An appraisal of impacts from major pollutant types on inland biodiversity for South Africa

Evidence Report

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Executive Summary & Key Recommendations

Why was this study undertaken?

A global scale analysis of pollution impacts on biodiversity in Official Development Assistance (ODA) countries was developed by the Joint Nature Conservation Committee (JNCC) and the Department for Environment, Food & Rural Affairs (Defra, United Kingdom). The ultimate aim of this project is to reverse biodiversity loss, build ecological resilience and improve human health. This in turn contributes to a broader project by the UK to scope and design a programme to enhance the ability of ODA-eligible countries, including South Africa (SA), to manage chemicals more sustainably and to reduce air, chemical, and waste pollution. The aim of the study reported here, which forms part of the local sense analysis for SA, was to appraise the impacts from major pollutant types on inland biodiversity for South Africa. This involved addressing the following objectives:

I. Generating a situational analysis for pollutant prevalence, threats and management in South Africa;
II. Conducting a local sense check of the results of the pollution global analysis to ensure appropriate mitigation measures are included and discussed so that relevant and valid information is taken into account when designing the wider programme; and
III. Making recommendations on the scope and design of a wider pollution programme to enhance the ability of low- to middle-income countries to manage chemicals and to reduce air, chemical, and waste pollution.

How did we undertake a scoping study on pollution impacts on biodiversity in South Africa?

The results of the pollution Global Analysis were local sense-checked to ensure appropriate mitigation measures are included and discussed so that relevant and valid information is taken into account when designing the wider programme. This was achieved through engagement with a range of local experts, and supported by literature drawn peer-reviewed sources, high level reports and credible media sources. The review highlights available datasets, monitoring, mitigation activity, existing networks (technical, community or other) and also draws on primary qualitative data collected via a stakeholder engagement process, all of which can inform the development of the wider programme.

What are the main findings for pollution impacts on biodiversity in South Africa?

A consolidated analysis of the published sources, secondary datasets and qualitative data emerging from the stakeholder engagement revealed the following:

- While the results are a part-reflection of the proportion of species threatened by pollution in South Africa, they do not fully and/or accurately depict the full extent to which flora and fauna are threatened by pollution in South Africa;
- Key taxonomic groups appear to have been overlooked or could be given more attention; e.g. of a number of important freshwater species, cryptic species such as diatoms, and invertebrate species;
- Pollutants within the Industrial and Military, and Domestic and Urban Wastewater categories are perceived to pose the greatest risk to biodiversity in South Africa, while Excess Energy was seen to be the lowest risk (Figure i).
- There are four major categories of pollutants that need to be mitigated, namely: Acid mine drainage (AMD); Air pollution; Agricultural pollution; and Pollutants from wastewater treatment works;

- Four major threat categories of emerging pollutants were identified: thermal; microplastics; traffic pollution; pharmaceutical chemicals and endocrine disrupting compounds;
- The South African pollution mitigation landscape needs to consider legacy issues such as the large number of abandoned mines and their impacts on water quality.

