and Senior Research Fellow at the Centre for the Advancement of Scholarship, University of Pretoria, about his recent book[1], *Universiteit Utrecht en Koloniale kennis—Bestuderen, Bemeten en Beleren sinds 1636*.

The book is now also published under the English title *Utrecht University and Colonial Knowledge; Exploration, Exploitation and the Civilizing Mission since 1636*[2] and is available open access at OAPEN (oapen.org). It is empirically rich, drawing on a largely unexplored archive at Utrecht University and a 40-year career.

What interested you in 'European' knowledge of the colonisation process?

For several decades, I was employed at the Bureau Buitenland (International Office) of Utrecht University in the field of 'development cooperation', which was all the rage in Europe after the Cold War ended. Increasingly, however, I felt uncomfortable about the notion of 'development collaboration' because I realised it was underpinned by what Mignolo called "The Dark Side of Western Modernity"[3].

In 2000 I ended my work at the International Office. In 2001, I defended my dissertation 'Slaves of Definition; in Quest of the Unbeliever and the Ignoramus'[4]; a scholarly reflection on 'development'. I wrote:

> *The development of higher education and research in Africa can best be interpreted as a process of prescriptive construction, or imposition, of an identity. In this process, Western science, being an intrinsic part of the processes of colonisation and globalisation, developed from a local, culturally and historically determined, contingent ethnoscience to a hegemonic discourse. This hegemonic ambition is based on a fundamental dichotomy 'developed' (and therefore modern) versus 'not (yet)-developed' (and therefore still primitive or traditional). 'We' are developed and therefore 'the Other' needs to be developed, after our image. 'We' in the West need this dichotomy.* [...] *The dichotomy unfolds between 'us', believer, messenger, academic, and 'the Other', unbeliever, receiver and ignoramus.*[4(p.122–124)]

My critical sentiments about engaging in 'development cooperation' sparked a curiosity to delve into the colonial past through the perspective offered by my alma mater and employer, Utrecht University, established in 1636.

This interest coincided with the increasingly vigorous and theoretically rich 'decolonisation move' in higher education studies, in which South African scholars play such a prominent role.

The book is a hybrid. It is the story of how the Global North 'co-created' (so to speak) the Global South through the power of a Northern epistemology.

However, this is also my life story. The writing process was unsettling: How relevant (or insightful) would the narrative of an older white Dutchman attempting to offer insights into colonialism be?

Can you say something about the theoretical framework used in the book?

Diverse theoretical models interpret a range of colonial positions, beginning with the **Diffusionist (**or **Modernisation) model** proposed by Walt Rostow's[5] *Stages of Economic Growth* (1960) and George Basella's[6] *The Spread of Western Science* (1967). The nucleus of this approach is that science and its development are essential elements of modernisation.

Then, I turn to the **Dependence model** developed by Andre Gunder Frank[7] (1929–2005) and Johan Galtung[8] (1930–2024) and the Metropole (the colonisers) versus Periphery (colonialised) nexus. Using Karl Marx as their

point of entry, Frank and Galtung viewed science as an instrument of imperial control and exploitation.

Later, I was influenced by the post-structuralist thinking of Edward Said's[9] (1935–2003) *Orientalism* (1978) and Valentin Mudimbe's[10] (1941–) *The Invention of Africa* (1988). Here, (Western-based) science appears in the guise of cultural imperialism. Despite the criticism against Said, his power–knowledge nexus remains very convincing. It points towards Walter Mignolo's[3] notion of 'the dark side of Western modernity' (2011).

This listing of ideas and practices neatly mirrors Utrecht University's colonial history. However, this was only possible because it operated initially within a **networked conception of 'the empire'** and, over time, within the idea of 'the international'. It is sobering to remember that the inequalities of power within these networks have not disappeared, and these fuel contemporary struggles over different modalities of knowledge.

A conventional view has been that the development of the modern world system was a diffusion of Western cultural and intellectual traditions. From this perspective, a dominant intellectual tradition commenced on the European continent, and, over time, it traversed the globe as part of Europe's expansion. During this process, other knowledge traditions were 'swallowed', as it were, by the eager maw of Western science.

The field of global intellectual history significantly revised this understanding. Rens Bod's[11] book, *A World of Patterns: The History of Knowledge (*2022), discusses the human search for patterns and principles in the world. This world encompasses multiple scientific cultures with extensive historical legacies. Arthur O. Lovejoy[12] stated that ideas are "the most migratory entities in the world". It was not a mere diffusion of Western science, nor a one-way flow from the West, but rather a convergence and often a clash of diverse intellectual traditions.

What story does the book tell?

From the mid-17th century, 'scientists' affiliated with Utrecht University were connected to the Dutch colonies in Indonesia, Suriname, and (South) Africa in various ways. Sometimes these scholars worked in the colonies, and sometimes they processed materials that were transported from the colonies to Utrecht. At times, Utrecht's academics wrote about the colonies – their people, religion, language, and the like.

The first phase of this process, which I call 'Confession and Conversion', related to the clergy trained in Utrecht from 1636 onwards. Some ministers ventured as missionaries to the colonies to serve in VOC churches. At the same time, students from the colonies (mainly of a mixed ethnicity) came to Utrecht to study theology. In the second half of the 19th century, dozens of young white men from South Africa went to Utrecht to study theology, including Andrew Murray, Johannes Henoch Neethling, John Murray, and Nicolaas Hofmeyr. One may argue that Stellenbosch University (established as an independent university in 1918), with its predecessors (the Seminary of the Dutch Reformed Church established in 1959, the Stellenbosch Gymnasium and College established in 1866, and since 1886 Victoria College), was conceptualised in the Common Rooms of Utrecht. In 1905, D.F. Malan – who was to become the country's fourth prime minister – did his doctorate at Utrecht University. In 1936, on its 300th anniversary, Utrecht University received a sculpture of the Boer leader Paul Kruger – interestingly, it is still on display in the Academy Building. It was gifted by students from the University of Pretoria who studied in Utrecht.[13-15] See also the short review of the book on Utrecht University and colonial knowledge, including the reference to Van Rinsum's book on Utrecht and South Africa by Erik van den Bergh[16].

Simultaneously, a keen interest in the new world was underway. This is the phase of 'Exploration and Classification'. As Sandra Harding says: "The world was added as a laboratory to modern science in Europe through European expansion."[17(p.58)] This collection and classification process also characterised the study of humans (in anthropology and related fields of study). In that context, the discourse of Western superiority originated – 'we' are developed, 'they' not (yet). The title of my book includes a word that I find hard to translate into English: *beleren.* It involves patronisingly lecturing, lecturing to children in the sense of '*de les lezen*', prescribing, and admonishing.

Cartesian rationality combined with the obsession with taxonomy and classification resulted in the development of the concept of race with the white race at the top. From reading the *Book of Nature*, based on Western superiority, there is a concise line to the practice of slavery. The modernity of an alleged universalism was to suppress the epistemologies in (what we now call) the Global South.

The phase of 'Exploration and Classification' was transformed during the 19th century into an era of 'Exploitation and Experimentation'. In the colonies, capitalist economic development of plantations, including sugar and coffee, required expertise from academics engaged in experimental research. In this manner, the university became increasingly entangled in the so-called five Cs: Christianity, capitalism, commerce, colonialism and civilisation.

In the early 20th century, a concept known as an 'ethical policy' emerged in relation to the Dutch colonial enterprise. This policy aimed to uplift the inhabitants of the colonies while maintaining the dominance of the imperial project. However, concerns arose within colonial business circles regarding the stability and durability of the Dutch empire.

In response to these shifting theories and practices, an educational programme was established in Utrecht for senior civil servants in the colonies. This programme was rooted in a conservative-liberal and Christian-historical ideology, focusing on the preservation of the colonies. At times, this approach even showed tendencies towards fascism. During this period, referred to as 'Educating and Controlling' (1925–1950), this initiative received substantial financial support from the oil and sugar industries, earning the Indological Faculty the nickname 'Oil Faculty'. Once again, Utrecht University found itself enmeshed in a complex web of ideology, capital, and education.

Interestingly, it was suggested by some officials of the 'Oil Faculty' that this educational programme of what they called the 'Utrechtse Koloniale School' might also be useful in assisting the Boers in South Africa in maintaining control.

The final phase of the book explores 'Development Cooperation'. This phase continued the 'ethical policy' approach of uplifting 'the other' from the Western scientists' privileged position.

Tracking the colonial past of a university located in a former imperial country such as the Netherlands from a position of Western superiority enabled me to reflect on the development and role of science(s) – and, obviously, the university – in global relations. Subsequently, I raise the question of the consequences that shedding a colonial yoke has on the role of science(s) and universities in our present time.

How do we go from 'legacies of the past' to 'lessons for the future'?

Looking at the colonial history of Utrecht University, I observe that the development of sciences, including health sciences, geology, botany, anatomy, and physical anthropology, benefited tremendously from the process of exploration, extraction and exploitation in colonial history. At the same time, local knowledge systems were marginalised and pushed to the periphery.

Universities in the Global South are currently facing demands to break free from dominant (read Western) knowledge modalities. Illustrative of this were the developments during 2015 and 2016 at the University of Cape Town, which led to the removal of the statue of Cecil John Rhodes. Neither those discussions nor the activities related to the decolonisation of knowledge ended with that: it even led to calls for 'the fall of science'.

But what about the status of universities in the Global North? Is it possible for Western universities to undergo a process of 'decolonisation' by shedding their facade of superiority and engaging in genuine collaboration with people from various cultural backgrounds and different regions of the world?

What would be the consequences of such a process for the 'normal' academic episteme of a university like Utrecht University? Should we not consider differentiation based on different academic disciplines? Take, for example, a subject like African Studies. Clearly, this field should

feature substantial scholarly contributions from Africa. I intentionally used the term 'substantial' because I anticipate valuable dialogue on these matters – the underlying point being that Africa is interconnected with the rest of the world.

The issue of what belongs and what is not, becomes more of a challenge to decolonise in a discipline such as molecular cell biology. After all, laboratory experiments in such fields are inherently objective and do not attribute significance to the gender, ethnicity, or other personal characteristics of the researcher. Or do they? It is increasingly evident that even in seemingly 'objective' domains like medicine, the perspectives and experiences of different demographic groups can significantly impact research outcomes. For example, studies have revealed that medical research often defaults to the white male as the norm, potentially overlooking nuances in health outcomes for women, children, or individuals from diverse backgrounds. This realisation underscores the intricate interplay between scientific research and its social and cultural context. Research and education transcend mere technical pursuits, being deeply enmeshed within broader social, economic, and historical frameworks. Consequently, all stakeholders in the scientific enterprise must cultivate a profound sensitivity to these multifaceted dimensions, acknowledging and engaging with cultural, social, economic, epistemological, and historical distinctions to foster equitable and inclusive knowledge production.

This perspective is reinforced by the understanding that we live in a world of increasing differentiation and diversity. Increasingly, transnational communities are emerging, also within what were once considered 'enlightened' metropoles. Influential thinkers from the Global South have made this point. So, Arjun Appadurai[18] (1949–) in *Modernity at Large* discusses a "diasporic public", while Kwame Anthony Appiah[19] (1954–) explores "cosmopolitan identities". Thus, it becomes imperative for a 'Western' institution like Utrecht to strengthen its relationships with universities on other continents and in other cultural contexts. This is not to 'develop' them but rather to engage in a genuinely critical dialogue that allows mutual development alongside partners possessing distinct identities.

However, another challenging perspective of decolonisation should unite the universities of the Global South and the Global North. In 2012, with my fellow anthropologist Wil Pansters[20], I used Habermas to analyse the university's "colonisation of lifeworld by system". In the "lifeworld", people find the resources required to make sense of society and their respective journeys through it, including culture, institutions and socialisation. The "lifeworld" is thus responsible for society's symbolic reproduction, which carries hope for the future. Opposed to this "lifeworld", Habermas positions "system", governed by the imperatives of government and economy. In line – may I say – with capitalist practices, the transformation of the hierarchical and bureaucratic model of university governance – some call this 'academic rule' – into a 'market model', which is said to be flexible, and dynamic, has emerged. It draws its legitimacy from an emphasis on management principles anchored in accountability. The result is a constant attempt to quantify performance as a quality measure while ranking and rating this through self-selection. However, its critics argue that efficiency, constant accountability, and Foucauldian forms of control make it impossible for the university to function as a 'real' academic or intellectual place.

Decolonisation means, for every university, including Utrecht University, the urgent need to search for a new public space in a new social constellation with a greater critical cultural diversity regarding gender, skin colour, origin, nationality, and the like. We must do this, recognising this is not the starting point of the diffusion of our knowledge system – thus maintaining the mask of superiority – but confident that only different intersections of knowledge will inspire the urgency of education and research.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. All authors read and approved the final version.

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Further assessment of a ~2-million-year-old hominin pelvis (DNH 43) from Drimolen Main Quarry, South Africa

The palaeocave site of Drimolen Main Quarry (DMQ) in Gauteng Province, South Africa, has produced fossil hominin material dating to 2.04–1.95 Ma, including craniodental remains attributed to *Paranthropus robustus* and the earliest specimen of *Homo erectus sensu lato* along with numerous postcrania of uncertain taxonomic affiliation. Among this collection is a partial pelvis (DNH 43), which includes the sacrum and elements of the right os coxae. Although previously described as showing similarities to the pelvis of *Australopithecus* and *Paranthropus*, comparisons across the broader hominin fossil record have been limited and DNH 43 has never been analysed quantitatively. Here we present a partial digital reconstruction of DNH 43 and compare it to an expanded data set of fossil specimens to determine its closest morphological affinities. Overall, the quantitative analysis is congruent with qualitative results reflecting the primitive features of DNH 43, suggesting an *Australopithecus*/*Paranthropus*-like anatomy, including small absolute size, relatively small sacroiliac articulation, moderately wide tuberoacetabular sulcus, gracile acetabulosacral buttress, and obstetric dimensions that are relatively broad. A study of this rare articulated pelvis shows that the orientation of the sacrum (pelvic incidence) is similar to that of recent *Homo sapiens*. Although DNH 43 shares some specific metric similarities with specimens MH2 (*Australopithecus sediba*) and OH 28 (cf. *Homo erectus*), the taxonomic relevance is unclear given the poor understanding of *Paranthropus* and early *Homo* postcranial variation. Affiliation with *Paranthropus robustus* (which dominates the DMQ craniodental assemblage) cannot be ruled out, and we consider assignment to that taxon to be a reasonable provisional attribution.

Significance:

- Associated pelvic elements (sacrum and ossa coxae) are rare in the hominin fossil record but provide information on overall body form, locomotion and obstetrics.
- Anatomical assessment and partial reconstruction of specimen DNH 43 from the Drimolen Main Quarry in the Cradle of Humankind, South Africa, thus provides additional insights into pelvic form in a ~2.0-million-year-old hominin.
- The fossil is best attributed to *Paranthropus robustus* and displays an overall primitive, gracile morphology, but presents with positioning of the sacrum similar to that of recent humans, which differs from prior interpretations of early hominin spinopelvic anatomy.

Introduction

Palaeontological work at the palaeocave site of Drimolen Main Quarry (DMQ; 25°58'08" S, 27°45'21"E) in Gauteng Province, South Africa has produced significant fossil hominin material since excavations began in 1994.[1] The assemblage includes craniodental remains attributed to *Paranthropus robustus* and the earliest known specimen of *Homo erectus sensu lato* dating to between 2.04 Ma and 1.95 Ma, demonstrating that *Paranthropus* and *Homo* were effectively contemporaneous at the site and coeval with *Australopithecus* from nearby fossil localities in South Africa.[2] Numerous postcranial elements of uncertain taxonomic affiliation have also been recovered, but these have received little attention. Among these is a partial pelvis (DNH 43) with most of the sacrum (DNH 43A) and elements of the associated right os coxae (DNH 43B) preserved. Although some details about the recovery of the DNH 43 specimen are unclear, information on the relevant excavation history at the DMQ and what is known about the site context for the specimen is provided in the Supplementary material, including a 3D plot of the fossil block's location within the quarry (Supplementary figure 1A–C).

The evolution of the pelvis bears on critical aspects of hominin biology, including locomotion, obstetrics, and variation in body size and shape related to climatic adaptation.[3-8] However, associated sacra and ossa coxae are especially rare in the early hominin fossil record[5], making DNH 43 of particular interest. Gommery and colleagues[9] described the specimen qualitatively, noted its similarities to the pelvis of other early South African hominins, and attributed it to *Paranthropus robustus*. However, comparisons across the broader hominin fossil record are lacking and the specimen has never been analysed quantitatively. The objective of the present paper is to make 3D polygon models of DNH 43 available online (including a partial virtual reconstruction) and to compare the specimen metrically to an expanded data set of hominin pelvic material to (1) determine the closest overall morphological affinities of DNH 43 to test the hypothesis of taxonomic attribution to *P. robustus*[9]; (2) investigate aspects of the palaeobiology, including locomotor and obstetric implications; and (3) assess the possible sex of the specimen.

Materials and methods

Virtual reconstruction

A detailed description of DNH 43, including information on preservation, is provided by Gommery and colleagues[9]. For the current study, the DNH 43 pieces were surface scanned using an Artec Space Spider. The resulting surface

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scans of the individual pieces of DNH 43, as well as the partial reconstruction, are provided in the University of the Witwatersrand's Drimolen Collection at https://human-fossil-record.org.

The sacrum (DNH 43A) includes a nearly complete plateau and most of the right side of the vertebrae, although the anterior aspect of the right-side ala is mostly missing. The left side of the sacral vertebral bodies and left-side ala are absent. The plateau exhibits plastic deformation such that the left half is shifted cranially; however, the right side is complete and undistorted (Figure 1A). On the right side, the cranial-most one-third of the sacral ala and auricular surface is absent, but the caudal two-thirds of the surface is reasonably well preserved and only minimally distorted. To partially reconstruct the sacrum, the virtual model of DNH 43A was sectioned at the midline and the more-complete right side was reflected to the left (Figure 1B) using Geomagic Control.

The partial right os coxae (DNH 43B) is preserved in two pieces that refit cleanly at a postmortem break approximately midway along the acetabulosacral buttress, which is the bony strut connecting the sacroiliac joint and the hip (Figure 1C). The anterior portion includes most of the lunate surface of the acetabulum (missing the superomedial and inferomedial horns), allowing for measurement of the superoinferior diameter. A small anterior portion of the iliac blade (which is mostly missing otherwise) projects superolaterally from the anterior inferior iliac spine, which is present but weathered. The superior portion of the ischium is preserved, including a somewhat polished ischial spine and approximately 1 cm of bone inferior to it. The ischial tuberosity is almost entirely absent, but a lip of bone representing the superior edge of what would be the roughened tuberosity is discernible, allowing assessment of the tuberoacetabular sulcus width. The posterior portion of DNH 43B includes a complete auricular surface and much of the iliac tuberosity. The iliac tuberosity is damaged posterolaterally such that the posterior-superior and posterior-inferior iliac spines are absent.

The two pieces of the os coxae were fitted together virtually and reflected to generate a left side for articulation with the reconstructed sacrum (Figure 1D–F). Each piece of DNH 43A and B was 3D printed using a Lulzbot Taz 6 printer (an 'extrusion' printer using fused-deposition modelling with a polylactic acid printing filament) at a layer height of 0.1 mm. The 3D prints were manipulated physically to evaluate the fit and to ground-truth the virtual articulation.

Comparative sample

To evaluate the closest morphological affinity of DNH 43, it was compared to a sample of recent *Homo sapiens* (12 male and 13 female individuals) and several fossil hominin specimens. The recent human sample for analysis of the isolated pieces came from the Maxwell Museum of Anthropology at the University of New Mexico and access followed the relevant research and ethics reviews of that institution. Fossils included specimens typically attributed to *Australopithecus afarensis* (AL 288-1), *A. africanus* (Sts 14 and Stw 431), *A. sediba* (MH1 and MH2), *Paranthropus robustus* (SK 50, SK 3155b, TM 1605), *Homo* sp. (likely representing various taxa including *Homo erectus* and its probable immediate descendants[10,11]: Arago XLIV, Kabwe E. 719, KNM-ER 1808, KNM-ER 3228, KNM-ER 5881, KNM-WT 15000 and OH 28), *H. floresiensis* (LB1), Neanderthals (Amud 1, Kebara 2, Krapina 207, Neandertal 1, and Tabun C1), and early *H. sapiens* (Omo-Kibish 1 and Skhūl IV). Comparative metric assessment of the articulated pelvis included additional data from the literature allowing the consideration of material attributed to either *Homo* sp. or Neanderthals (Sima de los Huesos Pelvis 1 and Pelvis 2)[12], *H. erectus* (BSN49/P26[13],

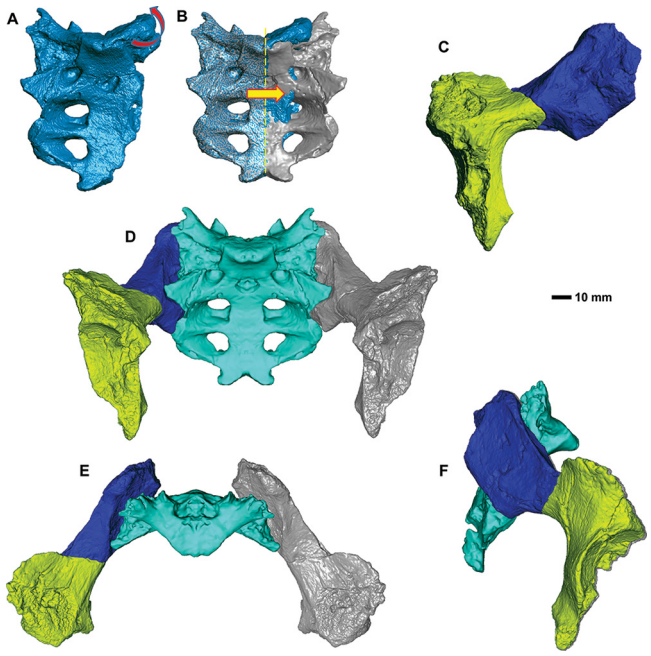

Figure 1: Three-dimensional polygon models derived from surface scanning of DNH 43: (A) sacrum (DNH 43A) with arrow indicating cranially directed deformation of the left side of the sacral plateau; (B) bisection and reflection of the relatively undistorted right side to reconstruct the left side; (C) medial view of the two refit pieces of the os coxae (DNH 43B); (D) anterior view of the articulated pelvis with the reconstructed sacrum and the right os coxae reflected to reproduce the left side; (E) superior view of the articulated pelvis; and (F) lateral view of the articulated pelvis.

although some have argued this could represent *P. bosei)*[14], a late Pleistocene *Homo sapiens* specimen (Ohalo II)[15], along with larger data sets of obstetric breadths and pelvic incidence from recent *H. sapiens* populations[15,16] and modern *Pan troglodytes*[15,17].

Measurements and analysis

Measurements were taken on 3D scans of the individual DNH 43A and DNH 43B specimens and compared with data from the fossil and recent *H. sapiens* samples. Measurements were taken by author E.B. (based on landmarks placed on the 3D scans using Stratovan Checkpoint, except for the sciatic notch proportions and measurements on the articulated reconstruction, which were taken by author C.M.O. using Geomagic Control or taken from the literature where indicated. Analysis of three repeated trials by the relevant observer returned mean technical errors of measurement[18] of ±0.4–0.8 mm (0.4–3.1% relative error) for the linear metrics of the os coxa and sacrum, ±0.6° (0.8% relative error) for sciatic notch angle, and ±0.02 (1.1% relative error) for the sciatic notch proportion ratio indicating good precision. Differential preservation limited measurement of some fossils, so analyses included subsamples accordingly. More detailed definitions of measurements and landmarks are provided in Supplementary table 1 and Supplementary figure 2.

Sacrum measurements captured total craniocaudal length and maximum mediolateral and anteroposterior dimensions of the plateau. Sacral proportions and shape have been suggested to differ among early hominin fossil taxa with possible taxonomic implications.[19]

Analysis of the os coxae focused on measurements available on as many fossils as possible, following metrics from Churchill et al.[20] The width of the tuberoacetabular sulcus (TAS: the 'gap' between the superior-most aspect of the ischial tuberosity and the inferior margin of the acetabulum) and breadth of the auricular surface (AUR) were evaluated relative to the superoinferior acetabular diameter (AD). Recent humans and fossils attributed to *Homo* tend to have a narrow tuberoacetabular sulci compared to earlier hominins, including *Australopithecus* and *Paranthropus.*[20-22] The index of the acetabulosacral buttress thickness (ASBT: mediolateral breadth superior to the greater sciatic notch) to the acetabulosacral buttress load arm (ASLA: anteroposterior length from acetabulum to the auricular surface) captures the relative robusticity of the lower ilium. Members of the genus *Homo* typically exhibit thicker acetabulosacral buttresses.[10,20] In addition to bivariate plots to examine the scaling of specific metrics, a cluster analysis of the indices TAS:AD × 100, AUR:AD × 100 and ASBT:ASLA × 100 was conducted using the unweighted pair group method with arithmetic mean (UPGMA) to assess the closest overall metric affinities.

Morphology of the sciatic notch in DNH 43B was quantified to investigate the possibility of assigning sex to this specimen and other early hominins based on recent human criteria. The greater sciatic notch shows sexual dimorphism in recent *H. sapiens*, with female individuals typically exhibiting a wider notch that is relatively symmetric with the apex shifted anteriorly such that the anterior and posterior arcs are closer in length than in male individuals.[13,23] Thus, the sciatic notch angle (SNA) was used to quantify the 'openness' of the notch while the relative position of the notch's apex quantified the sciatic notch proportions (SNP) following the method from reference.[13]

Mediolateral (transverse) dimensions with locomotor and obstetric implications were measured on the virtually articulated pelvis. These included the mediolateral diameter of the pelvic inlet (between the most lateral points on the right and left arcuate lines), the bispinous breadth (between right and left ischial spines quantifying the mediolateral dimension of the obstetric midplane) and biacetabular breadth (between the centres of the right and left acetabulae). Without a pubis, reconstruction of the anterior enclosure of the inlet is impossible and anteroposterior dimensions are unmeasurable. Sacral orientation, which is related to the degree of lumbar lordosis, varies among non-hominins, *Australopithecus*, and later members of the genus *Homo.*[15] Relative to extant apes, *H. sapiens* exhibit a high degree of anterior sacral tilt, which corresponds to an increased lumbar lordosis to position the superincumbent body weight over the hips.[15] Sacral orientation (Supplementary figure 3) was assessed in DNH 43 by quantifying pelvic incidence using a method following Peleg et al.[24] and comparing it with data from Been and colleagues[15].

Results

The DNH 43A sacrum has a minimum craniocaudal length of ~72 mm. This is probably an underestimate as only a portion of the fifth sacral vertebra is intact, but it closely matches the length of specimen AL 288-1 (73.5 mm) attributed to *A. afarensis*. The reconstructed sacral plateau measures 16.6 mm anteroposteriorly by 29.3 mm mediolaterally. An index of sacral plateau proportions is compared among hominins in Figure 2A. DNH 43A shows its closest affinities with sacra attributed to *A. afarensis* and *A. africanus,* although one male human matches DNH 43A in having a similarly anteroposteriorly compressed plateau.

Measurements of the DNH 43B os coxae are shown in Table 1, along with a comparative sample of fossils and recent *H. sapiens.* Fossils are grouped in Table 1 for brevity and the most useful overall comparisons, but individual specimen data are provided in Supplementary table 2. Bivariate plots of tuberoacetabular sulcus width versus acetabular diameter, auricular breadth (AUR) versus acetabular diameter, and acetabulosacral buttress thickness versus acetabulosacral load arm are shown in Figure 2B–D.

The UPGMA cluster analysis results are shown in Figure 3. The dendrogram exhibits two primary clusters: the recent *H. sapiens* sample plus the LB1 *H. floresiensis* specimen and a fully fossil hominin cluster. Within the fossil cluster, there are two further main divisions: (1) a cluster that includes DNH 43B along with ossa coxae assigned to *Australopithecus* or *Paranthropus* plus the OH 28 specimen (cf. *Homo erectus*); and (2) a cluster including ossa coxae referring to various Pleistocene members of the genus *Homo* (including early taxa such as *H. erectus* and later groups such as Neanderthals and "early *H. sapiens*"). Within the first cluster, DNH 43B shows its closest linkages to OH 28 and MH2 (*Australopithecus sediba*) (Figure 3).

Greater sciatic notch measurements (SNA and SNP) are shown in Table 1 and Figure 4. Mean SNA for female *H. sapiens* (81.9°; standard deviation = 5.7; range: 75.0–93.9°) is significantly different from that for the male *H. sapiens* (67.7°; standard deviation = 4.0; range: 59.4–72.6°) ($t = 7.14$, $p < 0.001$). The SNPs also differ significantly ($t = 3.8$, $p < 0.001$) between recent human female individuals (mean = 0.38; standard deviation = 0.08; range: 0.31–0 .52) and male individuals (mean = 0.24; standard deviation = 0.10; range: 0.12–0.45). For both variables, DNH 43B falls at the high end of the range for female *H. sapiens*.

Measurements from the articulated DNH 43 pelvis are provided in Table 2. DNH 43 has a pelvic inlet and bispinous breadth that are somewhat narrow mediolaterally but a biacetabular breadth similar to other individuals, including recent *H. sapiens* (which are absolutely broad when compared to *P. troglodytes*). The pelvic incidence angle of 56° (Supplementary figure 3) falls close to the *H. sapiens* mean (54±10° standard deviation) and is higher than those for all other fossil hominins and 4.5 standard deviations above the *P. troglodytes* mean (29±6° standard deviation).

Discussion

In absolute measurements, DNH 43 is small and similar to specimens attributed to *Paranthropus* and *Australopithecus* (Tables 1 and 2; Figure 2). The close correlations among acetabulum size, femoral head size and body mass[14] suggest that the individual represented by DNH 43 would have been of a similar overall body size to these early hominin taxa.

The DNH 43A sacral plateau is relatively narrow in the anteroposterior dimension compared with the mediolateral dimension, linking it with early hominins including *A. afarensis* and *A. africanus* versus the recent *H. sapiens* sample (Figure 2A). The Kebara 2 sacrum is also anteroposteriorly compressed, although it overlaps the low end of the human sample (as does the Sts 14 specimen attributed to *A. africanus*). However, although the sacral plateau is not well preserved in the Sts 431 sacrum (attributed to *A. africanus*) or for that of MH2 (*A. sediba*), the sacral body in these specimens is somewhat thicker anteroposteriorly than those of DNH 43A, AL 288-1, and Sts 14[28], suggesting some

Table 1: Summary data for the os coxae measurements

	AD	TAS	ASBT	ASLA	SNA	SNP	AUR	TAS/AD × 100	ASBT/ ASLA × 100	AUR/AD × 100
DNH 43	41.1	13.2	16.6	46.8	87.3	0.48	31.2	32.1	35.5	75.9
Australopithecus										
N	3	3	5	5	2	2	4	3	5	4
Mean	38.2	17.5	16.3	41.8	90.8	0.27	28.6	45.9	35.0	75.2
Standard deviation	1.8	4.7	1.7	3.8	–	–	2.6	13.8	5.6	6.5
Minimum	36.8	9.5	14.4	37.0	85.9	0.25	27.3	23.3	32.8	69.1
Maximum	40.7	18.6	18.6	45.3	95.6	0.28	33.7	50.5	46.5	82.8
H. floresiensis	36.0	15.9	18.5	39.1	81.0	0.44	41.0	44.2	47.4	113.8
***H. sapiens* fossil**										
N	2	2	1	2	2	2	2	2	2	2
Mean	59.3	11.1	24.0	54.7	81.1	0.41	45.7	18.7	53.6	77.3
Minimum	58.3	10.1	24.0	44.8	80.4	0.34	39.4	17.4	53.6	65.4
Maximum	60.3	12.1	24.0	64.6	81.8	0.48	52.0	20.0	53.6	89.1
***H. sapiens* recent**										
N	25	25	25	25	25	25	25	25	25	25
Mean	54.5	16.3	23.0	51.6	75.1	0.31	56.3	29.7	45.4	103.1
Standard deviation	4.5	3.5	3.2	5.4	8.7	0.11	6.0	5.2	9.6	5.4
Minimum	48.3	11.2	17.5	41.3	59.4	0.12	46.4	20.8	28.0	93.7
Maximum	65.0	22.1	30.6	64.2	93.9	0.52	71.4	40.0	74.0	112.7
***Homo* sp.**										
N	5	5	6	7	5	4	5	5	6	5
Mean	58.1	12.2	20.7	50.2	79.3	0.30	37.6	20.9	40.5	65.0
Standard deviation	3.3	2.6	2.5	7.4	6.8	0.07	3.7	4.3	5.6	8.8
Minimum	54.9	9.3	17.8	41.7	73.4	0.22	35.2	16.2	34.2	57.2
Maximum	62.0	15.5	24.1	63.0	86.3	0.36	43.9	26.0	48.1	80.1
Neanderthals										
N	4	4	4	4	3	3	3	3	4	3
Mean	57.8	9.7	22.3	53.1	64.7	0.16	36.5	19.5	41.9	63.6
Standard deviation	3.4	3.0	3.9	6.7	7.7	0.07	7.0	2.2	4.7	7.7
Minimum	53.6	5.3	17.6	45.2	59.8	0.08	31.1	17.8	37.3	58.1
Maximum	61.3	11.8	26.6	61.0	73.6	0.22	44.4	22.0	47.6	72.4
P. robustus										
N	2	2	3	3	2	2	2	2	3	2
Mean	38.4	20.2	16.2	47.9	82.6	0.50	39.0	52.7	33.2	101.7
Standard deviation	–	–	1.7	5.6	–	–	–	–	2.2	–
Minimum	38.0	16.1	14.6	41.9	80.7	0.49	31.8	41.5	30.8	82.0
Maximum	38.8	24.2	18.0	52.9	84.5	0.51	46.1	63.8	34.9	121.3

**AD, acetabular diameter (superoinferior); TAS, tuberoacetabular sulcus breadth; ASBT, acetabulosacral buttress thickness; ASLA, acetabulosacral load arm; SNA, sciatic notch angle; SNP, sciatic notch proportions; AUR, auricular surface breadth. All measurements included were taken for the current study with the exception of ASBT and ALSA for MH2 taken from Churchill et al.[20] Data for individual specimens are provided in the supplementary material.*

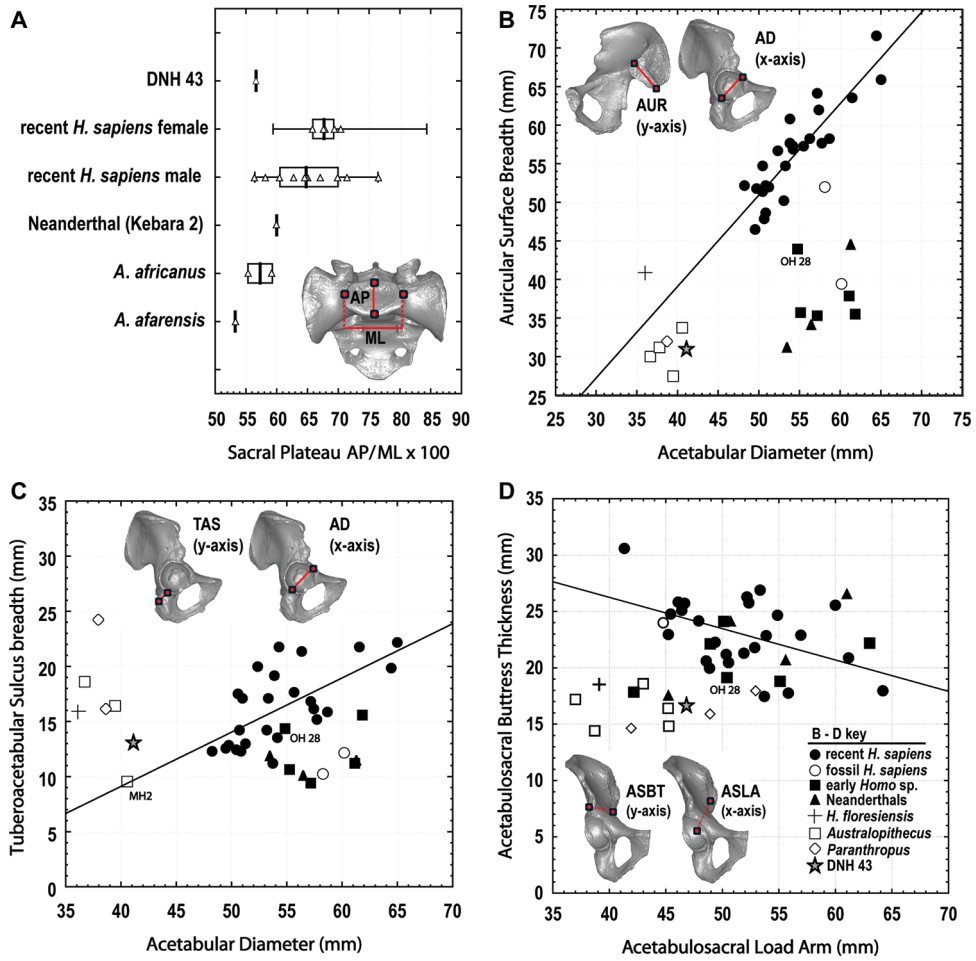

Figure 2: Anteroposterior versus mediolateral proportions of the sacrum (A) and bivariate plots of three features of the os coxae demonstrating scaling relationships between the auricular surface breadth and the superoinferior acetabular diameter (B), tuberoacetabular sulcus breadth and superoinferior acetabular diameter (C), and the acetabulosacral buttress thickness versus the acetabulosacral load arm (D). In all cases, the plotted least-squares regression lines are fit solely to the recent *Homo sapiens* sample. Inset images illustrate the variables in each plot as demonstrated on a human individual.

variation in sacral robusticity within *Australopithecus* that might have taxonomic implications, including heterogeneity in the Sterkfontein sample[19]. Unfortunately, there are no sacral specimens attributed to *Paranthropus* against which DNH 43A can be compared.

The DNH 43B os coxae exhibits an auricular surface that is small relative to the size of the acetabulum (Figure 2B) and a transverse acetabular sulcus that is only moderately wide relative to the size of the acetabulum (Figure 2C). As with most of the *Australopithecus* and *Paranthropus* specimens sampled, DNH 43B has a gracile communication between the sacroiliac joint and hip joint with an acetabulosacral buttress that is slender relative to its length (Figure 2D), as reflected in its low ASBT/ASLA × 100 index (Table 1).

Considering indices TAS:AD × 100, AUR:AD × 100 and ASBT:ASLA × 100 together in the UPGMA cluster analysis (Figure 3), DNH 43B has its closest linkage with specimen OH 28 (*Homo* cf. *erectus*) while its next closest linkage is to specimen MH2 (*Australopithecus sediba*). DNH 43B, OH 28, and MH2 all form a direct 'sister' group with the branch that includes the *Australopithecus* and *Paranthropus* specimens to the exclusion of most of the individual fossils typically attributed to the various *Homo* taxa. Although this reflects a general 'early hominin-grade' morphology for DNH 43, the pattern of clustering within DNH 43's group suggests that the quantified characters have limited utility in resolving taxonomy at a finer scale. The linkage distances that separate individual specimens within the *Australopithecus*/*Paranthropus* cluster are relatively small despite ostensibly representing at least four and possibly five different early hominin taxa; in fact, they do not exceed the largest distances separating specimens of the recent *H. sapiens* sample. Linkage of DNH 43 with OH 28 might reflect some "early *Homo*" characteristics in DNH 43B and the MH2 os coxae. Indeed, the MH2 pelvis has been argued to display some *Homo*-like features[20,28], and craniodental characters tentatively suggest a close common ancestor[33]. Alternatively, these results may simply reflect variability in the expression of shared primitive features among *Australopithecus*/*Paranthropus* and early *Homo* species. While MH2 is closer in absolute size to DNH 43 and represents *A. sediba* from the nearby Malapa site in South Africa, which is contemporaneous with the DMQ assemblage[2], the UPGMA link with OH 28 should be considered with greater caution based solely on the three included indices. OH 28 is much larger in absolute dimensions (Figure 2B–D) and exhibits an exceptionally robust acetabulocristal buttress (Supplementary figure 4) – characters expressed strongly in other ossa coxae attributed to early *Homo* sp.[34] but not evident in either DNH 43B or MH2. Indeed, Rose[34] noted close overall similarities among specimens such as OH 28, KNM-ER 3228, and recent *H. sapiens* vis-à-vis *Australopithecus* and *Paranthropus* in terms of iliac features.

Unfortunately, specimens SK 50 and TM 1605, usually considered to represent *P. robustus* from the sites of Swartkrans and Kromdraai, respectively[5], could not be included in the cluster analysis because damage precludes accurate measurement of the auricle breadth in both specimens and acetabular diameter in TM 1605. However, in preserved anatomy, these specimens exhibit apparently plesiomorphic characteristics of the lower os coxae. SK 50 has the widest tuberoacetabular sulcus relative to the acetabular diameter of any specimen in the sample and the acetabulosacral buttress is gracile

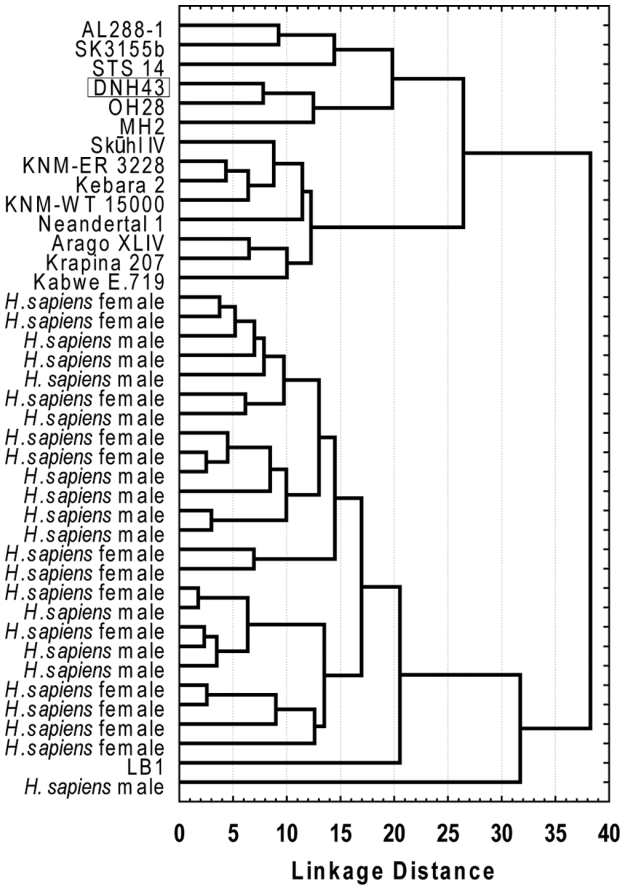

Figure 3: Dendrogram from the UPGMA cluster analysis.

relative to the acetabulosacral load arm in both SK 50 and TM 1605. It should be cautioned that even for these specimens from Swartkrans (whose craniodental sample is overwhelmingly attributed to *P. robustus*), the association with *Paranthropus* is circumstantial, lacking direct association with taxonomically identifiable jaws and teeth, and early *Homo* also occurs at the site.