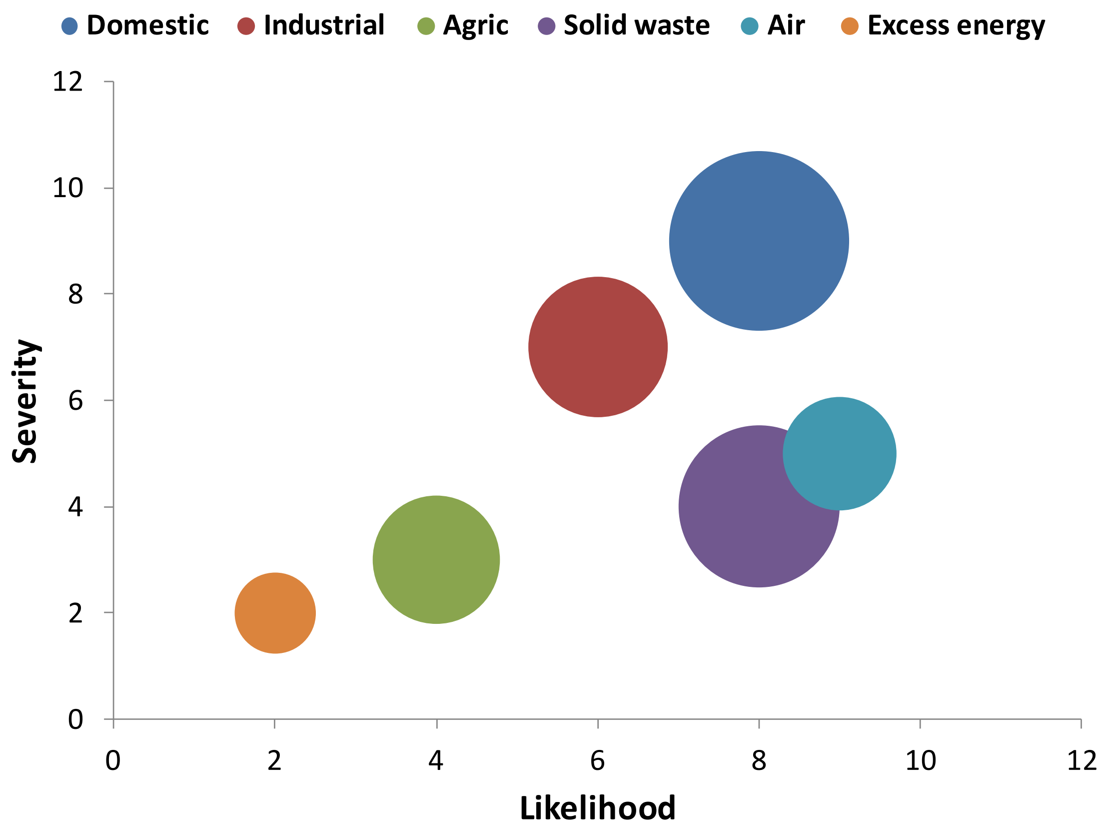

Figure i. Risk framework of impacts of major pollution categories on biodiversity, ranked according to likelihood and severity of impacts, while bubble size indicates relative importance.

What are the implications of this study for future action?

The different types of pollutants, and their negative impacts on biodiversity, are inter-connected and complex and should be interpreted using approaches that accommodate for this. Impacts of pollution on biodiversity are more likely to be chronic rather than acute; climate change will exacerbate the rate and extent of attrition on species and ecosystems. Chronic impacts can differentially result in sudden declines in species populations. Impacts of pollutants on biodiversity need to be understood in terms of the source type of the pollutant, viz. point versus non-point pollutants, relative to narrow-range endemics versus sensitive ecosystems. Our recommendations are as follows:

- The global hotspot analysis provides a useful initial tool for generating ongoing discussions and developing hypotheses; however, the maps for South Africa can be refined using additional inputs from a range of local data;
- There is a need to supplement the data used for the local analysis using existing databases and future research focused on established pollutants that pose a major threat (example those within the Industrial and military and Domestic and urban

wastewater categories), emerging pollutants (endocrine disruptors and light pollution) and taxa (e.g. plants) that are under-represented in the IUCN Red List database.

- There is a recognised need to collect relevant data that directly answers questions on the cause-and-effect links between pollution, climate change, and biodiversity loss. Currently, these links can largely only be made though inference.
- Major challenges in South Africa include poor enforcement, and a looming water quality crisis through poor wastewater management.
- There is a need for maximising spatial data collection through the use of citizen science monitors.
- Future research should contextualise ongoing programmes within a 'Theory of Change' framework, and incentivise positive outcomes by including an economic component that promotes a circular economy;
- We believe that a selection of diverse communication platforms will be useful for disseminating the findings of the project, and a target group-based approach is suggested. Of particular value will be a provincial-based approach which forms part of a National Awareness Campaign on the effects of pollution.

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1 Introduction

1.1 Background

Environmental pollution is one of the most serious global challenges that affect biodiversity, ecosystems and human health worldwide. The effects are far-reaching and impact land, soil, seas, freshwater and air. As part of the build-up to COP15 scheduled for the third quarter of 2022, Graça Machel, in her capacity as a steering committee member of the 'Campaign for Nature'[1], called for high level action in response to "the twin calamities of climate change and biodiversity loss [which] are destroying our natural environment far faster than it can recover, and we need to act now". This forms part of the Campaign for Nature's "30x30" global goal of conserving 30% of land and sea habitat by 2030.

Rising global air temperatures have recently been shown to be impacting the behaviour of the global water cycle, with greater volumes of freshwater moving pole-wards. The predictions are that drier subtropical regions are likely to become drier, with stronger and more frequent droughts and extreme rainfall events (Sohail et al*.* 2022). Climate change has been shown to impact food web structure (Gibert 2019), with possible mechanisms for this including decreased efficiency in trophic transfer of energy through food webs, particularly impacting larger consumer taxa, at higher trophic levels (Barneche et al*.* 2021).

While the debate about whether the earth has entered its sixth mass extinction still continues, evidence from species loss data and extinction rates clearly illustrate that the trajectory of extinctions is clearly headed towards this (Cowie et al*.* 2022). What separates this mass extinction from the previous five mass extinction events is that the current biodiversity crisis is entirely caused by humans (Cowie et al*.* 2022). Rates of human-induced biodiversity loss are exacerbated through the effects of global climate change, as highlighted in the previous paragraph. However, understanding the problem of negative impacts on biodiversity is more complex than simply understanding it in terms of the footprint of the impact. While it holds true that the number of species increases with the size of the area measured, and conversely that the footprint of the pollutant relates to its negative biodiversity losses, recent studies have also demonstrated that ecological complexity increases with area as a power law (Galiana et al*.* 2022). Consequently, wide-ranging impacts are likely to cause not only larger species losses but also lead to simplification of natural communities and lowered ecosystem resilience. This would also suggest that impacts of pollutants on biodiversity need to be understood in terms of the source type of the pollutant, viz. point versus non-point pollutants, relative to narrow-range endemics versus sensitive ecosystems.

From a carbon footprint to a water footprint, each item consumed also has a pollution footprint. The Anthropocene will not only be known for its massive impact on species loss and land cover transformation but also for its legacy of waste and tardiness in transitioning to a Circular Economy. Understanding the source-sink dynamics of different pollutants, and how these impact on species and ecosystems, is critical for designing pollution control programmes. This is because certain pollutants will have a local impact and solution set, while others will require regional or even global action. For example, plastics that are not contained in terrestrial systems will ultimately end up entering the ocean. The five circulating ocean currents, or gyres[2], critical for circulation of sea water, also concentrate

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[1] https://www.campaignfornature.org

[2] https://oceanservice.noaa.gov/podcast/mar18/nop14-ocean-garbage-patches.html

solid waste into floating islands of pollution. Similarly, large-scale global atmospheric air circulation, critical in redistributing thermal energy, dissipates air pollution into the atmosphere so that airborne pollutants extend beyond political or administrative boundaries.

Mitigating the impacts of the variety of pollutants generated by anthropogenic activities is also complicated by factors such as differential residence times, mobilities (both of which can be influenced by environmental conditions) and habitat-specific interactions. There is, therefore, value in trying to understand the impacts of pollutants in terms of local context and drivers. For example, salt applied to the roads during winter for de-icing of roads in northern Hemisphere countries is raising sodium chloride salt concentrations in rivers and lakes, negatively affecting zooplankton communities and causing an increase in algae (Hintz et al*.* 2022). While this is unlikely to be a problem in the South African context, the historical legacy of gold mining on the Witwatersrand is a uniquely South African pollution problem that has resulted in the waste from gold mines contaminating surface water with heavy metals, and groundwater through acid mine drainage (Chetty et al*.* 2021).

These examples highlight two important aspects that need to be considered within the context of pollution programmes aimed at reversing biodiversity loss, such as the Reducing Pollution through Partnership programme. The first is that the type of pollutant and how it dissipates in the environment governs the pool of stakeholders who should be involved in sharing solutions; and also the potential global reach needed in a relevant mitigation programme. Here, certain pollutants, such as ocean plastics, have a global footprint, while others, such as acid mine drainage, are a uniquely local problem that can only be understood through an analysis of history and local climate. The second aspect involves understanding the pollutant footprint relative to its biodiversity impacts in terms of species loss and ecosystem changes. Impacts may be local, in the form of point sources of pollution, yet potentially catastrophic for narrow-range endemic species. Impacts from non-point pollutants may be wide-ranging, negatively affecting whole ecosystems by altering species composition and ecosystem process. The pollution problem is thus defined spatially by its footprint, and temporally, by its biological effects as either acute or chronic. In the latter case, biodiversity loss could be gradual and linear, or sudden and catastrophic, even to the point of resulting in an alternative ecological state (Pattinson et al. 2022).

Alternative stable states have been recognised as a theory explaining abrupt changes in ecological systems for almost 50 years (Holling 1973), where ecosystem states change abruptly in response to exceedance of ecological thresholds. Such switches are distinct from gradual linear changes typical of natural systems versus abrupt catastrophic switches triggered by key variables in systems where resilience has been compromised (Scheffer et al*.* 2001). Alternative stable states do occur naturally, such as in the middle and lower Orange River of South Africa, where the river naturally switches between a clear-water, algae-dominated system and a highly turbid system that favours pest blackly outbreaks (Rivers-Moore and Palmer 2018). In this instance, a system switch is desirable because it can be a natural control mechanism for pest blackfly outbreaks. However, when systems switch to an unstable and undesirable state as a result of ecological degradation beyond a critical trigger point, this is likely to be accompanied by irreversible biodiversity loss and loss of ecosystem services (Scheffer et al. 2001).