P. robustus is the most frequently sampled hominin at DMQ[1,35,36], which has produced remarkably complete cranial remains of the species[37,38]. The morphology preserved in DNH 43 cannot rule out an affiliation with that taxon corresponding with the initial description.[9] However, early *Homo* (including *Homo erectus sensu lato*) has been documented at DMQ[2], so caution is warranted. Associated craniodental and pelvic remains of definitive early *Homo* are scarce generally[10,11] and unknown from the South African record, although *H. naledi* may represent a relatively plesiomorphic member of the genus[10]. Much of the postcranial skeleton is variable among fossil samples thought to represent taxa of truly early *Homo.*[11] *Homo naledi* pelvic remains from the Rising Star Cave system preserve fragmented ossa coxae that evince an *Australopithecus*/*Paranthropus*-like lateral iliac flare with an anteriorly placed and lightly expressed acetabulocristal buttress and an absolutely narrow acetabulosacral buttress but short *'Homo*-like' load arm[21] and a narrow tuberoacetabular sulcus. Notably, the LB1 *H. floresiensis* pelvis also exhibits a laterally flared ilium similar to *Australopithecus* and *Paranthropus*.[39] Although LB1 clusters with a single recent male *H. sapiens* individual in the UPGMA analysis (Figure 3) due primarily to its relatively large auricular surface (Figure 2B), it shows a relatively wide tuberoacetabular sulcus (Figure 2C) and gracile acetabulosacral buttress relative to load arm (Figure 2D), which is considered to be plesiomorphic.[39] The small body size of both *H. floresiensis* and *H. naledi* and their somewhat different morphologies of the lower os coxae suggest variation in these traits may not be the result of allometric effects (i.e. *'Homo*-like' features do not necessarily covary with differences in overall body size). Uncertainty concerning the magnitude of variation in these features among early diverging members of the genus *Homo* makes it difficult to evaluate their taxonomic utility vis-à-vis DNH 43.

Sex attribution of the DNH 43 pelvis remains uncertain. The specimen has an 'open' greater sciatic notch and the apex of the notch is situated anteriorly, giving it a semicircular appearance similar to what is observed commonly in the pelvises of recent *H. sapiens* female individuals. However, whether sexually dimorphic aspects of the modern human pelvis also characterise fossil taxa is not established.[13] Furthermore, the acetabular diameter of DNH 43 is somewhat larger than all *Australopithecus* and *Paranthropus* specimens sampled (Table 1); thus, an appeal to overall size does not further clarify whether DNH 43 is male or female. The rest of the fossils span the distribution of male and female individuals for both greater sciatic notch variables (Table 1 and Figure 4), although there is some clustering by group. If the sexually dimorphic features of recent *H. sapiens* characterise the fossil populations, then these clusters probably represent sampling error (i.e. mostly male or female individuals sampled in a fossil group). Neanderthal specimens included in the sample all exhibit a more 'male-like' sciatic notch (however, Tabun C1, which is thought to be female[32] could not be measured due to taphonomic damage), while the 'early *Homo* sp.' group all fall within the female distribution or close to the male-female borderline. Interestingly, all specimens typically assigned to *Paranthropus* fall at the high end of the female distribution of the two variables along with DNH 43. SK 50 exhibits some taphonomic damage to the posterior that might have a small effect on sciatic notch measurements. However, our observations on the fossil indicate that the crushing would have had at most the effect of narrowing the observed notch. As such, our metrics should be considered a minimum and 'reconstruction' of the damaged area would further exaggerate the already 'female-like' qualities of the morphology. In contrast, pelvises attributed to *A. afarensis* (AL 288-1), *A. africanus* (Sts 14), and the subadult *H. erectus* (KNM-WT 15000) show an unusual combination of a wide sciatic notch angle ('female-like') coupled with a more posterior notch apex ('male-like') (Figure 4). However, the KNM-WT 15000 measurement is based on fairly heavy reconstruction of the pelvis[29], which warrants some caution (although in our assessment it provides a reasonable estimate). Based on a broader evaluation of pelvic morphology, AL 288-1 and Sts 14 are generally considered to represent the female sex of their respective taxa due to small size[40] (but see Hausler and Schmid[41]) and KNM-WT 15000 is considered to represent a young male individual.[29] Among Neanderthals, Krapina 207 is an older subadult individual with an unfused iliac crest, which also falls closest to the recent human female distribution and there could be an ontogenetic influence on sciatic notch form, although this is uncertain (Figure 4). Determining whether specimens such as KNM-WT 15000, AL 288-1 and Sts 14 are outliers, or if the unusual combination of these greater sciatic notch features has phylogenetic valence, will require an expanded fossil sample.

Compared with available comparative material (Table 2), the DNH 43 pelvis is wide mediolaterally when considering a reasonable proxy of overall body size (superioinferior acetabular diameter). A mediolaterally broad pelvis is often considered a plesiomorphic trait associated with *Australopithecus,* although it is retained in the few available pelvises of early *Homo.*[4,13] The mediolateral breadth of DNH 43 is especially pronounced when considering the width between the hip joints (biacetabular breadth) and the narrowest point in a hominin birth canal (bispinous breadth). Indexed against the acetabular diameter, the biacetabular breadth of DNH 43 is 301% and bispinous breadth is 257% that of the acetabulum size. These relative dimensions are exceeded only in *A. afarensis* specimen AL288-1 (335% and 274%) and the BSN49/P27 pelvis (possibly a female *H. erectus*) at 320% and 280% of the superoinferior acetabular diameter.[12] The *A. sediba* specimen MH2 is similar to DNH43 in biacetabular breadth relative to the acetabular diameter (300%). Among other absolutely wide fossil pelvises, the biacetabular diameter of Kebara 2 is 228% that of the acetabular diameter (no bispinous diameter is available), although Kebara 2 is probably a male individual. The Sima de los Huesos Pelvis 1 biacetabular and bispinous breadths are respectively 235% and 198% of the reported[12] superoinferior diameter of the acetabulum (58.8 mm).

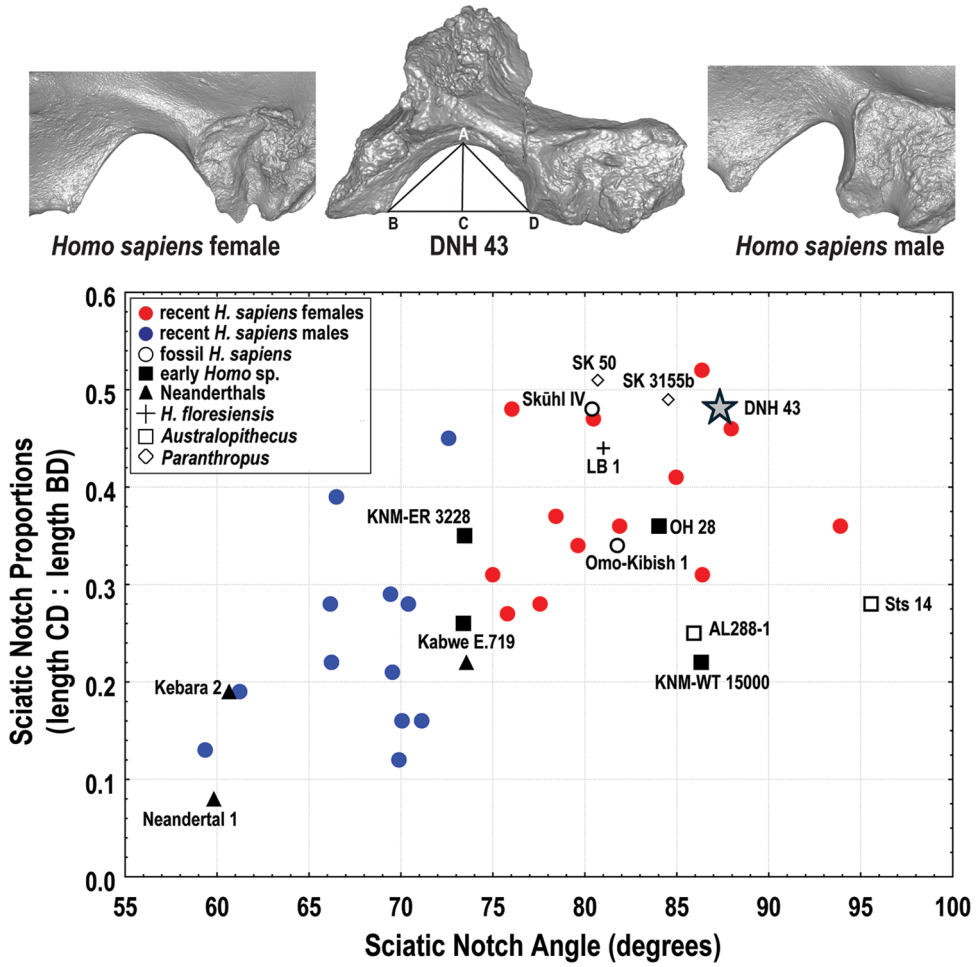

Figure 4: Examples of greater sciatic notch morphology (top: oriented in medial view with sacroiliac joint to the right) in DNH 43 versus a recent *Homo sapiens* female and male and a bivariate plot (bottom) of the sciatic notch proportions versus the sciatic notch angle in DNH 43 and the comparative sample.

In contrast to the early hominin fossil sample, in female *H. sapiens*, the mean biacetabular and bispinous breadths (Table 2) are 230% and 225% that of the mean acetabular diameter, while the same male dimensions are 196% and 172%, respectively. The exceptionally wide bispinous and biacetabular breadths of DNH 43 suggest a capacious pelvic outlet that might indicate a non-rotational birth mechanism as sometimes inferred for *Australopithecus.*[25,42] A pelvis that is mediolaterally broad from hip joint to hip joint may also influence lower limb kinematics by maintaining stride length in individuals with relatively shorter hindlimbs via the recruitment of greater pelvic rotation.[43-45] However, such an arrangement does not appear to increase locomotor cost.[46] A better sample of articulated fossil pelvises will shed further light on our understanding of the evolution of hominin encephalisation and its evolutionary interplay with locomotor biomechanics, although much of the theoretical and empirical basis of this relationship remains controversial.[3,7,47-51]

The pelvic incidence of DNH 43 (Table 2; Supplementary figure 3) indicates an anterior tilt to the sacrum and concomitant lumbosacral alignment that would facilitate a human-like lumbar lordosis.[15] Although the 56° pelvic incidence of DNH 43 is higher than the human mean and values for single specimens of *A. afarensis* (42°) and *A. africanus* (45°), all three of these fossils fall comfortably within the variation documented for recent *H. sapiens.*[15] Sts 14 is within one lower standard deviation of the human mean of 54° and AL 288-1 is well within the range (32–84°) (Table 2). In contrast, DNH 43 and the *Australopithecus* specimens highlight the peculiarly low pelvic incidence demonstrated for members of the Neanderthal lineage.[15] Kebara 2 and both Sima de los Huesos pelvises fall over two standard deviations below the human mean (Table 2), although pathology in Pelvis 1 from Sima de los Huesos might influence pelvic incidence.[15] Further work investigating variation in late Pleistocene spinopelvic anatomy is warranted. Nevertheless, these data suggest spinopelvic mechanics in *Australopithecus* (and likely *Paranthropus* if DNH 43 indeed represents the genus) were similar to recent *H. sapiens* in how they positioned the torso and head over the hip joint during bipedal posture and locomotion.

Conclusion

Overall, the quantitative analysis presented here is congruent with prior qualitative results reflecting the primitive features of DNH 43. *Paranthropus robustus* is a reasonable taxonomic assignment given the overall plesiomorphic morphology and that *P. robustus* remains dominate the DMQ hominin assemblage. However, caution is warranted as *H. erectus sensu lato* is documented at DMQ[2] and well-associated cranial and postcranial remains are scarce for both *Paranthropus* and early *Homo*. Because phylogenetic analyses based primarily on craniodental character sets indicate that *Paranthropus* and *Homo* may represent sister groups[33], these taxa would be expected to share some postcranial features based on that common ancestry. Consequently, basal members of *Homo* might be difficult to identify based solely on the pelvic traits visible in DNH 43. Thus, taxonomic assignment of postcranial remains such as DNH 43 may be subject to revision with a better understanding of the postcranial anatomy of *Paranthropus* and early *Homo,* which overlapped chronologically in both southern[2] and eastern Africa[52].

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Table 2: Measurements of the articulated pelvis

Taxon/group and specimen(s)	Mediolateral breadth of pelvic inlet (mm)	Biacetabular breadth (mm)	Bispinous breadth (mm)	Pelvic Incidence (degrees)
DNH 43[a]	108.9	123.6	106.3	56
Australopithecus afarensis				
AL 288-1[b]	132	118	101	42[c]
Australopithecus africanus				
Sts 14[d]	116.8	107.5	89.0–93.1	45[c]
Sts 65[e]	101.5 (109)	–	–	–
Australopithecus sediba				
MH 2[f]	117.6	122.3	–	–
Homo erectus				
KNM-WT 15000[g] (subadult)	100	102	–	–
Homo* cf. *erectus				
BSN 49/P27[h]	124.5	131.0	114.5	–
Homo heidelbergensis				
Sima de los Huesos:				
Pelvis 1[i]	139.3	138	116.4	28[c]
Pelvis 2	–	–	–	33[c]
Neanderthal				
Kebara 2[j]	138	129	–	34[c]
Tabun C1[k]	131	133.8	–	–
***Homo sapiens* (fossil)**				
Ohalo II	–	–	–	52[c]
***Homo sapiens* (recent)**[l]	132.5 ± 7.5	121.1 ± 8.1	117.2 ± 1.0	54 ± 10[c]
	(female $n = 218$)	(female $n = 163$)	(female $n = 143$)	range:
	1274 ± 7.4	111.2 ± 6.7	97.3 ± 9.2	32 – 84
	(male n =237)	(male $n = 200$)	(male $n = 162$)	($n = 53$)
Pan troglodytes[m]	100 ± 12.6	105.8 ± 35.6	–	29 ± 6[c]
	$n = 29$	$n = 29$		$n = 8$

[a] *DNH 43: all measurements from current study*

[b] *AL 288-1 breadth of pelvic inlet and bispinous breadth from Tague and Lovejoy[25]; biacetabular breadth from Berge and Goularas[17] based on Schmid[26]*

[c] *All pelvic incidence data (except for DNH 43) are from Been et al.[15]*

[d] *Sts 14: breadth measurements are from Berge and Goularas[17]*

[e] *Sts 65: breadth of the pelvic inlet (with higher-end estimate based on reconstruction with AL 288-1 sacrum) from Claxton et al.[27]*

[f] *MH2: breadth measurements from Kibii et al.[28]*

[g] *KNM-WT 15000: breadth measurements from Walker and Ruff[29]*

[h] *BSN49/P27: breadth measurements from Simpson et al.[13]*

[i] *Sima de los Huesos Pelvis 1: breadth measurements are from Bonmati et al.[12]*

[j] *Kebara 2 biacetabular breadth is the mean of two reconstructions from Adegboyega et al.[30] and bispinous breadth is from Rak[31]*

[k] *Tabun C1: pelvic inlet breadth from Weaver and Hublin[32] and biacetabular breadth measured on the 3D reconstruction from Weaver and Hublin[32]*

[l] *Recent* Homo sapiens *breadth of pelvic inlet, biacetabular breadth, and bispinous breadth data represent the weighted mean of six populations ± standard deviations from Tague[16]*

[m] Pan troglodytes *mediolateral breadth of pelvic inlet and biacetabular breadth data from Berge and Goularas[17]*

(Ethiopian Authority for Research and Conservation of Cultural Heritage) for access to fossil specimens. Alex Denning at the University of New Mexico's Maxwell Museum of Anthropology facilitated access to the skeletal sample of recent *Homo sapiens*. Jeremy DeSilva, Mike Plavcan and Karen Rosenberg kindly shared access to further fossil casts and scans for the study. Thanks to José Braga for photos from the 1997 excavations at Drimolen. Thanks to Coen Wilson for the photogrammetry model of Drimolen. Finally, we thank Matt Skinner and Mykolas Imbrasas for assistance in making the 3D models available online.

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Data availability

All the data supporting the results of this study are included in the article itself and in the supplementary material. For the current study, the DNH 43 pieces were surface scanned using an Artec Space Spider. The resulting surface scans of the individual pieces of DNH 43 as well as the partial reconstruction are provided in the University of the Witwatersrand's Drimolen Collection at https://human-fossil-record.org.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. This work appears in whole or in part in a thesis/dissertation.

Authors' contributions

E.B.: Conceptualisation, methodology, sample analysis, data collection, validation; writing – the initial draft; writing – revisions. A.S.H.: Methodology, data collection, validation, writing – revisions. A.G.W.: Methodology, validation, writing – revisions. M.S.M.: Methodology, data collection. M.W.T.: Methodology, data collection. S.E.B.: Conceptualisation, methodology, data collection, project leadership, project management. A.I.R.H.: Conceptualisation, methodology, data collection, project leadership, project management, funding acquisition. D.S.S.: Conceptualisation, methodology, project leadership, project management, funding acquisition, writing – revisions. C.M.O.: Conceptualisation, methodology, sample analysis, validation, data collection, student supervision, project leadership, project management, funding acquisition, data curation, writing – the initial draft, writing – revisions. All authors read and approved the final manuscript.

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A probable Pleistocene pangolin (Order: Pholidota) trackway from South Africa's Cape south coast

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A fossil trackway, attributed to a probable pangolin trackmaker, has been identified on a Pleistocene aeolianite surface of the Waenhuiskrans Formation in the Bosbokfontein Private Nature Reserve on South Africa's Cape south coast. The trackway consists of eight tracks and two probable tail traces. This appears to be the first description of a pangolin trackway in the global fossil record. The trackway was probably registered during Marine Isotope Stage 6 or 5. Trackway assessment and interpretation involved the integration of indigenous African and Western-based ichnological approaches, leading to a reasonably confident conclusion on the probable trackmaker's identity. Alternative trackmakers (felids, viverrids and canids) were considered, but excluded or regarded as less likely candidates. There are three Cenozoic body fossil records of pangolins from the southwestern Cape, which have been assigned to the giant pangolin (*Smutsia gigantea*). Only Temminck's pangolin (*Smutsia temminckii*) currently occurs in southern Africa. All eight extant pangolin species are considered to be threatened with extinction according to the IUCN Red List of Threatened Species.

Significance:

- A Pleistocene probable pangolin trackway has been identified east of Still Bay, Western Cape Province, South Africa.
- The identification involved integrating indigenous African and Western-based ichnological approaches.
- This appears to be the first known fossilised pangolin trackway.
- The trackway consists of eight tracks and two probable tail traces.
- This discovery could draw attention to the plight of pangolins.

Introduction

Through the Cape south coast ichnology project, over 350 Pleistocene vertebrate ichnosites have been documented along a 350 km stretch of South African coastline. The majority (80%) represent mammal tracks and traces.[1] Until now, no pangolin ichnofossils have been identified, either on the Cape south coast or, to the best of our knowledge, anywhere in the world. Here we describe a trackway on an aeolianite (cemented dune) palaeosurface in the Bosbokfontein Private Nature Reserve, east of Still Bay on the Cape south coast. The lines of evidence converge on a pangolin as the probable trackmaker.

The order Pholidota contains a single family, Manidae, with eight recognised, extant pangolin species from sub-Saharan Africa to India, southern China, southeast Asia and the Philippines.[2] A cryptic ninth Asian species was detected in 2023[3], and awaits formal description. Four of these species occur in Africa – two are arboreal and two (Temminck's pangolin and the giant pangolin) are ground-dwelling. Temminck's pangolin (*Smutsia temminckii*, previously *Manis temminckii*) is also known as the ground pangolin, the Cape pangolin, or the scaly anteater, and is the only pangolin species to currently occur in southern Africa.[2] In the Ju/'hoan language, Temminck's pangolin is known as *n‡hòqò*, and in Afrikaans as the *ietermagog*. The latter is probably of Bantu or Tswana derivation.[4]

All species of extant pangolin are threatened by poaching and habitat loss, and all are classified as Vulnerable, Endangered, or Critically Endangered on the IUCN Red List of Threatened Species.[5] Pangolin meat is regarded as a delicacy, and pangolin scales are used in traditional medicines.[6] There is evidence that pangolins are among the most trafficked wild animals on earth, and 400 000 African pangolins are estimated to be hunted for their meat annually.[7]

The tracks described here were initially identified in 2018 by Renée Rust and family. The tracks are evident on the surface of a large fallen aeolianite block. The putative trackmaker remained enigmatic until our joint analysis in 2023. Two of us (#.D., /.N.) are Indigenous Ju'/hoansi San Master Trackers, and had an immediate, strong sense of what was being examined. This presented the opportunity for Indigenous and modern scientific tracking exponents to engage in a productive exchange of ideas, combining culturally honed and experientially grounded intuitions with modern assessment techniques. This collaborative, interdisciplinary approach has allowed us to arrive at a shared conclusion on the identify of the probable trackmaker.

The purpose of this article is to describe the trackway, discuss the probable trackmaker, consider alternative trackmakers, and discuss the relevance of this discovery. We also reflect on the value of integrating Indigenous African and Western-based ichnological approaches.

Geological context

Pleistocene carbonate aeolianites of the Waenhuiskrans Formation[8], part of the Neogene Bredasdorp Group[9], are exposed along portions of the Cape south coast of South Africa, and have provided evidence for palaeo-shorelines

and palaeocoastal dune activity[10]. Carbonate aeolianites are consolidated coastal rock formations consisting of at least partially lithified calcareous wind-blown sand. The trackway described here would have been registered on an unconsolidated dune surface, which is now consolidated and cemented into aeolianite. Globally, aeolianites are fairly common in mid-latitude coastal regions between 20° and 40°.[11] Throughout the Pleistocene, global sea-level change meant that the Cape south coast landscape was dynamic. Vertebrate ichnosites encountered on these palaeosurfaces would have been situated at the margin of the Paleo-Agulhas Plain, most of which is presently submerged, but at times sea-level oscillations would have exposed the entire plain.[12] In contrast, sea level was 6–8 metres higher than at present at the height of the Marine Isotope Stage (MIS) 5e marine transgression at ~126 ka.[13]

Optically stimulated luminescence (OSL) dating of onshore aeolianites has shown that most date to MIS 5 and late MIS 6.[13-16] MIS 11 deposits[17] and MIS 3 deposits[18] have also been identified, with a resulting age range of dated deposits presently spanning ~400–35 ka. Roberts and Cole provided an explanation for the profusion of ichnosites, postulating a combination of a cohesive moulding agent (moist sand), rapid track burial (facilitated by high sedimentation rates), rapid lithification (via partial solution and re-precipitation of bioclasts), and finally re-exposure of track-bearing surfaces through shoreline erosion.[19]

In general, the grain size of the substrate inversely influences the preservation quality of fossil tracks. In Cape south coast Pleistocene deposits, tracks made on moderately coarse-grained dune surfaces tend to show poor to intermediate preservation quality, certainly inferior to that seen elsewhere in the world, for example in clay or mud substrates on cave floors. Belvedere and Farlow introduced a four-point preservation scale, in which 0 represents an unidentifiable track, and 3 represents a track of exceptional quality.[20] It is unusual for tracks within the Cape south coast deposits to rise above 2 on this scale.

Active shoreline erosion causes coastal cliffs to fragment or collapse, sometimes exposing new ichnosites, while known sites deteriorate in quality or loose blocks slump into the ocean. Ichnosites are thus ephemeral. The taphonomic erosive effects of wind and water, either pre-burial or post-re-exposure, can result in loss of track preservation quality. In the latter case, even if the tracks displayed anatomical fidelity at the time of re-exposure, over time their quality can deteriorate.[1] The causes of relatively poor preservation, such as moderately large grain size (in this case medium-grained sand), pre-burial erosion and post-exposure erosion, may be difficult to distinguish, especially if it is not known for how long the surface has been exposed.[21,22]

The Bosbokfontein tracksite is located in a remote section of coastline (Figure 1), characterised by aeolianite cliffs as high as 30 m. High tides and storm surges cause cliff sections to collapse, whereupon loose blocks come to rest on unstable slopes or near the high-tide mark at the cliff base.

One section in this region, situated ~8 km east of the Bosbokfontein site, had been dated prior to our studies.[13] Ages obtained through OSL dating produced a range of 140 ± 8 ka to 91 ± 5 ka. Our subsequent work has yielded several results of relevance here (in each case a five-digit number is preceded by 'Leic'). The closest of these lies 4.5 km east of the Bosbokfontein site, where an age of 126 ± 9 ka was obtained (Leic21005).[23] Other results from sites located slightly further east include 161 ± 12 ka (Leic20033), 139 ± 10 ka (Leic20031), 134 ± 9 ka (Leic21008), and 109 ± 9 ka (Leic20024).[23-25] Although direct stratigraphic correlation between these sites is not feasible, due to an absence of laterally persistent layers or marker beds, it nonetheless seems likely that the Bosbokfontein track-bearing surface occurs in deposits within the age range of ~161–91 ka, from MIS 6 or MIS 5.

Methods

Track measurements (in cm) included length, width, depth, pace length, and stride length. External trackway width was measured in cm, representing "the distance between the footfall of left and right feet, measured between the outside extremities of the tracks".[26] Global Positioning System locality readings were taken using a handheld Garmin 60 device. Locality data were stored with the African Centre for Coastal Palaeoscience at Nelson Mandela University, to be made available to researchers upon request.

The tracksite was photographed, and photogrammetric analysis was performed.[27,28] 3D models were generated with Agisoft MetaShape Professional (v. 1.0.4) using an Olympus TG-5 camera (focal length 4.5 mm; resolution 4000 x 3000; pixel size 1.56 x 1.56 µm). The final images were rendered using CloudCompare (v.2.10-beta). The tracks could be assessed by climbing to the top of the block and examining the surface, but for optimal recording, including photogrammetry studies, access via a portable ladder proved useful. A DJI Mini 2 drone with an inbuilt DJI camera/video was used to obtain further photographs.

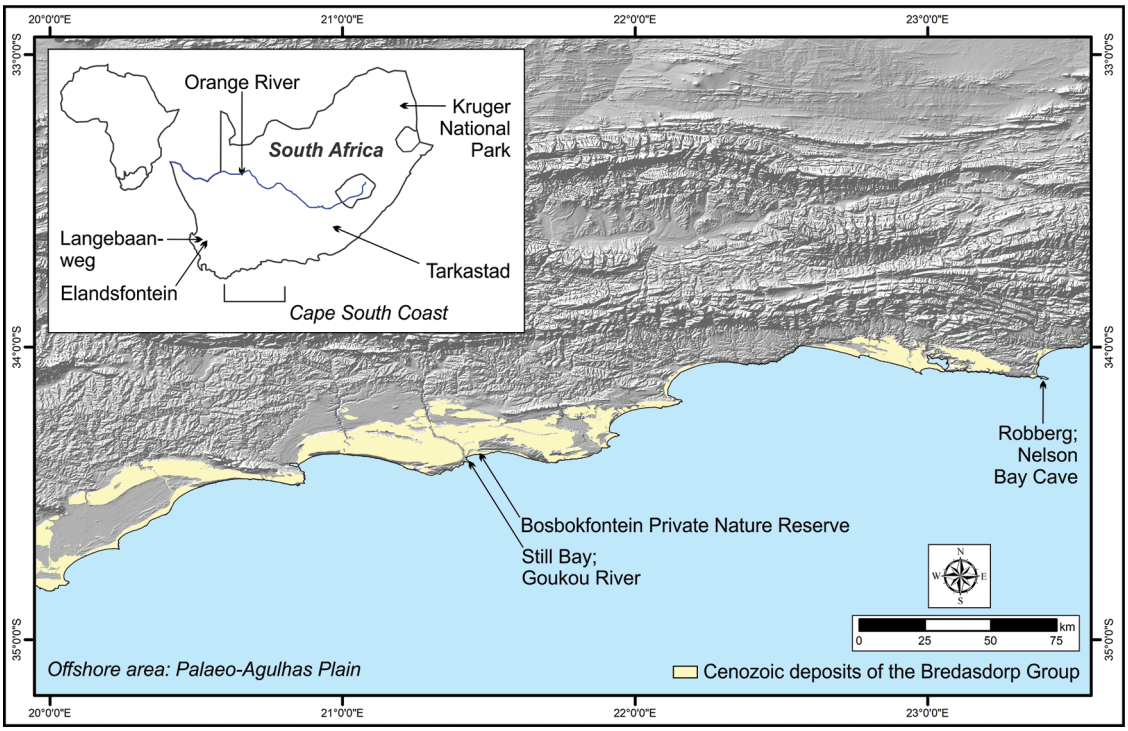


Figure 1: Map of South Africa's coast, indicating the Bosbokfontein site, the extent of Pleistocene deposits, and sites mentioned in the text.

After viewing the tracksite in detail together, and examining photographs and photogrammetry models, we reviewed our findings and opinions. This permitted further integration of the perspectives and interpretations of Master Trackers and Western-trained ichnologists. Furthermore, we engaged with some of southern Africa's tracking (neoichnology) experts, asking for their opinions on trackmaker identity based on photographic and photogrammetric images.

Results

The tracksite is located within the Bosbokfontein Private Nature Reserve, approximately 6.5 km east of the mouth of the Goukou River and the community of Still Bay. It occurs on the upper surface of a large ex-situ block, which has tumbled down the vegetated slopes from cliffs above and has come to rest above the high-tide mark (Figure 2). The maximum length of the block is ~7 m, with a maximum thickness of 4.5 m. However, the approximately triangular-shaped track-bearing surface is smaller, with maximum dimensions of ~200 x 180 cm. Slight deterioration in the preservation quality of the tracks and trackway has occurred since identification in 2018, but assessment and interpretation of tracks and trackway morphology remained feasible.

The block came to rest at an angle, and the track-bearing surface faces seaward and skywards, in a southeasterly direction. The trackway, which is ~160 cm in length, is thus aligned in a southeast-northeast direction as the loose block is currently orientated, but this may be subject to change following storm surges. Viewed in cross-section, the block exhibits laminar bedding, mostly parallel but with slight distortion in places and faint cross-bedding. The relative absence of cross-bedding suggests that the tracks might have been registered on a more level interdune area. The trackway is interpreted here with the viewer facing landwards and northwest, as if the trackmaker was progressing up the current slope of the loose block. The tracks are preserved in concave epirelief.

Eight tracks are evident (Figure 3), but the distal track occurs at the edge of the surface and is partial, and the two proximal tracks are partially obscured by two elongated depressions, aligned in approximately the same direction as the trackway. These are approximately 10.0–12.5 cm long and 4.5–6.0 cm wide. Tracks 3 through 7 therefore offer the best potential for analysis. The trackway curves gently to the left, such that its distal end is orientated ~30° leftward of that of its proximal end. Faint displacement rims partially encircle some of the tracks, suggesting that the tracks were registered on a slightly sloping surface.

Track lengths (5.5–6.0 cm) and track widths (5.0–5.5 cm) are relatively constant. Tracks 6 and 7 appear slightly wider in their anterior portions. Pace length in tracks 3 through 7 is relatively constant (18–20 cm). Track depth varies from 1.0 cm to 1.5 cm, with the anterior portions of the tracks slightly deeper than the posterior portions. The external trackway width appears narrow, at approximately 7.5 cm.

Discussion

The prehistoric and historic distribution of southern African pangolins

The global record of pangolins extends back to the Oligocene Epoch[29], as reviewed by Gaudin et al.[30] The prehistoric distribution of pangolins in southern Africa in the palaeontological record is meagre for the southern Cape and western Cape: there are only three reported Cenozoic fossils of pangolins from these regions.[31] These all represent skeletal evidence, and we are not aware of trace fossil records of pangolins in the global ichnology record. The three reported southwestern Cape fossil records are now summarised.

Hendey reported an unstudied early Pliocene pangolin from the 'E' Quarry at Langebaanweg in the Western Cape Province near the South African west coast.[32] Botha and Gaudin[29] formally described this specimen as probably ground dwelling, and possibly having engaged in a quadrupedal gait similar to that of the extant giant pangolin (*Smutsia gigantea*). It was suggested that it may have used its forelimbs more than *S. temminckii.* The specimen was assigned to *S. gigantea*, making it the oldest known representative of that species.[29]

Klein et al. described a pangolin assigned to the genus *Phataginus* from the Elandsfontein Main site in the Western Cape Province on South Africa's west coast, ~350 km WNW of the tracksite reported on here.[33] It was described as an "extralimitary species" that contributed to the exceptional faunal diversity of the site. The age of the faunal assemblage was estimated to be in the range of 1.0–0.6 Ma.[33]

The closest pangolin body fossil site to the Bosbokfontein site, temporally and spatially, was reported by Klein from Nelson Bay Cave near Robberg, 180 km east of Bosbokfontein.[34] It was located in Late Pleistocene deposits dating to 18–16 ka. It was described as the "Cape pangolin, *Manis* cf. *temminckii*"[34].

The southern African Holocene and historical record is more extensive for Temminck's pangolin. Possible sources include historical accounts, ethnographic records, rock art and place names. Möller noted that Temminck's pangolin had a wide distribution and occurred all over southern Africa, and that the lack of early reports might be attributable to its nocturnal habits.[4] Skead[35] reported that a probable pangolin had been recorded in 1825 from the Tarkastad or Queenstown area (in the current Eastern Cape Province), and that this probably constituted the southernmost record for the species (~32° S). Skead[35] quoted Layard[36] that the pangolin was "not now" found in the Cape Colony (i.e. south of the Orange River), perhaps implying that it had occurred previously within it. Shortridge[37] reported that it was absent from "Little Namaqualand" but noted a pangolin skin from the Upington area and records south of the Orange River from Prieska and Colesberg. The 1865 holotype is from

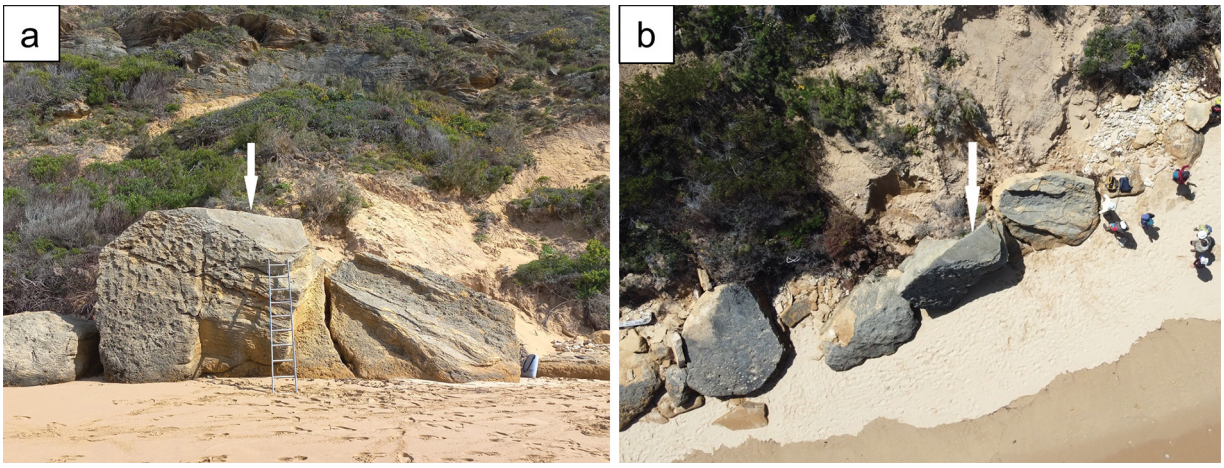


Figure 2: (a) The large loose block containing the purported pangolin trackway on its upper surface; the ladder length is 410 cm. (b) The track-bearing block, viewed from above using a drone; adult human figures for scale. Arrows point to the track-bearing surface.

Litakun (Latakou), ~250 km north of the Orange River, and north of present-day Kuruman.[30] Lichtenstein[38] and Burchell[39] also reported the occurrence of the pangolin in the Litakun area.

Möller provided two place names, Ietermagô and Khwaru, that refer to pangolins.[4] Both are in the Kruger National Park in South Africa's Limpopo Province, ~1500 km northeast of the Bosbokfontein site. They are therefore unhelpful regarding a potential southern Cape distribution range.

Rock art can provide information on prehistoric pangolin distribution, although it only implies the artist's awareness that the species existed, not its occurrence in that precise locality. Despite consultation with rock art experts, we are not aware of rock art depicting pangolins in southern Africa, other than at a site in the Limpopo Province (Figure 4a), where a frieze of engraved animal tracks of eight species contains an engraving of a possible pangolin hindfoot track.[40] 'Fragile Images', a YouTube video, includes footage of the engraving at 12 minutes and 10 seconds: https://www.youtube.com/watch?v=Ra12BKeH7Js.

In summary, the body fossil record demonstrates the presence of pangolins in the southwestern Cape region of South Africa during the Pliocene and Pleistocene. The situation is perhaps analogous to that of the giraffe (*Giraffa camelopardalis*), for which there is no body-fossil evidence from the Pleistocene in the southwestern Cape, but a trace fossil record confirms its presence.[41] The giraffe tracksite

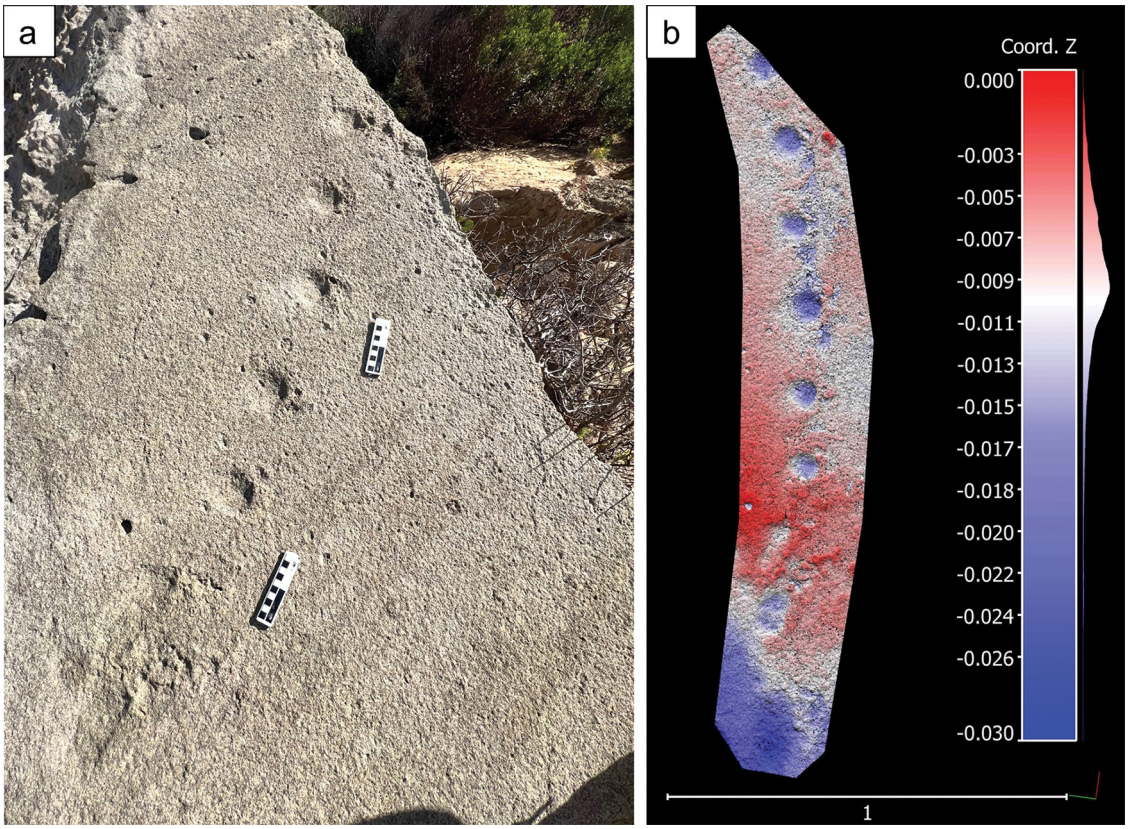
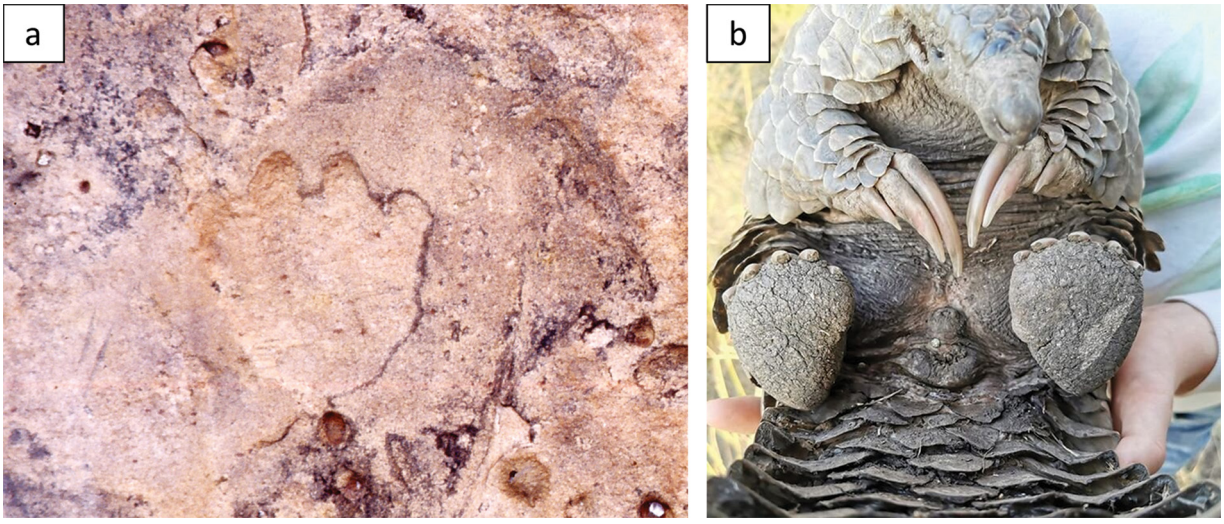


Figure 3: (a) The purported pangolin trackway; scale bars = 10 cm. (b) Photogrammetry colour mesh of the trackway; vertical and horizontal scales are in metres.



Images with permission from Chris and Mathilde Stuart (a) and Simon Naylor (b).

Figure 4: (a) Rock engraving of a probable pangolin track in Limpopo Province. (b) The forefeet and hindfeet of a Temminck's pangolin, viewed from below.

lies less than 8 km east of the Bosbokfontein tracksite. The presence of giraffe tracks implies the presence of trees and a probable savanna palaeoenvironment.[41] This may have been suitable for Temminck's pangolin, with a preferred habitat of savanna woodland. The record from Nelson Bay Cave[34] lies just within the last glacial period, when aspects of this habitat might still have been present. Historical records, place names and rock art do not contribute to an understanding of pangolin distribution in the southwestern Cape.

Pangolin track morphology

Southern African neoichnologists are fortunate to have five tracking manuals to which to refer.[26,39,42-44] Each describes Temminck's pangolin tracks, reviewed here in order of publication date. Figure 4b depicts the forefeet and hindfeet of a Temminck's pangolin.

Liebenberg described five toes on the forefeet (the first with a small nail and the central three with long, strongly curved claws), and five toes on the hindfeet, each with a short nail-like claw that sometimes registers an impression in the tracks.[42] The body was noted to be balanced on the hindfeet when walking, with the forefeet and tail held off the ground. Tracks were noted to show the rounded pads of the hindfeet with four nails usually touching the ground. The occasional tail scrape and traces made by the front edges of the front claws were also noted. Hindfoot tracks were reported as 6 cm in length.[42]

Van den Heever et al.[26] also noted that both forefeet and hindfeet have five toes, and that the first and fifth toes of the front feet are reduced, leaving three middle toes with long curved claws, well adapted for digging. The forefoot track (when present) was noted to record the upper surfaces of the three middle claws, which curl under the foot. The hindfoot was described as padded and triangular with five toes, and as being ~5 cm in length. Movement was described as bipedal, with the forefeet seldom touching the ground. Scuff marks made by dragging the tail were reportedly occasionally present.[26]

Walker[43] described the pangolin as moving along on its hind legs, occasionally dropping onto all fours or using the tail and forelegs for balance. Claws were noted to be prominent, and claws 2, 3 and 4 (presumably on the forefeet) were well developed and recurved. Pangolins were noted to walk mainly on their hind legs in an upright position. Hindfoot tracks were reportedly ~4.5 cm long and wide.[43]

Stuart and Stuart described (questionably in our opinion) a "typical tramline-like trail", resulting from the fairly wide spacing of the hindfeet, on which Temminck's pangolin normally walks, with the short, heavily clawed forefeet held clear off the ground.[40] The forefeet were noted to be used mostly for digging. Hindfoot track length of 6 cm was reported, with slight intoeing. An image of a pangolin trackway was not provided.[40]

Gutteridge and Liebenberg described the "interesting spoor" of the pangolin, which usually moves bipedally on the rounded hindfeet.[44] These were noted to drag, as the pangolin walks in a kind of shuffle. The unique marking made by the tail was also noted. Hindfoot track length was reported as being 6.5 cm.[44]

While there are slight differences in the focus of these descriptions, there is substantial agreement, involving a predominantly bipedal gait, with hindfoot tracks 4.5–6.5 cm in size, occasional forefoot traces, and occasional tail drag marks.

Interpretation and trackmaker identity

During the 2023 visit, the Master Trackers in our team (#.D. and /.N.) examined the surface unprimed by any hypotheses on trackmaker identity. Once they had presented their analysis, the rest of our team provided their own hypotheses and interpretations. The heuristic conclusion of the Master Trackers was of a probable pangolin trackway. They inferred a bipedal gait with tracks "*soos 'n ronde stok wat in die grond ingedruk is*" ("like a round stick poked into the ground") – for them indicative of a pangolin trackmaker. Their reading of the external trackway width and pace length fortified their conclusion. For the rest of us, unfamiliar as we were with such tracks, the proposal of a pangolin was a novelty. When photogrammetry images became available, we jointly re-reviewed the lines of evidence.

Other plausible trackmaker candidates include felids such as serval (*Leptailurus serval*), caracal (*Caracal caracal*) and African wild cat (*Felis lybica*), the viverrids African civet (*Civettictis civetta*), rusty genet (*Genetta maculata*) and large-spotted genet (*Genetta genetta*), and canids such as jackals and foxes (in a soft, sandy substrate the claw impressions of canids might not be preserved). Bipedal avian trackmakers would be expected to leave at least some evidence of didactyl, tridactyl or tetradactyl morphology[45], and the two elongated depressions are inconsistent with an avian origin. There is no evidence in the Pleistocene fossil record or among extant southern African species of other animals that could have made these tracks. One caveat is that carnivoran size (hence track size) varied during the Pleistocene, being reportedly larger during glacial phases.[46]

The tracks, 5–6 cm in size, are consistent with those of both extant Temminck's pangolin and serval, although a pangolin's hindfoot track length is marginally greater than those of a serval's forefoot and hindfoot. *Contra* Stuart and Stuart[40], the narrow external trackway width is consistent with the trackways of both Temminck's pangolin and, on occasion, serval. However, the trackway widths of caracal[44] and especially civet (our own observations) are distinctly broader. While the African wild cat can also produce a round track, the smaller size of its track and pace length exclude it. Similar considerations exclude both species of genet. Jackal tracks, in the 5 cm range, are relatively slender and more elongated (especially in the case of the smaller hind foot), definitely not "*soos 'n ronde stok wat in die grond ingedruk is*". The same is true of fox tracks (Cape and bat-eared), with the front foot of the bat-eared fox (*Octocyon megalotis*) measuring only 4.5 cm[44] and the hind foot even less.

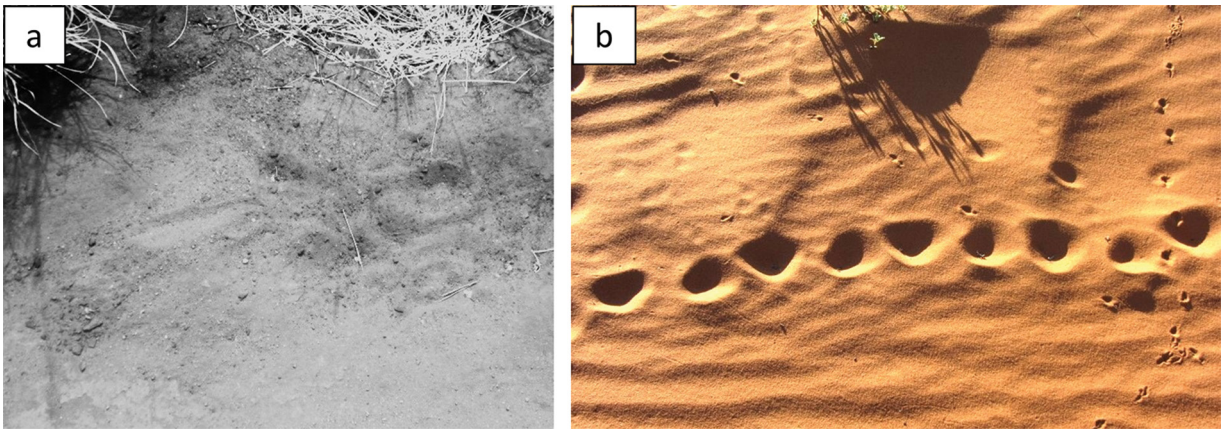
Whereas Temminck's pangolin hindfoot tracks are triangular (with the apex pointing backwards, away from the direction of travel) and well-preserved serval tracks exhibit pad and digit impressions, none of these features might be present in Cape south coast aeolianites. This may either be because of a soft, non-cohesive substrate at the time at which the tracks were registered, the effects of grain size, or pre-burial or post-re-exposure erosion.[1] Consequently, the tracks of both Temminck's pangolin and serval might appear round, without further morphological details. In such a situation, trackmaker identity would depend more on trackway morphology than on individual tracks. With the Bosbokfontein trackway, however, there is a hint of a triangular track morphology, or at least of some tracks appearing wider in their anterior portions.

The inference of trackmaker direction is based on some tracks appearing slightly wider in their anterior portions, the overall indentation pattern, and the orientation of the two elongated depressions. These impressions at the proximal end of the trackway and in line with it are consistent with the scuff-marks made by the pangolin tail (Figure 5a), and less consistent with tail traces made by servals or other potential trackmakers.

Pace length is consistently 18–20 cm, and therefore the distance between tracks is about three times the size of each track. While a pangolin sometimes walks with a shuffle and a relatively short pace length (Figure 5b), it can also walk with a longer pace length when not foraging, as in the Bosbokfontein trackway and in Figure 6.

Another potential distinguishing factor involves the relative lightness of the gait. A serval, like all cats, walks or runs lightly. A Temminck's pangolin, bulky, slower and bipedal, has a more ponderous gait. Therefore, pangolin tracks tend to be deeper than serval tracks. While this is not an absolute criterion, the depth of the tracks in question (1.0–1.5 cm), bolstered by the notion of the round end of a stick poked into the ground, is more consistent with a pangolin trackmaker.

Opinions from expert southern African trackers were most helpful. We approached Louis Liebenberg of CyberTracker, Alex van den Heever of the Tracker Academy, Richard McKibbin (wildlife guide and a moderator of the Facebook group 'Tracks and Signs South Africa'), Steff McWilliam (trail guide associated with the African Pangolin Working Group and the Johannesburg Wildlife Veterinary Hospital), Wendy Panaino (pangolin



Images with permission from Bruno Nebe.

Figure 5: (a) Scuff marks registered by the tail of a Temminck's pangolin. (b) A trackway of a Temminck's pangolin, showing (in this case) a short pace length.

Image with permission from Scott Hurd.

Figure 6: A Temminck's pangolin walking with a longer pace length.

researcher at the Tswalu Foundation's Kalahari Endangered Ecosystem Project), and Nicci Wright (Co-chair of the African Pangolin Working Group).

Their feedback was measuredly supportive. None thought that the tracks were inconsistent with those of a pangolin. Liebenberg provided a confident assessment:

> *I agree with trackers that this is pangolin. Definitely not a cat, since the gait is not that of a four-legged animal, whose footprints would be in pairs (front and hind close together). Pangolin is only bipedal gait with feet this shape and stride length.*

McKibbin cautioned that a serval's faded tracks could also appear very round and could present with a narrow straddle, but, as we have indicated, the track depth tilts towards a pangolin.

Wright provided a detailed comment:

> *To me, the tracks look like those of Temminck's pangolin, bipedalling along. The length between prints would be determined by the animal's overall size. Young pangolins have a much smaller gap between their footprints. The largest adult pangolin I have dealt with was 18.5 kgs, which nowadays is unusual to find. I think that if it had moved, fast-paced, through soft mud or sand, the length between prints would have been around 18–20 cm or even a bit longer, and would be deeper than those of a young pangolin which would weigh less.*

Furthermore, one of the three very knowledgeable anonymous reviewers of this manuscript (under strict confidentiality of the peer review process) sent the image of the fossilised trackway to two colleagues who have worked with Temminck's pangolin for many years on a day-to-day basis.

Both the reviewer and the two colleagues agreed with the interpretation of a pangolin trackway.

In the less likely scenario that the tracks were registered by a serval, a 'direct register' would be inferred whereby the hindfoot was placed precisely on top of the forefoot track. (Stealth hunters often employ this economical, sound-minimising foot-placement pattern.) From a prehistoric distribution perspective, a serval trackmaker is plausible. Avery reported Pliocene serval records from Gauteng Province, and Pleistocene and Holocene records from, inter alia, the southwestern Cape.[31]

Our overall conclusion is that the trackway cannot be attributed with absolute certainty to any trackmaker. However, it is most consistent with a Temminck's pangolin trackmaker, distinctly more than a serval or any other candidate species. The Pleistocene distribution range of the Temminck's pangolin included the southwestern Cape, in a situation that is analogous to that of the giraffe, the preferred habitat of both species being savanna woodland. Such habitat might have been present on the now-submerged Palaeo-Agulhas Plain.[47]

Conclusions

A Temminck's pangolin probably walked across a soft, sandy dune surface near the margin of the Palaeo-Agulhas Plain, most likely during MIS 6 or MIS 5, leaving a trackway. Eight tracks and, suggestively, two tail traces are preserved and amenable to interpretation. For many, fossil trackways are to body fossils what movies are to photographs, and evocative trackways tell a story of something that might have walked by yesterday, or over 100 000 years ago.

While the loose block containing the track-bearing surface is too large to physically recover, the photogrammetry data can be used to make a replica of the trackway, which could be exhibited in the Blombos Museum of Archaeology in Still Bay. What to date is probably the first reported pangolin trackway in the world could thus serve to draw attention to the plight of pangolins worldwide.

In a recent publication, we described the advantages of collaboration between Indigenous Master Trackers and Western-trained ichnologists in interpreting Pleistocene trackways.[48] The title of a book by Liebenberg specified that the art of tracking was "the origin of science"[49]. In our experience, the outcomes and conclusions that result are richer for integrating ancient and modern science.

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Data availability

The data supporting the results of this study are available upon request to the corresponding author.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

C.W.H.: Lead author, corresponding author, conceptualisation, field work, project leadership, photogrammetry. A.S.C.: Conceptualisation, OSL dating expertise, data analysis, review of drafts and revisions. H.C.C.: Conceptualisation, data analysis, geological analysis, review of drafts and revisions. #.D.: Conceptualisation, data analysis, field work, review of drafts and revisions. J.C.D.V.: Conceptualisation, data analysis, field work, review of drafts and revisions. P-J.G.: Conceptualisation, data analysis, field work, review of drafts and revisions, photography. /.N.: Conceptualisation, data analysis, field work, review of drafts and revisions. C.R.T.: Conceptualisation, data analysis, geological analysis, field work, review of drafts and revisions. All authors read and approved the final manuscript.

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Designing an ideal essential oil combination nanoemulsion formulation for the management of respiratory tract infections

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Essential oils are well studied for their antimicrobial effects; however, blends extending to formulations are rarely scientifically explored. In this study, we aimed to quantify and optimise the synergy of an essential oil blend by means of computational interpretation in order to create a nanoemulsion formulation ideal for use against respiratory tract pathogens. The nanoemulsion blend consisted of essential oils from *Hyssopus officinalis* var. *angustifolius* in combination with *Salvia rosmarinus* var. *angustifolius*. The prediction tool SynergyFinder (Version 2.0) was implemented to determine optimal synergy blends. According to the synergy maps derived, an optimal blend of these two essential oils is composed of 49.57% of *H. officinalis* and 50.43% of *S. rosmarinus*. This optimised blend was then formulated into a nanoemulsion, using the two-component, self-emulsification technique. The essential oil nanoemulsion showed strong in vitro antimicrobial activities against pathogens of the respiratory tract including *Streptococcus pneumoniae* (ATCC 49619), *Haemophilus influenzae* (ATCC 19418), *Klebsiella pneumoniae* (ATCC 13883) and *Moraxella catarrhalis* (ATCC 23246), with an average six-fold improvement in antimicrobial effect when compared to the neat essential oils. The blended *H. officinalis* and *S. rosmarinus* essential oil nanoemulsion therefore holds potential to be developed as a natural antimicrobial agent for the management of respiratory tract infections.

Significance:

This study holds significance as it goes beyond the use of single essential oils to explore the effect of essential oil blends for synergistic potential. By leveraging computational tools, we have optimised the combination of *Hyssopus officinalis* and *Salvia rosmarinus* oils for a potent antimicrobial effect. The subsequent creation of a nanoemulsion formulation enhances the stability and bioavailability of these oils and remarkably causes them to exhibit six-fold greater antimicrobial efficacy against respiratory pathogens when in formulation than as individual oils. As antibiotic resistance looms, this natural remedy offers a promising alternative for managing respiratory infections. In bridging the gap between theory and practice, this research contributes to essential oil science, potentially shaping future antimicrobial strategies.

Introduction

Essential oils were used for their antimicrobial properties as early as 4500 BCE, when the Ancient Egyptians made use of these oils in cosmetics and in ointments for medicine.[1] As a result of the empirical knowledge of this antimicrobial potential, which has been preserved for thousands of years, research performed in laboratories globally has substantiated these effects, thus promoting the application of pharmaceutical products containing essential oils.[2]

Despite the antimicrobial and other pharmacological properties associated with essential oils, their pharmaceutical use is often limited because of challenges in formulation development. Limitations in the development of essential oils into pharmaceutical products include physicochemical properties (e.g. poor water solubility), toxicity, and environmental instabilities as a result of heat, oxygen and moisture.[3] Essential oils are hydrophobic (which is a limitation for inclusion in some delivery systems); however, novel pharmaceutical technology, such as nanoemulsions, can be employed to improve the inclusion capabilities of essential oils in formulations.[4,5] Emulsions are formulated from two immiscible fluids, with one fluid dispersed as droplets, created by a barrier provided by a surfactant within the other fluid.[6] When an emulsion contains droplets with a mean diameter smaller than 200 nm, it is referred to as a nanoemulsion.[6] According to the literature, oil-in-water (O/W) nanoemulsions are especially suitable for the delivery of essential oils because of their oil-based core, high-loading capability, and the large variety of available emulsifiers and stabilisers available for use.[6,7] Previous studies incorporating essential oils into nanoemulsion systems for antimicrobial purposes have provided promising results.[8,9] In an earlier study, Sugumar et al.[10] aimed to determine the antimicrobial effect of the essential oil of *Eucalyptus globulus* Labill. (eucalyptus) when encapsulated into a nanoemulsion system. The nanoemulsion demonstrated a greater antimicrobial effect against *Staphylococcus aureus* than when compared to the essential oil alone.[10] Further studies have demonstrated similar improved antimicrobial effects.[2,11]

Much of the work produced concerning essential oils incorporated into nanoemulsion formulations has considered the effect of the essential oils when used alone.[12-18] Despite the positive findings that support the potential use of these individual essential oils in nanoformulations for antimicrobial purposes, the practice of aromatic medicine predominantly makes use of essential oils in combination with other essential oils to achieve an enhanced therapeutic effect.[19,20] Few studies have explored the effects of essential oils in combination when formulated as nanoemulsions for antimicrobial purposes.[21-25] Much of the published findings are limited to essential oils used against pathogens associated with food spoilage. The rationale for combination use for synergistic antimicrobial purposes within a pharmaceutical formulation is to encourage the use of lower doses of each component while maintaining optimised

antimicrobial effects.[21,22] In order to optimise the antimicrobial activity of an essential oil combination for formulation development, it is advisable to use an experimental design to define the most suitable proportions of each ingredient (oil) in an effective mixture.[22] The use of computer-aided software to quantify synergy for drug design and development has been used within the pharmaceutical industry for a number of years, with great success.[26] In pre-clinical formulation studies involving a combination of drugs, functional screening assays that probe the effects of the drug combination as per a dose-response matrix assay are commonly employed.[27] The use of this technology aims to develop innovative formulations based on optimised interactions and is considered the favoured method for interactive assessment in formulation design.[21]

In our previous studies[28,29], we provided results of the antimicrobial potential of essential oils alone and in equal combinations against nine pathogens of the respiratory tract. Based on the findings of these studies, one unique combination composed of the essential oils *Hyssopus officinalis* var. *angustifolius* (M.Bieb.) Benth. (hyssop) and *Salvia rosmarinus* (previously classified as *Rosemarinus officinalis*) var. *angustifolius* (Mill.) DC. (rosemary) was identified as the most promising for use, having broad-spectrum antimicrobial activity, and anti-inflammatory and non-toxic effects when used in equal ratio combinations.[28,29] In this study, we therefore aimed to explore this unique combination of essential oils to quantify the optimum essential oil dose ratio that would provide antimicrobial synergy, and to further explore this combination as an antimicrobial nanoformulation.

Methods

One essential oil combination was selected for this study: *Hyssopus officinalis* var. *angustifolius* and *Salvia rosmarinus* var. *angustifolius*. These essential oils were procured from a flavour and fragrance industry provider, Prana Monde (Hainaut, Belgium). The two essential oils used in this study have been previously chemically characterised using gas chromatography coupled with a mass spectrometer (GC-MS) and reported on in our earlier studies.[28,29] The major chemical constituents of these oils are provided in Supplementary table 1.

As a result of the lipid nature of essential oils, caprylocaproyl macrogol-8-glyceride (Labrasol) was selected as the surfactant for the formulation. Labrasol is a non-ionic water-dispersible surfactant specifically used in lipid-based formulations to solubilise poorly water-soluble ingredients. Labrasol was obtained as a donation from Gattefossé (Saint-Priest, France). Propylene glycol, procured from Sigma-Aldrich (St. Louis, Missouri, USA) was selected as a co-surfactant to the formulation to provide further stability to the essential oil nanoemulsion.

Preparation of microbial cultures

Microbial cultures were selected based on their relevance to respiratory infections and included the Gram-positive strains *S. aureus* (ATCC 25924), *Streptococcus agalactiae* (ATCC 55618), *Streptococcus pneumoniae* (ATCC 49619) and *Streptococcus pyogenes* (ATCC 12344). The Gram-negative strains included *Haemophilus influenzae* (ATCC 19418), *Klebsiella pneumoniae* (ATCC 13883) and *Moraxella catarrhalis* (ATCC 23246). The non-pathogenic *Mycobacterium* strain *Mycobacterium smegmatis* (ATCC 19420) was investigated to determine the antimicrobial effect of these essential oils against tuberculosis strain classes, as well as against the yeast strain *Cryptococcus neoformans* (ATCC 14116) because of its pathogenic effect in the respiratory tracts of immunocompromised patients. All cultures were prepared as per our earlier studies.[28,29] A waiver for the use of these microorganisms was granted by the University of the Witwatersrand Human Research Ethics Committee (reference W-CJ-160720-2).

Antimicrobial combination optimisation using SynergyFinder

SynergyFinder (Version 2.0) (Helsinki Institute for Information Technology) facilitates the analysis of drug combination experiments and provides an interface for visualising the drug combination landscapes in an interactive manner.[27] The essential oil combination selected (Supplementary table 2) was investigated at varying ratios as a means to complete a dose-response matrix for evaluation by the SynergyFinder software, using the broth microdilution assay as previously reported.[30]

The 96-well microtitre plates were prepared by aseptically adding 100 μL of sterile broth into each of the wells. (Tryptone Soya broth was used for all bacterial cultures, with the exception of the *Streptococcus* species, *H. influenzae* and *M. smegmatis* for which *Haemophilus* test medium base with *Haemophilus* test medium supplement (ThermoFisher) was used.) A stock concentration of each essential oil (32 mg/mL in acetone) was added to the first row at varying ratios (as indicated in Supplementary table 2). The essential oil combinations were then serially diluted to concentrations ranging from 8 mg/mL to 0.06 mg/mL. A 100 μL of the positive, negative and culture controls were included for each microorganism. The positive controls (Sigma-Aldrich) were 0.01 mg/mL ciprofloxacin (for bacteria) or 0.10 mg/mL amphotericin B (for the yeast), and were included to ensure microbial susceptibility. The negative control of 32 mg/mL water in acetone was included to exclude the attribution of antimicrobial effects as a result of the solvent. The culture controls consisted of growth medium with the relevant pathogen to ensure that the appropriate broth supported microbial growth.

Streptococcus agalactiae, S. pneumoniae, S. pyogenes and *H. influenzae* were grown in *Haemophilus* test medium base and supplement, while *Mycobacterium smegmatis* required Middlebrook broth supplemented with glycerol and ADC enrichment. All other tested bacterial pathogens and *Cryptococcus neoformans* were cultured in Tryptone Soya broth (TSB). An inoculum concentration of approximately 1×10^6 colony-forming units per mL (CFU/mL) was prepared, as per the McFarland standard for each microorganism studied, and 100 μL of the inoculum was added to each well. Before incubation, each microtitre plate was sealed with sterile adhesive sealing film. Incubation conditions varied by bacterial species. The pathogens *M. smegmatis* and *C. neoformans* were incubated aerobically for 48 h at 37 °C, while *S. pneumoniae, S. pyogenes* and *H. influenzae* were maintained in anaerobic environments with 5% CO_2 at 37 °C for 24 h, and *S. agalactiae* and other test organisms were incubated aerobically at 37 °C for 24 h. Following liquid culture, all bacterial and fungal samples were streaked onto appropriate selective media to verify culture purity and ensure experimental reliability.

Following incubation, 40 μL of 0.04% w/v *p*-iodonitrotetrazolium violet solution (Sigma-Aldrich) was added into each well of the microtitre plate to determine microorganism viability. A change of colour in the well from clear to a purple-pink indicates microbial growth. Therefore, the lowest concentration displaying no colour change was recorded as the minimum inhibitory concentration (MIC). Each experiment was performed in triplicate and the mean value was recorded.

The data generated from the varied ratio combination MIC assay were entered into SynergyFinder (Version 2.0). A log-logistic model was applied to the varied ratio MIC findings in order to generate dose-response curves for the essential oils in each combination. Essential oil combination antimicrobial responses were then plotted as heat maps to identify the concentration ratios at which the essential oils used in combination had the maximum inhibitory effect on microbial growth. The degree of synergy per essential oil combination was analysed using the response surface model based on the Bliss reference synergy model. The synergy score determined for the essential oil combination investigated was averaged over all the dose combination measurements, and a 3D synergy map was generated that highlights synergistic and antagonistic dose regions in red and green, respectively.[27] On interpretation, the summary synergy scores of less than −10 were considered antagonistic, a range from −10 to +10 as additive, and greater than +10 as synergistic.[31]

Preparation of the nanoemulsion

The development of an essential oil nanoemulsion formulation was undertaken because of their oil-based core, high-loading capability and widely adopted application as the drug vehicle of choice in pulmonary delivery.[32] The nanoemulsion was prepared using the two-component, self-emulsification method.[33] Labrasol was first mixed with propylene glycol at a ratio of 2:1 and stirred magnetically (IKA Plate, RCT digital, Deutschland, Germany) for 5 min at a speed of 500 rpm. The essential

oils were subsequently added at optimal ratios to produce a formulation of a final concentration of 2.5% (v/v) to the Labrasol and propylene glycol mixture, which was stirred for a further 15 min. Sterile distilled water was then added dropwise and stirred magnetically until a homogeneous translucent appearance was achieved. The completed formulation was then stored at ambient temperature in sealed amber bottles to prevent any loss of the essential oil by evaporation.

Characterisation of the nanoemulsion

The physical attributes of a nanoemulsion formulation determine the formulation stability and efficacy, as well as its in vitro behaviour.[34] Important physical attributes include the average particle size distribution and the polydispersity index (PDI). The particle size distribution and PDI of the samples were determined using dynamic light scattering at 25 °C using a zeta-potential and particle size analyser (ELSZ-2000, Otsuka Electronics Co. Ltd. Japan). In the case of pulmonary drug delivery for systemic absorption, aerosols with a small particle size are required to ensure peripheral penetration.[35,36] Particles smaller than 3 μm have an approximately 80% probability of reaching the lower airways, while around 50–60% of these particles will be deposited in the alveoli, and hence this was a parameter for formulation.

The essential oil nanoemulsion was centrifuged at 1956 × *g* for 30 min to evaluate the stability. Stability was investigated by storing 5 mL of the nanoemulsion at 4±1 °C, 25±1 °C, 37±1 °C and 60±1 °C in duplicate for one month.[34,35] The samples were observed for visual indications of instability, including creaming or flocculation.

Antimicrobial activity of the nanoemulsion

The broth microdilution method[37] was used to quantify the antimicrobial activity of the formulated essential oil nanoemulsion against pathogens selected for their relevance to respiratory infections. The microtitre plates were prepared aseptically, as per the antimicrobial studies undertaken for the combination optimisation using SynergyFinder (Version 2.0). Variations to the method included the addition of 100 μL of the essential oil nanoemulsion, added to the first row. The positive controls remained 0.01 mg/mL ciprofloxacin (for bacteria) or 0.10 mg/mL amphotericin B (for the yeast) to ensure microbial susceptibility. The negative control of 15% (v/v) Labrasol and 7% (v/v) propylene glycol in distilled water was included to exclude the attribution of antimicrobial effects from the formulation's solution base. The culture controls consisted of growth medium with the relevant pathogen to ensure that the appropriate broth supported microbial growth. Following incubation, 40 μL of 0.04% w/v *p*-iodonitrotetrazolium violet solution (Sigma-Aldrich) was added into each well of the microtitre plate in order to determine the MIC. Each experiment was performed in triplicate and the mean value was recorded.

Results and discussion

Antimicrobial optimisation

The antimicrobial interaction of *H. officinalis* essential oil in combination with *S. rosmarinus* essential oil against a selection of nine respiratory pathogens was investigated using SynergyFinder (Version 2.0). According to the synergy maps (Figure 1), an average synergy score of 9.76 was determined against all nine pathogens studied. The highest synergy was noted against *H. influenzae,* for which a synergy score of 27.621 was determined, with greater incidence of synergistic interactions assigned to ratios higher in *H. officinalis* than *S. rosmarinus*. Synergy was also noted against *S. pyogenes, M. smegmatis* and *C. neoformans* with synergy scores of 10.470, 11.864 and 13.263, respectively. Marginal synergy was determined for the combination against the pathogen *S. aureus* (synergy score = 9.505), while additive scores were noted against all other pathogens, with scores of −0.029 (*S. agalactiae*), 7.602 (*S. pneumoniae*), 3.763 (*K. pneumoniae*) and 3.780 (*M. catarrhalis*). The results of SynergyFinder (Version 2.0) established that the optimal blend of each essential oil consists of 49.57% of *H. officinalis* and 50.43% of *S. rosmarinus* to achieve an average synergy score ranging from 14.25 to 57.14 against the pathogens studied.

Characterisation of the nanoemulsion

The blended *H. officinalis* and *S. rosmarinus* essential oil nanoemulsion was stable to coalescence. The average particle size of the blended *H. officinalis* and *S. rosmarinus* essential oil nanoemulsion was determined as 47.89 nm using a zeta-potential and particle size analyser (Figure 2). Oil in water emulsions are classified based on the size of the droplet, with nanoemulsions classified by droplet sizes of less than 100 nm.[38] Therefore, these findings indicate that the emulsion was within nano-range. Other studies incorporating the use of essential oils in nanoemulsions have defined a range of nanodroplet sizes between 23.4 nm and 100 nm with droplet sizes varying depending on the constituents selected, the operating conditions and preparation methods used.[39-42] The PDI value provided by the nanosizer informs if the nanoemulsion droplets are well dispersed, with a measure of 0.20 to 0.50 expected for pharmaceutical preparations.[43] The PDI value for this study was determined to be 0.202, which is desirably low and suggestive of a well-dispersed nanoemulsion. The obtained value of 0.202 falls within the narrow size distribution range (0.08 to 0.30), indicating high uniformity of droplet size. Monodispersed samples have PDI values lower than 0.08, while PDI values between 0.08 and 0.30 prove a narrow size distribution, and PDI values greater than 0.30 indicate a broad size distribution.[44] Therefore, higher PDI values suggest lower uniformity of droplet size in nanoemulsions.

Stability of the nanoemulsion

The appearance of the blended *H. officinalis* and *S. rosmarinus* essential oil nanoemulsion following formulation was of a clear and transparent liquid, without observed turbidity or precipitate (Figure 3A). After centrifugation, the formulation maintained the same clear and transparent appearance (Figure 3B). The particle size of the nanoemulsion droplets was again measured using a zeta-potential and particle size analyser. The droplet sizes were maintained after centrifugation, with droplet sizes slightly reduced to 37.55 nm, with a PDI of 0.189. The reduction in PDI value after centrifugation is not statistically or practically significant. The slight drop is expected and, because of the negligible variance, is indicative of a stable formulation. This stability suggests that the nanoemulsion maintains its structural integrity under stress conditions, which is crucial for pharmaceutical applications.

The nanoemulsion, stored at 4±1 °C, 25±1 °C, 37±1 °C and 60±1 °C for one month, showed no phase separation or creaming properties at all temperatures, indicating stability of the formulation (Figure 4).

Antimicrobial validation of the formulation

The blended *H. officinalis* and *S. rosmarinus* essential oil nanoemulsion was investigated against nine pathogens of the respiratory tract by means of MIC analysis. A noteworthy antimicrobial effect was determined for the blended *H. officinalis* and *S. rosmarinus* essential oil nanoemulsion against all nine respiratory pathogens, with MIC values ranging between 0.07 mg/mL to 1.17 mg/mL (Table 1). The average MIC of the combined essential oils prior to formulation against the nine pathogens studied was 2.17 mg/mL.[30] The nanoemulsion exhibited better inhibitory effects across all pathogens studied, with a six-fold increase in antimicrobial activity compared with when the neat essential oils were blended.

The findings of this study are congruent with those of previous studies that showed that the conversion of essential oils into nanoemulsions produces an improved antimicrobial effect. A previous study[45] aimed to create an essential oil nanoemulsion containing *Cymbopogon flexuosus* (Nees ex Steud.) Will. Watson for antimicrobial use. The neat oil of *C. flexuosus* showed activity against *Candida albicans* at a concentration of 1.22 mg/mL while the nanoemulsion of the essential oil demonstrated a MIC of 0.28 mg/mL. This improved antimicrobial effect was also noted against the microorganisms *Cryptococcus grubii* (MIC of neat oil was 0.58 mg/mL and the nanoemulsion was 0.28 mg/mL) and *Pseudomonas aeruginosa* (no antimicrobial effect by neat oil, and the nanoemulsion showed potential bactericidal activity at concentrations above 11.33 mg/mL). These findings are further supported by previous essential oil studies, e.g. *Origanum vulgare* L.[46] and *Thymus daenensis* Čelak[47]. It has been noted that this enhanced antimicrobial effect demonstrated by essential oils when encapsulated into a nanoemulsion is a result of the nanometric size and resultant improved diffusion of nanoemulsions.[48] These enhanced characteristics offered by nanoformulations provide opportunity for further exploration of varying essential oil blends.

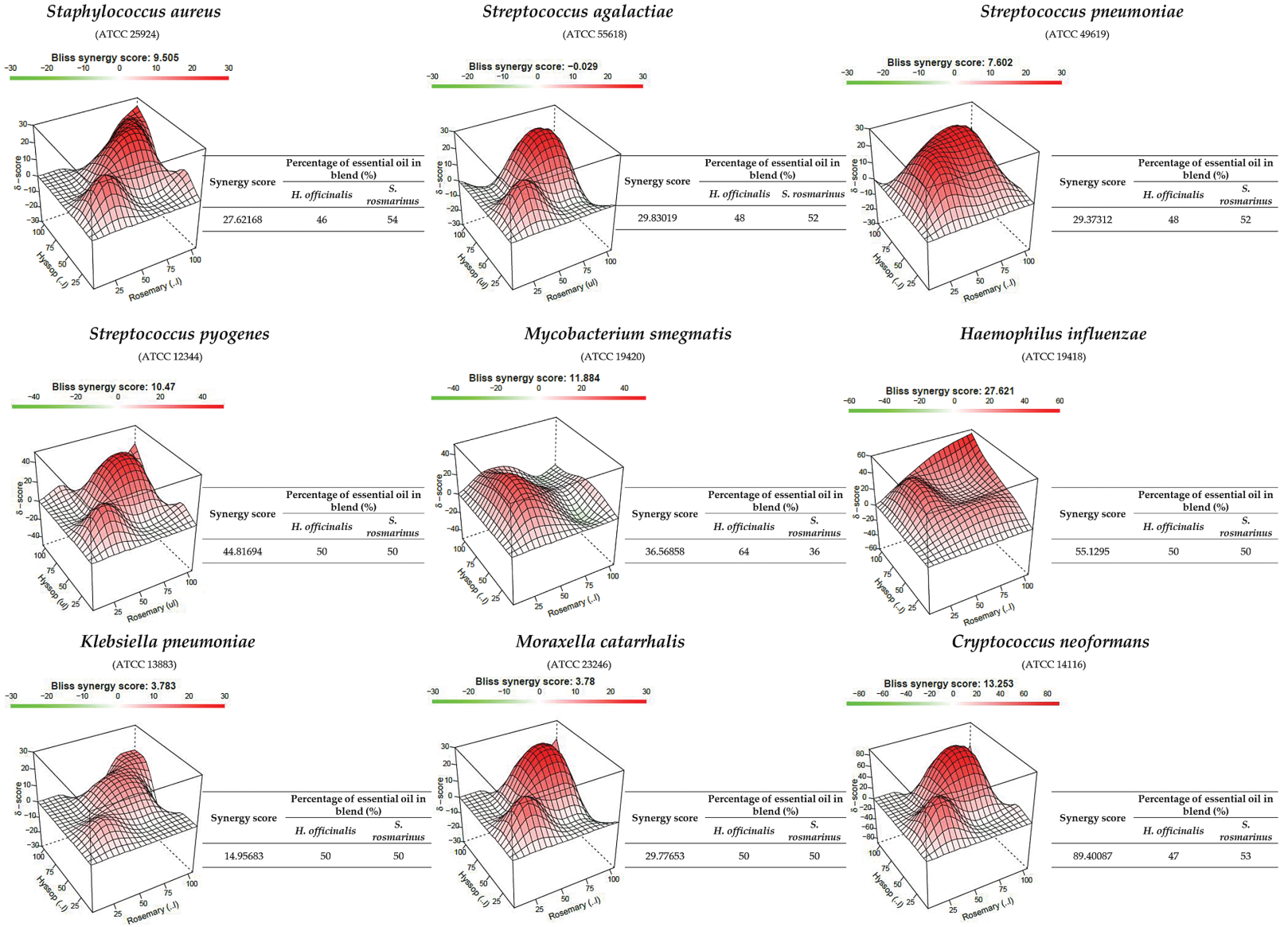

Figure 1: Visual representations of the antimicrobial interaction of the combination of *Hyssopus officinalis* and *Salvia rosmarinus* essential oils against nine microorganisms responsible for respiratory tract infections. Positive (red regions) of the response surface plot indicate synergistic effects, while negative (green regions) indicate antagonistic effects. Optimal ratios of *H. officinalis* and *S. rosmarinus* essential oils are indicated in adjacent tables, per microorganism.

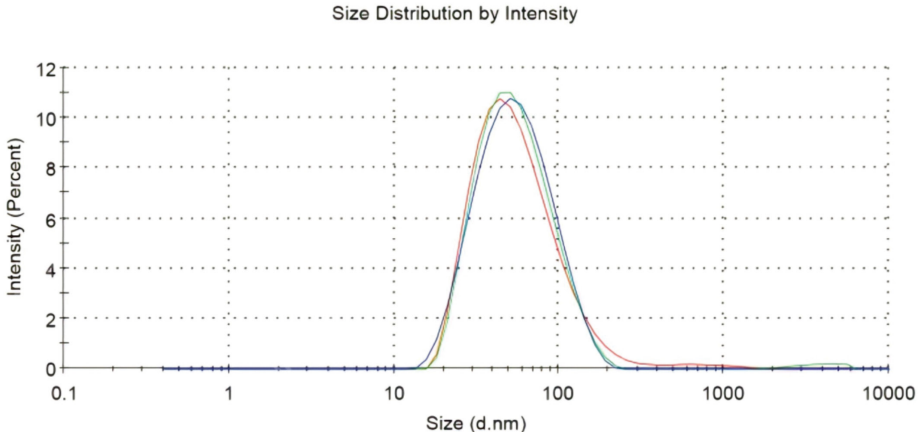

Figure 2: Particle size of the essential oil nanoemulsion as determined by zeta-potential and particle size analyser. The assorted colour bands represent repeat measurements of the same sample.

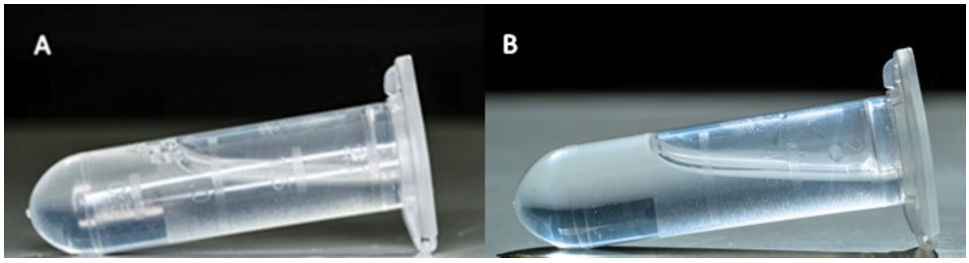

Figure 3: (A) The appearance of the blended *Hyssopus officinalis* and *Salvia rosmarinus* essential oil nanoemulsion following formulation as a clear and transparent liquid, without observed turbidity or precipitate. (B) Following centrifugation, the formulation maintained the same clear and transparent appearance.

Figure 4: The appearance of the blended *Hyssopus officinalis* and *Salvia rosmarinus* essential oil nanoemulsion (in duplicate), following storage at 4±1 °C, 25±1 °C, 37±1 °C and 60±1 °C for one month, showed no phase separation or creaming properties at all temperatures.

Conclusion

In conclusion, to our knowledge, this study is the first to apply SynergyFinder software for the visual interpretation of antimicrobial synergy between the essential oil combination *H. officinalis* blended with *S. rosmarinus*. The essential oil combination of *H. officinalis* and *S. rosmarinus* demonstrated broad-spectrum antimicrobial potential with a Bliss model synergy score of 9.76. As a result of this potential, a nanoemulsion formulation was created for a blend of *H. officinalis* and *S. rosmarinus* essential oils at optimised ratios as per the generated synergy maps for nine respiratory-associated pathogens. At the optimal concentration (49.57% of *H. officinalis* and 50.43% of *S. rosmarinus*) of the blended *H. officinalis* and *S. rosmarinus* essential oil nanoemulsion, the average particle size was 47.89 nm and PDI was 0.202. The nanoemulsion maintained good stability and dispersion after centrifuging and at various storage conditions. Furthermore, at optimum concentrations, the blended *H. officinalis* and *S. rosmarinus* essential oil nanoemulsion showed noteworthy antimicrobial activity against all nine pathogens studied, with MIC values ranging from 0.07 mg/mL to 1.17 mg/mL. The optimised nanoemulsion formulation exhibited better inhibitory effects across all pathogens studied, with a six-fold increase in antimicrobial activity than when the neat essential oils were blended.

Aerosolised nanoemulsions are promising alternatives for non-invasive drug delivery to the respiratory tract because of their improved and targeted antimicrobial approach. These characteristics of a nanoemulsion system and the proven enhanced interactions of the blended *H. officinalis* and *S. rosmarinus* essential oil nanoemulsion against pathogens of the respiratory tract further provide a rationale for the potential therapeutic use of this blend. This research indicates the potential for optimised essential oil combinations to be identified using a computational

Table 1: The mean minimum inhibitory concentration in mg/mL ($n = 3$) of the blended *Hyssopus officinalis* and *Salvia rosmarinus* essential oil nanoemulsion investigated against test pathogens

Pathogen	Neat essential oils in combination[29]	Essential oil nanoemulsion	Ciprofloxacin (positive control)	Amphotericin B (positive control)	Formulation solution base (negative control)
Staphyloccocus aureus (ATCC 25924)	2.00	0.07	0.50×10^{-3}	NA	> 4.93
Streptococcus agalactiae (ATCC 55618)	2.00	0.29	0.50×10^{-3}	NA	> 4.93
Streptococcus pneumoniae (ATCC 49619)	3.00	1.17	0.50×10^{-3}	NA	> 4.93
Streptococcus pyogenes (ATCC 12344)	1.00	0.29	0.50×10^{-3}	NA	> 4.93
Mycobacterium smegmatis (ATCC 19420)	1.50	0.29	0.50×10^{-3}	NA	> 4.93
Haemophilus influenzae (ATCC 19418)	4.00	0.29	0.25×10^{-3}	NA	> 4.93
Klebsiella pneumoniae (ATCC 13883)	4.00	0.59	1.00×10^{-3}	NA	> 4.93
Moraxella catarrhalis (ATCC 23246)	2.00	0.15	0.50×10^{-3}	NA	> 4.93
Cryptococcus neoformans (ATCC 14116)	0.09	0.07	NA	0.50×10^{-3}	> 4.93

software workflow and further formulated into nanosystems for targeted antimicrobial effects. As of now, research on the application of essential oils into nanoemulsions as antimicrobial agents is in a fast-growing phase; however, there is a paucity in the literature on the use of essential oils in combination. Advancements in this field of research require further exploration for commercial consideration and potential product development.