1.2 Scope

It is against the backdrop of pollution impacts on biodiversity described above that the Joint Nature Conservation Committee (JNCC) and the Department for Environment, Food & Rural Affairs (Defra, United Kingdom) have developed a global scale analysis of pollution in official development assistance (ODA) countries. It is important that the results of this global analysis are local sense-checked to ensure appropriate mitigation measures are included and discussed so that relevant and correct information is taken into account when designing the wider programme. This can only be achieved through early engagement with a wider range of local experts. This in turn contributes to a broader project by the UK to scope and design a programme to enhance the ability of ODA-eligible countries to manage chemicals more sustainably and to reduce air, chemical, and waste pollution.

This report constitutes the evidence component of the local sense check study for South Africa. It is framed by a detailed literature review on pollution in the pilot country aimed to collate available information and evidence to inform the development of the wider pollution programme. The review highlights available datasets, monitoring, mitigation activity, existing networks (technical, community or other) and also draws on primary qualitative data collected via a stakeholder engagement process, all of which can inform the development of the wider programme. Consideration is given to include social and cultural implications of certain pollutant sources, species, ecosystems or interventions.

1.3 Aim and Objectives

The ultimate aim of this project is to reverse biodiversity loss, build ecological resilience and improve human health. For the purposes of this study, the focus was on inland pollution impacts on biodiversity. This was addressed via the following objectives:

I. Generating a situational analysis for pollutant prevalence, threats and management in South Africa;
II. Conducting a local sense check of the results of the pollution global analysis to ensure appropriate mitigation measures are included and discussed so that relevant and valid information is taken into account when designing the wider programme; and
III. Making recommendations on the scope and design of a wider pollution programme to enhance the ability of low- to middle-income countries to manage chemicals and to reduce air, chemical, and waste pollution.

2 Methodology

In this section, we provide a brief description of the approaches used to gather information on pollution impacts on biodiversity for South Africa. For this, we used a mixed-methods approach to collect information from a wide range of sources based on a research toolkit of three Data Collection Methods (DCM; Table 1).

Table 1. Research toolkit used for the data collection phase of the project.

DCM	Approach
1. Desktop review	Systematic literature and policy review
2. Quantitative	Meta-analysis of secondary data
3. Qualitative	• Rapid assessment surveys administered during the online workshop via live polls • Key informant interviews and direct observations

2.1 DCM 1: Desktop Review

The Search, Appraisal, Synthesis, and Analysis (SALSA) framework (Grant and Booth, 2009) was utilized to conduct a systematic search and review of pollution impacts on biodiversity with a focus on South Africa. The various steps of the SALSA framework (Figure 1) enable a systematic, yet robust analysis of literature while minimizing the potential for bias. According to Grant and Booth (2009), the comprehensive search process and critical review which results from the adoption of the SALSA framework results in evidence-based synthesis. Relevant literature were sourced that provided information on relevant policies, frameworks, guidelines, case studies, etc. Popular articles and publications as well as public relations/educational material produced by relevant stakeholders were included in the review. This component identified and highlighted available datasets, monitoring programmes, and mitigation activities relevant to the pollution aspects emerging from the Local Sense Check information package.

Figure 1. Flow diagram of the SALSA framework (adapted from Gunnarsdottir et al., 2020).

2.2 DCM 2: Meta-analysis of secondary data

The review was based on a literature search using Google Scholar, which draws on a wide range of sources, Web of Science and Scopus as the first point search engines since they in turn query additional databases including Science Direct, Elsevier and JSTOR. The search was based on a set of keywords, and symbols to avoid duplication of information. More specifically, the selection of the relevant keywords for the search was based on reducing false positives, and for this purpose the '*' and '?' (and Boolean search) symbols were used to capture as many variations in spelling of keywords as possible. Keywords were searched in title, abstract content and indexed keywords in each primary study.

2.3 DCM 3: Workshops, interviews and direct observations

Identification of appropriate stakeholders for the local sense workshop (see process used in Figure 2) was key to ensuring that the exploration of the data and results from the Global Analysis of pollution developed and provided by JNCC are robust. While the facilitators drew heavily on the workshop information package and survey produced by JNCC for the workshop, they also ensured that provision was made for participants to interrogate the information shared with them and point the South African partners in the direction of parameters, data repositories and organisations/individuals that can have valuable inputs on the subject matter being addressed. Alongside the survey, the facilitators also designed and administered a series of open-ended questions and online polls to provide qualitative data which could be applied to the development of the Reducing Pollution through Partnership programme (Appendix 1).