Limitations and future directions

This study has demonstrated the potential of a nanoemulsion formulation using a synergistic blend of *Hyssopus officinalis* and *Salvia rosmarinus* essential oils for managing respiratory tract infections. However, several limitations should be considered. The findings are based on in vitro studies against selected pathogens; therefore, the lack of in vivo validation means the formulation's efficacy and safety in biological systems remain unknown. The toxicity and safety profiling of this formulation was not comprehensively evaluated. Additionally, limited stability testing was performed, leaving questions about long-term stability. To address these limitations, future research may consider expanding the pathogen scope to include emerging resistant strains. In vivo studies may be considered to validate therapeutic efficacy, bioavailability, and safety in physiological conditions following detailed toxicity profiling. By addressing these limitations and advancing research in these directions, this study provides a foundation for the development of innovative, natural antimicrobial solutions for respiratory health.

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Data availability

The data supporting the results of this study are available upon request to the corresponding author.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. A waiver for the use of these microorganisms was granted by the University of the Witwatersrand Human Research Ethics Committee (reference W-CJ-160720-2).

Authors' contributions

S.L.: Acquisition, analysis, or interpretation of data; drafting the work or revising. A.V.: Conception or design; drafting the work or revising. P.K.: Conception or design; drafting the work or revising. S.v.V.: Conception or design; drafting the work or revising. All authors read and approved the final manuscript.

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Atmospheric mercury dispersion over the South African Highveld

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Coal combustion in coal-fired power plants is the dominant source of mercury (Hg) emissions in South Africa. The majority of these plants are located in the South African Highveld, an area that experiences poor air quality. Despite this, the specifics of Hg emissions – such as the amounts emitted, mercury species emitted and their spatial variability – from these plants remain unclear. This study presents the first dispersion modelling of Hg concentrations and wet and dry deposition in the Highveld using CALPUFF. It focuses on inorganic gaseous elemental (Hg^0), inorganic reactive gaseous (Hg^{2+}) and inorganic particle-bound Hg (HgP) emissions from 12 coal-fired power plants from 2011 to 2014. Results show that Hg concentrations are highest near the central cluster of power plants, with levels ranging from 0.0028 to 0.0631 ng/m^3 for Hg^0, 0.0028 to 0.0497 ng/m^3 for Hg^{2+} and 0.0008 to 0.0137 ng/m^3 for HgP. Significant wet and dry deposition, measured at 0.07–7.46 and 0.03–3.33 (g/ha)/year, respectively, also occurs in these areas, indicating that proximity to power plants leads to higher deposition. A health risk assessment suggests that nearby populations may be at risk of acute health impacts from Hg^0 inhalation. However, the accuracy of this assessment is limited by the overestimation of Hg^0 concentrations in dry deposition modelling. The findings highlight the need for further studies to characterise and quantify methylmercury, the most toxic form of Hg, in the environment. This study also potentially shows important locations where new Hg monitoring stations should be placed.

Significance:

The research presents the results of the first-ever dispersion modelling study regarding mercury concentrations and wet and dry deposition over this region using CALPUFF. The findings significantly contribute to scientific knowledge on the spatial variation and deposition of Hg in this region. The study conducts a brief health risk assessment, suggesting that the population working and living near power plants may be at risk of acute adverse health impacts due to inhalation of Hg^0. The findings indicate that further studies are needed to characterise and quantify methylmercury concentrations, as this is mercury's most toxic environmental form, and point to important future research directions.

Introduction

The industrialised South African Highveld Area has been identified as an area associated with poor air quality due to high emissions of criteria pollutants such as particulate matter (PM), SO_2 and NO_x, and a potential area of high concentration of atmospheric mercury (Hg) species.[1] This region is well-known for its various anthropogenic emission sources: coal-fired power plants, coal ash disposal sites, metallurgical smelters and mines, agriculture, transportation and domestic fuel combustion.[2,3]

Globally and annually, combustion in coal-fired power plants is the dominant anthropogenic source of environmental Hg[4], contributing approximately 56%[5]. Coal-fired power plants were estimated as the leading possible anthropogenic source of ambient Hg emissions in South Africa, contributing 72–78% to atmospheric emissions during 2006.[1] The concentration of Hg emitted by the power plants is mainly dependent on the type of emission control device installed. The emission control devices South African power plants use are electrostatic precipitators, fabric filters, desulfurisation/flue-gas conditioning, or a combination thereof.[6] These devices reduce the amounts of particulate matter and sulfur, as well as Hg, with the power plants fitted with fabric filters reducing the highest Hg per GWh.[7,8]

Moreover, a past study listed South Africa as the second-highest global atmospheric Hg emissions source. According to their study, the country contributed about 16% of global Hg emissions.[5] However, these estimates were based on incorrect Hg-content coal values and triggered subsequent Hg studies. Using correct values, the Hg inventory was updated, and South Africa was listed as the sixth leading emitter of the pollutant.[3]

Mercury is a highly toxic and ubiquitous volatile metal, which is environmentally persistent and prone to long-range atmospheric transport.[9] It subsequently leads to adverse health effects in distant regions far from where it was emitted.[10] Mercury is, therefore, regarded as a global pollutant, threatening both the health of humans and ecosystems.[9-12] It is known that the ecological behaviour of the Hg emitted depends on the different environmental forms, as these chemical forms have other chemical properties.[11,12]

Unlike other heavy metals in the environment, atmospheric Hg generally occurs in its gaseous phase.[13] It may be emitted into the atmosphere as inorganic gaseous elemental (Hg^0), inorganic reactive gaseous (Hg^{2+}) and inorganic particle-bound Hg (HgP).[14,15] Atmospheric emissions of Hg are dominated by Hg^0 (53%), followed by Hg^{2+} (37%) and HgP (10%).[16] Although Hg^0 is the predominant form in the gaseous phase[16,17], Hg^{2+} significantly influences the total deposition of atmospheric Hg as it is more reactive and soluble[18]. Under certain conditions, Hg^0 may be removed by dry deposition processes.[19] Mercury is transported over long distances in the atmosphere, even reaching the poles.[10] Due to the concentration of significant sources over the Highveld, it is expected that Hg is transported and deposited over large portions of South Africa.[2] However, there are not many measurements to support this, except for some over the Highveld[20,21] and at background sites (e.g. Bredenkamp[22]).

To investigate and better understand the environmental fate and behaviour of Hg, and given the complex nature of air quality evaluation, air quality models have been developed and established.

In South Africa, the atmospheric dispersion of Hg has been simulated at Cape Point using GEOS-Chem[23,24], GLEMOS, ECHMERIT[24] and the CAM-Chem[25] models. No literature has been found to describe air pollution dispersion modelling of Hg on the industrialised Highveld or with CALPUFF for South Africa. This research aims to fill this knowledge gap and build upon the region's recent and first-ever Hg concentration characterisation study.[20] A health risk assessment was also conducted based on the results obtained from the model for Hg species concentrations.

Material and methods

Understanding the difficulties related to source-specific air pollution control and air quality management can be quite challenging because a wide range of contaminants are emitted from various sources over different spatial and temporal scales. Therefore, specialists in controlling and managing air pollution rely on these models to aid them in decision-making processes for different pollution control settings. Rather than comparing an air pollution source's compliance to results obtained from air pollution sampling, they are based on emission estimates from atmospheric dispersion models.[26]

These models use different tools and strategies, such as Lagrangian, Eulerian, Computational Fluid Dynamics and Gaussian models.[27] It was decided that the Lagrangian California Puff (CALPUFF) modelling system is the best for this study based on its pros and cons and regulatory approval by the South African government.[28] The US EPA also endorses the model for complex topographies and for modelling the atmospheric dispersion of pollutants prone to long-range transport.[29] This recognition was a significant consideration, especially given the intricate topography of the Highveld region and the large size of the domain being studied in the present study. The model has been used to approximate population exposure from power-generating plant emissions to $PM_{2.5}$, SO_2, SO_4, NOx, NO_3 and HNO_3 in Beijing, China[30]; an exposure assessment to Zn, Pb and Cd from a Zinc smelter in Spelter, West Virginia[31]; and for a health risk assessment to Hg emissions from a solid waste gasification plant located southeast of Milan, Italy[32].

Modelling structure and domain

A 250 km by 250 km modelling domain spanning the South African Highveld Area was selected for this study (Figure 1). The Lambert Conic Conformal projection minimises map distortion over this domain size. The components of the CALPUFF modelling system (version 6.42) sequentially consist of CALMET, CALPUFF and CALPOST. In addition, CALSUM was used, which allows the user to combine multiple outputs from CALPUFF into a single file to lessen the runtime considerably.

The modelling domain hosts various anthropogenic sources of Hg, including the 12 power plants illustrated in Figure 1. The power plants, arranged alphabetically, are labelled from 'a to l'. Other possible sources of Hg that were not modelled are combustion in gasification plants, ferrous and non-ferrous metal production, domestic burning, crude oil refining, cement production, waste deposition and incineration, and illegal artisanal gold mining.

CALMET

CALMET meteorological model generates hourly temperature and wind files for the selected domain on a three-dimensional grid.[30] In addition, two-dimensional surface and dispersion characteristics, properties and atmospheric mixing height files are created.[33] For this study, CALMET was run in a hybrid mode from January 2011 to December 2013 at a resolution of 1 km by 1 km using fifth-generation prognostic Mesoscale Model (MM5) data. The MM5 model had a grid resolution of 12 km by 12 km, incorporating Dudhia's simple-ice microphysics, the medium-range forecast Planetary Boundary Layer scheme and a multilayer soil model. The MM5 model was set up using the NCEP Global Reanalysis data, featuring a global grid resolution of 2.5 by 2.5 degrees. The MM5 data set comprises precipitation, wind speeds and vectors, boundary layer heights and temperatures. Pretorius et al.[34] used the same domain and meteorological fields from CALMET to evaluate health risk exposure to PM, SO_4 and NO_3. Pretorius et al.[34] assessed the performance of CALMET for the Highveld region and found the created fields adequately simulated the actual fields. The default CALMET options were mainly used, but some were altered to suit the needs of this study. These alterations and their motivations are summarised in Table 1 and were based on a peer-reviewed report.[35] South Africa does not have the MM5 data set commercially available yet, and it was purchased from

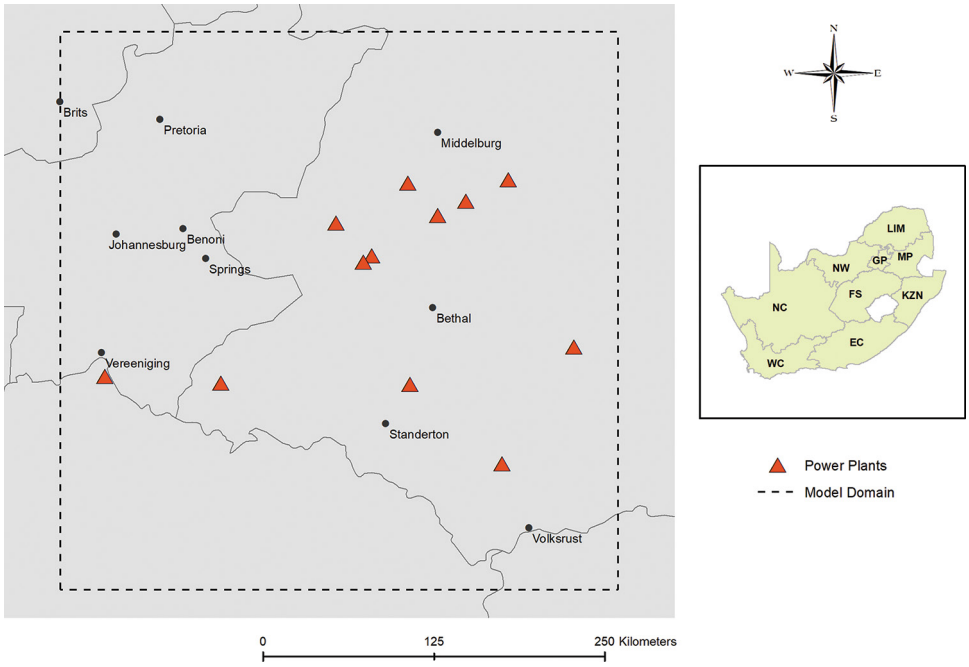

Figure 1: Locations of the 12 coal-fired power plants used to model the atmospheric dispersion of Hg^0, Hg^{2+} and HgP in this study. The black box represents the modelling domain.

Table 1: CALMET options that were altered from the default settings[35]

Description	Default setting	Used setting	Motivation
Map projection	UTM	LCC	To keep map distortion to a minimum
No observation mode	Observations only	No surface, overwater or upper air observation. Use of MM5 data for these observations	Limited observational data
Extrapolation of surface wind	Ignore upper air station data	No extrapolation	Exclusion of observations
Gridded prognostic wind field	No	Yes	Exclusion of observations
3D Relative humidity	Use observations	Use prognostic data	Exclusion of observations
3D temperature	Use observations	Use prognostic data	Exclusion of observations

Table 2: Per annum emission rate of Hg^0, Hg^{2+} and HgP during 2011–2013, in grams per second (g/s) investigated in this study, and the emission control device/s installed at each power-generating plant

Power plant	Emission control device	Emission rate per annum (g/s)			Power plant figure label
		Hg^0	Hg^{2+}	HgP	
ARNOT	FF	0.00212	0.00148	0.0004	a
CAMDEN	FF	0.00318	0.00222	0.0006	b
DUVHA	ESP+FF	0.01431	0.00999	0.0027	c
GROOTVLEI	ESP+FF	0.00848	0.00592	0.0016	d
HENDRINA	FF	0.00212	0.00148	0.0004	e
KENDAL	ESP	0.05406	0.03774	0.0102	f
KOMATI	ESP	0.00954	0.00666	0.0018	g
KRIEL	ESP	0.02915	0.02035	0.0055	h
LETHABO	ESP	0.0636	0.0444	0.0102	i
MAJUBA	FF	0.00689	0.00481	0.0013	j
MATLA	ESP	0.03233	0.02257	0.0061	k
TUTUKA	ESP	0.03339	0.02331	0.0063	l

Lakes Environmental Software, Canada. At a resolution of 12 km along with 18 vertical heights, it was the best accessible data set, with its centre at 26.47 S 29.03 E.

CALPUFF

CALPUFF does not have a dedicated chemical scheme to handle the conversion and transformation of Hg in the atmosphere. A recent study addressed this absence by modifying version 7 of the software to simulate Hg in flue gases and airsheds.[36] However, the present study used the default HNO_3 scheme of the model for reasons discussed hereafter.

The model was used to simulate the hourly concentrations of the three critical atmospheric species of Hg (Hg^0, Hg^{2+} and HgP) and concurrent wet and dry deposition over the domain. The emission rates of Hg utilised in this study were calculated using emission rates for each power-generating plant, obtained directly from ESKOM based on their 2014 Hg emission calculations from each power plant stack (Table 2). The Hg speciation was assumed to be consistent with values reported by Carpi[16], namely Hg^0 (53%), Hg^{2+} (37%), and HgP (10%). Source-specific characteristics of the 12 power-generating plants are summarised in Table 3. The chemical and deposition parameters required for the wet and dry deposition simulation were obtained from Xu et al.[36] and McGuire et al.[37] and are summarised in Table 4.

Generally, the Hg^{2+} and HgP species are dispersed locally, and their deposition patterns depend on local sources.[38] In this study, similar to a previous one, the deposition parameters for Hg^{2+} are assumed to be like those of nitric acid (HNO_3) provided in the model[33], as they provide a conservative basis of deposition for this species[37]. This assumption is conservative as one cannot be sure that the deposition prediction is 'correct'. Here, conservative means that the selected parameters, as detailed below, lead to higher deposition. Hg^{2+} and HNO_3 have similar[36] but not precisely the same aqueous solubility. The modelling parameters for Hg^{2+} are usually assumed to be similar to those of HNO_3 in many settings[39], as both these species are highly soluble and reactive[39,40]. From the limited measurements made regarding the deposition of Hg^{2+}, it may be derived that its deposition velocity magnitude is analogous to HNO_3.[39] The parameters for HgP were adopted from those given for NO_3 in the model.[33,39] This assumption was made to provide a conservative basis for the deposition of this species, and it was decided to make the same assumption. Theoretically, this assumption seems plausible because HgP mainly consists of particles smaller than 2.5 μg/m³.[40,41]

According to [42] and [43] to further justify this assumption, NO_3 is one of the dominant constituents of the fine PM fraction. Deposition velocities of particulate species mainly depend on their size distribution.[39] Therefore, a mass mean diameter of 0.48 μm was selected as particulates resulting from combustion sources are generally less than one micron[37],

Table 3: Source-specific parameters of each power-generating plant investigated in this study

Power plant	Coordinates		Output capacity (MW)	Stack height (m)	Effective stack diameter (m)	Exit velocity (m/s)	Exit temperature (K)
	x (Easting)	y (Northing)					
ARNOT	–25.944	29.792	2100	195	16	25	418
CAMDEN	–26.62	30.091	1600	155	17	14	423
DUVHA	–25.961	29.339	3600	300	18	27	413
GROOTVLEI	–26.77	28.5	1200	152	13	22	418
HENDRINA	–26.031	29.601	2000	155	16	22	418
KENDAL	–26.088	28.969	4100	275	19	24	413
KOMATI	–26.091	29.422	1000	220	17	10	418
KRIEL	–26.254	29.18	3000	213	20	19	413
LETHABO	–26.740	27.975	3700	275	17	28	433
MAJUBA	–27.28	29.771	4100	250	17	35	398
MATLA	–26.28	29.142	3500	275	19	26	408
TUTUKA	–26.776	29.352	3600	275	17	19	413

Table 4: Deposition and chemical parameters of the three species modelled in this study[33,36,37]

Dry deposition (gases)					
Species	**Diffusivity (cm^2/s)**	**Alpha Star**	**Reactivity**	**Meso resistance**	**Henry's Law coefficient**
Hg^0	0.1628	1	18	0	1.00E-07
Hg^{2+}	0.1628	1	18	0	1.00E-07

Dry deposition (particles)		
Species	**Geometric mass mean diameter (microns)**	**Geometric standard deviation (microns)**
HgP	0.48	2

Wet deposition		
Species	**Scavenging coefficient (liquid) s^{-1}**	**Scavenging coefficient (frozen) s^{-1}**
Hg^{2+}	6.00E-05	0
HgP	0.0001	3.00E-05

providing an additional conservative basis for this study. An earlier study used similar deposition parameters for this species, assuming the same geometric mass mean diameter.[44] To make deposition modelling of HgP more reliable[39], suggests that prospective studies regarding the size of these particles should be improved. The deposition parameters for Hg^{2+} and HgP were selected because they imply that the highest possible amount of these deposition-prone species can be removed from the atmosphere, which will have a subsequent and indefinite impact on the modelled Hg concentration. This supposition is not made for Hg^0 as[11] describes wet deposition processes as being inefficient in the removal thereof. For its dry deposition, however, it was modelled to have dry deposition parameters identical to those of Hg^{2+}. A subsequent study by Xu et al.[36] indicated that the dry deposition of Hg^0 should be modelled using a diffusivity value of 0.1194 cm^2/s—lower than the 0.1628 cm^2/s applied in this study. The reactivity value was also supposed to be 8 and not 18. Additionally, the study suggested that the diffusivity for Hg^{2+} should be aligned with that of mercury chloride ($HgCl_2$), which is 0.086 cm^2/s, rather than the 0.1628 cm^2/s previously used. In other words, the dry deposition values reported here are conservative in that the assumed parameters will greatly overestimate the dry deposition of Hg^0 and may underestimate the ambient concentrations underpredicted.

After each run, the 36 output files (12 each for concentration, wet deposition and dry deposition) were merged using CALSUM. This merging was feasible because the modelling periods were consistent, and the species were identical and in the same sequence across runs. Subsequently, CALPOST processed these files to determine the combined concentrations and total wet and dry deposition.

Assessment of potential health risk

As described previously, exposure to Hg could cause adverse impacts on human health. To put the model results into perspective, the potential impact of the simulated emissions from the power plants on health is assessed. A previous study in this region assessed human health

exposure to PM, SO_2 and NO_x emissions from power plants based on intake and intake fraction.[34] The methodology used in this assessment is discussed in detail in previous publications.[45-47] Examples of the method application include evaluating the health risk to Hg from a Malaysian coal-fired power plant[48] and, more recently, exposure to total gaseous mercury from industrially influenced Polish sites[49]. It essentially entails executing four steps, which are discussed in the following sections.

Hazard identification

Hazard identification is an exercise to determine whether the exposure to the pollutant under investigation can cause an intensification in the occurrence of a specific severe health effect in humans. Mercury, a non-carcinogenic pollutant[50], may cause neurological and behavioural conditions in humans[51]. These conditions can be acute, chronic and even fatal[52], and their severity depends on the level of exposure[51]. The primary exposure pathway for Hg^0 is inhalation, particularly in occupational settings where Hg-vapour is present. However, exposure to Hg^0 compounds through ambient air is minimal for the general population.

In contrast, exposure to organic methylmercury primarily occurs via ingestion from dietary sources such as seafood, fish and sea mammals.[52] Reactive and particulate Hg are commonly removed near their sources due to their high atmospheric solubility and reactivity.[53,54] They risk human health after deposition, when methylmercury, the most toxic form of Hg, may be formed.[55,56] This study, however, only considers the inhalation exposure pathway to Hg^0.

Dose response

Fundamentally, this step of the risk assessment process establishes an exposure-response relationship. The toxicological factors demonstrating this relationship are Reference Concentration (RFC) and Reference Dose (RFD). The RFC evaluates inhalation risks, while the RFD assesses the risks associated with oral exposure. Both reference doses are benchmarks of daily human exposure[45,50], defining them as average daily exposure levels that are not likely to threaten human health throughout a lifetime. Typically, this step requires the implementation of an equation to calculate an RFD value, which can be adjusted to calculate RFC. However, this practice is not recommended in studies investigating inorganic compounds[57] because they differ fundamentally from organic compounds containing carbon-hydrogen bonds. As an RFC value was readily available, this study deviates from the standard procedure. The RFC value used in this risk assessment, associated with Hg^0 inhalation, is adopted from IRIS[50] (0.3 $\mu g/m^3$). This value is used to characterise the risk exposure to Hg^0 in the fourth step of this process. It is also assumed to be identical for acute and chronic exposure periods.[50]

Assessment of exposure

The exposure of the human population to Hg^0 was predicted, where the highest cumulative concentration of Hg^0 was simulated during the three years using CALPUFF as described in the CALPUFF section previously. The simulation returned modelled hourly, 8-hourly and periodic (cumulative annual) Hg^0 concentrations. These values assessed potential acute and chronic impacts on human health. Notably, the chosen exposure continuity – reflecting typical working hours – allows for a comprehensive evaluation of health risks associated with ambient air concentrations.[58]

Two scenarios were considered: a baseline scenario that evaluated the minimum Hg^0 concentrations, and a worst-case scenario that assessed the maximum concentrations for both acute and chronic exposure.

Characterisation of risk

The US EPA[57] recommends Risk Exposure Levels (REL)[59] as the preferred choice to assess acute inhalation values. Like an RFC, a REL is the air concentration at or beneath which no severe health impacts are expected in the population over a given exposure period. The population includes susceptible subgroups such as children, senior citizens and maternal exposure.[57] In our analysis, we utilised the RFC value for assessing chronic exposure, while the US EPA-recommended REL values were employed for acute exposure scenarios. While RFC and REL serve distinct purposes, they were used interchangeably in the formula below for comparative purposes. The cumulative hourly, 8-hourly and annual Hg^0 concentrations are compared to acute (1 hourly and 8-hourly) and chronic REL values to assess potential health impact. Additional information, including associated uncertainty factors, is provided in Table 5.

For the characterisation of a health risk for a non-carcinogenic pollutant by way of inhalation, the hazard must be quantified through the use of the hazard quotient (HQ)[57] given by Equation 1:

$$HQ = EC/RFC \qquad \text{Equation 1}$$

where EC represents the exposure concentration in the air ($\mu g/m^3$), and RFC is the reference concentration ($\mu g/m^3$). If HQ is smaller than 1, it indicates that the pollutant concentration is less than the RFC benchmark value. If this is the case, no subsequent action is necessary because the likely risk is within the permissible threshold. In other words, it means that $HQ < 1$ is considered safe. It does not mean that $HQ > 1$ should be construed as causing potential severe health impacts. It should instead be deduced as an indication of potential severe health impacts.[60]

Results and discussion

Atmospheric dispersion of Hg species

The modelled spatial distribution of Hg^0, Hg^{2+} and HgP concentrations is illustrated in Figure 2. The highest cumulative ambient concentrations of all three Hg species were calculated over the central parts of the modelled domain (0.0497–0.0631 ng/m^3 for Hg^0 and Hg^{2+} and 0.0123–0.0137 ng/m^3). As expected, this is the same spatial distribution as the other primary pollutants from power plants modelled for the Highveld region.[34] Moreover, as expected, the highest modelled concentrations were observed for Hg^0 and the lowest for HgP. The modelled concentrations for Hg^0, Hg^{2+} and HgP ranged from 0.0028 to 0.0631 ng/m^3, 0.0028 to 0.0497 ng/m^3 and 0.0008 to 0.0137 ng/m^3, respectively. These results are comparatively lower than the ambient monitored total gaseous mercury concentrations (comprising Hg^0 and Hg^{2+}) at three study domain sites (Balfour, Middelburg and Standerton).[20] During a one-year monitoring period in 2009, average concentrations at the sites were measured at 1.99 ± 0.94 ng/m^3, 1.04 ± 0.62 ng/m^3 and 1.25 ± 1.38 ng/m^3, respectively. In comparison to the USA[61], reported ambient total gaseous Hg (Hg^0+Hg^{2+}) concentrations near a coal-fired power plant (<1 km) ranged from 1.5 ± 0.2 ng/m^3 to 1.7 ± 0.3 ng/m^3. Additionally, studies in Australia indicate average Hg_0 concentrations of 0.90 ± 0.10 ng/m^3,[62]

Table 5: Uncertainty associated with REL values (OEHHA, 2014)[59] used for comparison

RFC comparison	REL ($\mu g/m^3$)	Species	Study population	Exposure continuity	Exposure duration	Composite uncertainty factor
Acute (1 hour)	0.6	Rats	12	–	1 hour per day	3000
Acute (8 hours)	0.06	Humans	236	8 hours per day, five days a week	13.7–15.6 years	3000
Chronic	0.03	Humans	236	8 hours per day, five days a week	13.7–15.6 years	300

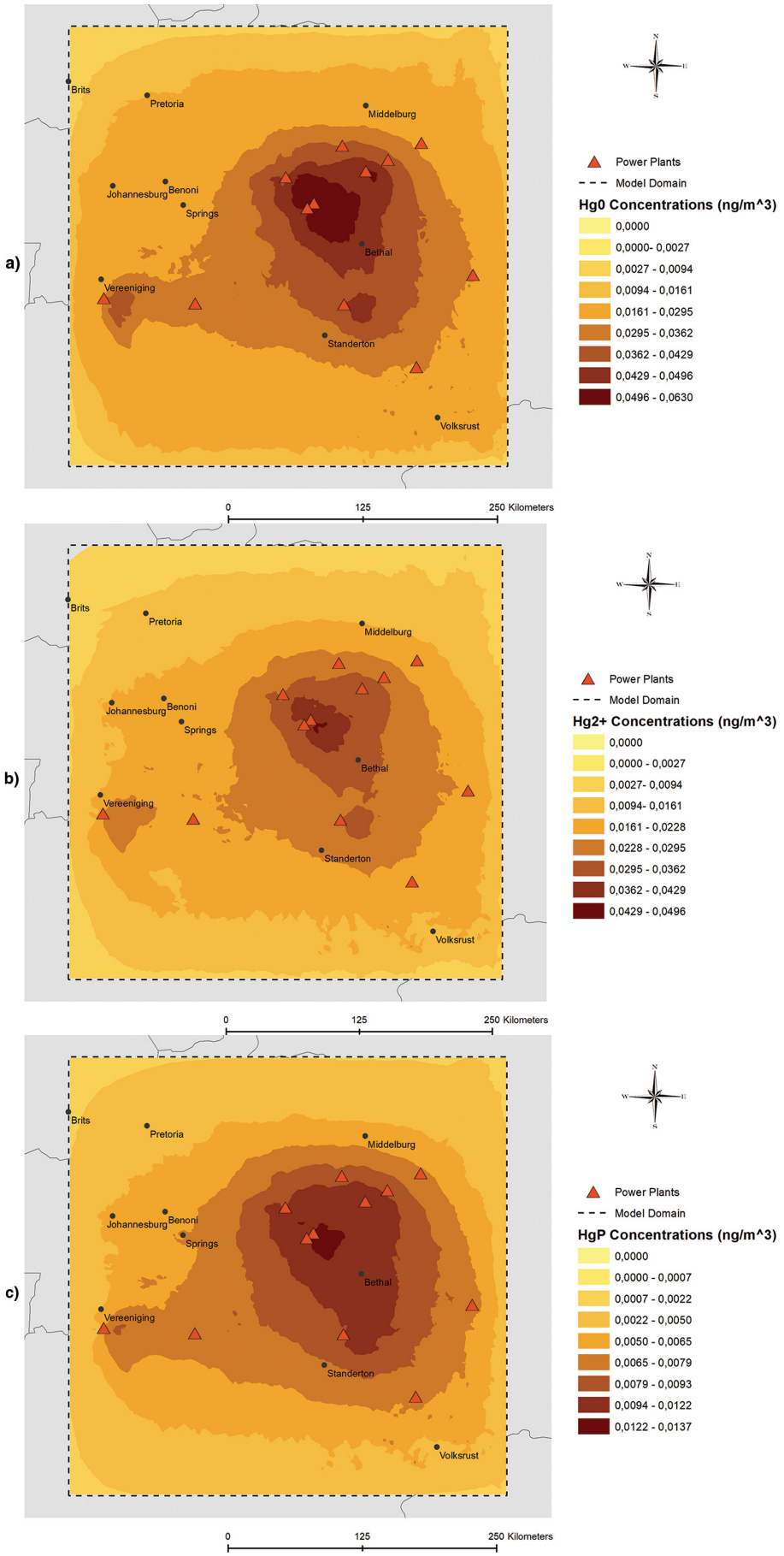

Figure 2: The spatial distribution of three-year (2011–2013) modelled average (a) Hg^0, (b) Hg^2+ and (c) HgP concentrations (ng/m^3), originating from power plants on the South African Highveld.

while total gaseous Hg concentrations in eastern China were significantly higher, at 4.91 ± 3.66 ng/m^3.[63]

The monitoring sites, depicted in Figure 1, were influenced by different Hg emission sources, from local fossil fuel combustion to sparse regional contributions. A notable finding from the study was that domestic burning constituted the most significant source of emissions throughout the monitoring period. Domestic burning is a low-level source with emissions likely to be confined beneath the boundary layer, so this source should be factored into future Hg modelling efforts. The proximity of Kriel and Matla power plants, which may act as a single emission source due to their closeness, contributes to an accumulation of polluted air in an area already burdened with high Hg concentrations. Their proximity and lower emission heights and dispersion potential could lead to localised increases in Hg levels. Nevertheless, it is crucial to acknowledge that the peak concentrations are influenced by specific source characteristics and local atmospheric conditions rather than the mere expansion of the modelling domain.

The size of the modelling domain can influence the extent to which deposition processes remove Hg species. This influence on removal potential is particularly true for Hg^0, which, due to its solubility and reactivity, has a longer atmospheric lifetime and, thus, a greater potential for deposition over a larger area. However, it is essential to recognise that the concentration gradients of Hg species, including Hg^0, are primarily governed by their emission rates, atmospheric chemistry and local meteorological conditions. These factors collectively determine the dispersion and deposition patterns observed in our model.

Wet and dry deposition

The modelled spatial wet distribution of Hg^{2+} and HgP concentrations is illustrated in Figure 3. The wet deposition of Hg^0, due to reasons

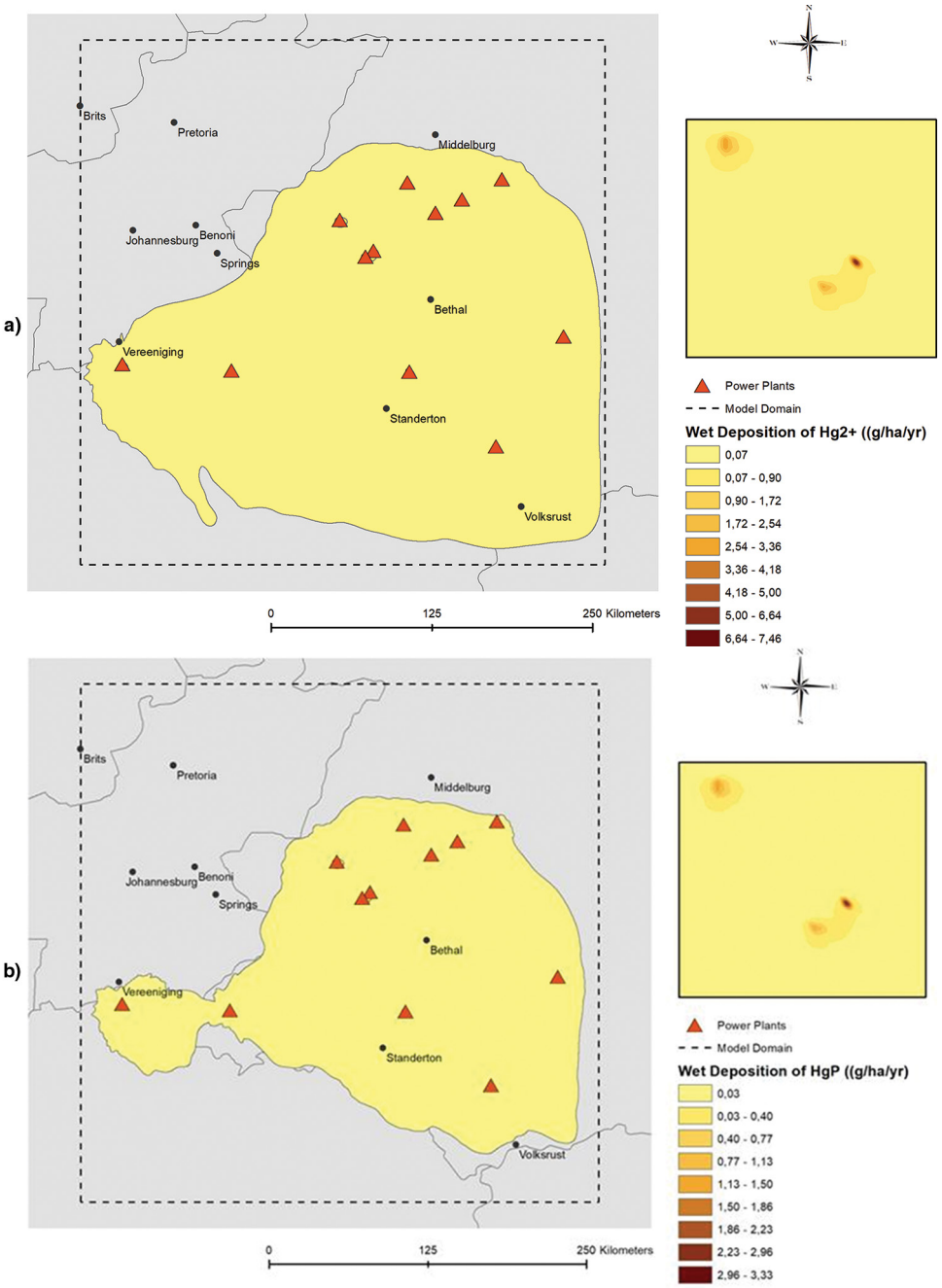

Figure 3: The spatial distribution of averaged three-year modelled wet deposition (g/ha)/year) of (a) Hg^{2}+ and (b) HgP on the South African Highveld. The reference box to the right shows a zoomed-in view of the modelled deposition over Kriel and Matla.

discussed previously, is ignored. The results reveal that relatively low amounts of each species were removed from most of the modelled region. However, over four locations on the domain, higher amounts were removed in the locations' immediate vicinity (<1km) – not visible on the maps unless zoomed in to a power plant. The previous was simulated in the atmosphere surrounding Kriel, Matla, Lethabo, Kendal and Tutuka. This observation may be explained by the fact that species of Hg tend to be deposited near their emission source.[16,64] The simulated wet deposition of Hg^{2+} and HgP during the modelling period ranged from 0.07 to 7.46 and 0.03 to 3.33 (g/ha)/year, respectively. Notably, the present study's wet deposition values are significantly higher than those measured in suburban, agricultural and traffic areas in China (0.001–0.007 (g/ha)/year).[65] This disparity can be attributed to the fact that the current study focused on modelled rather than measured wet deposition. Additionally, the differences may stem from the assumed modelling parameters used in this study.

The modelled spatial dry distribution of Hg^{2+} and HgP concentrations is illustrated in Figure 4. Notably, the dry deposition of Hg^0 was interpreted cautiously, as its dry deposition parameters were assumed to be identical to those adopted for Hg^{2+}, which provides conservative estimates of this species' highest potential dry deposition. Dry deposition is another mechanism by which species of Hg may be transferred from the atmosphere to aquatic and terrestrial surfaces. This mechanism, of course, occurs in the absence of precipitation. The modelled dry deposition of Hg^0 and Hg^{2+} closely resembles one another, with the central parts of the domain being the region most affected, followed by the southwestern part. Dry deposition rates decrease from the centre of the domain to the outskirts. The dry deposition of Hg^0, Hg^{2+} and HgP ranged from 0.003 to 0.104, 0.002 to 0.081, and 0.00002 to 0.00052 (g/ha)/year, respectively. Comparatively, the annual Hg^{2+} dry deposition levels observed in the Four Corners area ranged from 0.022 g/ha/year at the Molas Pass high-elevation remote mountain site to 0.115 g/ha/year at the Mesa Verde National Park site, suggesting that our modelled values are generally lower than those found in the USA.[66] The maximum modelled deposition of Hg^0 (1.4 (g/ha)/year) was simulated to occur mainly over Kriel town (also known as Ga-Nala) (–26.1131; 29.0834) and its immediate vicinity (including Thubelihle settlement). The dry deposition of Hg^{2+} was somewhat different, occurring predominantly near Kriel (–26.1241; 29.0174) and Matla (–26.0731; 29.0700) power plants. On the other hand, the highest dry deposition of HgP was simulated on the outskirts of the domain, increasing from the centre of the domain.

While Hg^0 and Hg^{2+} share similar diffusivity and reactivity (due to the similarity assumption made in the present study), leading to comparable dry deposition rates, HgP's distinct physical properties, such as its geometric mean diameter and standard deviation, result in different deposition behaviour. This variance in physical characteristics may contribute to the observed disparity in dry deposition rates across the domain.

Assessment of potential health risk

The hazard quotient (HQ) has been calculated for emissions of Hg^0 from surrounding Kriel and Matla as a spatial minimum (baseline scenario) and maximum (worst-case scenario) within the study area (Table 6). These values provide a range of HQ that, at its highest, offers an estimate of health risk to the population within 20–40 km from the two power plants. The calculated acute (1 hour and 8 hours) and chronic HQ values for the baseline scenario indicate a tolerable exposure level to concentrations of Hg^0, with all HQ values being less than one (HQ < 1). This scenario's minimum predicted exposure concentrations are below the recommended REL values.

In contrast, for the worst-case scenario, the acute (1 hour and 8 hours) HQ values exceed one (HQ > 1), indicating a potential for severe health effects due to peak emission events. The maximum predicted exposure levels are also above the REL values for these acute exposure periods. However, the HQ value for chronic exposure remains below one (HQ < 1), suggesting that while short-term risks may be significant, long-term risks are within acceptable limits.

In atmospheric dispersion modelling, particularly for hazardous air pollutants Hg^0, several known uncertainties can influence the accuracy of predicted concentrations. Variability in emission factors is a primary source of uncertainty, as actual emissions can fluctuate due to changes in power plant operations, fuel composition and the effectiveness of emission control technologies. Meteorological data like those from MM5 drive the dispersion patterns in models like CALPUFF and may introduce another layer of uncertainty. Examples include inaccuracies in wind speed, direction, atmospheric stability and other weather-related variables that can significantly alter the model outputs. As shown by de Lange et al.[67], the simulated planetary boundary layer may also have had a large impact on the dispersion as this region does not have information on the vertical structure of the atmosphere. The specified deposition rates, chemical transformation rates and mixing heights are often based on assumptions or limited data, which can lead to either overestimation or underestimation of concentrations. Despite these uncertainties, modelling remains vital for assessing potential health risks from air pollution. However, it is essential to interpret the results within the context of these limitations and the lack of a South African national ambient standard for mercury.

Conclusions

As expected, the concentrations of the Hg species are highest over the cluster of power plants situated in the centre of the domain. Moreover, the results convey that concentrations of the species are accumulating in an area of already high concentrations over Kriel and Matla. The concentrations are already high given the proximity of the power plants and other Hg sources to one another and because power plants are the predominant source of Hg in South Africa. This part of the domain also yielded maximum wet and dry deposition. It is thus clear that the proximity of the power plants leads to higher deposition. Once deposited, inorganic mercury can be converted into methylmercury, a highly toxic form that bioaccumulates in aquatic food chains, by certain microbial processes in water systems. The formation of methylmercury is, therefore, likely to occur due to the possibility of these high-modelled concentrations being removed by deposition. The high wet deposition results for Hg^{2+} cover the same spatial area as the modelled concentration, corroborating the above statement. It could expose the population that depends on fishing to supplement their nutritional needs, such as the Rietspruitdam and Steenkoolspruit rivers near Kriel town. Although conservative estimates, the results identify a potential need to assess the possible impact of toxic methylmercury on the South African Highveld. While acute exposure to peak emissions of Hg^0 from the power plants in the study area may pose severe health risks, chronic exposure remains within acceptable limits. The conservative assumptions used in dry deposition modelling overestimated the expected concentrations of Hg^0 in the ambient air. This discrepancy underscores that this study's health risk assessment is uncertain.

Table 6: Hazard quotient (HQ) assessment of potential health risk to emissions of Hg^0 from modelled power plants

Exposure period	Lowest predicted exposure (μg/m³)	Maximum predicted exposure (ug/m³)	REL (μg/m³)	RFC (μg/m³) used for HQ quantification	Baseline HQ	Worst-case HQ
Acute (1 hour)	0.002	2.001	0.6	0.3	0.007	6.67
Acute (8 hours)	0.001	0.791	0.06	0.3	0.003	2.637
Chronic	0.0000497	0.0000631	0.03	0.3	0.0001657	0.0875

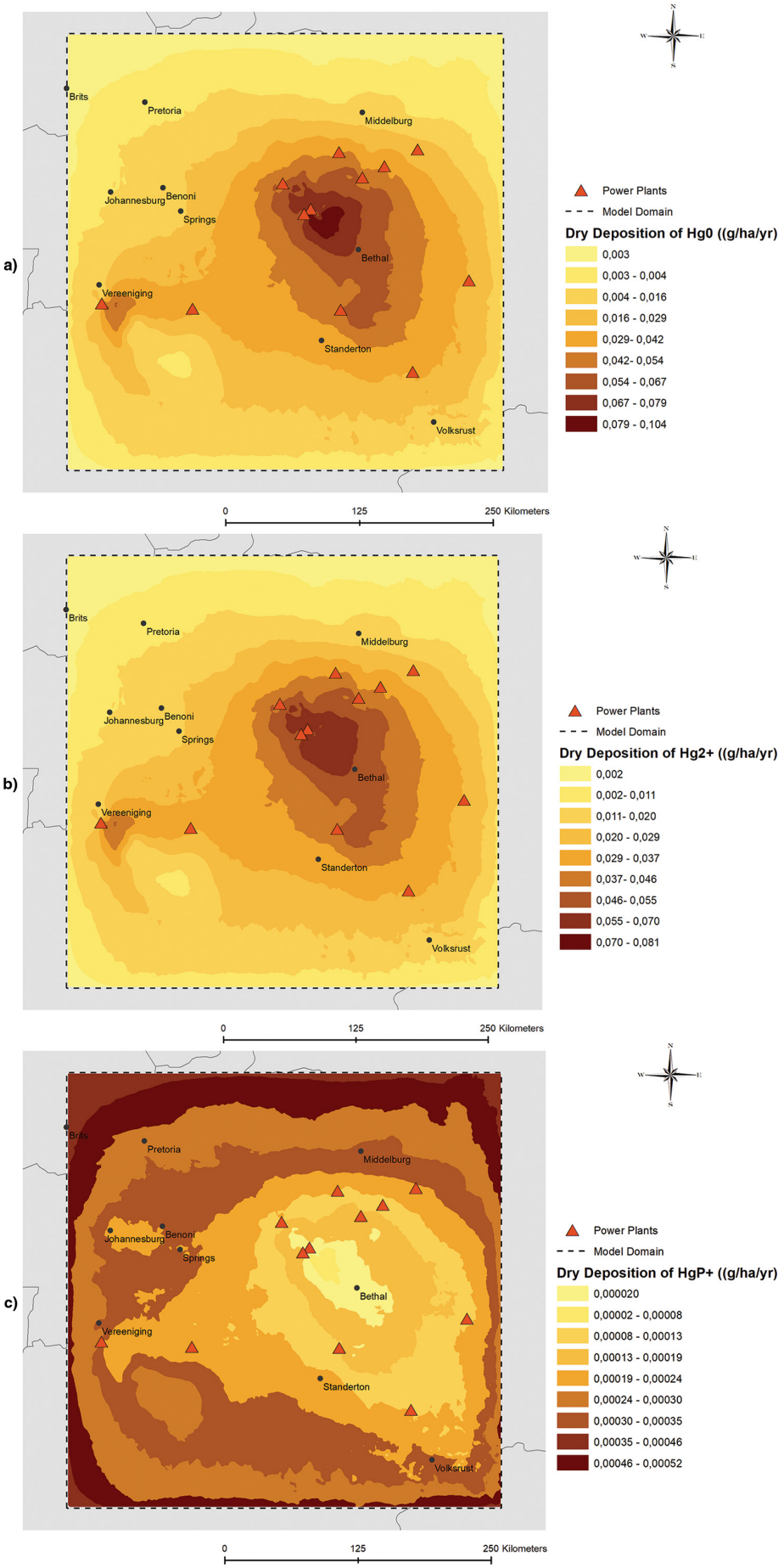

Figure 4: The spatial distribution of averaged three-year modelled dry deposition (g/ha)/year) of (a) Hg^0, (b) Hg^2+ and (c) HgP on the South African Highveld.

Prospective Hg modelling studies and related health risk assessments should improve on this study using the appropriate dry deposition values of Hg^0. The prospective modelling of Hg over this region should include all Hg sources and be evaluated against ambient monitored concentrations during the modelling period to account for uncertainty and fractional bias. The findings suggest potential locations for new Hg monitoring sites. The concurrent use of reanalysis data sets of precipitation may enhance this to provide more refined deposition modelling.

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Data availability

The data supporting the results of this study are available upon request to the corresponding author.

Declarations

This paper emanates from M.D.B.'s MSc dissertation from 2016. We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

M.D.B.: Data curation, methodology, formal analysis, investigation, writing – original draft. N.A.: Investigation, software, writing – review and editing. R.P.B.: Resources, methodology, supervision, writing – review and editing. A.D.V.: Supervision, writing – review and editing. S.J.P.: Resources, methodology, supervision, writing – review and editing. All authors read and approved the final manuscript.

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Source apportionment and transport of pollutants within the South African paper recycling chain

Recycled paper is a valuable commodity that forms an intrinsic part of promoting sustainable resource utilisation. In this study, we aimed to investigate the possible sources and transport of semi-volatile organic pollutants in paper grades used in the recycled paperboard value chain. Accelerated solvent extraction followed by gas chromatography-mass spectrometry were employed for the analyses. The results show that diethylhexyl phthalate and dibutyl phthalate were the most prominent pollutants, whilst tris (2,4-di-tert-butylphenyl) phosphite and butylated hydroxytoluene were the least significant pollutants. Tris (2,4-di-tert-butylphenyl) phosphate was predominantly detected at the recycling sites, with a maximum concentration of 3.054 mg/kg, whereas N-butylbenzene sulfonamide was found in retail and post-consumer samples but not at pre-consumer sites. Manufacturing additives and retail activities were identified as possible exposure sources. Post-consumer usage, collection, sorting and mingling of various waste materials were also identified as factors that influence the prevalence of pollutants. The presence of pollutants in pre-consumer samples indicates that certain compounds may potentially accumulate or circulate within the paper recycling chain and that other pollutants may be removed during the reprocessing of recycled fibre.

Significance:

To the best of our knowledge, this study is the first performed in South Africa on the identification of chemical constituents of different recycling paper grades, that considers the unique South African paper recycling chain. The pollutants identified indicate that the South African paper recycling chain has pollutants in common with those reported in Global North studies as well as unique pollutants. These included butylated hydroxytoluene, N-butylbenzene sulfonamide, tris (2,4-di-tert-butylphenyl) phosphite and its degradation product tris (2,4-di-tert-butylphenyl) phosphate.

Introduction

The pursuit of a more sustainable approach to resource utilisation and waste management has driven the need for waste management protocols that promote the diversion of waste away from landfill.[1] The United Nations Sustainable Development Goal 12.5 target is aimed at the substantial reduction of waste generation through prevention, reduction, recycling and reuse.[2] The promulgation of the Extended Producer Responsibility in South Africa and globally has further pushed the drive towards recycling materials. Paper is recycled more than any other packaging material in Europe and is the second most recycled material in South Africa, after beverage cans.[3-5] In 2023, the South African recovery rate of recyclable paper was 65%, which was equivalent to 1 825 944 metric tonnes.[5] This allowed for a reduction in land used for end-of-life disposal and provided resources as starting material for the manufacture of new goods.[6]

In this study, semi-volatile organic pollutants were quantified in pre-consumer, retail and post-consumer samples using the internal standard calibration method for 11 of the pollutants and semi-quantification of 1 pollutant. The study focused on the various paper grades used in the manufacture of recycled paperboard and corrugated board in the South African paper recycling chain. For this reason, the pre-consumer and retail samples were board, whilst the post-consumer samples included newsprint, magazines, office paper, cartonboard and corrugated board. Accelerated solvent extraction was used for effective isolation and pre-concentration of semi-volatile pollutants in different types of recycling paper grades before gas chromatography-mass spectrometry (GC-MS) analysis. To gain further insight into this untapped research area, interviews were conducted to understand the actual practices used by formal and informal paper recycling role players.

Literature review

The main stages of recycling are collecting, sorting and reprocessing of fibre into new products.[7] Apart from being sustainable, the collection and sorting of paper waste is a major source of job creation in South Africa.[8] In most developing countries, many of the poor and underprivileged rely on recycling for income generation and sustenance.[9] Poorly administered waste management systems in these countries often result in the inconsistent collection of waste, unrestricted waste collection points and inappropriate disposal of waste in open dumps, making recyclable waste easily accessible to informal waste pickers.[9] The manner in which recovered or collected paper is sorted greatly influences the quality of the resulting recycled paper product. Sorted paper has been shown to have fewer undesirable chemical substances.[10] The majority of paper destined for recycling in South Africa makes use of commingled collection systems where paper and board, glass bottles, cans and plastics are collected together and then sorted at recycling or material recovery facilities. Such sites have been found to have a considerable portion of highly contaminated, unusable material.[11] Once collected, the paper is then sorted according to its specific grade. The South African standard grades of recovered paper and board consist of 16 grades for mixed grades, mechanical grades (newspaper, magazines), high grades (office-type paper), kraft grades (corrugated and kraft paper) and special grades (liquid packaging and directories).[12] In comparison, the Confederation of European Paper Industries lists almost 100 grades of paper, and the United States Institute of Scrap Recycling Industries defines over 40 paper recycling grades, including specific grades for flyers, grocery bags and wet-strength bags.

It is thereby evident that South Africa has considerably less segregation between different grades based on the few types of recovered paper grades.

To estimate contaminant transfer to recycling products, the assessment of recycling must incorporate the risk posed by the accumulation and dispersion of contaminants present in paper.[13] Recycled paper is made by repulping collected wastepaper, followed by the removal of impurities.[14] In addition to the fibre component, chemical additives are fused into paper and paperboard packaging for branding purposes, consumer convenience, to resist various conditions and to protect the packaged goods. These include functional additives such as wet-strength aids, fillers and sizing agents; aesthetic additives consisting of, amongst others, varnishes, waxes, coatings and printing inks; along with control additives in the form of biocides, defoamers, drainage aids and control agents.[15] Layers of paperboard are often held together by different types of adhesives to make corrugated boards or to form folding cartonboards.[16] The manufactured recycled paper may also contain reaction products, degradation products or by-products of chemical additives.[17] Extensive research in the Global North has identified several typical pollutants in recycled paper which include, amongst others, phthalates, phenols, benzophenone and naphthalenes.[10,18-22] For virgin, unconverted paper, the most prominent pollutants reported in the literature are anthraquinone[23], used as a pulping aid in paper manufacturing, as well as phenols such as 2,4-di-tert-butylphenol, by-products of semi-chemical pulping[24].

In addition to compounds originating from the manufacturing and converting processes, pollutants may arise from recycling collection and mingling of waste as well as post-consumer usage.[25] Research on the identification of potential pollutants in recycled paper has been limited in South Africa. Historically, local research on paper recycling has focused on waste management processes[1,26-29] and not on the intrinsic chemical constituents of the recycling paper grades. The scientific data gathered in the Global North cannot simply be transposed to the South African paper recycling chain without scientific investigation. Many European countries collect paper destined for recycling as a single fraction[30] as opposed to co-mingled systems; such segregation is currently not extensively practised in South Africa. Differences in the waste collection processes, incorporation of waste pickers, sorting protocols and consequential mingling could potentially influence pollutant prevalence. The use of informal waste pickers is not unique to South Africa. According to the International Alliance of Waste Pickers, waste pickers are part of recycling chains in 32 countries in the Global South in Latin America, Asia and Africa, including Brazil, India, Niger, the Democratic Republic of Congo and Mali.[31] This study may therefore be important in understanding recycling in other developing countries.

Materials and methods

Reagents and preparation of standard solutions

Acetone (HPLC grade), dichloromethane (HPLC grade), pentane (GC grade), ethanol (LC grade) and hexane (HPLC grade) were purchased from Merck, Johannesburg, South Africa. The internal standard, deuterated dibutyl phthalate (d-DBP), was obtained from Sigma Aldrich, Johannesburg, South Africa. Analytical grade standards for quantification (Supplementary table 1) were used to prepare calibration solutions with 1 μg/mL of d-DBP. Butylated hydroxytoluene (BHT), benzylbutyl phthalate (BBP), dibutyl phthalate (DBP), diethylhexyl phthalate (DEHP), diethyl phthalate (DEP), diisobutyl phthalate (DIBP), didecyl phthalate (DIDP), tris (2,4-di-tert-butylphenyl) phosphite (AO168), N-butylbenzene sulfonamide (NBBS) and tris (2,4-di-tert-butylphenyl) phosphate (AO1680) were sourced from Sigma Aldrich, Johannesburg, South Africa. Benzophenone (BP) was acquired from Merck, Johannesburg, South Africa. The standard solutions were prepared in a 5:2 acetone: hexane solvent mixture for trace analysis covering the concentration range of 0.2 to 12 μg/mL. Another set of calibration standards was prepared in the concentration range of 5 to 200 μg/mL.

Sample collection

Samples were collected from various points of the paper recycling chain in Cape Town, South Africa, as shown in Figure 1, making up a population of 108 samples (Supplementary figure 1 and Supplementary table 2). The five pre-consumer samples consisted of unconverted and unprinted paperboards from five paper mills, which were made from recycled fibre and from a combination of virgin and recycled fibre. Four pre-consumer converted corrugated boards were sourced from two corrugators. Retail samples were collected at five retail stores and consisted of 10 cartonboards and 9 corrugated boards. The post-consumer samples were sourced from two household waste sites, two solid waste disposal sites, two recycling facilities and three informal waste pickers. For the post-consumer sites, 25 cartonboards, 22 corrugated boards, 7 magazines, 10 office papers, 13 newsprint and 3 coloured papers were collected.

Sample pre-treatment

Each sample was cut into small pieces and shredded using a kitchen blender purchased from a local store. Samples were prepared in triplicate. Target compounds in paper materials were extracted by accelerated solvent extraction using a Dionex 350 ASE system (Anatech, Cape Town, South Africa). The selection of a suitable solvent for extraction was based on recommendations of the US Environmental Protection Agency (EPA)'s Method 3545A[32], which recommended the

Figure 1: Sample collection sites in the paper recycling chain.

use of acetone:dichloromethane (DCM) (1:1), acetone:hexane (1:1) or acetone:pentane (2:1) for the extraction of soils, clays, sediments, sludges and waste solids; as well as studies where hexane:acetone (4:1) was used in the analysis of recycled paperboard for food packaging[33]. These solvent combinations and different temperatures of extraction were evaluated to ensure the sufficient extraction of target compounds from paper. The final extraction conditions entailed the extraction of 3.5 g of a shredded paper sample using a 5:2 acetone:hexane mixture at 70 °C. The resulting final 40 mL volume of extract was then reduced to 1 mL through evaporation using a Biotage TurboVap (Anatech, Cape Town, South Africa) under nitrogen at 45 °C[34,35], followed by filtration with a 0.45-µm syringe filter prior to GC-MS injection.

Gas chromatography-mass spectrometry analysis

Analysis was performed using a Thermo Scientific Trace GC Ultra ISQ MS with a TriPlus RSH Autosampler (Anatech, Cape Town, South Africa) fitted with a Phenomenex ZB-5ms capillary column with a guard column (30 m+10 m Guardian × 0.25 mm ID × 0.25 µm thickness) (Separations, Cape Town, South Africa). A constant flow of high-purity helium (Air Products, Cape Town, South Africa) at 1.2 mL/min was employed. The inlet temperature was set at 260 °C with the 1-uL injection volume performed in splitless injection mode. High-purity helium gas purchased from Air Products (Cape Town, South Africa) was used as the carrier gas with an initial pressure of ~7 psi. The oven temperature was initiated at 40 °C and held for 5 min before ramping to 315 °C at 8 °C/min (held for 15 min) before being cooled down to 220 °C at 15 °C/min. For MS measurements, the scan mode was set from 40 to 1100 m/z. The scan mode was used for preliminary screening to identify target compounds aligned to the South African paper recycling chain. The 2020 National Institute of Standards and Technology (NIST) electron ionisation GC-MS spectral library was used to identify compounds with spectral matches with reverse similarity indexes above 800 and with commercially attainable chemical reference standards for the target analytes. Once identified, their respective prominent ions (as shown in Supplementary table 3) were then used in single ion monitoring (SIM) mode for quantification.

Quality assurance

Calibration curves were plotted factoring in the peak area of the 1 µg/mL of d-DBP internal standard to the peak area of the target compound against the concentration of each investigated target compound. This allowed for the determination of linearity for each compound as the coefficient of determination (R^2). Diisopropylnaphthalene (DIPN) was found to elute as a mixture of five isomers on the GC-MS. It had already been established that this compound exists as 10 isomers.[36] In this study, 5 of the 10 isomers were identified in paper-based samples using the 2020 National Institute of Standards and Technology spectral library and Brzozowski et al.[36] These five isomers were tentatively identified as 1,3-diisopropylnaphthalene (1,3-DIPN), 1,7-diisopropylnaphthalene (1,7-DIPN), 2,6-diisopropylnaphthalene (2,6-DIPN), 2,7-diisopropylnaphthalene (2,7-DIPN) and 1,6-diisopropylnaphthalene (1,6-DIPN) (Supplementary figure 1). For the purposes of this study, semi-quantification was performed using Equation 1, assuming a response factor of one and applying it to the sum of the DIPN isomers peak areas:

$$C_{sample} = \frac{C_{is}}{A_{is}} \times A_{sample} \qquad \text{Equation 1}^{37}$$

where C_{sample} represents the concentration in the sample, C_{is} is the concentration of the internal standard d-DBP, A_{is} is the area of the internal standard and A_{sample} is the sum of the individually integrated DIPN isomer peaks.

To measure the sensitivity of the applied analytical method, the limit of detection (LOD) was measured at a signal-to-noise ratio of 3, whilst the limit of quantification (LOQ) was determined by a signal-to-noise ratio of 10. The accuracy and precision of the analytical method were evaluated by spiking samples in triplicate at three different concentration levels of 0.12, 0.2 and 3 mg/kg. Two sample substrates were used for evaluating the recovery as a measure of accuracy for paper and paperboard, to reflect the sample population. In each case, such samples were virgin, unprinted and unconverted paper material. These paper samples were expected to contain minimal pollutants.

Data analysis

Data analysis was performed using Thermo Scientific XcaliburTM, Thermo Scientific Freestyle 1.8 SP2, MetaboAnalyst 5.0 and Microsoft® Excel. Partial least squares (PLS) discriminant analysis, a chemometrics tool, was performed using MetaboAnalyst 5.0 to establish the variable importance in projection (VIP) scores. VIP scores were used for calculating the cumulative measure of the influence of individual variables, in this case, target analytes in the system[38] using Equation 2:

$$VIP_{score} = \sqrt{K \times \left(\frac{\left[\sum_{a=1}^{A} \left(W_a^2 \times SSY_{comp,a} \right) \right]}{SSY_{cum}} \right)} \qquad \text{Equation 2}$$

where the VIP_{score} is a weighted combination over all components of the squared PLS weights (W_a), where $SSY_{comp,a}$ is the sum of squares of Y explained by component a, A is the total number of components, K is the total number of variables and SSY_{cum} is the cumulative sum of squares of Y.[38]

Interviews

Interviews were conducted with role players involved in paper recycling in South Africa. The incorporation of qualitative interview data into the quantitative analysis results was important in gaining further insight into the factors that influence the collection and sorting of recyclable paper grades, given the limited South African research in this field of study. The 16 participants included both informal and formal waste collectors, sorters, as well as managers, research analysts and plant supervisors.

Results and discussion

Selection of method parameters

The present study was designed for the identification and quantification of semi-volatile organic pollutants present in the South African paper recycling chain. It was crucial to establish a suitable sample extraction method that was efficient in isolating the target analytes prior to their chromatographic analysis. The extraction of target compounds from paper materials was based on accelerated solvent extraction, where a randomly selected cardboard sample collected at a recycling site was used for the optimisation of the extraction method. Initially, different solvent combinations were evaluated in the form of acetone:dichloromethane (1:1), acetone:hexane (1:1), acetone:pentane (2:1) and hexane:acetone (4:1) for the extraction of target compounds at 60 °C by comparing the chromatographic peak shapes, baseline, resolution and overall abundance. The solvent choice had to be able to attain the desirable extraction results for the analytes whilst still being compatible with the ASE equipment solvent specifications as well as the Phenomenex ZB-5ms capillary column non-polar 5% phenyl-arylene, 95% dimethylpolysiloxane stationary phase.

Preliminary findings obtained when performing the extraction indicated that an increase in the non-polar component, namely hexane, of the solvent mixture led to what was likely a hydrocarbon 'hump' and reduced chromatographic resolution. This was in agreement with the observation already reported in the literature where the same hump was evident and could be attributed to unresolved alkane C_{11}–C_{25} chains.[18,39] The benefit of the combination of a polar aprotic (acetone) and non-polar solvent (hexane) was that it was found to extract a wider range of compounds, in comparison to the dichloromethane and acetone combination where both solvents were polar aprotic. The ratio of acetone and hexane was thus varied, and acetone:hexane (5:2) was found to be the best solvent mixture for the extraction of target compounds in paper samples.

The extraction temperature was optimised to ensure efficient extraction without the loss of thermally sensitive compounds.[19] The extraction temperature was evaluated at 60 °C, 70 °C and 85 °C by comparing the peak area ratios attained for the target analyte to the internal standard. An increase in extraction temperature from 60 °C to 70 °C improved the extraction process. This could be due to the improved solubility of the target compounds in the extraction solvent mixture. Furthermore, the extraction temperature likely weakened the cellulose-based fibre bonds, allowing for the dissociation of the smaller target compounds, thus resulting in their extraction into the solvent mixture. The higher temperature of 85 °C indicated that the extraction efficiency was possibly lost due to the thermal effects on the matrix and/or over-saturation.[33] Consequently, all other extractions were performed using a temperature of 70 °C. Thus, the final extraction conditions were a sample mass of 3.5 g loaded into the ASE cell where the extraction process was done at 70 °C using a mixture of acetone: hexane mixture (5:2) for a static time of 12 minutes performed for three cycles. To minimise cross-contamination after each extraction, the ASE stainless cells were washed in warm water, rinsed with the extraction solvent and then baked out in the oven for 4 h at 160 °C.

Method validation

For the sensitivity of the analytical method, LODs and LOQs were investigated by analysing the extracted paper-based material spiked with the target compounds and internal standard at a concentration level of 1 µg/mL (Supplementary table 3). The LODs and LOQs ranged from 0.944 to 3.147 ηg/g and 4.488 to 14.962 ηg/g, respectively, as shown in Supplementary table 3. The LOQs attained in the present study were comparable to those found in the literature[35,40,41] for the analysis of the same compounds in plastic and paper-based materials using GC-MS. Linearity was confirmed with a coefficient of determination (R^2) greater than 0.99 for the target compounds over a wide concentration range. The recoveries obtained for the target compounds extracted from both the paperboard and paper spiked at different concentrations ranged from 73% to 104% (Supplementary table 3), which was indicative of an efficient analyte extraction method from the investigated samples. It was noted that recoveries for the paper sample were slightly higher than those of the paperboard sample for most of the target compounds, except for NBBS and AO168O. This indicated that, in general, the higher grammage fibre in paperboard may adsorb compounds more strongly than smaller grammage paper samples.

Overview of pollutant prevalence

The concentrations of the target compounds detected in pre-consumer, retail and post-consumer (Supplementary table 4) were quantified using calibration curves whilst semi-quantification of DIPN was performed using Equation 1. DBP, DEHP and BP were found to have the highest detected concentrations (Supplementary figure 2). A corrugated board collected at a recycling plant was found to have the highest concentration of BP (24.71 ± 0.57 mg/kg), and a cartonboard from household waste was found to have the maximum concentration of DEHP (37.12 ± 6.72 mg/kg). AO168O was found to have the lowest maximum concentration of 3.054 mg/kg for cartonboard found at a recycling site. The target compound found in the highest concentration was DBP detected in a corrugated board sample from household waste with a concentration of 55.64 ± 5.68 mg/kg paper (Supplementary figure 2). When comparing this finding to previous research, this concentration was within the ranges found in the literature.[35,40,42] The three highest combined concentrations were found in a corrugated box from household waste, which was found to have the highest combined concentration of pollutants at 85.68 mg/kg, a magazine collected at a recycling site (54.66 mg/kg) and a toilet paper core from household waste (37.98 mg/kg) (Supplementary table 4). This result indicates that consumer usage and exposure to different elements may influence the concentration. An overview of the average pollutants under investigation (Figure 2) showed considerably lower amounts of pollutants in pre-consumer samples than those from retail and post-consumer sites.

The combined average concentrations detected were 4.06 mg/kg for pre-consumer samples, 12.88 mg/kg for retail samples and 14.98 mg/kg for post-consumer samples. DBP and DEHP were the most prominent pollutants in pre-consumer samples. The results suggest possible latent compounds present in the pre-consumer samples. It is also possible that lower concentrations of pollutants could have been introduced during manufacturing processes, leading to possible cumulative effects as the samples moved from retail to post-consumer. An increase in detected pollutants in the cartonboard at the retail stage was attributed to pollutant exposure opportunities during transportation, packing and distribution of consumer goods as well as during converting processes. The difficulty in postulating this was that the original state of these particular retail samples was unknown. The fibre composition of the retail and post-consumer

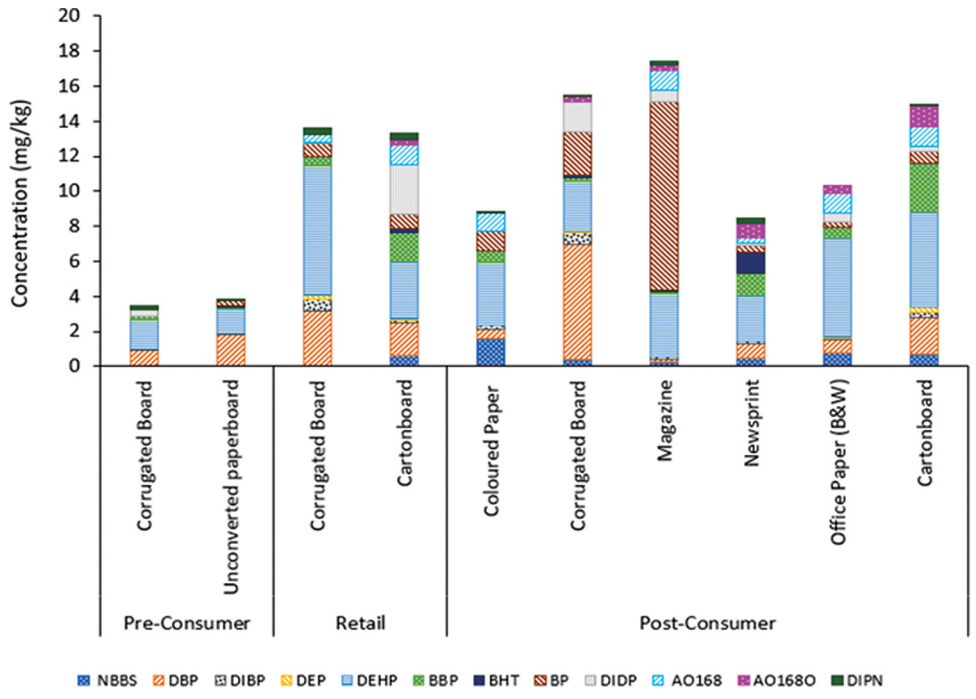

Figure 2: Overview of the concentrations of target compounds in different sources.

samples may have been virgin, recycled or a combination of these, which would also likely influence the detected concentrations. At the post-consumer level, additional pollution exposure may have arisen from the mingling of waste as well as from the leaching of phthalates from the goods packaged in paperboard materials. Clothing, plastic goods, personal care products and furnishings items[42] often contain phthalates which could adhere to paper packaging at the post-consumer stage, further influencing the various pathways. In general, paper packaging is often used as secondary packaging with goods in primary contact with plastic. This likely promotes the interaction of paper and plastic during storage and use.

Paper grade apportionment of pollutants

A plot of PLS-VIP scores, plotted using MetaboAnalyst 5.0, was used to identify the importance of each pollutant relative to the paper recycling grade, as shown in Figure 3.

The VIP scores were used to assess the prominence of each pollutant in the population and to project the likely source of pollutants based on the paper grades using a heat map where 'high' indicated a strong correlation and 'low' indicated a weaker correlation. According to Galindo-Prieto et al., VIP scores larger than 1 indicate the most significant variables.[38] From the plot, it is seen that DEHP and DBP were the most prominent pollutants in the samples, whilst AO168 and BHT were the least significant pollutants. This was probable because DEHP is a common phthalate found in paper and plastic goods.[21] In paper-based packaging, phthalates are used in inks, lacquers and adhesives.[18] The prominence of DEHP, DBP, DIBP, BBP, and DEP in the present study corresponded with findings reported in the literature[18,25,43] in which the same phthalates have been identified in waste paper and recycled paper and board.

With respect to DIPN, Geueke et al.[25] postulated that, because DIPN was used in carbonless copy paper, the recycling of office paper grades would lead to its presence in recycled paper. DIPN was found in a large fraction of the pre-consumer samples, which contained a recycled fibre component. Moreover, DIPN was detected in other samples (Supplementary table 4), including an egg carton, paperboard, cardboard, magazine and newsprint. Although the fibre component of these was not known, its presence demonstrates that the sources of DIPN may not be limited to just the presence of office paper or recycled fibre in recycling paper grades. In the study by Guazzotti et al., DIPN was detected mostly in pigmented, coated packaging samples.[44] This shows that, in addition to a recycled fibre component, the use of certain printing inks may influence the detection of DIPN. The presence of BHT and AO168, although not as significant, was possibly due to their use in chemical additives as well as exposure to different materials during packaging and recycling. Both BHT and AO168 are typically used as antioxidants and have been associated with plastic packaging and multi-materials[21,45,46] as well as printing inks used in printed paper material[47]. BHT is also used as an antioxidant and stabiliser in cosmetics, as a food additive, jet fuels, rubber, plastics, animal feeds, paints and lacquers, adhesive hardeners, cleaning agents, printing products, pharmaceuticals and thinners.[48]

When apportioning pollutants to recycling paper grades in Figure 2, cartonboard samples were strongly associated with DBP. Cartonboards generally consist of paperboard shaped into folding boxes and held together by some sort of adhesive. The prominence of DBP may thereby be linked to the likely use of adhesives. DEHP, DIBP, NBBS and AO168 were associated with coloured paper, whilst BBP, DEP and BP were linked to magazine samples. Black and white office paper was associated with

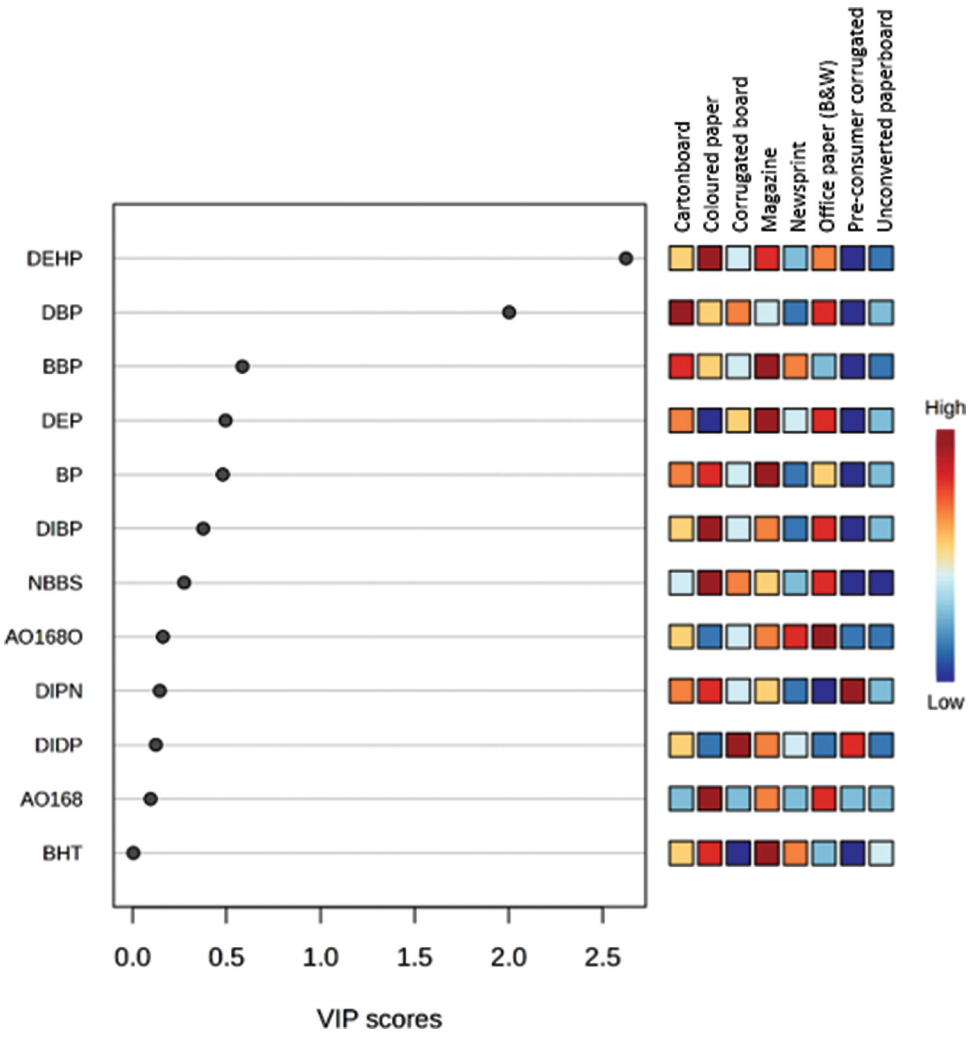

Figure 3: Plot of PLS-VIP scores.

AO168O. It was interesting to note that pre-consumer corrugated board was associated with DIPN, whilst the unconverted paperboard had the least associated pollutants. This therefore indicated that pollutant prevalence could be projected based on the paper grade used.

The case of NBBS

NBBS, an organophosphate emerging contaminant[49], has been reported as a wastewater contaminant[50]. NBBS was not detected in any of the pre-consumer samples or the retail corrugated board. It was, however, detected in retail cartonboard as well as other grades of post-consumer samples, as shown in Figure 4. When looking at the NBBS occurrence in the population, 87% were post-consumer samples, the majority of which were coloured paper and office paper. Neither coloured paper nor office paper were collected at pre-consumer and retail sample sites; it could therefore be possible that NBBS may be associated with the manufacture of these mechanical grades. The possibility of contamination from other sources is also probable based on its detection in groundwater[50] as well as its use in cooking utensils.[51] The possible removal of NBBS during repulping of recycled fibre could not be excluded as a possible reason for not being detected at pre-consumer level.

The prevalence of AO168 and AO168O

The organophosphate ester AO168O, referred to as a novel pollutant[47,52], was initially identified in e-waste dust[52] as well as indoor dust[53]. The first report of its presence in paper-based material was in 2021 by Liu and Mabury, who linked to the use of printing inks in magazines and dry food paper packaging.[47] In this study, AO168O was predominantly detected at the recycling sites with the highest concentration found in a cereal cartonboard followed by a coffee cartonboard and newsprint insert (Figure 5). AO168O was also detected in papers collected from household waste whilst AO168 was detected in samples from retail and solid waste sites. This suggests that, over time, AO168 degrades and can easily transfer during mingling of waste. Common physical traits were noted in samples found to contain AO168 and/or AO168O. Most of the samples had a glossy or coated finish, were electronics packaging or had black printing. This suggests that AO168 may be used in paper packaging to prevent the possible fading of darker printing inks or to possibly maintain

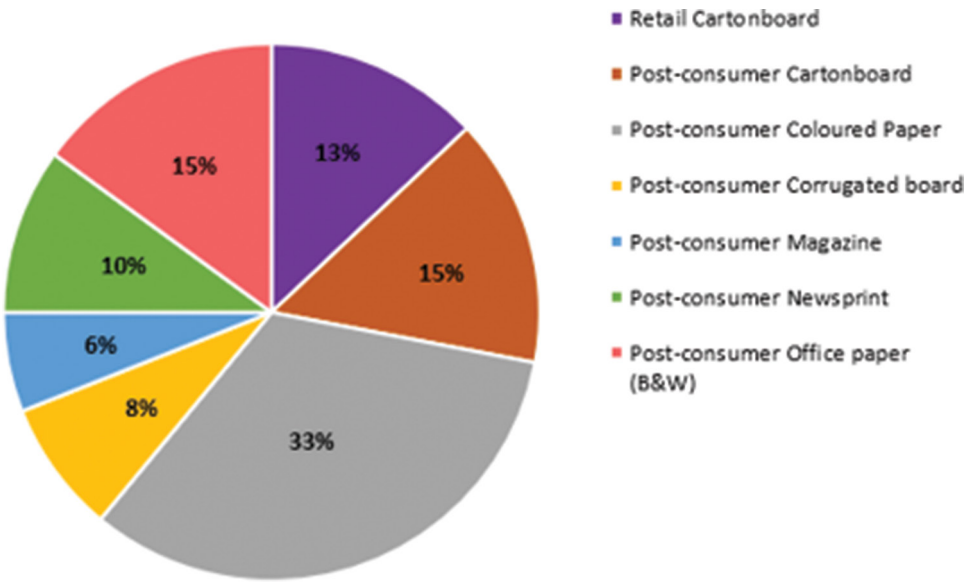

Figure 4: Fraction of retail and post-consumer grades containing NBBS.

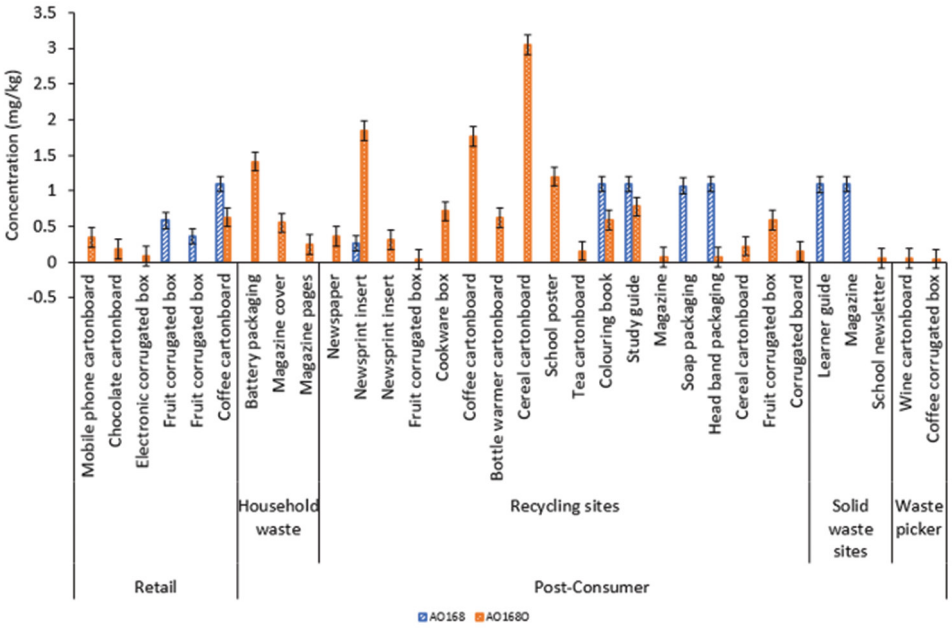

Figure 5: The prevalence of AO168 and AO168O.

a gloss or coated finish.[54] The detection and quantification of AO168 and AO168O highlight how the mingling, use of chemical additives and chemical degradation may lead to the prevalence of certain pollutants. Neither AO168 nor AO168O were detected in pre-consumer samples, suggesting that there may be a lower probability of these compounds circulating in the paper recycling chain, that current reprocessing of recycled fibre removes them and/or that the concentrations of these compounds may be very low and beyond the detection limits of this study.

The influence of paper recycling grades

The sorting of paper into various grades is important when it comes to the intended application of the subsequent recycled paper product and the quality required.[14] The roles of the participants interviewed in this study are shown in Supplementary table 5. The interviews conducted indicated that, for the participants, the average number of different recycling paper grades known was 5.25, with the five most identified grades being newspaper, cardboard, common mixed waste, magazine and office paper (Supplementary table 6). This figure represents 0.33 of the South African defined paper grades. Knowledge and awareness of the various paper recycling grades were expected to influence the sorting, collection and mingling of the various paper grades in the paper recycling chain. Socio-economic factors also likely influenced sorting and collecting; the most sought-after paper recycling grades were those with the highest value, and general sorting involved separating these out first (Supplementary table 7). According to the South African recycling grades, post-consumer used newspapers and magazines fall into a single grade referred to as 'special news' For the target compounds analysed in this study, newspapers and magazines were found to have different pollutant patterns (Figures 1 and 2). The combination of these would thereby increase the probability of mingling of their typical pollutants.

The most diverse paper recycling grade was identified as 'common mixed waste'. By definition, this grade includes a mixture of grades of paper and board without restrictions on fibre content. Interview participants mentioned that sorting is generally performed through elimination, whereby the valuable and known grades made from cardboard, white paper and office paper are removed first and the remaining recovered paper is deemed 'common mixed waste' (Supplementary table 8). This common mixed waste predominantly consists of used cartonboards (such as cereal boxes, fast-food packaging, chocolate cartonboards and pharmaceutical packaging) as well as posters, miscellaneous papers and boards, and could thus be considered an unsorted paper grade. Although a pre-consumer cartonboard grade exists in the form of 'IMW', that is, cartonboard cuttings, there is currently no designated post-consumer strictly designated for a post-consumer cartonboard grade. The two lowest combined concentrations of target pollutants in this group were a retail chocolate cartonboard at 0.377 mg/kg and a cereal cartonboard at 0.832 mg/kg; and the two highest were a toilet paper core (37.99 mg/kg) and pharmaceutical packaging (20.43 mg/kg), both obtained from household waste. Wide variations in concentrations were found at the different post-consumer sites, making it difficult to fully predict the behaviour of this paper recycling grade. The drive for sustainable paper-based packaging in recent years[55] means that packaging that was previously polymer-based is now manufactured from paper, including paper-based fruit punnets, confectionery products packaging, paper straws and other fast-food packaging. These products form part of the common mixed grade when collected for recycling, further adding complexity to the mixed paper grade.