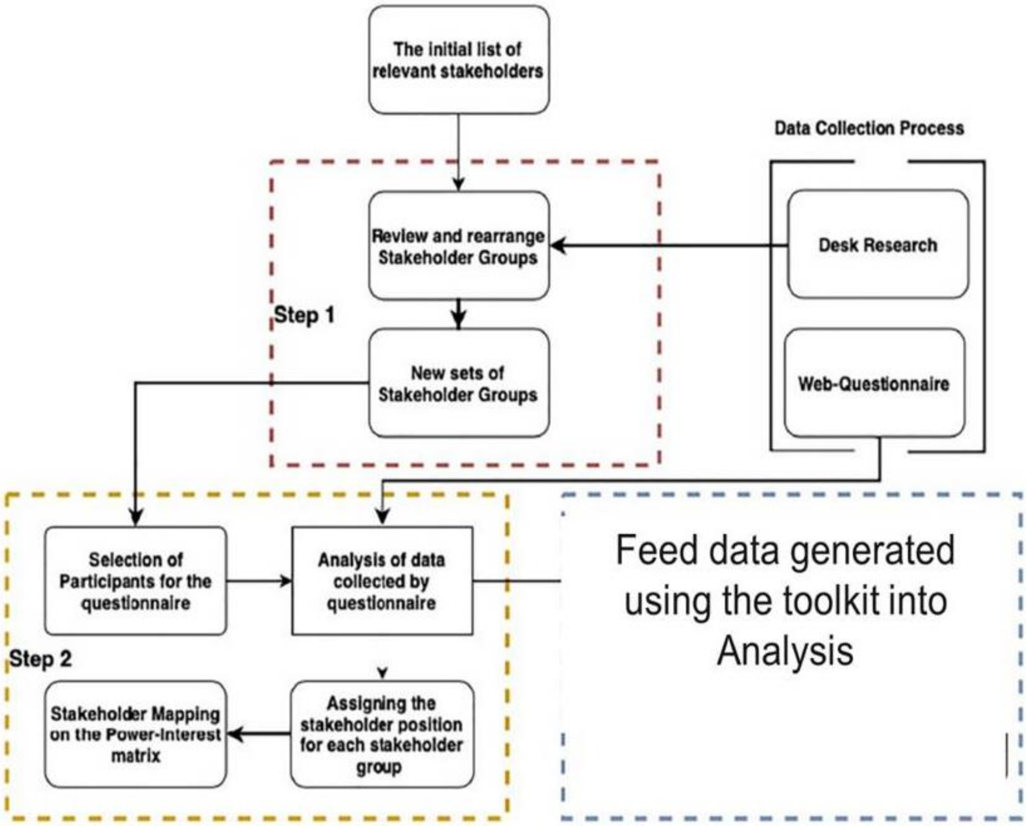

Figure 2. Summary of stakeholder identification process.

The South African partners developed a preliminary stakeholder database using literature, policies, programmes, plans and strategies and through consultation with experts from various sectors including research and government. This database was thereafter supplemented and refined based on additions and suggested exclusions provided by the Project Management Team (PMT; South African partners and the JNCC). These stakeholder groups were then used to conduct a stakeholder mapping exercise which included establishing their interest in and influence on pollution, climate change and/or biodiversity conservation. Thereafter, this was used to identify the target participants for the online workshops. An electronic invitation was sent to all target stakeholders, and the information package prepared by JNCC was presented to relevant stakeholders via an online workshop.

Due to COVID-19 restrictions, the workshops were conducted online, which allowed for stakeholders to participate from around the country without needing to travel, thus saving time and resources. The results of the Global and Local Analysis of pollution for South Africa, and the pool of questions provided by JNCC as part of the Information Package, were used to design the data collection instruments, viz. a workshop and post-workshop questionnaire, and the activity schedule for the workshop. A focus group methodology was used for the 2-hour workshops with a number of tools being employed for engagement. The tools were used to engage stakeholders at the workshops in the following activities with active facilitation:

- a rapid online questionnaire administered with live data capturing using the real-time Polly App[3] on MS Teams; and
- open discussion to unpack/build on the responses to the poll questions.

The questionnaire and schedule of activities used to promote open discussion were designed around the following themes:

- status quo of pollution impacts of species in South Africa;
- emerging pollution threats;
- pollution controls, including policy and management structures;
- additional factors to consider when assessing pollution in South Africa;
- data guiding decision-making around pollution in South Africa; and
- subsequent steps for pollution research and mitigation in South Africa.

Following on from the workshop, as a means of deepening quantitative feedback on pollution and species projects, a post-workshop questionnaire was sent to the participants (Appendix 2). This allowed workshop participants more time to consider their responses and probe aspects that could not be addressed in sufficient detail during the workshop. The post-workshop questionnaire was accompanied by the Pilot Country Pollution Analysis Report for South Africa, and the presentation video on the Local Analysis for South Africa, when it was sent out to participants.