Concluding remarks

A validated analytical method was developed using accelerated solvent extraction and gas chromatography. Quantification of semi-volatile pollutants in conjunction with interview data, available literature and chemometrics were then used to investigate the possible sources and propagation of these compounds within the paper recycling chain. Paper and board pollutant prevalence was found to be influenced by external factors arising from exposure to undesirable pollutants during sorting, collecting and recycling. This was shown by the higher combined concentrations of the target analytes in the paper material collected at post-consumer sites. The use of manufacturing and converting additives in the initial manufacturing and reprocessed fibre, as well as the possible retention of chemical compounds in recycled fibre were also identified as important factors in the prevalence of the study analytes. The findings of the present study suggest that the South African recycled paper chain consists of pollutants prevalent in paper, plastic and multi-material goods with the detection of known plasticisers, antioxidants and photoinitiators. Further, the mingling of waste and/or use of additives containing such compounds may contribute to the prevalence of these pollutants in paper-based products. The further segregation of common mixed grades and special news could minimise contaminants entering product cycles from cartons, newspapers and magazines. The results emanating from this study are crucial for understanding the possible sources and the influence of recycling practices on the prevalence of pollutants in the recycling paper grades. Moreover, this study may serve as a critical baseline to grow the body of knowledge in this research area. More extensive evaluations of a wider scope of target analytes at much lower concentrations are needed.

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Data availability

All the data supporting the results of this study are included in the article itself and the supplementary material.

Declarations

N.N.M. is employed by Mpact Operations Pty (Ltd). Ethical clearance was obtained from the University of the Witwatersrand (H21/07/29). We have no AI or LLM use to declare.

Authors' contributions

N.N.M.: Conceptualisation, methodology, analysis, writing – original draft, project administration, visualisation, funding acquisition. L.M.M.: Supervision, validation, visualisation, writing – reviewing and editing, project administration. L.C.: Conceptualisation, supervision, validation, writing – reviewing and editing, project administration. All authors read and approved the final manuscript.

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A critical view of applying life cycle assessment on disposable diapers in a rural context

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The environmental impacts of disposable diapers in comparison to reusable diapers have been a matter of interest within the life cycle assessment (LCA) community for many years. However, the majority of LCAs have been conducted in developed countries with well-developed waste management infrastructure. This study takes a critical view of the application of LCA to evaluate the environmental impacts of disposable diapers in rural areas. In the study area, the majority of diapers were openly dumped (43.8%), sent to unsanitary landfills (26.1%) or burned (18.6%). The production phase contributed the most to the majority of impact categories, excluding freshwater exotoxicity, marine exotoxicity and human carcinogenic toxicity. These impacts were instead dominated by end-of-life impacts and also had the highest relative significance when normalisation was conducted. The lack of and/or poor waste management has resulted in the end of life of diapers being a significant environmental risk. However, current life cycle impact methodologies are not able to fully cover the scope of impacts presented by mismanaged diaper waste. This study demonstrates the importance of geographical contexts when conducting diaper LCAs wherein, in some scenarios, it may be necessary to include impacts beyond the scope of a traditional LCA.

Significance:

- This is the first LCA conducted on diapers in the rural context of Africa.
- The majority of impacts were attributed to the production of disposable diapers.
- The majority of disposable diapers were dumped or sent to unsanitary landfills.
- However, LCA cannot take into consideration improper disposal, giving an incomplete picture of the environmental impacts.

Introduction

Since their invention, disposable diapers have become increasingly popular around the world. There is limited information on diaper usage in South Africa. According to a study conducted by Berrian et al.[1], in the Mpumalanga Province of South Africa, 80% of respondents reported using disposable diapers. A further study in 2021 estimated that 67 000 to 160 000 tonnes of absorbent hygiene products were generated in metropoles depending on their size.[2] Whilst diapers have aided in increasing sanitation in developing countries, they have presented a further challenge in terms of the waste created.

The environmental impacts associated with diapers have been a matter of interest in the life cycle assessment (LCA) community for a number of years. The LCA is often conducted from a comparative perspective, that is, reusable versus disposable diapers.[3-5] A meta-analysis conducted in 2021 found that reusable diapers are the better choice in the majority of scenarios.[5] However, this depends on a number of factors, including the reusable diaper laundering process and diaper disposal practices.

With the evolution of technology and the development of new materials, studies have been conducted to evaluate their potential impacts.[6-8] Mirabella et al.[8] investigated the environmental impacts of substituting petrochemical-based plastics with bio-based alternatives, finding that while they provide some benefits, it is important to pay attention to their agricultural phase. Mendoza et al.[7] found that substituting adhesives with a novel bonding technique reduced raw material consumption, primary energy demand and greenhouse gas emissions.

The majority of diaper LCA studies have been conducted in developed countries[5], with one conducted in Brazil[9]. Thus, improper disposal methods have rarely been considered, with landfilling and incineration being the most common methods of waste treatment modelled. Furthermore, there are limited insights into scenarios in which there is limited access to water, sanitation and waste management infrastructure.

This study contributes to the lack of studies in developing countries. Furthermore, it investigates the rural context. This is of particular importance as the geographical context was identified as one of the critical factors influencing the environmental impacts of diapers.[5] This article is structured according to the generic steps of an LCA:

- Goal and scope definition
- Life cycle inventory
- Life cycle impact assessment (LCIA)
- Interpretation

Data sources and modelling approach

The diaper modelled was based on primary and secondary information. Specifically, the foreground data were informed by primary data provided by a major local diaper manufacturer. The data were provided for the year 2021. This was supplemented by secondary data sourced from the literature. Background data were based on

the Ecoinvent v3.9 cut-off system model database. The section on 'Life cycle inventory' details the cases in which the different types of information sources are used. The LCA was modelled on SimaPro LCA Software v9.4.0.1.

Primary data for the waste scenario were based on a series of questionnaires conducted in the Kruger 2 Canyon (K2C) Biosphere Region in South Africa in 2022. The K2C Biosphere Region was chosen for this study due to its unique combination of rural settings, high population density of 1.5 million people[10] and limited waste management infrastructure. This region also has a significant human–wildlife interface, making waste management, particularly the improper disposal of absorbent hygiene products such as diapers, a pressing environmental and health issue. The area presents an ideal context in which to study the environmental impacts of disposable diapers, as most existing LCAs have focused on urban or more developed regions with well-established waste management systems. By focusing on a rural area with diverse and inadequate waste disposal practices, this study fills a critical gap in understanding how geographical context affects the environmental impacts of diapers, particularly in areas lacking formal waste collection services.

The questionnaires were part of a larger study investigating diaper usage and disposal practices in the area. In total, 1575 questionnaires were completed across eight villages in the area.

Goal and scope

The goal of this study was to evaluate the potential environmental impacts of disposable diaper usage in rural areas. It places a particular focus on the end-of-life aspects not yet investigated in previous research.

Functional unit and reference flow

Previous studies have used a number of functional units. For example, several studies have utilised the average number of children's diapers used over 2.5 years.[3,9,11] In some cases, the functional unit seems arbitrarily chosen, such as the 1000 units used by Mendoza et al.[7] According to the distributed questionnaires, the average number of diapers used per day was 4.47. This figure is similar to those in studies by Hoffmann et al.[9] and Aumónier et al.[3] in which they estimated 5 and 4.16 diapers per day, respectively. Thus, for this study, the figure used for the number of diapers used per day was 4.47.

System boundaries

A cradle-to-grave LCA was conducted, from raw material extraction to disposal. Both informal and formal disposal methods were taken into consideration. Transport and distribution were partly included, and use phases were excluded (further discussed in the following sections). The system under consideration is depicted in Figure 1. The packaging for the diapers was not included in the model. This choice was supported by the results of the LCA conducted by Cordella et al.[6] wherein they found the impacts of packaging across the life cycle to be negligible.

Life cycle inventory

Diapers are constructed from a large variety of components, including tapes, elastics and adhesives. The primary raw materials used are similar with differences in their construction and additives employed. Table 1 shows the primary materials used. The most important part of the diaper, the absorbent core, is composed of pulp and super-absorbent material (sodium polyacrylate) and accounts for the majority of the mass of a diaper at 65.2% (according to a South African manufacturer of disposable diapers). This is to be expected as its primary function is the absorption and retention of excreta. The liner, which comes into contact with the wearer, is often made from a polymer mix which allows the passage of fluids to the absorbent core. The outer cover is made of a breathable material which is also polymer based. Adhesives are used to secure the different diaper components.

Diaper components

There were limited data regarding the production of diaper components. The manufacturer provided information on the types of components, their weights and their primary materials. They also provided the country of origin, as some of the components are imported. However, no information was provided on the manufacturer in the exporting country or the processes employed. Therefore, the modelling of these components was based on data sets available in Ecoinvent and modified as far as possible to reflect the conditions in the country of origin, for example, substituting the electricity for the local electricity mix from the Ecoinvent database.

Many of the diaper components are composed of composite materials. However, in this study, only the primary materials were modelled per component, similar to that done by Cordella et al.[6] and Mendoza et al.[7]

Diaper manufacture

Data regarding diaper manufacture were provided by a major diaper manufacturer in South Africa. These data included weights of diaper components used, electricity consumption as well as waste generation and disposal.

Use phase

The use phase was not modelled due to the wide variety of transport distances and methods utilised by consumers to reach retailers. The questionnaires indicated that there was a wide variety of retailers available to respondents, which were located at varying distances.

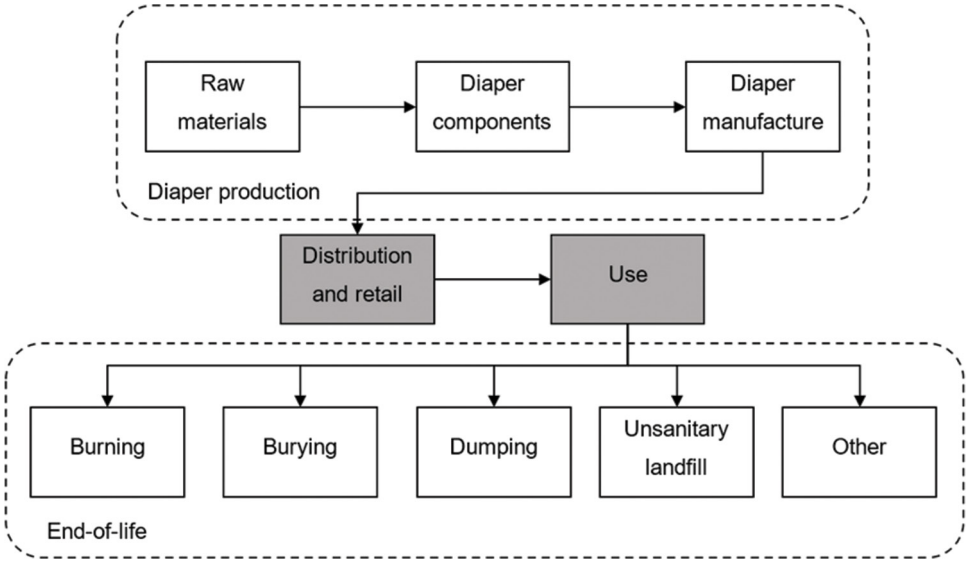

Figure 1: Diaper life-cycle stages.

Table 1: Primary raw materials used in diaper manufacturing and their contribution to diaper weight

Material type	Percentage contribution
Pulp	33.9
Sodium polyacrylate (SAP)	31.2
Polypropylene (PP)	20.8
Polyethylene (PE)	9.8
Elastics	1.0
Adhesive	3.2

Source: South African manufacturer

Furthermore, different transport methods were used to reach the retailer, including public transport, private transport or walking.

Transport

Transportation of the imported diaper components was included in the model. The diaper components are shipped from the originating country to South Africa. The distances were approximated using a major port in the country of origin as the source and Durban Harbour, on the east coast of South Africa, as the destination. The components are then transported by road to the factory.

An average distance of 1880 km was used for transport to distributors and retailers in the town of Hoedspruit, within the K2C Biosphere. This distance represented the distance from the factory to the Hoedspruit area and was obtained using Google Maps. Further details could not be modelled, however, as the diapers could have passed through several hands before they were retailed to consumers, for example, distributors to wholesalers to spaza shops.

End of life

Waste resulting from the diaper production process accounted for only 3% of materials, as reported by the diaper manufacturer. This figure is higher than that in the study by Mendoza et al.[7] which utilised 1%. These residues are reportedly sent for further beneficiation by other value chain members. However, we were not privy to the nature of these beneficiation methods; therefore, it was not possible to model the waste scenario in this case.

Based on the interviews, respondents used a variety of methods for the disposal of diapers. They did not necessarily adhere to one method and might have used different options based on convenience. Only skip bins were collected by the municipality and taken to an unsanitary landfill, whereas the respondents used dustbins as a temporary waste retainer until they could dump the waste. Dumping took place in multiple environments: riverbeds, bush/veld and next to roads. The most popular method was dumping in the bush/veld followed by burning. Other disposal methods involved dumping in pit latrines or other methods not specified in the questionnaire.

Three waste treatments (Table 2) were modelled using the models developed by Doka[12]: open burning, open dumps and unsanitary landfills. The underlying data were modified to reflect the region using the available information. Burying was modelled as an unsanitary landfill; however, it is acknowledged that this does not fully represent the method. Disposal in pit latrines and 'other' were modelled using a dummy waste treatment; thus, the impacts are not reflected in the life cycle impact assessment (LCIA). The impacts of this modelling choice are explored in the section on 'Pit latrine modelling choice'.

The impacts of the disposal of urine and faeces were not modelled. Instead, the potential impacts are discussed under 'Improper diaper disposal'. This includes impacts that cannot be accounted for in LCAs, such as ingestion by animals and dumping in rivers.

Table 2: Waste scenario

Open dump	43.8%
Unsanitary landfill	26.1%
Burning	18.6%
Other	11.5%

Life cycle impact assessment

Previous studies have used the CML 2001 or ReCiPe methods for calculating the potential environmental impacts.[5] In this study, a long-term approach was taken to assess the environmental impacts. Thus, the impact assessment was conducted using the ReCiPe Midpoint (H) method, which uses global models to evaluate environmental impacts. The method also provides a comprehensive set of indicators.

Contribution analysis

The results of the characterisation phase are presented in Table 3. A contribution analysis was performed on each indicator so as to highlight the major contributors (Figure 2). The impacts were then normalised, using default ReCiPe values, to enable the determination of the relative significance of the different impact categories.

As can be seen in Table 3, diaper production, from cradle to gate, accounted for the majority of impacts on average (>65%) except for freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity. In these cases, the disposal of diapers was the highest contributor, accounting for 96% or more.

The absorbent core was a notable contributor across all impact categories during diaper production. In particular, it accounted for 92% of land use impacts; this can be attributed to the land needed to grow the trees from which pulp fluff is made. South African generated electricity used in diaper production was also a significant contributor to a number of categories, including global warming potential, stratospheric ozone depletion, particulate matter formation and terrestrial acidification. This can be attributed to the fact that most of the electricity in South Africa is coal based. Another notable contributor across all impact categories was a locally made polypropylene (PP)-based component. Similar to the electricity mix, PP is fossil fuel based in South Africa; propylene in South Africa is produced as a by-product of the coal gasification process.

Global warming potential

The total global warming potential was 0.610 $CO_{2\,eq}$, with diaper production accounting for 0.559 kg $CO_{2\,eq}$. The major contributors were diaper manufacturing (DM) electricity (0.148 kg $CO_{2\,eq}$), the super-absorbent material (0.112 kg $CO_{2\,eq}$) and the locally produced PP component A (0.0935 kg $CO_{2\,eq}$). The electricity contribution is not surprising as South Africa's electricity is mostly coal based. In addition, locally, the precursor for PP, propylene, is produced from coal via the Fischer–Tropsch process and is processed using coal-based electricity as an energy source. Transportation to distributors and the waste scenario make minor contributions of 4.0% and 4.3%, respectively.

Stratospheric ozone depletion

Electricity consumption during diaper manufacturing was a top individual contributor to stratospheric ozone depletion at 34.8%. This can be traced back to the use of coal as an energy source. Open burning of diapers contributed a relatively small amount in comparison to diaper production (8.7%).

Ionising radiation

Diaper production contributed 96.7% to ionising radiation, with transportation making up the balance. DM electricity consumption was once again a top contributor, accounting for 33.9%. The electricity contribution can be attributed to the presence of nuclear energy in the national energy mix.

Table 3: Life cycle impact assessment characterisation results

Impact category	Unit	Total	Diaper production	Transport to distributors	Waste scenario
Global warming	kg CO_2 eq	6.10E-01	5.59E-01	2.44E-02	2.61E-02
Stratospheric ozone depletion	kg CFC11 eq	3.19E-07	2.81E-07	1.04E-08	2.78E-08
Ionising radiation	kBq Co-60 eq	1.52E-02	1.47E-02	5.07E-04	0.00E+00
Ozone formation, human health	kg NO*x* eq	2.35E-03	2.10E-03	2.20E-04	3.41E-05
Fine particulate matter formation	kg $PM_{2.5}$ eq	1.27E-03	1.11E-03	5.33E-05	1.06E-04
Ozone formation, terrestrial ecosystems	kg NO*x* eq	2.39E-03	2.13E-03	2.24E-04	3.83E-05
Terrestrial acidification	kg SO_2 eq	3.38E-03	3.25E-03	1.27E-04	1.15E-05
Freshwater eutrophication	kg P eq	5.50E-04	3.60E-04	8.25E-06	1.82E-04
Marine eutrophication	kg N eq	3.07E-05	2.18E-05	4.06E-07	8.48E-06
Terrestrial ecotoxicity	kg 1,4-DCB	1.74E+00	1.29E+00	4.51E-01	2.87E-03
Freshwater ecotoxicity	kg 1,4-DCB	2.34E-01	1.80E-02	6.89E-04	2.15E-01
Marine ecotoxicity	kg 1,4-DCB	3.49E-01	2.45E-02	1.16E-03	3.23E-01
Human carcinogenic toxicity	kg 1,4-DCB	1.85E+01	3.72E-02	1.52E-03	1.84E+01
Human non-carcinogenic toxicity	kg 1,4-DCB	8.16E-01	6.02E-01	2.40E-02	1.91E-01
Land use	m^2a crop eq	9.17E-02	8.91E-02	2.60E-03	5.20E-05
Mineral resource scarcity	kg Cu eq	1.49E-03	1.41E-03	7.59E-05	0.00E+00
Fossil resource scarcity	kg oil eq	2.19E-01	2.11E-01	8.30E-03	0.00E+00
Water consumption	m^3	5.23E-03	5.14E-03	8.70E-05	0.00E+00

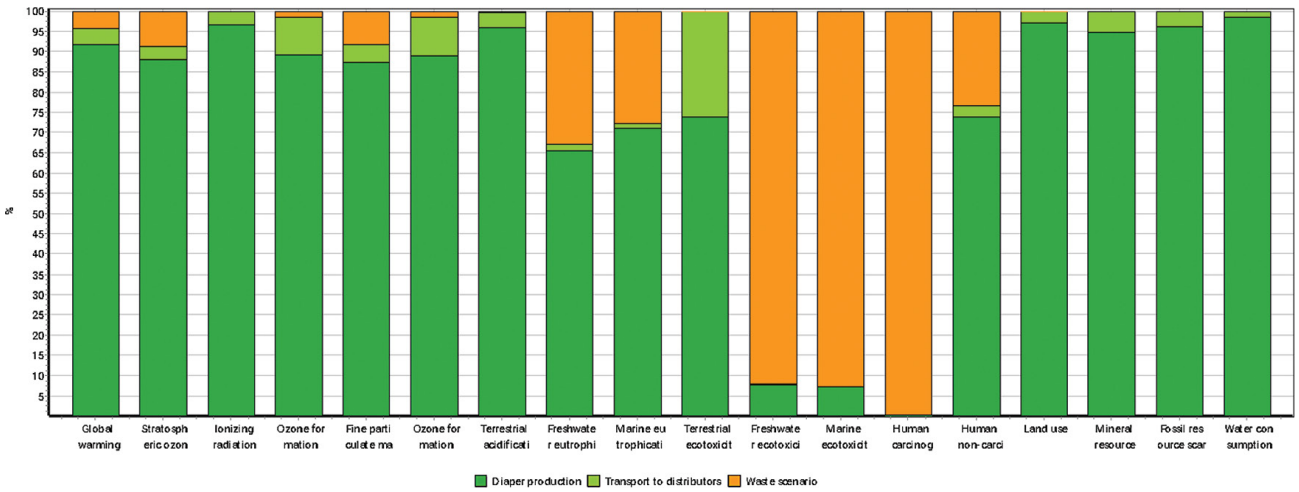

Figure 2: Relative contribution of life-cycle stages to different impacts.

Ozone formation, human health

Again, DM electricity consumption was a top contributor to ozone formation, accounting for 27.7%. This is due to the use of coal to generate electricity; the combustion of coal leads to the release of many pollutants, including nitrogen oxides. The absorbent core of diapers contributed almost the same percentage (27.0%) to ozone formation. This can be attributed to the use of heavy fuel oil and marine diesel oil to provide energy to freight ships for shipping.

Fine particulate matter formation

Diaper production contributed 87.4% to particulate matter formation. Local electricity produces particulate matter when the coal is combusted to produce steam for the generation of electricity. Thus, it contributed 33.5% to the total emissions. The absorbent core was a notable contributor as well, accounting for 22.9%. Open burning also releases particulate matter, which accounted for 8.4%.

Ozone formation, terrestrial

The results for terrestrial ozone formation (0.000239 kg $NO_{x\ eq}$) were similar to those for ozone formation and human health (0.00235 kg $NO_{x\ eq}$). Unsurprisingly, the top contributors were therefore the same: DM electricity (27.3%) and absorbent core (27.0%). Transport contributed 9.4%.

Terrestrial acidification

Diaper production accounted for 95.9% of terrestrial acidification impacts. Electricity contributed 41.7%; this can be traced back to the use of coal

for energy production. Sodium polyacrylate (SAP) and PP component A were also notable contributors at 12.9% and 15.1%, respectively.

Freshwater eutrophication

Diaper end of life was a notable contributor to freshwater eutrophication, accounting for 33.1% of the impact. This was due to leachate produced in open dumps and unsanitary landfills. The treatment of spoil from coal mining was also a contributor to emissions (49.6%).

Marine eutrophication

Similar to freshwater eutrophication, diaper dumping and unsanitary landfills contributed to marine eutrophication (27.6%). Treatment of coal spoil in the electricity production process was a major contributor at 54.3%.

Terrestrial ecotoxicity

The waste scenario was a minuscule contributor to terrestrial ecotoxicity (1.74 kg 1,4-DCB) at 0.17%. Diaper production and transport to distributors contributed 73.9% and 25.9%, respectively. Emissions were from a variety of sources, including SAP production, SAP and pulp transportation from the Durban Harbour to the factory, DM electricity consumption and locally made PP.

Freshwater ecotoxicity

Unsanitary landfilling of diaper waste accounted for the majority (92.0%) of freshwater ecotoxicity impacts (0.234 kg,4-DCB). Diaper production and transport accounted for 7.69% and 0.29%, respectively.

Marine ecotoxicity

Once again, unsanitary landfilling was the major contributor to marine ecotoxicity at 92.7%. This may be attributed to the uncontrolled release of leachate that is formed in the landfill.

Human carcinogenic toxicity

Unsanitary landfilling of diapers was virtually the only contributor to human carcinogenic toxicity, contributing 99.8%. This may be attributed to the emission of carcinogenic gases from the landfill in the form of volatile and semi-volatile organic compounds which are characteristic of landfill gases.[13]

Human non-carcinogenic toxicity

Diaper production contributed 73.7% to human non-carcinogenic toxicity, whilst the waste scenario contributed 23.4% to the total emissions. A variety of contributors arising from the diaper production stage, including DM electricity, PP components and SAP, were identified.

Land use

Pulp was the major contributor (97.1%) to land use. This is to be expected as the production of pulp is dependent on the growing and harvesting of softwood trees.

Mineral resource scarcity

Diaper production was the only contributor to mineral resource scarcity. PP components manufactured in South Africa were significant contributors, accounting for 55.6%. The waste scenario was not a contributor. This can be attributed to the fact that the diaper disposal methods do not require any mineral resources to be executed.

Fossil resource scarcity

The total fossil resource scarcity emissions were 0.211 kg oil eq. A variety of DM production materials and processes contributed to this impact category, including plastic polymer production, DM electricity and SAP. Transport to distributors was a minor contributor.

Water consumption

As was to be expected, the top contributor was pulp (33.9%) due to water consumption during farming and pulp production. This was followed by SAP which contributed 18.9%.

Table 4: Life cycle impact assessment normalisation results

Impact category	Total
Global warming	7.62E-05
Stratospheric ozone depletion	5.32E-06
Ionising radiation	3.17E-05
Ozone formation, human health	1.14E-04
Fine particulate matter formation	4.96E-05
Ozone formation, terrestrial ecosystems	1.35E-04
Terrestrial acidification	8.26E-05
Freshwater eutrophication	8.48E-04
Marine eutrophication	6.67E-06
Terrestrial ecotoxicity	1.14E-04
Freshwater ecotoxicity	9.29E-03
Marine ecotoxicity	8.02E-03
Human carcinogenic toxicity	1.79E+00
Human non-carcinogenic toxicity	2.61E-05
Land use	1.49E-05
Mineral resource scarcity	1.24E-08
Fossil resource scarcity	2.23E-04
Water consumption	1.96E-05

Normalisation

Normalisation calculates the magnitude of an impact relative to a reference value. In this case, global reference values were used. The results of the normalisation can be seen in Table 4. From this, the most significant impact is human carcinogenic toxicity. Unsanitary landfilling of diapers was virtually the only contributor to human carcinogenic toxicity, contributing 99.8%. Thus, whilst waste disposal was not a major contributor across all the impact categories, it had the largest impact when translated into real-world terms. The waste scenario was also a major contributor to freshwater and marine exotoxicity, which also had relatively significant impacts upon the exclusion of human carcinogenic toxicity. Once again, these were dominated by unsanitary landfilling of diapers accounting for 92.0% and 92.7%, respectively. However, this does not mean that the other categories should be completely ignored; instead, the normalisation highlights hot spots for improvement.

Further results

Pit latrine modelling choice

Pit latrines are essentially pits that are dug for the purpose of human defecation. A shelter is often built around the hole, which may include an air vent. Once the pit is almost full, the waste is covered with soil and another pit is dug.

As mentioned in 'End of life', in the base case, waste scenario disposal in pit latrines was modelled as a dummy treatment. The consequences of these choices were investigated by modelling pit latrines as open dumping and unsanitary landfill and thus as waste scenarios 2 and 3, respectively.

As can be seen in Figure 3, no changes in impacts are observed for some of the impact categories, including ozone formation, fine particulate matter formation and ionising radiation. In the cases in which changes

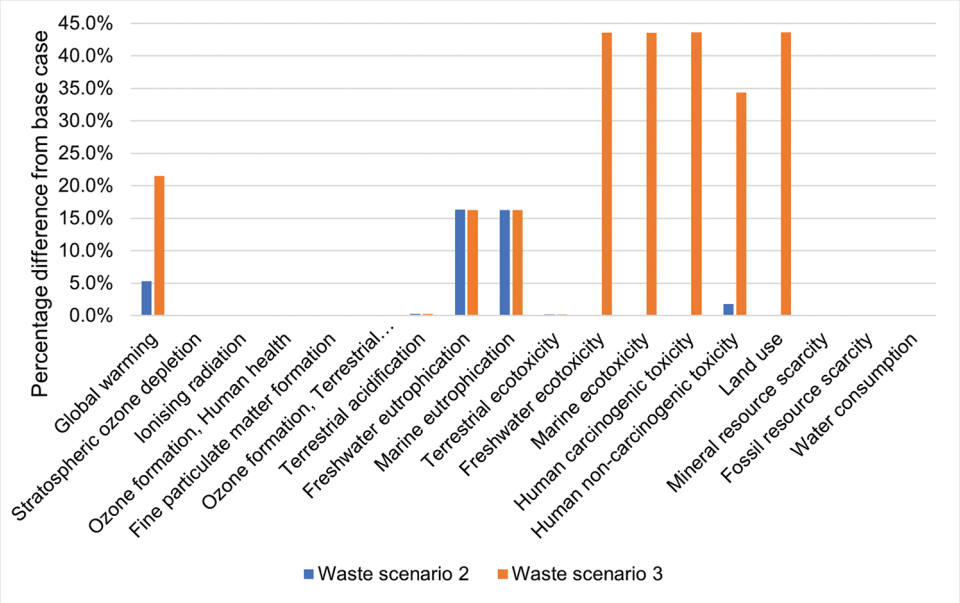

Figure 3: Comparing modelling choices for pit latrines.

were observed, waste scenario 3 had the highest increases in impacts. Waste scenario 3 was particularly significant for human toxicity and ecotoxicity. Thus, the modelling choice for pit latrines is significant when it comes to waste scenario emissions.

Improper diaper disposal

As mentioned in 'End of life', it was not possible to accurately portray the end-of-life impacts within the LCA. In particular, the impacts of improper disposal of excreta in the environment were not addressed. In K2C, only 12.8% of the respondents reported emptying the stool before diaper disposal, meaning the bulk of diapers were disposed of with stool in them. This is a danger to the environment as well as to human and animal health. Used diapers carry viruses and diseases, and their proper disposal is essential to limit human exposure to these.[14-16] Excreta has been associated with many diseases, including cholera, typhoid and hepatitis.

Burning diapers releases a variety of pollutants, including carcinogens such as dioxins and greenhouse gases.[15] It is a difficult process due to the wetness of the excreta. This may result in a residue that may be ingested by dogs or other animals such as goats and cows. Furthermore, the ash created can leach pathogens into surface and groundwater sources when it rains.[16]

Burying, whilst it puts the waste out of sight and less available to humans and animals, has the potential to contaminate groundwater sources with pathogens.[14,16] This is similar to unsanitary landfilling and open dumping where there is no leachate control, so it is free to absorb into the soil and potentially contaminate groundwater. Furthermore, gases that permeate through the landfill and are released into the air may contain harmful pollutants.

Open dumping leaves diapers out in the open, which may attract dogs and small children. This results in exposure to diseases as described earlier and, additionally, creates the risk of ingestion by animals. Another route for potential risk to health is the dumping of diapers next to rivers or onto dry riverbeds. This has the potential to directly contaminate the river water when the river starts to flow again. This is a significant risk to community members who rely on the river as a water source. Dumping in rivers also has the potential to damage infrastructure such as bridges, as reported by municipal officials. This damage was attributed to flash floods that occur when the waste dam blocks a river and the water eventually breaks through.

A pit latrine has the potential to leach into underground water sources, thus contaminating them. Further, the disposal of diapers in a pit latrine results in the pit filling up quickly, requiring more to be dug.

Interpretation

Across the life cycle of diapers, the production phase was the main contributor to impacts, except for freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity, which were also the impacts with the highest relative importance. Aumónier et al.[3] also found the production of diapers to contribute the most to environmental impacts. During the production phase, manufacturing electricity was consistently a top contributor across the majority of impacts. This raised the contribution of the diaper manufacturing phase, which is the opposite of what Mendoza et al.[7] found in their study. The electricity impacts can be attributed to the fact that South Africa's generation of energy is predominantly based on local coal deposits. Consequently, electricity being a top contributor is a situation unique to the South African context.

The absorbent core was also found to be a top contributor to impacts. In the case of SAP, its production could be traced as the primary contributor to impacts. This is similar to the results obtained by Mendoza et al.[7], who found pulp and SAP together contributed 44% to 88% of impacts. The pulp also played a notable role in impacts associated with the ecosystem. Pulp was found to be the top contributor across the majority of impacts by Cordella et al.[6] (from 29% for global warming potential to 96% for cumulative energy demand renewable), with SAP being the second most significant. The contributions of SAP and pulp can be influenced by the ratios of the absorbent core. In this case, the pulp:SAP ratio is 1:0.92, whereas Mendoza et al.[7] reported a ratio of 1:4. Some studies have been conducted on the efficacy of changing the ratio of SAP:pulp in diapers, finding that a reduction in materials leads to a reduction in environmental impacts.[6,7]

The emergence of these processes highlights potential hot spots for improvement. In terms of electricity, the diaper manufacturing factory can look towards using renewable energy sources and, thus, reducing reliance on the national grid, which is already strained.[17]

Whilst there is a national push for the use of locally produced materials, it is important to note the potential impacts associated with such a shift. This was demonstrated by the features of locally produced PP components, for example, flap material as a notable contributor in many impact categories. This can be attributed to the fact that the precursor for PP is a by-product of coal processing via the Fischer–Tropsch process. Chitaka et al.[18] found that PP produced in South Africa had higher global warming potential than the production of the same material in the USA and Europe. Thus, the push for localisation comes with additional environmental burdens.

Diaper disposal was dominant in only three impact categories: freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity. However, the importance of these categories was shown to be significant after normalisation. It is important to note that diapers can take up to 500 years to decompose; thus, they are largely inert in landfills and dumps.[19] Furthermore, the impact assessment methodology chosen has only a 100-year time frame.

Diaper disposal presents a greater scope of impacts than can be assessed by current LCA models, and research is required to address this limitation. As discussed under 'Further results', improper diaper disposal presents a real threat to the health and safety of humans and animals. Thus, when developing interventions to reduce the environmental impacts of disposable diapers, emphasis should be placed on waste disposal. Cordella et al.[6] recommend better disposal methods, such as recycling, to reduce end-of-life impacts. However, developing countries have much further to go. Improvements need to be made in service delivery, where the waste is actually collected before treatment options can be discussed.

Conclusions

Diaper production, from cradle to gate, accounted for the majority of impacts on average (>65%), except for freshwater ecotoxicity, marine ecotoxicity and human carcinogenic toxicity. In these three cases, the disposal of diapers was the highest contributor, accounting for 92.0% to 99.8%. Based on the normalisation, the most significant impacts from disposable diapers are those contributing to human and ecological toxicity. Thus, it is important to address these impacts. In order to do this, there needs to be proper waste management of diaper waste. Therefore, interventions to address the impacts of diapers should be focused on the proper management of used diapers. For example, improvement in waste management service delivery to the villages and improved landfill conditions before more high-tech solutions can be considered.

Local electricity used in the manufacture of diapers is a top contributor to the majority of impact categories, including global warming potential (24.3%), stratospheric ozone depletion (34.8%), fine particulate matter formation (33.5%) and terrestrial acidification (41.7%). This indicates the need for increased energy efficiency and a shift towards renewable sources of energy.

The absorbent core is another area that can be earmarked for improvement. This may be in the form of material reduction or substitution of materials, which may lead to the potential impact reduction results that have been demonstrated by previous studies.[6,7]

In rural areas, the impacts of disposable diapers extend beyond what can be captured by a LCA. Thus, there needs to be further research as to how these impacts can be integrated into LCIA methodology. Finally, it is important to consider the wider consequences of the use and disposal of diapers in different geographical contexts.

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Data availability

The data supporting the results of this study are confidential and are not available in any format.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. Ethical approval was received from the Humanities and Social Science Research Ethics Committee of the University of the Western Cape (HSSREC Reference Number: HS22/1/2).

Authors' contributions

T.Y.C.: Conceptualisation, methodology, data collection, data analysis, writing – original draft, writing – revisions. C.N.: Conceptualisation, data collection, project management, writing – revisions. C.S.: Conceptualisation, funding acquisition, supervision, writing – revisions, project leadership. All authors read and approved the final manuscript.

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Radiological risk assessment of cement used in contemporary South African buildings

Using a calibrated NaI(Tl) and a well-shielded detector connected to a computer-resident quantum multichannel analyser, the radionuclide contents of primordial radionuclides (^{226}Ra, ^{232}Th and ^{40}K) were evaluated in commonly used cement brands in South Africa, and the associated radiation risk parameters were calculated. The reported activity concentrations varied from 8.00 ± 2.83 to 45.00 ± 2.79 Bq/kg, 12.00 ± 0.90 to 32.00 ± 0.51 Bq/kg and 454.00 ± 0.56 to 1765.00 ± 0.93 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K, respectively. The absorbed gamma dose rate, annual effective dose equivalent, annual gonadal dose equivalent, excess lifetime cancer risk, gamma index and alpha index were utilised as the radiological health impact metrics to evaluate the potential radiation risks. The determined radiological health impact parameter results were below the relevant radiation safety authorities' recommended reference levels for building materials. Therefore, the use of cement products as building materials presents no significant risk in the study areas.

Significance:

The results of this study contribute to understanding the radiological risks associated with different brands of commonly used cement in South Africa and provide fundamental data for the activity concentrations of primordial radionuclides ^{226}Ra, ^{232}Th and ^{40}K. These studies have been instructive from a building materials radiation safety viewpoint and reveal that the assessed risk parameters fall within the recommended safety limits. This is significant from the perspective of environmental health and radiological protection concerning the safe use of the studied cement. The methodology and findings can also inform similar studies in other regions, enhancing global awareness of material safety standards.

Introduction

It is indeed of great significance to have a better knowledge of the risk associated with the radiation emitted from dwellings due to the various building materials that contain radionuclides of different types, which constitute radiation exposure to the resident.[1] The radiation exposure takes place daily, and the capability of radionuclides to quickly find their way into the air makes them be transferred into human environments.[2,3] Most humans spend approximately 80% of their lifetime indoors, so assessing the radionuclide contents in cement used as building materials and related radiological health hazards for humans is essential.[4] Naturally occurring radionuclides of primordial origin in types of cement used as building materials are responsible for irradiation in dwellings.[5] The radiations come from potassium-40 and gamma radiation from the uranium and thorium families.[6] Gamma radiation exposure causes external exposure when it is directly absorbed.[7] Internal exposure, however, is brought on by radium-226 and thorium-232, as well as their daughter nuclides, including radon-222 and thoron-220, and their progenies.[8] Varying degrees of radiation exposure in man have been reported to lead to deterministic and stochastic effects, including cancer and genetic defects such as chromosome aberrations and mutation.[9,10]

The South African population has increased annually by about 2% since 1980.[11] In the same vein, South Africa's sales of types of cement have progressively increased from 7 million tonnes in 1980 to 11 million tonnes in 2010.[12] There is a clear indication of a corresponding increase in demand for housing as a basic human need due to population increase. Therefore, to cater to the ever-increasing demand for housing by the populace, increased demands for construction materials are inevitable. In both rural and urban areas of South Africa, cement is one of the most essential building materials used to construct homes and other structures.[13] It is used in concrete and block production, flooring and covering of the building floors and walls.[13] Thus, cement has played and will keep on playing significant roles in meeting South Africa's developmental agenda because buildings with cement as an essential component are virtually everywhere.[14] Buildings must contain cement because of its many beneficial properties, such as its 'bond'-like function, its role in filling the spaces between fine and coarse aggregates and its hydration reaction properties that allow buildings to gain strength continuously[15], and until now, no suitable materials with better or similar qualities have been discovered as an alternative to cement in buildings.

The research on primordial radionuclide concentrations in cement used as building materials in numerous countries throughout the world has garnered much attention over the years.[16-18] The determination of radioactivity concentrations in cement is essential to assess the possible radiological health hazards to residents and to develop radiation protection strategies and reference levels for optimising the protection of the public when using and managing cement as a building material, as required by the International Atomic Energy Agency's (IAEA) General Safety Requirements (GSR) Part 3.[19] The study emphasises the importance of investigating radiation exposure from building materials containing radionuclides to understand and mitigate associated risks, aligning with the IAEA GSR Part 3 frameworks and the International Commission on Radiological Protection (ICRP) Publication 103.[19,20] Therefore, we sought to evaluate the radiological health and safety risks associated with radiation exposure due to the radioactivity concentrations of the primordial radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in cement commonly used for buildings in South Africa.

Materials and methods

Collection and preparation of samples

Samples of cement were obtained from multiple suppliers of building materials in Pietermaritzburg, South Africa. The sampling was purposive, focusing on commonly used brands in the area that represent a significant portion of the market. Specifically, cement samples were collected from suppliers stocking products from the Pretoria Portland Cement Company (PPC), Natal Portland Cement Company (NPC) and Dangote Cement South Africa (Sephaku). These brands were selected based on their prevalence and representation in the local construction industry. The sample size was determined based on practical considerations and standard practices in environmental and materials science research.[2,18] The collected samples were air-dried and sieved with a 2-mm mesh for homogeneity. An amount of 200 g of each sample was placed in Marinelli bottles with the same shape as the reference material for gamma spectrometric analysis. The bottles were well-labelled and sealed tightly with tape to prevent radon escape. There were a total of seven samples divided among three popular cement brands.

Gamma spectrometric analysis

The radioactivity concentrations of the naturally occurring radionuclides in the studied samples were measured with a thallium-doped sodium iodide (NaI(Tl)) gamma-ray spectrometric system at the Radiation Physics Research Laboratory of the University of Medical Sciences, Ondo, Ondo State, Nigeria. A multichannel computer-resident quantum analyser (MCA2100R) and a well-shielded detector were attached to the system. Spectral analysis was done using Palmtop MCA computer gamma analysis software (Model: MCA8k-01, Serial: 0202).

The reference standard source for the detector efficiency calibration was the Analytical Quality Control Service (AQCS, USA), which validated the activities of the radionuclides of interest.

The efficiency calibration was conducted by acquiring a calibration standard spectrum until the total absorption peak count rate was determined with a statistical uncertainty of less than 1% at a 95% confidence level. For the calculation of photo peaks, the net count rate was established to evaluate the output for all the energies used during the measurement. The output was then correlated with the count rate and the standard source using Equation 1[21]:

$$E_\gamma = \frac{N_E}{S_c \times \gamma_E \times t_c} \qquad \text{Equation 1}$$

where N_E is the full energy peak net count, E_γ is the energy probability of gamma photons, γ_E is the probability of gamma emission, S_c is the activity of the standard source, while the counting time is t_c.

Gamma rays emitted from the standard reference source were measured, and the resulting spectrum was used to create the efficiency curve. Subsequently, power fitting was applied to optimise the R^2-value, as depicted in Figure 1.

The samples being counted had the same geometry as the standard references. The gamma transition energies of 1764.5, 2614 and 1640.8 keV were used to estimate the sample's radioactivity levels for ^{226}Ra, ^{232}Th and ^{40}K. Each sample was counted for 36 000 s (10 h). The counting time of 10 h (36 000 s) is selected to achieve high statistical accuracy by accumulating a large number of photon counts. This extended duration helps minimise statistical uncertainties in the measured gamma spectra, ensuring precise determination of radionuclide concentrations in the cement samples.[22]

Equation 2 was used to calculate the radioactivity concentration of the radionuclide from a measurement of the detector's efficiency[23-25]:

$$C_{sp} = \frac{N_{sam}}{P_E \cdot \varepsilon \cdot T_c \cdot M} \qquad \text{Equation 2}$$

where ε is the detection system's overall counting efficiency, C_{sp} is the activity concentration of the radionuclides of interest in Bq/kg, N_{sam} is the radionuclide's net count in the sample, P_E is the probability of gamma ray emission (gamma yield), M is the sample's mass (in kg) and T_c is the sample counting time. The Data Analytical tool in Microsoft Excel 2010 running on Windows 10 was used for statistical analysis. To determine the minimum detection limit (MDL) for radionuclides ^{226}Ra, ^{232}Th and ^{40}K using gamma spectrometry, the background counts and the system's detection efficiency were evaluated. This calculation yields the smallest detectable radioactivity level above the background noise. The gamma spectrometric system's MDLs for ^{226}Ra, ^{232}Th and ^{40}K were 0.69, 0.78 and 2.35 Bq/kg, respectively. The MDL values provided signify the system's sensitivity to detect these radionuclides at extremely low levels, reflecting its capability under defined measurement conditions.