A combination of facilitator observation and snowball sampling (i.e. where an interviewee highlights additional experts to contact) was used to identify eight key informants, i.e. high-level decision-makers and/or experts in the fields of pollution management/monitoring, biodiversity management or climate change, who were invited to participate in semi-structured interviews to probe the findings emerging from the workshop. The questions posed in the interviews were similar to those posed in the workshops but were probed in more detail. The interviews were held online and conducted via the Zoom platform. They followed a semi-structured questionnaire (Appendix 3) and lasted for approximately one hour. Some questions featured here, particularly those related to the Global Analysis and the Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis were, however, unique to this DCM. The interviewers confirmed that the interviewees agreed to be interviewed before recording the meetings, and informed them that their private information is protected based on the Institute of Natural Resources' (INR) protection of personal information

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[3] Polly is an innovative live polling application purpose-built for MS Teams and Slack to facilitate virtual engagements such as team meetings and surveys. Polly was utilized to present pop-up polls of the survey questions to enhance the interactive experience of participants and promote active engagement.

compliance framework. The interviewees received the information package documents (Local and Global Analysis presentation videos, and the Pilot Country Pollution Analysis Report for South Africa) prior to the interview.

2.4 Synthesis and Analysis of data from DCMs 1-3

The synthesis and analysis of information gathered from the three data collection methods - literature review, workshops and key informant interviews - involved assimilating the information into key themes, from which key points and recommendations could be distilled. Overall, we followed an iterative filtering process through which key points for country analysis pollution maps were distilled, as a method to align recommendations. The process began with collating and categorising the outcomes from the workshops and interviews in terms of main themes, data gaps, and potential sources of new data. We selected three case studies of how relevant local data could be used to supplement the existing global analysis.

This was succeeded by an assessment of the adequacy of International Union for Conservation of Nature (IUCN) species data used against national species data from the 2018 National Biodiversity Assessment (SANBI 2019). On the basis of this information, major taxonomic groups were scored on a scale of one to five with reference to each major pollution category, in terms of relative impact of pollutant and level of perceived representation in the pollution hotspot analyses.

As part of the overall discussion, all of this information was summarized in a conceptual model describing the relative spatio-temporal scales of point versus non-point pollutant impacts and how these related to chronic versus acute impacts on species populations or ecosystems, and the relative roles of media information versus peer-reviewed information. We also represented the relative impacts of each pollution category on biodiversity in a risk framework based on severity and likelihood of impacts (Scholes et al. 2016). This is a useful tool for prioritizing future pollution mitigation programmes. Given that pollution impacts on biodiversity are neither static over time nor understood in isolation, we developed a theoretical model to demonstrate two potential future scenarios of changes in pollution 'amounts' from a current starting point of unity (= 1). The relative changes in national pollution signatures relative to biodiversity losses were plotted to demonstrate that gains in one pollution category may be offset by increases in pollution for other categories in response to altered economic priorities. Lastly, a 'Strengths, Weaknesses, Opportunities and Threats' (SWOT) analysis around pollution monitoring and mitigation in South Africa was included as a method of summarizing and categorizing a large amount of information into one section.

3 Situation Assessment

3.1 SciVal meta-analysis

A high level bibliometric analysis using the web-based analytics solution SciVal was performed to characterize South Africa's research output and foci in relation to pollution. More specifically, SciVal was used to visualize research performance relative to other countries and identify established and emerging research trends in terms of research on the relationships among pollution, biodiversity and climate change. SciVal analyses are based on data from over 55 million publication records from more than 22,000 journals of 5,000+ publishers worldwide.

The database query was based on a keyword/title search where all publications had to have the string '*pollution+species+South Africa'* and could have the words '*biodiversity+risk+climate change'* published globally. The search was confined to the period 2011 to 2021 (Figure 3).

The detailed results of this analysis are available in Appendix 4. In summary, the results showed that a relatively low number (152) of publications on pollution in South Africa were published between 2011 and 2021 with the majority of this research being published by researchers based at African/South African institutions. The bulk of the research focuses on the effects of metals on fish and pollution effects on birds. Pollution research on dams, macroinvertebrates, lakes and wetlands seems to be in a declining trend, followed by research on indicator species and bioremediation, while research on topics like bioaccumulation, water quality, estuaries, organo-chlorine, pesticides, mercury, rivers, mines tailings, effluent, acid mine drainage, introduced species and health risks appears to be growing.

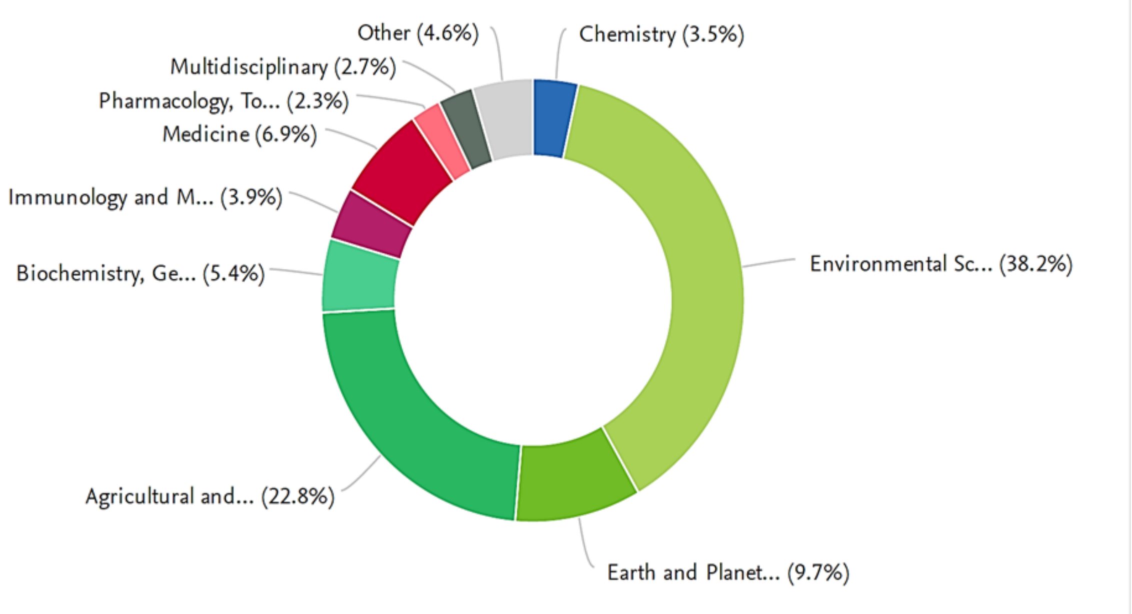

Figure 3. Publications on pollution by subject area for South Africa.

3.2 Review of scientific and 'grey' literature to determine key themes emerging

This section is based on a targeted selection of relevant literature on pollution types either in South Africa, or global studies where methods might apply to the South African context. We include relevant information on the synergistic impacts of climate change and pollution on biodiversity losses.

3.2.1 Domestic and urban wastewater

This category includes sewage, run-off, and domestic/urban wastewater. Pollutants in this category can include a wide range of chemicals, many of which are not routinely monitored in South Africa due to prohibitive costs. By way of example, this category includes items entering drains: phosphates from washing powders; ammonia from cleaning agents; sewerage and residues from pharmaceutical products in water-borne sewage systems or sewage runoff from pit latrines; and hydrocarbons from roads washed into stormwater drains during rainfall events. Either through direct entry, or having passed through wastewater treatment works (WWTWs), the water in these systems ultimately ends up in rivers.

Much has been written about these pollutants, both in the media and in scientific publications. Typically the most dominant issue revolves around contamination of water due to faecal coliforms, including the human coliform bacteria *Escherichia coli* (*E. coli*). This has been attributed to both human and animal sources in the literature through direct deposition or spills/input from sewage treatment plants and farm effluent (Sinton et al. 1998). However, stakeholders engaged during this study, together with direct observations made by members of the South African team, indicate that improperly discarded nappies that enter water storage facilities and fresh water bodies may also be contributing to the contamination release of pathogens into fresh water sources. There are suggestions of this possibility in the literature but further confirmation is necessary (Brown et al. 2013; Bouzid et al. 2018). Another emerging issue both globally and in South Africa that is gaining attention is that of endocrine-disrupting hormones (EDHs) that enter the water cycle through processed pharmaceuticals excreted in human urine (Grill et al. 2016; Horak et al. 2021). The former are routinely monitored as a relatively inexpensive water quality variable, while the latter are not, being both expensive and with concentrations often below detection limits.

Similarly, a largely undocumented problem in terms of water quality is the accumulative effect of pharmaceutical products on aquatic ecosystems. These chemicals impact aquatic communities by altering dynamics at particular trophic levels. Antihistamines for example, have been shown to negatively affect resource recycling in streams (Jonsson et al. 2015), while ubiquitous psychiatric drugs alter overall patterns of macroinvertebrate communities by directly impacting baetid mayfly abundances (Jarvis et al. 2014).

The global gold standard for disposal of human excrement is through water-borne reticulation systems. Contamination of freshwater through faecal matter is a global issue that transcends economic and social boundaries[4]. Excluding water losses through consumptive use by cities and industries, the majority remainder of the water used is re-circulated, as it is within the larger global water cycle. The returning water from cities and

[4] https://www.theguardian.com/tv-and-radio/2022/feb/28/wasteland-americas-growing-sewage-crisis-docuseries

industries is often heavily polluted with nutrients and chemicals, with an associated cost to clean this (Richter 2014). The loss of availability of potable water translates into economic costs, with a World Bank report for China estimating that $24 billion is lost annually in lost water availability due to pollution (World Bank 2007). In South Africa, the situation is no different, with about 5 billion litres of raw sewage discharged every day, of which 84% (4.2 billion litres) enters rivers daily in untreated form, in what is described as a "tsunami of human waste"[5].