Radiological health hazard indices assessment

In cement samples from the study area, activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K have been studied for potential radiological risks that could impact human health due to radiation exposure. The radiological health impact metrics examined are the absorbed gamma dose rate, annual effective dose equivalent, annual gonadal dose equivalent (AGDE), excess lifetime cancer risk (ELCR), gamma index and alpha index.

Absorbed gamma dose rate

The following equations were applied to the measured activity concentrations to calculate the indoor and outdoor absorbed gamma dose rates (D_{in} and D_{out}) produced by gamma radiation caused by ^{226}Ra, ^{232}Th and ^{40}K at a height of 1 m above the ground[26]:

$$D_{in}(nGyh^{-1}) = 0.92\,C_{Ra\text{-}226} + 1.1\,C_{Th\text{-}232} + 0.081C_{K\text{-}40} \qquad \text{Equation 2a}$$

$$D_{out}(nGyh^{-1}) = 0.462\,C_{Ra\text{-}226} + 0.0604\,C_{Th\text{-}232} + 0.0417\,C_{K\text{-}40} \qquad \text{Equation 2b}$$

where the conversion factors for the doses associated with the radioactive concentrations of ^{226}Ra, ^{232}Th and ^{40}K for materials used as

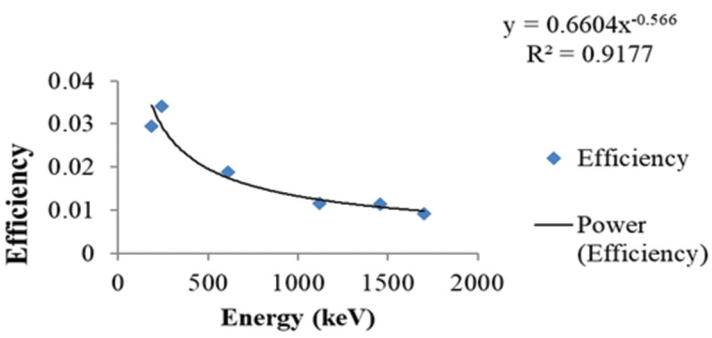

Figure 1: Efficiency calibration curve showing the detection efficiency of the detector.

building materials are 0.92, 1.1, 0.081, 0.462, 0.0604 and 0.0417 in nGyh^{-1}/Bq/kg for indoor and outdoor, respectively.

Annual effective dose

The annual effective dose (E) has been calculated using Equation 3a–3c[26,27]:

$$E_{in}(\mu Svy^{-1}) = 4.91 \times D_{in}(nGyh^{-1}) \quad \text{Equation 3a}$$

$$E_{out}(\mu Svy^{-1}) = 1.23 \times D_{out}(nGyh^{-1}) \quad \text{Equation 3b}$$

$$E_{tot}(\mu Svy^{-1}) = E_{in} + E_{out} \quad \text{Equation 3c}$$

The annual effective doses for indoor, outdoor and total exposure are E_{in}, E_{out} and E_{tot}, respectively. The annual effective dose (E) was estimated using the following factors: the number of hours in a year (8610), the percentage of time spent indoors and outdoors (0.8 and 0.2) and the dose conversion factor of 0.7 Sv.Gy^{-1},[26] from the air-absorbed dose rate to an effective dose.

Annual gonadal dose equivalent

The exceptionally high radiosensitivity of the human gonads, bone marrow and bone surface cells makes them organs of interest.[28] To calculate the AGDE, Equation 4 was utilised[28]:

$$AGDE\ (\mu Svy^{-1}) = 3.09C_{Ra\text{-}226} + 4.18C_{Th\text{-}232} + 0.0314C_{K\text{-}40} \quad \text{Equation 4}$$

where $C_{Ra\text{-}226}$, $C_{Th\text{-}232}$ and $C_{K\text{-}40}$ are ^{226}Ra, ^{232}Th and ^{40}K activity concentrations in Bq/kg, respectively. Values 3.09, 4.18 and 0.0314 are the conversion factors for the doses associated with the radioactive concentrations of ^{226}Ra, ^{232}Th and ^{40}K in materials used as building materials, respectively.

Gamma index and alpha index

To determine if the cement had complied with the radiological safety criteria for construction materials, the gamma index (I_γ) was calculated using the following equation[29]:

$$I_\gamma = {}^{C_{Ra}}\!/_{300} + {}^{C_{Th}}\!/_{200} + {}^{C_{K}}\!/_{3000} \quad \text{Equation 5a}$$

The alpha index (I_α), which symbolises the surplus alpha radiation brought on by breathing in radon-222 from the cement, was calculated using Equation 5b.

$$I_\alpha = {}^{C_{Ra}}\!/_{200} \quad \text{Equation 5b}$$

Table 1: The reported ^{226}Ra, ^{232}Th and ^{40}K levels in the cement samples

Sample ID	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
NPC 1	22.00 ± 2.51	20.00 ± 3.59	1662.00 ± 1.15
NPC 2	15.00 ± 2.64	32.00 ± 0.51	569.00 ± 0.72
NPC 3	8.00 ± 2.83	12.00 ± 0.90	1765.00 ± 0.93
Mean	15.00 ± 2.66	21.33 ± 1.66	1332.00 ± 0.94
Alpine 1	54.00 ± 4.80	29.00 ± 0.42	454.00 ± 0.56
Alpine 2	16.00 ± 4.70	25.00 ± 0.24	1285.00 ± 1.73
Alpine 3	35.00 ± 2.41	17.00 ± 0.48	1195.00 ± 1.33
Mean	35.00 ± 3.97	23.67 ± 0.38	978.00 ± 1.21
Dangote	45.00 ± 2.79	15.00 ± 1.28	1249.00 ± 0.63

where $C_{Ra\text{-}226}$, $C_{Th\text{-}232}$ and $C_{K\text{-}40}$ are ^{226}Ra, ^{232}Th and ^{40}K activity concentrations in Bq/kg, respectively. 300, 200 and 3000 are the dose conversion factors associated with the radioactive concentrations of ^{226}Ra, ^{232}Th and ^{40}K for materials used as building materials for gamma index, while 200 is the dose conversion factor associated with the radioactive concentrations of ^{226}Ra in building materials for alpha index.

Excess lifetime cancer risk

The annual effective dose (E) values computed as specified in Equation 6a–6c were used to calculate the ELCRs[26,30]:

$$ELCR_{in} = E_{in} \times D_l \times R_f \quad \text{Equation 6a}$$

$$ELCR_{out} = E_{out} \times D_l \times R_f \quad \text{Equation 6b}$$

$$ELCR_{tot} = ELCR_{in} + ELCR_{out} \quad \text{Equation 6c}$$

R_f and D_l are the fatal cancer risk factors for stochastic effect (estimated 0.05 Sv^{-1} for the general public) and lifetime duration (65.10 years for South Africa), respectively.

Results and discussion

Natural radioactivity concentrations

As shown in Table 1, the measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in cement samples are unevenly distributed.

The average activity concentration of ^{226}Ra in the cement samples was 27.857 Bq/kg, ranging from 8.00 ± 2.83 to 45.00 ± 2.79 Bq/kg. Dangote Cement (Sephaku) had the highest value of ^{226}Ra, while NPC 3 had the lowest value. With an average value of 21.43 Bq/kg, the measured activity concentrations of ^{232}Th in the cement samples ranged from 12.00 ± 0.90 to 32.00 ± 0.51 Bq/kg. NPC 2 and NPC 3 contained the highest and lowest results for ^{232}Th, respectively. With an average value of 1168.43 Bq/kg, the recorded activity concentrations of ^{40}K in the cement samples ranged from 454.00 ± 0.56 to 1765.00 ± 0.93 Bq/kg. Pretoria Portland cement (Alpine 1) had the lowest value, whereas NPC 3 had the highest value for ^{40}K, respectively. The world average values of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in building materials are 50, 50 and 500 Bq/kg, respectively.[28] Alpine 1 had ^{226}Ra activity concentration value of 54.00 ± 4.80 Bq/kg, which is slightly higher than the world average value. The measured values and averages of the activity concentrations for ^{226}Ra and ^{232}Th in virtually all of the examined cement samples were found to be lower than the world average values. The average activity concentrations of ^{40}K in all the examined cement samples were found to be higher than the world average values, except for Alpine 1, which had an activity concentration value of 454.00 ± 0.56 Bq/kg, slightly lower than the world average. In general, the mean activity concentrations of ^{40}K were the highest in all the cement samples compared to the other two naturally occurring radionuclides (^{226}Ra and ^{232}Th), respectively. This is typical and expected from any geologically derived materials because potash feldspar minerals are relatively enriched in the natural environment.[31] The concentrations of ^{226}Ra, ^{232}Th and ^{40}K in cement samples from the study locations are depicted in Figure 2.

The results of earlier research from various parts of the world were also compared with the calculated average values of the activity concentrations of naturally occurring radionuclides in the studied cement samples. Table 2 displays the comparison.

Radiological hazard indices

Table 3 displays the findings of the assessed radiological health hazard parameters. The table shows that the assessed indoor and outdoor absorbed gamma dose rates (D_{in} and D_{out}) varied from 95.089 to 176.862 nGyh^{-1} and 49.985 to 91.549 nGyh^{-1}. All of the cement samples' indoor absorbed gamma dose rates were above the population-weighted average of 84 nGyh^{-1}.[26] The annual effective dose for indoor, outdoor

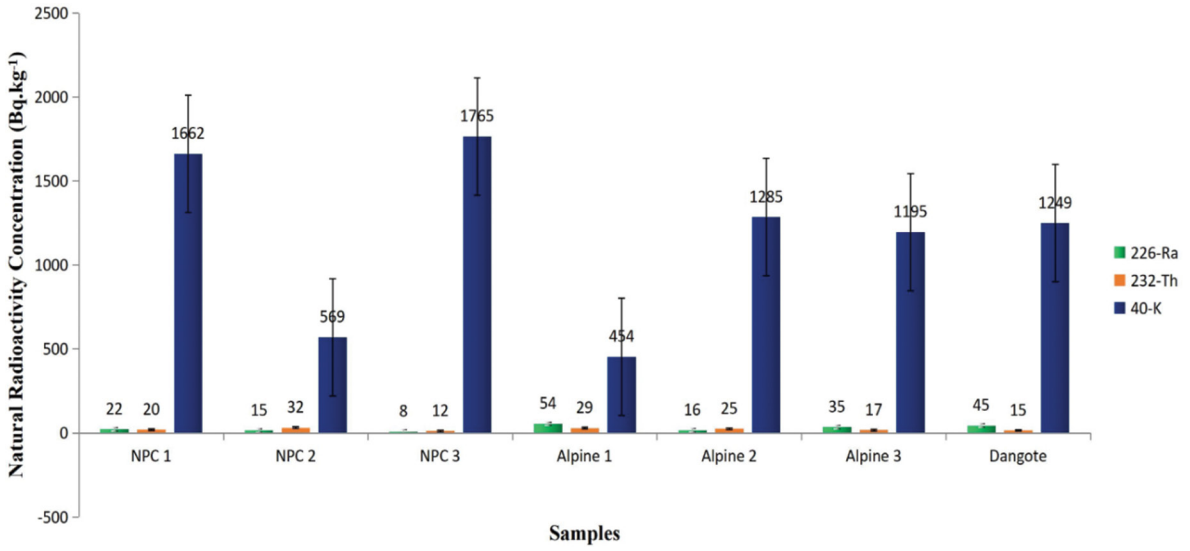

Figure 2: Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K activity in the cement samples under study.

Table 2: Comparing the average concentrations of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in cement samples to those discovered in other countries

Sample ID	Country	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Reference
NPC	South Africa	15.00 ± 2.66	21.33 ± 1.66	1332.00 ± 0.94	Present study
Alpine	South Africa	35.00 ± 3.97	23.67 ± 0.38	978.00 ± 1.21	Present study
Dangote	South Africa	45.00 ± 2.79	15.00 ± 1.28	1249.00 ± 0.63	Present study
Cement sample	Albania	179.70 ± 8.90	55.00 ± 5.80	17.00 ± 3.30	32
Cement sample	Algeria	41.00 ± 7.00	27.00 ± 3.00	422.00 ± 3.00	33
Cement sample	Bangladesh	61.00	65.00	952.00	34
Cement sample	Cameroon	27.00 ± 4.00	15.00 ± 1.00	277.00 ± 117.00	35
Cement sample	China	118.70 ± 14.20	36.10 ± 17.80	444.50 ± 163.10	36
Cement sample	China	59.00	39.00	181.00	37
Cement sample	Egypt	36.00 ± 4.00	43.00 ± 2.00	82.00 ± 4.00	38
Cement sample	Egypt	134.00	88.00	416.00	39
Cement sample	Ghana	35.94 ± 0.78	25.44 ± 0.80	233.00 ± 3.95	40
Cement sample	India	26.00	29.00	260.00	41
Cement sample	Iraq	24.25 ± 1.45	25.41 ± 1.65	93.17 ± 7.30	42
Cement sample	Laos	41.12 ± 2.44	16.60 ± 2.37	141.48 ± 4.50	43
Cement sample	Malaysia	29.00 ± 7.00	31.00 ± 9.00	205.00 ± 71.00	44
Cement sample	Morocco	31.00 ± 5.00	19.00 ± 3.00	238.00 ± 13.00	45
Cement sample	Nigeria	20.00	8.00	51	46
Cement sample	Pakistan	25.00 ± 10.00	37.00 ± 9.00	245.00 ± 95.00	47
Cement sample	Serbia	37.00	15.00	43.00	48
Cement sample	Senegal	112.69 ± 26.02	13.12 ± 1.88	73.35 ± 18.12	49
Cement sample	Turkey	34.00 ± 4.00	15.00 ± 2.00	220.00 ± 13.00	50
Cement sample	Turkey	26.00	10.00	130.00	51
Building materials	World average	50	50	500	28

Table 3: Calculated radiological health hazard indices

Sample ID	D_{in} (nGyh^{-1})	D_{out} (nGyh^{-1})	E_{in} (μSvy^{-1})	E_{out} (μSvy^{-1})	E_{tot} (μSvy^{-1})	AGDE (μSvy^{-1})	I_γ	I_α	$ELCR_{in}\times 10^{-3}$	$ELCR_{out}\times 10^{-3}$	$ELCR_{tot}\times 10^{-3}$
NPC 1	176.862	91.549	868.392	112.606	980.998	203.767	0.727	0.110	2.827	0.367	3.193
NPC 2	95.089	49.985	466.887	61.482	528.369	197.977	0.400	0.075	1.520	0.200	1.720
NPC 3	163.525	84.545	802.908	103.990	906.898	130.301	0.675	0.040	2.613	0.338	2.952
Mean	145.159	75.360	712.729	92.692	805.422	177.348	0.601	0.075	2.320	0.302	2.622
Alpine 1	118.354	61.396	581.118	75.517	656.635	302.336	0.476	0.270	1.892	0.246	2.137
Alpine 2	146.305	76.077	718.358	93.574	811.932	194.289	0.607	0.080	2.338	0.305	2.643
Alpine 3	147.695	76.270	725.183	93.811	818.994	216.733	0.600	0.175	2.360	0.305	2.666
Mean	137.451	71.247	674.886	87.634	762.520	237.786	0.561	0.175	2.197	0.285	2.482
Dangote	159.069	81.933	781.029	100.778	881.807	240.969	0.641	0.225	2.542	0.328	2.870

and total exposure ranged from 466.887 to 868.392 μSvy^{-1}, 61.482 to 112.606 μSvy^{-1} and 528.369 to 980.998 μSvy^{-1}, respectively. In NPC 1 and NPC 2, the highest and lowest values of the indoor and outdoor absorbed gamma dose rate and the indoor, outdoor and total annual effective dose were recorded. All of the samples' annual effective dose values were below the reference level of 1000 μSvy^{-1}.[26] The AGDE ranged from 130.301 to 302.336 μSvy^{-1}. While NPC 3 had the lowest value, PPC (Alpine 1) had the highest value of AGDE. Except for Alpine 1, whose yearly gonadal dose equivalent value was slightly higher at 302.336 μSvy^{-1}. All of the samples' recorded values were below the 300 μSvy^{-1} world average. The alpha index (I_α) ranged from 0.040 to 0.270, and the gamma index (I_γ) ranged from 0.040 to 0.727.

The gamma (I_γ) and alpha (I_α) index values fell below the recommended upper limit of unity.[52] For indoor ($ELCR_{in}$), outdoor ($ELCR_{out}$) and total ($ELCR_{tot}$) ELCR, respectively, the ELCR values ranged from 1.520×10^{-3} to 2.827×10^{-3}, 0.200×10^{-3} to 0.367×10^{-3} and 1.720×10^{-3} to 3.193×10^{-3}. The $ELCR_{in}$ and $ELCR_{tot}$ reported in this study are higher than the world average values of 0.29×10^{-3} and 1.45×10^{-3} reported by Mohammed and Ahmed.[53] The values of ELCR equivalent to 1000, 100, 10 and 1 μSvy^{-1} will increase the chance of developing fatal cancer by 4%, 0.4%, 0.04% and 0.004%, respectively.[44,54] The values of the risk obtained for this study are within the acceptable risk limits.

Conclusion

According to the study, there were uneven distributions of the measured natural radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the cement samples. In almost all of the analysed cement samples, the measured values and averages of the activity concentrations for ^{226}Ra and ^{232}Th were lower than the global average. In contrast, in almost all of the analysed cement samples, the observed values and average activity concentrations for ^{40}K were higher than the global average levels provided by the UNSCEAR 2000 Report. The findings show that ^{40}K is the radionuclide in the environment with the highest measured radioactivity content. Radiological health impact measures, including absorbed gamma dose rate, annual effective dose, AGDE, ELCR, gamma index, and alpha index, were established to evaluate the potential radiation risks. The cement samples' indoor absorbed gamma radiation rates were higher than the population-weighted global average of 84 nGyh^{-1} provided by the UNSCEAR in 2000. The annual effective dose and annual gonadal dose equivalent values for all the samples were lower than the reference level of 1000 μSvy^{-1} and the world average value of 300 μSvy^{-1}, respectively. The gamma index (I_γ) and alpha index (I_α) values were all below the reference level of unity. Even if all of the determined ELCRs are higher than the global average value, there is very little chance that this will increase cancer risk in the long run. However, ^{40}K naturally occurring radioactivity content was higher than the global average, which could serve as a warning to the radiation safety authority.

Data availability

The data supporting the results of this study are available upon request to the corresponding author.

Declarations

This study was carried out as part of O.Y.O.'s PhD research under the supervision of N.C. and co-supervision of A.O.I. at the University of KwaZulu-Natal, South Africa. We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

O.Y.O.: Collected the samples and prepared them for gamma ray spectrometry. N.C.: Conceived the study and supervised and guided the process of the research. A.O.I.: Co-supervised the research and participated in the spectrometric analysis. All authors read and approved the final manuscript.

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Optimising water use in copper flotation with the design of experiments and machine learning

As part of the management of water resources at the industrial level, especially with the drop in water levels caused by drought, we resort to the recycling of water in the copper flotation process at Bleida Mine in Morocco. This study aims to take into consideration both the environmental conditions in terms of the reduction in water reserves and economic conditions in terms of ensuring sufficient metal recovery. Experimental findings demonstrated that the use of recycled water has a significant impact on copper recovery and grade. For that, this impact was investigated in order to determine the optimal proportion of recycled and fresh water that can be used in the mining process to ensure sufficient metal recovery. Through the design of experiments with the integration of machine learning, especially for the choice of the model, the optimal proportion was determined, which made it possible to achieve a metal recovery of more than 80% using a 50/50 mix of fresh and recycled water. This result was confirmed with real tests by trying several proportions in the Denver flotation cell in the laboratory. This approach not only advances the field of water resource optimisation but also provides a practical experimental framework for similar applications in other industries' challenges by searching for a balance between environmental sustainability and economic efficiency.

Significance:

The use of 100% fresh water can lead to higher efficiency, but its high cost makes it economically unfeasible. However, using a mixture of 50% fresh water and 50% recycled water can be both cost-effective and efficient. Furthermore, the use of experimental designs to optimise reagents can help companies achieve the best possible efficiency despite using recycled water. Therefore, this approach can be a sustainable and cost-effective solution for companies looking to maximise their profits while reducing their environmental impact.

Introduction

In recent years, we have resorted to the use of recycled water in industry to compensate for the decline in fresh water. On the one hand, it helps conserve freshwater resources, but it also poses problems at the industrial level as this recycled water contains harmful elements that can negatively influence industrial processes, such as the copper flotation process, which is an important process used for the extraction of copper from its ores.[1-3] Among the factors that impact the efficiency of the flotation operation, we find the quality of the water used.[4-11] In recent years, there has been rising interest in using recycled water in copper flotation due to the decrease in the quantity of water in the resources.[12]

The effect of recycled water on copper flotation has been studied extensively in scientific research. Various studies have demonstrated that the use of recycled water can have a negative effect on copper flotation because it may contain contaminants that can disrupt the flotation process. Contaminants can be dissolved salts, organic compounds and minerals.[13]

To resolve this issue, researchers have focused on determining the ideal proportion of fresh water to use in copper flotation to ensure adequate efficiency.[14-16] To do this, tests on different proportions of fresh and recycled water were carried out to determine the optimal proportions that will ensure sufficient metal recovery.

Several studies[17-19] using recycled water in copper flotation have been conducted. Researchers have found that the use of recycled water can decrease copper recovery compared to fresh water and may increase the consumption of reagents as it contains elements such as calcium, magnesium and sulfate ions that react with reagents used in the flotation, and this also affects the pH and chemical composition of the flotation pulp.

However, Wang et al. found that the use of recycled water had no significant impact on recovery; even with recycled water, if the concentration of impurities was low, the effect on recovery was negligible.[20]

In addition, Feo et al.[21] studied the use of recycled water in copper flotation and found that it did not significantly affect the recovery of copper; on the contrary, it helped to reduce the consumption of fresh water and reagents because the recycled water already contained a quantity of the recycled reagents used before.

In summary, the impact of recycled water on copper flotation recovery depends on its quality, the flotation conditions and the nature of residual impurities. On the one hand, several studies have found a negative impact of recycled water on copper recovery, but on the other hand, others have found no significant impact or even a positive influence. Therefore, further research in this context is needed to fully understand the impact of recycled water on copper flotation recovery in order to achieve sufficient recovery while optimising the use of fresh water in the mining industry.

Traditional optimisation methods are mainly based on the design of experiments, which allows us to model the phenomena by mathematically linking the factors (fresh water and recycled water) with the response (metal recovery). However, a problem arises when choosing the model because all the phenomena are not linear. In the present study, to solve this challenge, machine learning was integrated into the step of choosing an adequate model during the design of experiments. By applying this approach, the optimal water proportion can be determined efficiently.

Materials and methods

To investigate the impact of different proportions of fresh and recycled water on copper flotation recovery, a series of laboratory experiments was conducted. A representative sample of the copper ore was collected and mechanically prepared by crushing, followed by grinding and then screening to achieve the liberation mesh of malachite ($Cu_2(OH)_2CO_3$), which is about 125 µm. The tests were then carried out in a Denver flotation cell in the laboratory, each time varying the proportions of fresh and recycled water.[22] Then, the experimental design was followed by selecting a range of different proportions of fresh and recycled water to be used in the experiments and systematically varying these proportions to identify the optimal ratio that provided the best recovery. During each experiment, recovery of copper and the grade of the concentrate were collected to analyse the impact of the different proportions. The data collected were then analysed using statistical graphics to identify the impact of the different proportions of fresh and recycled water on the copper flotation recovery. The results obtained from the experiments and the data analysis results were interpreted to conclude the optimal proportion of fresh and recycled water for copper flotation recovery.

To sum up, conducting a series of laboratory experiments with different proportions of fresh and recycled water is an effective way to investigate the impact of water quality on copper flotation recovery. By systematically varying the proportion of fresh and recycled water, researchers can identify the optimal ratio that provides the best results and optimise the use of water in copper flotation processes.[23,24]

The overflow from the hydrocyclone is conditioned and then fed into a flotation line where various reagents are added, such as collector, frother and activator.

Below is the flow sheet of the flotation process, which begins with a feed with a dimension of 120 µm. It undergoes two types of roughing, sulfide and then oxide, followed by cleaning, before directing the froths rich in copper towards the concentrate and the remaining material towards the gangue. The same circuit was applied at the laboratory level in a Denver flotation cell to assess the impact of water on copper recovery. All other parameters were fixed; we worked at ambient temperature and pressure and only the water proportions were changed. In this context, a data set containing the observations of metal recovery at different water proportions was collected during the tests (Figure 1).

Factor levels (proportions) and affectations are shown in Table 1.

The calculation of the number of tests is shown in Table 2.

Results and discussion

After conducting the four tests according to the complete factorial design at two levels, each test was triplicated, and the value indicated in Table 3 represents the mean.

Concerning the choice of the model, we carried out machine learning in which we trained the linear and polynomial models on a data set containing the observations of metal recovery at the different water proportions.

Table 4 presents the metrics of the two models, and we can conclude that the polynomial model is the most appropriate given the high values of *R*-squared, adjusted *R*-squared and cross-validated *R*-squared compared to the linear model as well as the lowest mean squared error, which means that the polynomial model had a lower error and better explains the relationship between factors and response.

Table 1: Low and high levels of the factors

Factor	Low level (–1)	High level (1)
Fresh water (FW)	0%	100%
Recycled water (RW)	0%	100%

The test (FW 100% and RW 100%) is an experimental constraint, brought back to an equilibrium of 50% FW and 50% RW.

Table 2: Calculation of the number of tests

Number of factors	Number of levels	Number of tests
2	2	$2^2 = 4$

Table 3: Results of tests

N° Test	Fresh water (%)	Recycled water (%)	Metal recovery (%)
1	–1	1	72.82
2	1	–1	87.55
3	1	1	81.73
4	–1	–1	0

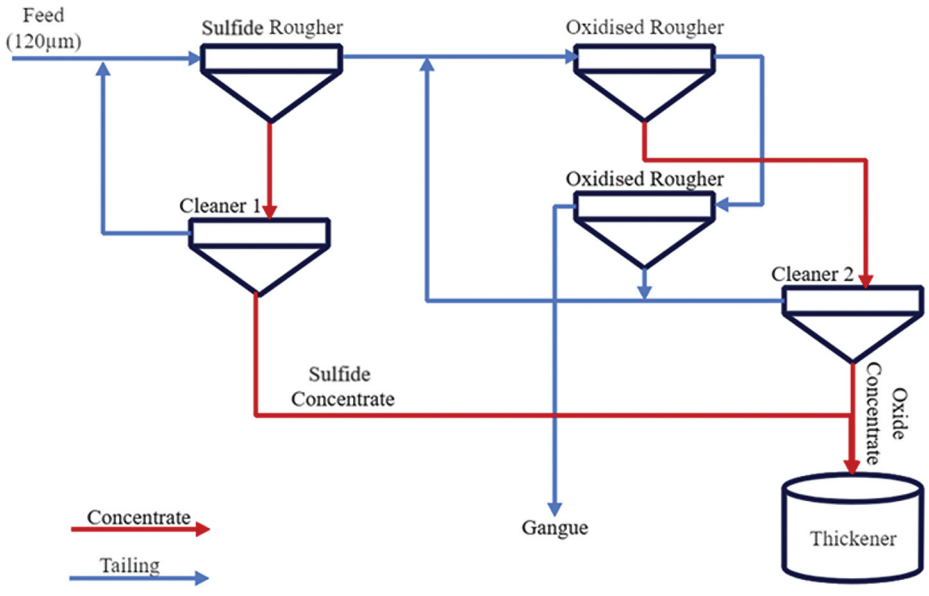

Figure 1: Flotation process flow sheet.

The postulated mathematical model is a polynomial model with respect to each factor. After calculating the main effects of fresh water (FW) and recycled water (RW) as well as the effect of their interaction, we obtained this mathematical modelling equation in uncoded units.

$$MR = 60.5250 + (24.1150) \times FW + (16.7500) \times RW + (0.0000) \times FW^2 + (-19.6600) \times FWRW + (0.0000) \times RW^2$$

This modelling equation mathematically links the response, which is metal recovery (MR), to the two factors: fresh and recycled water. Therefore, metal recovery can be predicted at any value of the factors without conducting the test. Other information that can be derived from this equation concerns the significant effect of fresh water compared to the effect of recycled water and their interaction. This is evident as its coefficient in the previous equation, in its absolute value, is higher. This observation can be confirmed by the Pareto diagram (Figure 2a) as well as the diagram of the main effects below.

These diagrams allow us to identify the most influential factor in a response: we notice that fresh water has a greater influence on turbidity because a small change significantly affects it, whereas recycled water requires larger variations to observe its effect (Figure 2b), and this confirms the result obtained with the Pareto diagram (Figure 2a).

Table 4: Results of tests

Metric	Linear regression	Polynomial regression
R-squared	0.28	0.84
Adjusted *R*-squared	0.27	0.83
Mean squared error	39.32	8.48
Cross-validated *R*-squared	–14.91	0.16

The response surface gives two points where the metal recovery is maximum (80%): the first point using the maximum fresh water and the second using a mixture of 50% fresh water and 50% recycled water (Figure 3).

It is clear that by using fresh water, the metal recovery will be at its maximum thanks to the absence of penalising elements which disrupt the flotation process, such as calcium, magnesium, sulfates and carbonates; in this case, the flotation is done under the best conditions.

By recycling the water at almost 50%, we see that the recovery is close to that obtained by using fresh water, which means that this recycled quantity is optimal for flotation, and we can explain this by saying that the dose of recycled reagents is not yet disruptive and contributes to the activation and collection of copper elements, yet the influence of other elements is not noticed.

In order to confirm this result, we first compared the kinetics of the copper grade during the flotation process for the two types of water – fresh and recycled; several tests were conducted in the laboratory. Table 5 shows the results of these tests.

Sulfide copper was better recovered using fresh water than using recycled water, while oxidised copper was better recovered using recycled water than fresh water. This can be explained by the fact that recycled water already contains a quantity of sulfates resulting from the decomposition of the activator (NaHS), which forms a first layer on the sulfide copper. When the collector is added, a double layer is formed, which depresses the sulfide copper. On the other hand, using fresh water forms a single layer, and flotation takes place under favourable conditions. The good content of oxidised copper using recycled water can be explained by the fact that it contains a quantity of decomposed sulfates, which adds to the amount of NaHS added, surrounding the oxidised copper with a sulfur layer, which leads to its activation, as the oxidation rate is around 75% (Figure 4).

After conducting several copper flotation tests with different types of water, we obtained the results shown in Table 6.

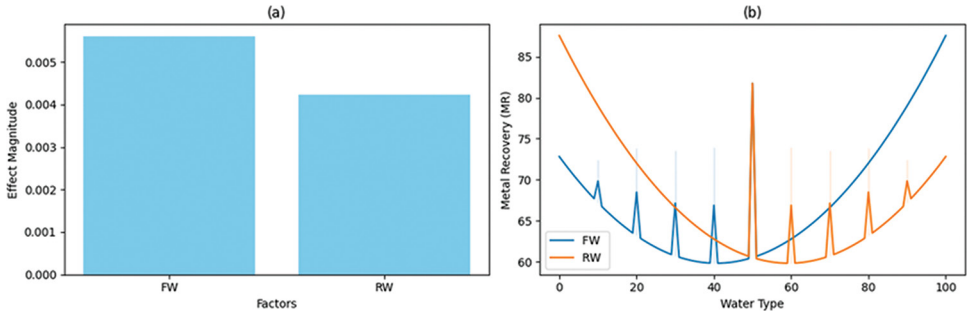

Figure 2: (a) Pareto chart; (b) main effects plot for metal recovery.

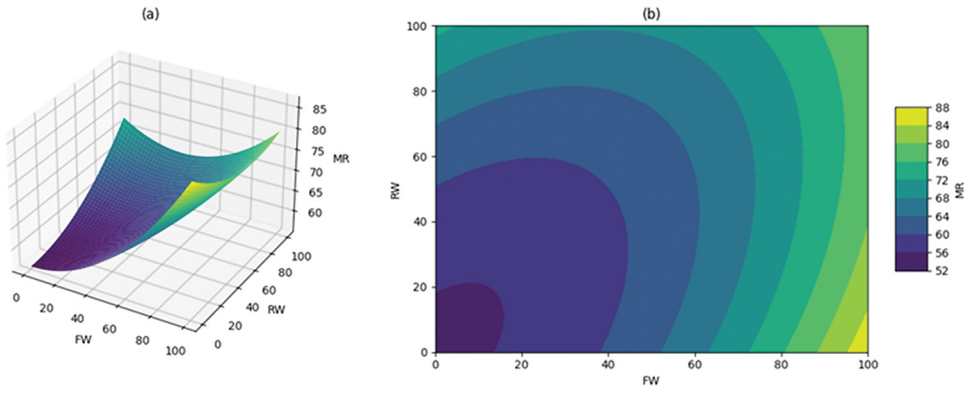

Figure 3: (a) Surface plot of metal recovery; (b) contour plot of metal recovery.

Metal recovery decreases with the increase in the proportion of recycled water. This can be explained by the fact that fresh water does not contain or contains low quantities of penalising elements such as Ca, Mg, sulfates and carbonates. However, introducing recycled water in quantities greater than 50% is detrimental to recovery due to the high number of penalising elements that are recycled and disrupt the flotation process (Figure 5).

Ca and Mg consume reagents, especially the frother, which causes the foam to explode during the collection of useful copper elements, leading to their release into the pulp instead of flotation. Recycling water, which already contains a quantity of reagents (collector and activator), adds to the quantity added during flotation, causing the phenomenon of the double layer, which depresses oxidised and sulfurised copper elements.

Recycling at 50% is acceptable because it allows for sufficient recovery (80%). This is due to the recycling of an acceptable amount of pre-conditioned and dissolved reagents, which converges towards an optimal quantity when added to the reagents added during flotation, and this result confirms what we obtained using the design of experiments (Figure 5).

Table 5: Results of the kinetics of the copper grade during flotation

	Concentration (%)	
Flotation stages	**Using fresh water**	**Using recycled water**
Sulfide rougher 1, 2	28.36	24.93
Oxidised rougher 1, 2	9.25	11.35
Oxidised rougher 3, 4, 5	7.29	7.85
Oxidised cleaner 1, 2	3.85	6.8
Final reject	0.12	0.33

Conclusion

While the use of 100% fresh water demonstrates high profitability in terms of metal recovery (87.55%), it is economically unsustainable due to its high

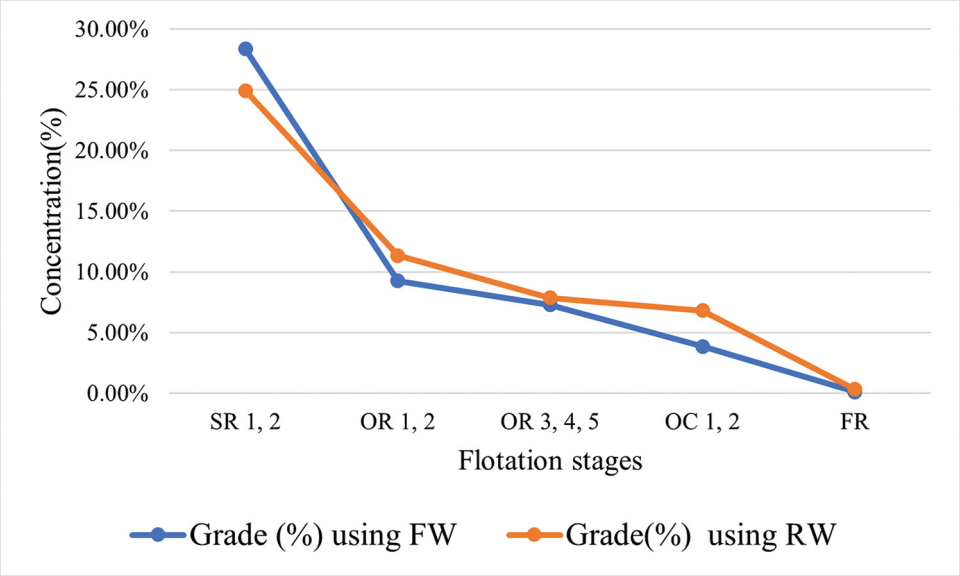

Figure 4: Grade kinetics as a function of flotation stages (FW = fresh water; RW = recycled water).

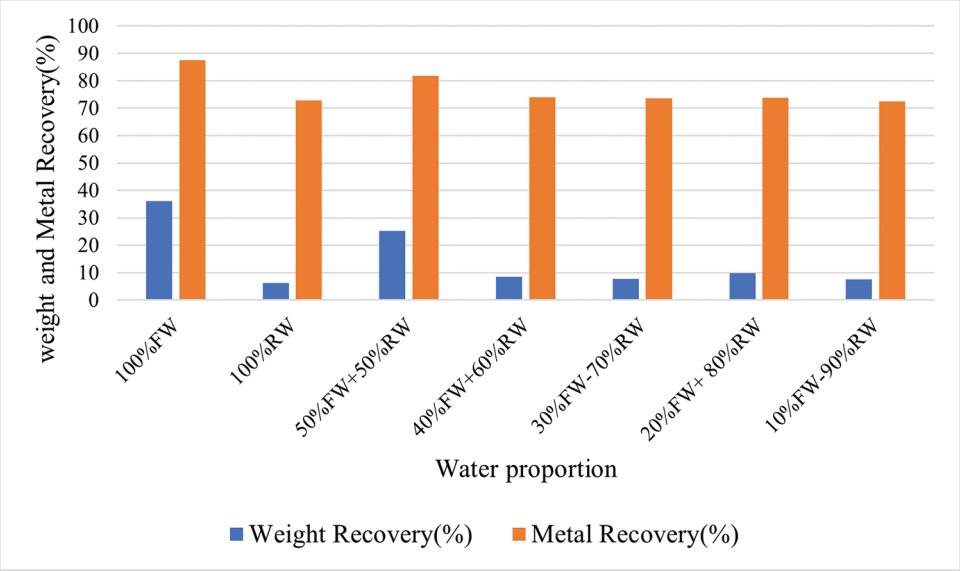

Figure 5: Impact of recycled water on metal recovery (FW = fresh water; RW = recycled water).

Table 6: Weight recovery and metal recovery as a function of water type

Water type	Grade (%)	Metal recovery (%)
Fresh water (FW)	36.14	87.55
Recycled water (RW)	6.3	72.82
50%FW + 50%RW	25.2	81.73
40%FW + 60%RW	8.45	73.94
30%FW + 70%RW	7.7	73.56
20%FW + 80%RW	9.74	73.8
10%FW + 90%RW	7.48	72.48

costs and the environmental challenges associated with declining water reserves. However, the use of 50% fresh water and 50% recycled water is both profitable, given a sufficient recovery, and economical as 50% of water used is recycled from the dike. Thus, this approach of combining the design of experiments and machine learning represents not only a good way to manage water resources, but also a sustainable and profitable solution for mining industries while minimising their environmental impact.

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Data availability

The data and code supporting the results of this study are available upon request to the corresponding author.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

R.E-B.: Collected and curated the data; performed the methodology, analysis and interpretation; and drafted the manuscript. A.S.: Aided in writing and revising the manuscript. H.A.: Supervised the work. S.R.: Supervised the work and contributed to interpreting the results. All authors discussed the results and read and approved the final manuscript.

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Influence of Cambridge International Education on environmental content in seven African syllabi

Cambridge International Education (CIE) presents a Western science based generic syllabus for use in foreign countries. Amid calls to decolonise the curriculum, this study investigated the extent to which seven African countries have decolonised the ecological and environmental content of their biology syllabi by departing from CIE. A decolonised syllabus may reduce the alienation students experience when they encounter Western science by infusing African epistemology into the syllabus, incorporating Indigenous knowledge, and using relevant familiar examples to illustrate scientific concepts. The seven African biology syllabi presented a Western science perspective, with five syllabi exhibiting CIE influence, ranging from very close similarity (Namibia and Lesotho) through some similarity (Rwanda and Botswana) to mostly dissimilar (Malawi). Uganda and South Africa displayed little CIE influence and incorporated more relevant content than other countries. Countries other than Botswana, Uganda and South Africa chose inappropriate examples to illustrate concepts and neglected the local environment and local Indigenous knowledge. Although all seven countries developed their own syllabi, sometimes in collaboration with CIE, not all have decolonised or contextualised their biology syllabi.

Significance:

This paper shows that seven African countries have adopted Western science epistemology for the ecology and environment sections of their biology syllabi. Five syllabi follow CIE syllabi to some extent, and few include Indigenous knowledge and content relevant to local context. I conclude that few of the seven countries have decolonised their syllabi.

Introduction

This study was precipitated by my experience as an author of secondary school biology textbooks in African countries, which required close engagement with the official national syllabus for each country. Many of these syllabi resembled Cambridge International Education (CIE) syllabi for biology. Amid calls from African university students to decolonise the curriculum, I asked: To what extent have African biology syllabi been decolonised from Western science and CIE? I also looked at how relevant African biology syllabi are to local ecosystems and environmental issues.

Cambridge International Education

CIE originated from the University of Cambridge Local Examinations Syndicate, which administered examinations in British colonies from 1864.[1] After attaining political independence, many previous colonies continued to offer imported qualifications such as the Cambridge Overseas School Certificate, Cambridge Overseas Higher School Certificate, International O-Level and International A-Level.[2,3]

Many African countries later opted to develop national curricula for their public schools with or without assistance from agencies such as the Cambridge Assessment Group.[2,3] 'Public schools' exclude 'international schools' which offer qualifications emanating from the Global North, including CIE.[4] The University of Cambridge Local Examinations Syndicate offered an advisory service to ex-colonies to run their own examinations following the Cambridge model. The West African Examinations Council, established in 1952, was the first of such partnerships.[5] Cambridge Partnership for Education aims to partner with governments to transform societies through quality education. It assists countries to design, establish and implement curricula and assessments that will work best for the country.[6]

Curriculum design can take one of three forms: a bespoke curriculum designed by CIE; co-development of a curriculum by CIE with curriculum developers from the commissioning country; or adaption of a Cambridge curriculum to suit the country's context.[6] The Learning Passport provides guidance for adaption using five principles[7] which apply in any situation where local experts are developing a national curriculum.[8] The adaption guidance principles are[7,8]:

1. Take account of the country's curriculum and education policies.
2. Select an appropriate language of instruction.
3. Frame selected content so that it is culturally relevant.
4. Incorporate Indigenous knowledge.
5. Support learner well-being, inclusion and success.[7,8]

Guidance principles 3 and 4 provide the framework on which the present study is based. Guidance principle 3 includes choosing content and examples relevant to students, such as local plants and animals, ecosystems and environmental issues.[8] Culturally relevant content equips students with skills that are useful in their everyday lives and accommodates the worldview prevailing in the target community.[3,9,10] Guidance principle 4 recommends including local Indigenous knowledge (IK) in the curriculum, thereby affirming people's traditional knowledge of their environment and promoting students' interest and motivation.[8,11]

Guidance principles 1–5 enable CIE and its partners to adapt their generic curricula to different contexts.[7] The present study investigated the extent to which CIE influences biology syllabi in seven African ex-colonies and seeks evidence of decolonisation by inclusion of African epistemology, locally relevant content and IK in the syllabi.

Worldviews, IK and decolonising the curriculum

Western science is believed to occupy a privileged status above the worldviews of non-dominant groups in current science curricula.[10,12,13] African IK and its worldviews are defined as "culturally specific knowledge systems that relate to the knowledge of Africa, their oral culture and traditional ecological knowledge, as affected by their worldview; the knowledge that incorporates their social and natural wellbeing, their cosmos and their spiritual world"[3(p.28)]. An indigenous worldview is a way of understanding the natural world, as distinct from IK, which is local, traditional knowledge that informs actions in everyday life. African indigenous worldviews hold that a vital force connects all natural phenomena into a unity of being. All living and non-living things possess spiritual powers which emanate from God and exist in decreasing amounts through the ancestors, living people, animals, plants, rocks and soil, mountains, streams and the earth itself. Knowledge is collectively owned and transmitted from the ancestors through the elders by means of story-telling, games, songs, rituals and cultural practices.[9,14]

Worldwide, Indigenous groups share a worldview of spirits interconnecting all of nature and all humanity, creating a pluriverse of onto-epistemologies. Such worldviews make communities responsible and accountable for their actions in the natural environment, centring community goals over individual and economic gains.[12,15] Indigenous worldviews and IK have been infused into school science curricula in nations such as Canada, New Zealand, Australia, some jurisdictions in the USA[16] and some Central American and Latin American countries[17]. IK offers rich, relevant and authentic contexts for science learning, particularly about the environment and the sustainable use thereof. It also provides opportunities for students to develop more balanced and holistic worldviews characteristic of Indigenous knowledge systems (IKS) but not Western science.[15]

African scholars support calls to recognise IK in school science curriculum but acknowledge that Western science and technology benefit society and the ecological environment. Science curriculum should be relevant to students' "cultural attitudes towards, and local knowledge about, their environment"[14(p.17)], including knowledge of local ecosystems and its sustainable use for survival[3,18]. While African students need to learn about their IKS and IK for their identity formation, some scholars recommend that they learn Western science in a hybrid subject integrating IK and Western science.[3,19,20] Hybrid science improves student interest and motivation[16,20] and could lead to improved performance in science, although evidence supporting this is limited[10,11,13]. It is a 'two-eyed seeing' model which uses IK to illustrate Western scientific concepts[10], thereby reducing the alienation felt by African students in science classes[3,13].

An alternative to hybrid science is to use overlaps between IKS and Western science, one of which is a commitment to careful description and observation.[21] One can then combine IK for descriptive and observational studies with Western scientific explanations of the observed phenomena.[21] Hybrid science is rejected by some authors on the grounds that it sterilises diversity of worldviews by 'scientising' IK which emerges from non-scientific worldviews.[22] True decolonisation requires accommodating interpretations of reality and knowledge criteria that pertain to non-science worldviews such as IKS.[22] The socio-cultural context of the knower is important in both IK, which pertains to a specific context, and Western science, which is confined to a scientist's situated cognitive domain rather than being unbiased.[21,22] Knower awareness enables students to realise that the motivations of the knower are important[22]: for IK practitioners, the motivation may be relevance to everyday life, while for Western scientists, the motivation may be to advance understanding of a theory.

Violent student protests on South African university campuses in 2015–2016 included calls for decolonisation of curricula, citing alienation, exclusion and racism experienced by (mostly) black students in universities dominated by (mostly) white academics.[19] The protests revealed that university staff were unaware of the lived experiences of students and their cultural knowledge was not legitimised.[19] To overcome the perceived alienation, Jegede[14] recommended that science teaching in Africa should begin with the traditional worldviews of students and progress towards imbibing scientific culture. Induction of African students into Western science is best achieved by using a conceptual ecocultural paradigm in which an individual's perception of knowledge grows and develops from their sociocultural environment.[14] Relevance is of primary importance in Jegede's argument for African science.[14]

Researchers who promote the concept of powerful knowledge[23] which best prepares students for future life[24] oppose including IKS and IK in the curriculum. Science has an impressive track record of successfully explaining many natural phenomena and using the explanations for technological development.[22] Powerful knowledge inducts students into conceptual organisation of isolated facts into generalisable principles.[23] A curriculum constructed around students' life experiences does not develop their human powers of reasoning nor prepare them for a technological future as Western science does.[14,23,24] Most powerful scientific knowledge is counterintuitive and generic, unlike IK. Proponents of powerful knowledge may agree that IK can set the context for scientific knowledge, but they reject appeals for African students to learn only things that are important for everyday life and living.[23,24]

Philosophers of science regard faith-based or spiritual worldviews as incompatible with science. Western scientists seek rational explanations for natural phenomena, excluding spiritual or supernatural causes.[25] Science presupposes that natural mechanisms and entities explain or potentially can explain all natural phenomena. Science does not rule out supernatural intervention but separates supernatural from natural explanations because it is concerned with material objects of study that obey natural laws and are open to scrutiny.[25,26]

Caution is urged to avoid romanticising Indigenous epistemologies and IK.[27] Indigenous peoples do not all live in harmony with nature, respecting the living and non-living world and behaving for the good of the community.[15,16] For example, trade in medicinal plants has become a competitive business to the detriment of traditional practices of sustainable harvesting.[28] Africa's environmental challenges include air pollution, unsustainable land management practices, waste and littering, overpopulation and rapid urbanisation.[29] The continent's rich biodiversity faces threats from illegal trade in plants and animals, mono-cropping, deforestation, climate change and invasive alien species.[18] These realities contradict claims of harmonious coexistence for Indigenous communities.[15,16]

Influence of CIE and relevance to local contexts

CIE syllabi present a generic Western science oriented worldview. Where a country has collaborated with CIE to develop its own curriculum, one expects to find content that is locally relevant, includes local IK and acknowledges indigenous worldviews. Even if formal collaboration did not take place, CIE's influence may be revealed through similar content selection and wording of learning outcomes. The first research question investigates the influence of CIE on African syllabi through two avenues:

1. Do seven African biology syllabi select similar content to equivalent CIE syllabi?
2. Does the wording of content units match the wording of CIE outcomes?

The second research question investigates adaption of generic ecological and environmental content to African IKS, IK about local ecosystems and local environmental concerns.[19] Questions asked here are:

1. What proportion of each syllabus is locally relevant?
2. What opportunities to contextualise the syllabus have been missed?

Seven African countries were selected based on curriculum documents available to me. Countries previously colonised by Great Britain and their years of attaining independence were South Africa (self-governing dominion until 1961), Uganda (1962), Malawi (1964), Botswana (1966)

and Lesotho (1966). Rwanda obtained independence from Belgium in 1962. Namibia was governed by South Africa from 1915 until independence in 1990.[30]

Methods

Constructing a reference list

I used CIE Biology syllabi 0970 for IGCSE[31] and 9700 for AS and A Level[32] to construct a reference list of generic content related to ecology and environmental issues, using both core and supplement learning outcomes from IGCSE Topic 19 (Organisms and their environment) and Topic 21 (Human influences on ecosystems)[31], supplemented with a few relevant outcomes from AS & A Level Topic 18 (Classification, biodiversity and conservation)[32]. The final reference list had two topics, eight sub-topics and 71 learning outcomes[31,32], shown in Table 1.

Some CIE learning outcomes were subdivided but were counted as a single outcome. For example, an outcome relating to the nitrogen cycle has eight subdivisions, but it is counted as one outcome.

Matching African syllabi with CIE reference list

Documents analysed and the years of study to which they apply are shown in Table 2.

Table 1: Cambridge International Education reference list for Topics 19 and 21

	Number of learning outcomes
Topic 19: Organisms and their environment	
19.1 Energy flow	2
19.2 Food chains and food webs	21
19.3 Nutrient cycles	5
19.4 Population size (includes definitions of communities and ecosystems)	10
Topic 21: Human influences on ecosystems	
21.1 Food supply	5
21.2 Habitat destruction	4
21.3 Pollution	9
21.4 Conservation (includes sustainability)	15

Namibia[33], Lesotho[35] and Uganda[38] acknowledge assistance from CIE in their curriculum development.

Identifying content in African syllabi

Content organisation differed among the African syllabi. Headings from which content was extracted were 'Ecology' in Botswana[37(p.25–26)]; 'Relationships of organisms with one another and with their environment' in Namibia[33(p.31–34)] and Lesotho[35(p.6–11)]; 'Environment' in Malawi[39(p.19–25)]; 'Environmental Studies' in South Africa[36(p.33–34,51–55)]; 'Soil'[38(p.22–23)] and 'Interrelationships' in Uganda[38(p.45–48)]; and 'Ecology and conservation' in Rwanda[34(p.51–52,82–90)]. Statements in each syllabus were grouped to form conceptually coherent units, which were counted only once if they recurred elsewhere in the syllabus. For example, five statements listed in Rwanda's Unit 5 were repeated from Unit 4 and were not counted as new units. The complete spreadsheet showing reference list outcomes and units from each syllabus is available as supplementary material.

CIE influence on content selection

Content units from African syllabi were assigned to matching reference list outcomes. Many units matched more than one reference outcome, meaning that the number of matches could exceed the number of content units in a syllabus.

Similarity in the wording of the content units provided further evidence of CIE influence. Similarity was coded on a scale of 1–3, using the following descriptors:

1 = similar idea, but wording does not match reference list

2 = similar idea, wording somewhat matches reference list

3 = wording closely matches reference list

Table 3 shows an example of coding for similarity.

Coding for relevance to each country's context

Three aspects derived from CIE adaption guidelines[7,8] indicate that a syllabus was relevant to a country:

1. Including African worldviews pertaining to ecology and environmental issues[3,19]
2. Referencing local IK
3. Referencing local ecosystems and environmental issues

The list of units in each African syllabus was scrutinised for mention of African IKS and coded for whether it was generic or relevant to the local context. To qualify as relevant, a unit had to specify a national/local ecosystem, issue or IK.

Table 4 summarises how coding was carried out, as well as the terms used throughout this paper.

Table 2: Countries and syllabus documents analysed in this study

Country	Syllabus	Years of schooling	Qualification	Years in which ecology and environmental issues are taught
Namibia	Namibia Senior Secondary Certificate (NSSC)[33]	9–11	NSSC O-Level	10 and 11
Rwanda	Rwanda O-Level[34]	7–9	Ordinary Level	8 and 9
Lesotho	Lesotho GCSE[35]	10–11	Cambridge GCE O-Level	10 and 11
South Africa	National Curriculum Statement[36]	10–12	National Senior Certificate	10 and 11
Botswana	Botswana General Certificate of Secondary Education[37]	11–12	Botswana GCSE	11 and 12
Uganda	Uganda Lower Secondary[38]	8–11	O-Level	9 and 11
Malawi	Malawi School Certificate of Education (MSCE)[39]	9–12	MSCE	11 and 12

Findings

Influence of CIE on content selection

There were 13 content units in Botswana, 15 in Malawi, 21 in Uganda, 23 in South Africa, 38 in Lesotho, 46 in Namibia, 50 in Rwanda, and 71 outcomes in the reference list. Many units in African syllabi matched more than one CIE outcome. The proportion of the reference list matched varied from a high of 62% in Rwanda and 61% in Namibia to lows of 23% in Uganda and 20% in Malawi (Table 5). The percentage match indicates that Namibia and Rwanda were most like CIE in terms of broad content selected.

All seven African syllabi matched both topics in the reference list. Namibia's syllabus matched 68% of the outcomes in Topic 19, while Botswana's matched only 18%. Botswana omitted population size in Topic 19, while Malawi, South Africa and Uganda omitted energy flow. Rwanda's syllabus matched 64% of the outcomes in Topic 21, while Malawi's matched only 12%. Lesotho, Malawi, and Uganda omitted food supply and Malawi omitted conservation. Apart from those omissions, every reference subtopic was represented by at least one unit in each syllabus.

Non-matching content indicates independence from CIE. A total of 57% of Ugandan units did not match the reference list, followed by 52% in South Africa, 40% in Malawi and 39% in Rwanda. Botswana, Namibia, and Lesotho had very few units that departed from the reference list.

Rwanda and South Africa added the biosphere and biomes, while Rwanda, South Africa, Uganda and Malawi included interspecific interactions such as predator–prey relations, competition and commensalism. CIE syllabi omit the abiotic factors of an ecosystem which are present in the Rwandan, South African, Ugandan and Malawian syllabi. Uganda emphasised the structure of soil, its importance in the environment

Table 3: Example of coding for similarity between Cambridge International Education (CIE) reference list and matching units from African syllabi

CIE reference list	19.4 Identify and state the factors affecting the rate of population growth for a population of an organism, limited to food supply, predation and disease.[31(p.40)]	
Syllabus	**Matching outcomes/units**	**Similarity code**
Lesotho and Rwanda	State the factors affecting the rate of population growth for a population of an organism (limited to food supply, predation and disease), and describe their importance[32(p.84),34(p.23)]	3
Namibia	State the factors affecting the rate of population growth for a range of living organisms.[30(p.32)]	2
South Africa	Population size: immigration, emigration, mortality, births; fluctuations. Limiting factors and carrying capacity.[35(p.49)]	1

Table 4: Example of coding and terminology used in the study. Highlighted text shows where matches were made.

Content unit from an African syllabus	**Number of units**	**Number of matches**	**Similarity index**	**Generic / relevant**
Discuss how poor agricultural methods result in destruction of the ecosystem, e.g. monoculture, excessive use of fertilisers and pesticides, overstocking, deforestation.[36,(p.26)]	1	4		Generic
Matching outcomes from reference list				
21.1.1 State how modern technology has resulted in increased food production in terms of: …chemical fertilisers to improve yields; insecticides to improve quality and yield; herbicides to reduce competition with weeds……			1	
21.1.2 Describe the negative impacts to an ecosystem of large-scale monocultures of crop plants			2	
21.1.3 Describe the negative impacts of intensive livestock production.			1	
21.2.4 Explain the undesirable effects of deforestation on the environment.			1	

Table 5: Number and percentage of matches between seven African syllabi and the Cambridge International Education reference list

	Namibia	**Rwanda**	**Lesotho**	**South Africa**	**Botswana**	**Uganda**	**Malawi**
Total matches ($n = 71$ outcomes)							
Number of matches	43	44	39	35	21	16	14
% of reference list matched	61%	62%	54%	49%	30%	23%	20%
Topic 19: Organisms and their environment ($n = 38$ outcomes)							
Number of matches	26	23	27	18	7	9	10
% of reference list matched	68%	58%	34%	47%	18%	24%	26%
Topic 21: Human influences on ecosystems ($n = 33$ outcomes)							
Number of matches	17	21	12	17	14	7	4
% of reference list matched	52%	64%	36%	52%	42%	21%	12%

and its conservation. Actions to promote conservation are included in six syllabi, the exception being Lesotho. Other non-matching units are diverse.

Similarity in the wording of units is a strong indicator of CIE influence on African syllabi. The percentage of matches scored at similarity levels 1, 2 and 3 are presented in Figure 1.

High proportions of matches at similarity levels 2 and 3 indicate CIE influence. The Namibian syllabus showed the most similarity, followed by Lesotho, Rwanda and Botswana. High proportions of Level 2 matches in Malawi and Botswana indicate an attempt to re-word CIE outcomes, but the units were still recognisably derived from CIE. The proportion of matches at level 1 indicate independence from CIE, which is highest in Uganda and South Africa.

Inclusion of African worldviews, IK and relevant content

All the African syllabi presented a Western science perspective without mentioning African worldviews. Local IK is specifically mentioned only once in the South African syllabus.

Figure 2 shows the percentage of units in each syllabus that are generic or relevant to the country. Clearly, South Africa and Uganda prioritised relevant content, where other countries had more generic than locally relevant content. Namibia, Lesotho and Malawi rarely mentioned local context, while Rwanda and Botswana had more than a quarter of their units relevant to the local context.

Table 6 explores the proportion of generic and relevant content by topic. All units in Topic 19 were generic in Namibia, Lesotho and Botswana, while Malawi and Rwanda had more generic than relevant units. Uganda had half generic units and half relevant, while South Africa had more relevant units than generic. In topic 21, Malawi had only generic units, while Namibia and Lesotho had mostly generic units. Rwanda had somewhat more generic than relevant units, while Botswana had half of its units generic and half relevant. Uganda and South Africa had far more relevant than generic units.

Two examples of how units were generic or relevant to local context are shown below.

Example 1:

Reference list outcome 19.4.6 "Define ecosystem as a unit containing the community of organisms and their environment, interacting together, e.g. a decomposing log, or a lake".[31]

Namibia[33] and Lesotho[35] closely matched the wording of outcome 19.4.6, including the decomposing log and lake as examples of ecosystems.

Uganda contextualised the concept as: "Look at a map showing the main physical features of East Africa and identify at least five ecosystems; stating their distinguishing features"[38(p.45)] and "Investigate an ecosystem close to the school"[38(p.33)].

Example 2:

Two reference list outcomes mention discarded waste:

- Outcome 21.3.2: "State the sources and effects of pollution of water (rivers, lakes and the sea) by chemical waste, discarded rubbish, untreated sewage and fertilisers."
- Outcome 21.3.4*:* "Discuss the effects of non-biodegradable plastics in the environment, in both aquatic and terrestrial ecosystems.*"*

Botswana re-phrased outcome 21.3.2 generically as "Describe the undesirable effects of water pollution by sewage and inorganic waste."[37(p. 26)]

South Africa contextualised water pollution, eutrophication, the effect of mining on water quality and thermal pollution by requiring students to observe an example of human influence on the local environment.[36(p.51)]

Missed opportunities and inappropriate examples

There are numerous missed opportunities in the African syllabi as well as inappropriate examples. The decomposing log and lake are inappropriate examples of ecosystems for Namibia and Lesotho, both of which have interesting and unique local ecosystems. Neither Rwanda nor Malawi

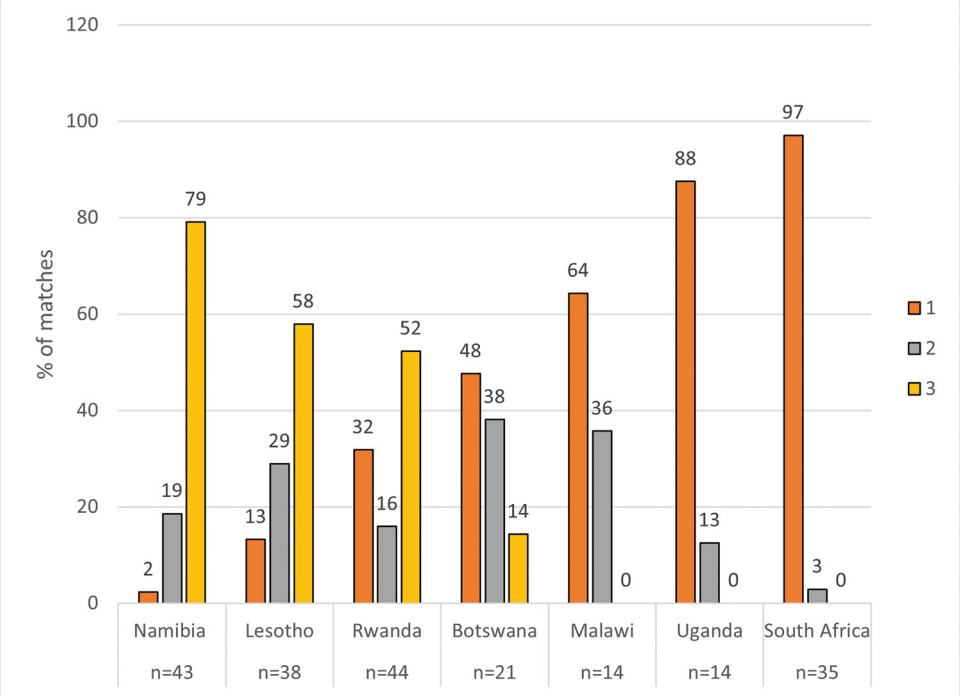

Figure 1: Percentage of matches between CIE outcomes and units in African syllabi at similarity levels 1–3. 1 = dissimilar, 2 = somewhat similar, 3 = closely similar.

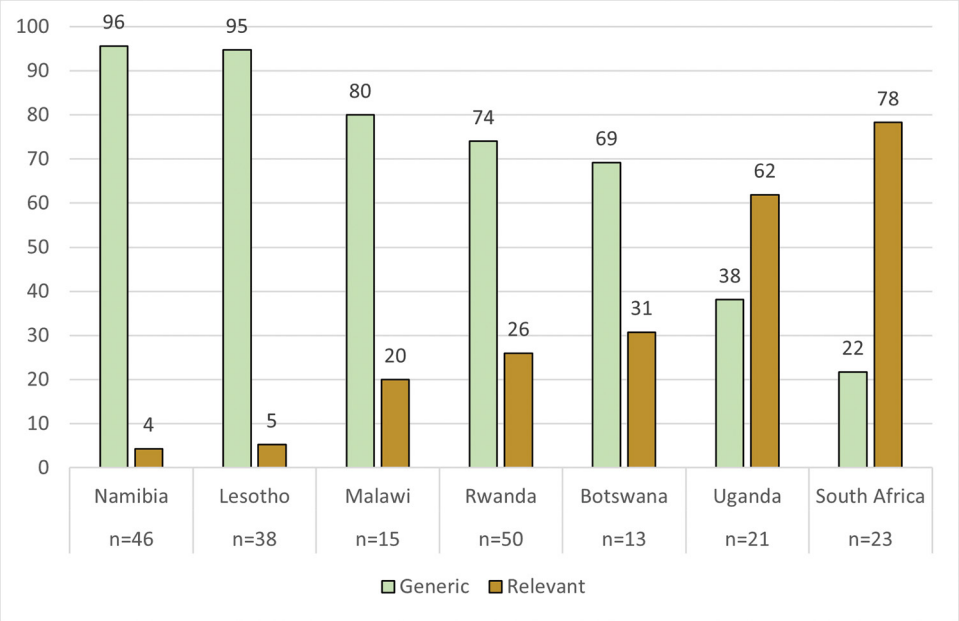

Figure 2: Percentage of generic and relevant content units in seven African syllabi (n = number of units).

Table 6: Number and percentage of generic and relevant units per topic and country

	Namibia	Lesotho	Malawi	Rwanda	Botswana	Uganda	South Africa
Total number of units	46	38	15	50	13	21	23
Topic 19: Organisms and their environment							
Generic	27 (100%)	25 (100%)	7 (70%)	27 (82%)	5 (100%)	7 (47%)	5 (36%)
Relevant	0	0	3 (30%)	6 (18%)	0	8 (53%)	9 (64%)
Topic 21: Human influences on ecosystems							
Generic	17 (85%)	11 (79%)	5 (100%)	10 (59%)	4 (50%)	1 (17%)	0
Relevant	2 (10%)	2 (14%)	0	7 (41%)	4 (50%)	5 (83%)	9 (100%)

prescribed study of a local ecosystem. South Africa and Uganda provided opportunities to investigate biomes and/or local ecosystems in their countries. Malawi chose non-local camels, polar bears and sharks to illustrate adaptations to various environments rather than local species. No country prescribed the identification of food chains and food webs in their local environment.

Pollution by waste and littering is identified as an environmental problem in southern African countries.[29] Lesotho and Botswana did not contextualise the outcome, while Namibia, Uganda and South Africa did so through activities.

The subtopic 'conservation' provides opportunities to highlight endangered plants and animals and efforts to protect them in each country. Lesotho and Malawi did not identify endangered species in their own countries, while Rwanda prescribed that students research endangered species in Africa broadly. Botswana contextualised the concept by suggesting that students investigate local threatened species and the need to conserve them. Both Rwanda and Uganda omitted the threatened mountain gorilla populations in their countries, a missed opportunity for this charismatic species. Namibia and South Africa used local contexts by suggesting that students investigate rhinoceros poaching in their countries and South Africa listed elephants in the Kruger National Park as an example of culling. Sustainable harvesting of food, building materials and traditional medicines was absent from all syllabi.

IK was rarely mentioned in any of the African syllabi. South Africa listed IK related to sustainable use of plants in the local environment, while Botswana asked students to "Find out from the local community which plants and animals have become scarce and why."[37(p.25)] Uganda did not mention indigenous or traditional knowledge specifically but required students to "discuss what steps farmers and gardeners in their locality take to maintain the fertility of their soils"[38(p.23)]. Malawi asked students to: "Identify organisms using local and scientific names."[39(p.22)] Omitting IK is a missed opportunity to include traditional knowledge about the sustainable use of natural resources.

Discussion

The findings lead to the following interpretations of the influence of CIE on African curricula:

- The syllabi of Namibia and Lesotho were strongly influenced by CIE, as indicated by a high proportion of close matches with the reference list, and a small number of non-matching units. Both countries had a few units that were relevant to their context. They have reduced the breadth of CIE syllabi. The syllabi were co-developed with CIE[6] but very little adaption has taken place.
- Rwanda's syllabus matched CIE's content selection and used similar wording to CIE outcomes in many of its units. Departure from CIE is indicated by the large number of non-matching units. About a quarter of its units were relevant to the context, particularly the human influence topic. Rwanda has adapted the CIE syllabi to its context[6], but it also departs from CIE with additional units.
- Botswana has a much narrower syllabus than CIE, but most of its units matched CIE outcomes with only one non-matching

unit, indicating a strong CIE influence on the selection of content. It re-worded CIE outcomes and contextualised a significant proportion of the human influences topic. Botswana has adapted the CIE syllabus to its local context.[6]

- Malawi has a much narrower syllabus than CIE syllabi with 40% of its units not matching the reference list. Nevertheless, 36% of its matches are at level 2, indicating some CIE influence. Most of its syllabus is generic. It has not adapted CIE syllabi, nor added content that is relevant to the local context.
- Uganda has 57% of its units not matching the reference list and very few close matches with CIE wording. Its content is mostly relevant to its context. Its syllabus appears independent of CIE influence, yet it acknowledges assistance from Cambridge Education and Curriculum Foundation.[38] It is consistent with co-development between CIE consultants and local curriculum developers.
- South Africa matches almost half of the reference list, indicating a similar selection of content to CIE. Wording of matching units differs from CIE outcomes, and South Africa adds a significant proportion of non-matching units. Most of its units are relevant to the country's context. South Africa's syllabus is independent of CIE influence.

None of the syllabi mentions Indigenous ways of understanding ecosystems.[9,14,19] All seven syllabi have adopted Western scientific epistemology and generic scientific content. The continued influence of CIE in some African syllabi might be interpreted as neocolonialism[4] or a device to perpetuate cultural imperialism[40] and the privileged status of Western science[3,10,13]. 'Neocolonial mind-snatching'[40] and 'curriculum epistemicide'[41] describe subtle processes which cause Indigenous peoples to devalue their own epistemologies in favour of Western science. The 'ghost of colonialism past' could account for CIE's influence in countries which followed Cambridge syllabi after independence (e.g. Lesotho and Botswana), but does not account for CIE's influence in non-British colonies such as Rwanda and Namibia, nor departure from CIE in Uganda and Malawi.

Each syllabus included in this study was locally constructed by curriculum developers with or without assistance from CIE or other organisations from the Global North. CIE cannot be assumed to have promoted Western science at the expense of African epistemologies as its adaption principles promote relevance, meaningfulness, respect and responsiveness to students' culture and worldviews.[8] It is more likely that African countries recognise the incompatibility between Western scientific worldviews and IKS[22] and the value of powerful knowledge[23,24]. The silence regarding African epistemologies does not assist African students who claim to feel alienated from Western science.[3,19]

Guidance principle 4 recommends including local IK in the curriculum.[7] Relevant IK could equip students with knowledge and appreciation of their natural environments, and the skills and attitudes to appreciate and improve the sustainable use thereof.[15] However, there are very few examples of local IK in the African syllabi studied here. Difficulties with prescribing African IK include its local, culturally specific and orally transmitted nature[3], and its inaccessibility due to lack of written documents. Rapid urbanisation, modern medicines, materials and foods, the mingling of different cultures[27] and exponential advances in information technology have detached many African students from their traditional roots, rendering local IK obsolete in modern contexts[14]. Scientific research and technological development underpin future prosperity and quality living in African countries, and Western science is recognised as the vehicle to achieve economic development.[3,10,14]

Guidance principle 3 advises that syllabi should include locally relevant examples.[6,8] Five of the seven African syllabi gave more attention to generic than to local contexts. South Africa and Uganda showed how local, relevant examples can illustrate ecology and environmental issues. It is most unfortunate that so few countries teach students about their local environment.

None of the seven countries has decolonised their Biology syllabus by incorporating African worldviews. Four syllabi show close affinity with CIE, supporting continued CIE influence in their curriculum development. Five syllabi mostly failed to heed Jegede's[14] call to teach science that is relevant to the sociocultural environment of the student. Learning about local contexts would encourage students to take informed custodianship of their natural environment and address the environmental issues that threaten African countries.[18] It makes no sense for students to study non-local ecosystems when their own unique ecosystems are vulnerable, nor for students to study foreign plants and animals instead of threatened species in their own countries. Uganda and South Africa provide examples of how a locally relevant syllabus for ecology and the environment might be constructed.

Data availability

The data supporting the results of this study are available upon request to the author.

Declarations

I have no competing interests to declare. I have no AI or LLM use to declare.

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South Africa's male homicide epidemic: Who is killing men and why do we ignore the victims?

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Two recent articles highlighted that ~90% of homicide victims in South Africa in 2017 were men. Here we present summary methods and findings and reflect on why there has been no concerted public health response to address the massive sex disparity in homicide risk. Based on routine data collected through forensic and police investigations, we found that male homicide rates were higher than female homicide rates across all ages, and were up to 8.4 times higher among youths and young adults. There was considerable interprovincial variation, with the highest male:female incidence rate ratio of 11.4 recorded in the Western Cape. Of the perpetrators, 93% were men, and usually acquaintances (63%). Most deaths were the result of sharp force injuries (stabbing), with gunshots the second leading cause. Of the 7% of men killed by female perpetrators, 60% were killed by their intimate partners. There were distinct temporal patterns associated with alcohol use. Male homicides were clustered around festive periods and school holidays. Amongst perpetrators, alcohol use was reported in 50% of homicides by acquaintances and 41% of homicides by family members, but other drug use was less common (9% overall). The omission of men from the prevention agenda is an equity issue that affects not only men, but also women and children in South Africa's most marginalised communities. Broad population-based approaches are required to address the insidious effect of recalcitrant societal norms and structural interventions to overcome the root causes of poverty and inequality and the poor control of alcohol and firearms.

Significance:

Two recent articles, Matzopoulos et al. (PLOS Glob Public Health 2023;3(11), e0002595) and Matzopoulos et al. (BMJ Global Health 2024;9, e014912) highlighted that ~90% of homicide victims in South Africa in 2017 were men, thereby confirming that men are especially vulnerable to fatal violence. We present summary methods and findings and reflect on why there has been no concerted public health response to address this massive sex disparity in homicide risk.

Introduction

As victims and perpetrators, adult men are implicated in most homicides. However, in South Africa, very little is known about these men, except as perpetrators of female and child homicides. The South African Medical Research Council's response was to fund a comprehensive Female and Male Homicide and Injury Mortality Study. This study followed the methodology used in national female homicide studies for 1999 and 2009[1,2], but comparable information describing the personal and situational risks for male victims was collected.

We conducted a retrospective descriptive study of routine data collected through forensic and police investigations using a multistage stratified cluster sample. Our sampling frame consisted of 58641 postmortem reports from 121 medicolegal laboratories operational in South Africa in 2017. From these, 65 mortuaries from eight provinces were selected with an expected sample of 22 733 records. These were complemented by records from 16 laboratories in the Western Cape, where the health department maintains a surveillance system with compatible data. We applied analysis weights to account for selection probabilities of laboratories within survey strata. In a second sampling process, we randomly selected 20% of cases in which the deaths of men aged ≥18 years were registered as a homicide or injury death of undetermined intent for further investigation by linking autopsy reports with police investigations. Postmortem information included age and sex, date, external cause and apparent manner of death, and blood alcohol concentration. Police information included the victim–perpetrator relationship and additional perpetrator details.

We calculated victim and perpetrator homicide rates by age, sex, race, external cause, employment status and setting, stratified by victim–perpetrator relationships and male-to-female incidence rate ratios. For perpetrators, we reported drug and alcohol use, prior convictions, gang involvement and homicide by multiple perpetrators. Further details on methods and detailed results are provided elsewhere.[3,4]

Results

Among the findings of the first study was that men accounted for 87% of homicides in 2017, with a much higher age-standardised homicide rate than women (59.7 vs. 9.0 per 100 000 population), equivalent to 7 male deaths for every 1 female death.[5] Although male individuals are known to experience higher homicide rates than female individuals globally, the relative rate for male individuals in South Africa versus the global average of 7.4:1.0 (95%CI: 6.9–8.0:1.0) was significantly higher than that for female individuals in South Africa (5.9:1.0 ;95%CI: 5.3–6.3:1.0). Male homicide rates were far higher than female homicide rates across all age groups, but particularly among youths and young adults aged 15 to 29 years, for whom the male rate of 101.2 /100 000 population was 8.4 times higher than the female homicide rate in that age category. There was considerable interprovincial variation by sex. The highest male:female incidence rate ratio of 11.4 male deaths for every female death was recorded in the Western Cape.[3,4]

KEYWORDS:
male homicide, perpetrators, violence prevention

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The perpetrator study found that men were perpetrators of 93% of male homicides. Of the 7% of men killed by female perpetrators, 60% were killed by their intimate partners. For most male homicides, perpetrators were acquaintances (63% of cases in which a main perpetrator was identified). Most deaths were the result of sharp force injuries (stabbing), with gunshots as the second leading cause.[4]

Both studies highlighted temporal patterns associated with alcohol use. Male homicides clustered around festive periods, i.e. December/Christmas and April/Easter, and the July and September school holidays. Almost half of male homicides were recorded on weekend days, when disproportionately more men than women were murdered, particularly Saturdays (9.3 male deaths for every female death). A significantly higher percentage of male homicide victims tested positive for blood alcohol (11.4 male deaths for every female death). Amongst perpetrators, alcohol use was reported in 50% of homicides by acquaintances and 41% of homicides by family members, but other drug use was less common (9% overall).

Discussion

Interpersonal violence is a major public health issue and there is a massive, disproportionate homicide risk borne by South Africa's adult men, particularly young men, consistent with global homicide patterns. In 2012, 60% of the homicides worldwide were in male individuals aged 15–44 years, making it the third leading cause of death for male individuals in this age group globally; low- and middle-income countries bear the heaviest burden, with homicide accounting for >90% of male deaths in this age group.[6]

South Africa experiences one of the highest homicide rates and disease burdens from interpersonal violence of any country.[7] However, reducing male homicide rates has not received national attention and focus. The dominant gendered narrative nationally seems to replicate the foundational aspirational assumptions of hegemonic masculinity that men are strong and invulnerable and some fighting between them is normal and acceptable.[8] It is not that men are not victims of trauma, but rather that a man experiencing trauma at times is regarded as part of 'being a man' and therefore is not problematic nor requires the focus of national policy attention. This contrasts with responses to femicide, which are much discussed and planned, including in a *National Strategic Plan on Gender-based Violence & Femicide*.[9,10] The contrasting gendered response to men's use of violence against other men is inequitable. Changing national norms on men's use of violence is critical for preventing violence against other men and violence against women.

Disproportionately high rates of homicide amongst men are not a new finding. The elevated risk was reported in previous national estimates, with male individuals accounting for 84% of homicides in 2000 and 86% in 2009.[11,12] Ignoring the modal group for a particular disease or outcome is certainly contrary to the well-established principles of good science, but not unique to interpersonal violence.

One premise is that the high homicide rates among men are ignored because men are overwhelmingly the perpetrators of violence. This may be true for adults but cannot be applied to children, with homicide rates amongst boys 70–80% higher than amongst girls from birth until 14 years, whereafter the relative rates for male individuals increase rapidly. Even among adults, ignoring male homicides is unacceptable, both in regard to male health and because violent and aggressive behaviours are passed on between peers and intergenerationally, to the detriment of society more broadly.[13] Threats to safety cut across gender, race and class, with an estimated lifetime prevalence of trauma of 73.8% according to the country's only nationally representative mental health survey.[14] These extraordinary levels of trauma have been linked to both a high prevalence of intimate partner violence and extremely high rates of all forms of homicide[1], suggesting that any relationship between trauma and interpersonal violence does not cluster by any gender specifically.

Certainly, violence at its core is gendered, and South Africa remains a country with a capacity for extremely gendered violence.[15] However, a plethora of co-occurring, complex and intersecting factors exacerbates the violence risk. These include social and economic inequality, patriarchal versions of masculinity, lack of social cohesion, alcohol, firearms, and legacies of colonialism, migrant labour, slavery, other forms of discrimination and human rights violations. For many men, achieving dominance is expected and there is a cultural condonation of the use of coercion and force to control partners.[16] Interviews with incarcerated South African men highlight that violence is considered a normative resource to establish control in their lives.[17] South Africa's troubled history, in which many men were drafted into combat, has further entrenched a militarised form of masculinity that sanctions violence as a legitimate response. Moreover, perceptions of the drivers of intimate partner violence in community-based studies of men highlight widespread alcohol abuse, rampant unemployment and patriarchal views on gender roles as critical to high levels of gendered violence.[18]

In-depth interviews with men who have killed their partners reveal life histories with numerous interrelated adverse circumstances that undermine self-esteem and self-efficacy. High levels of exposure to violence from an early age include stringent discipline (that could be regarded as abuse) from multiple caregivers, emotionally unavailable parents, absent fathers and adult substance abuse.[15] For boys exposed to domestic violence, the increased risk of violent and aggressive behaviour is not restricted to perpetrating violence against women, but also manifests at their places of work and in their communities.[19] In many poor communities, criminal gangs provide social support and recognition to young men, further entrenching antisocial and violent behaviour.[15] Collectively, this drives an intergenerational cycle of violence with men as conduits. These conditions are moderated by a set of intersecting and dynamic factors such as the class, age and sexual orientation of men across the developmental and relational stages of their lives, thus explaining the obvious fact that not all men are predisposed to violence.[20]

Although many people growing up in harsh poverty and violent contexts do not resort to crime or violence, social and economic inequality are widely considered as drivers in South Africa. Acts of criminal violence are regarded as attempts to address the experience of being 'invisible citizens' in a country where economic access is constrained.

In this sense, poverty is considered 'unbecoming' of a man in South African society, where men are frequently constructed as breadwinners, providers, physically strong, emotionally resilient and unconditionally powerful. Such roles are completely inaccessible to many men. This tension between these ideals of 'manhood' and the structural constraints on fulfilling them appears to provide at least some of the catalytic conditions for addressing conflict violently. In the domestic or familial setting, this violence is directed at intimate partners and children.[21-23] Within the context of contact crimes, in which men are significantly more at risk of experiencing violence, the mere presence of a male adult is associated with the escalation of violence towards other victims.[24]

In the public space, alcohol, which precipitates aggressive behaviour, is causally linked to interpersonal violence.[25-28] In South Africa, men are more likely than women to engage in heavy episodic drinking, the pattern most associated with an increased risk of, and vulnerability to, violent behaviour.[29] This is reflected in the gender distribution of homicides attributable to alcohol, present in 55% of male and 38% of female homicide cases, and the predominance of homicides on weekends and holidays associated with heavy episodic drinking. The immediate impact of limiting alcohol availability was demonstrated in South Africa during the COVID-19 pandemic when alcohol sales bans implemented alongside lockdown restrictions were associated with substantial reductions in non-natural deaths and trauma cases.[30,31] The epitome was possibly the empty trauma ward at Johannesburg's Chris Hani Baragwanath Hospital on New Year's Day 2021, a calendar date usually synonymous with alcohol-fuelled harm. Yet, despite the irrefutable evidence of population level reductions in violence, there has not been any sustained or meaningful attempt to change policies to restrict alcohol availability.

A similar omission relates to firearm control. Firearm deaths disproportionately affect male individuals, and the implementation of the *Firearms Control Act* was associated with significant reductions in firearm homicides nationally for a decade from the early 2000s. Since then, lapses in firearm control measures and poor enforcement have been associated with a surge in gun deaths, with male individuals accounting for the larger share of the increase.[32]

In summary, a now robust body of research highlights patterns and prominent risk factors for male homicide. Critically, it confirms both the wilful neglect of male violence as a public health priority and a lack of political will to implement evidence-based interventions. The omission of men from the prevention agenda is an equity issue that affects not only men, but also women and children in South Africa's most marginalised communities. We believe our analysis provides new data on the differences between male and female homicide victims, and insights into the perpetrators of homicide that can inform interventions to reduce homicide risks overall.

Broad population-based approaches to address the insidious effect of recalcitrant societal norms are a central tenet. Concurrently, structural interventions are needed to overcome the root causes of poverty and inequality and the poor control of alcohol and firearms. The slow pace of change for social determinants may be because they are notoriously difficult to address; however, the powerful alcohol and gun lobbies share much of the responsibility for the lack of profound change.

We hope that this research will not only influence policy by highlighting this pressing public health issue, but also help to foster the nascent but critical research agenda in men's health issues, and that the data can serve as a resource for other scholars. Only through challenging the normative perception of male invulnerability do we begin to address the enormous burden of violence impacting men, which ultimately affects all people, everywhere.

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Data availability

Availability of data used in the study is subject to permission being granted by the Health Research Ethics Committee and provincial authorities that approved the original study. This is a recently completed study and the data set will initially be used for capacity development among the emerging researchers on the study team. Thereafter, access to a de-identified data set will be made available upon reasonable request. Requests should be sent to the convenor of the SAMRC's Research Ethics Office, Ms Adri Labuschagne (Adri.Labuschagne@mrc.ac.za), for consideration. Guidelines for applications and related materials are available at: https://www.samrc.ac.za/research/rio-research-ethics-office. A period of 24 months after publication of the main study results should elapse before requests are made, to allow the authors to publish sub-studies and further analyses, but we welcome approaches to progress collaborative research, provided that emerging researchers on the study team can be included.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. R.M., R.J. and N.A. receive salaries from the South African Medical Research Council. Ethical approval was granted by the SAMRC (EC 008-5- 2018). Permission to access data was obtained from the National and Provincial Departments of Health and the police.

Authors' contributions

R.M.: Conceptualisation, methodology, data analysis, writing – initial draft, writing – revisions, project leadership, funding acquisition. M.C.: Conceptualisation, writing – initial draft, writing – revisions. B.B.: Conceptualisation, writing – initial draft. L.J.M.: Conceptualisation, methodology, writing – revisions, read and approved final version. R.J.: methodology, writing – revisions. N.A.: Conceptualisation, methodology, data collection, data analysis, validation, data curation, writing – revisions, project leadership, project management, funding acquisition. All authors read and approved the final version.

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