In South Africa, water quality is routinely monitored at varying levels of sampling intensity and scale across different Municipalities in South Africa, with data typically collected at monthly or quarterly intervals. Data is collated as a time-series, which can in turn be subjected to analyses for compliance against water quality thresholds using, for example, return interval curves and probabilities of exceedance of thresholds (Figure 4). Despite the availability of such data and reports for many of the major cities in South Africa (see, for example, Day et al 2020; Cullis et al. 2019; Rivers-Moore 2016; Dabrowski et al. 2014; Coleman and van Niekerk 2007), the problem remains on a deteriorating trajectory. Even with a solid knowledge base of the impacts of water quality on aquatic ecosystems (e.g. Dallas and Day 2004), much of the problem reduces down to non-compliance of municipal WWTW to water quality standards. The annual compliances of municipal WWTWs are assessed against national and international drinking water quality standards, which are reported nationally. Despite the existence of the National Greendrop Certification Programme managed by the national Department of Water and Sanitation (DWS), its successful implementation at the local authority level is hampered by a range of factors including a lack of capacity and poor management (Ntombela et al. 2016). While previously reported annually, this reporting process had a nine-year hiatus prior to the July 2020/ June 2021 reports[6].

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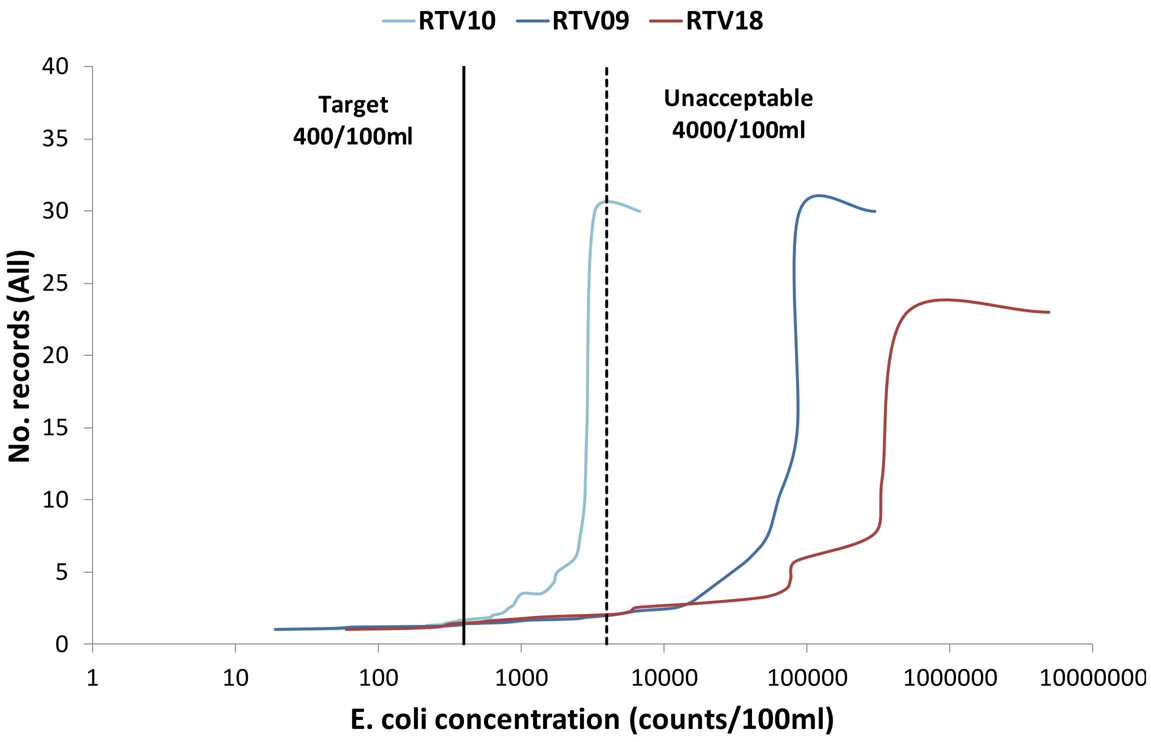
[5] https://www.news24.com/news24/analysis/anthony-turton-a-tsunami-of-human-waste-inundates-our-rivers-and-dams-and-its-a-security-issue-20220303

[6] https://www.timeslive.co.za/sunday-times-daily/news/2022-04-06-wastewater-treatment-report-shows-sa-is-even-deeper-in-the-kak/



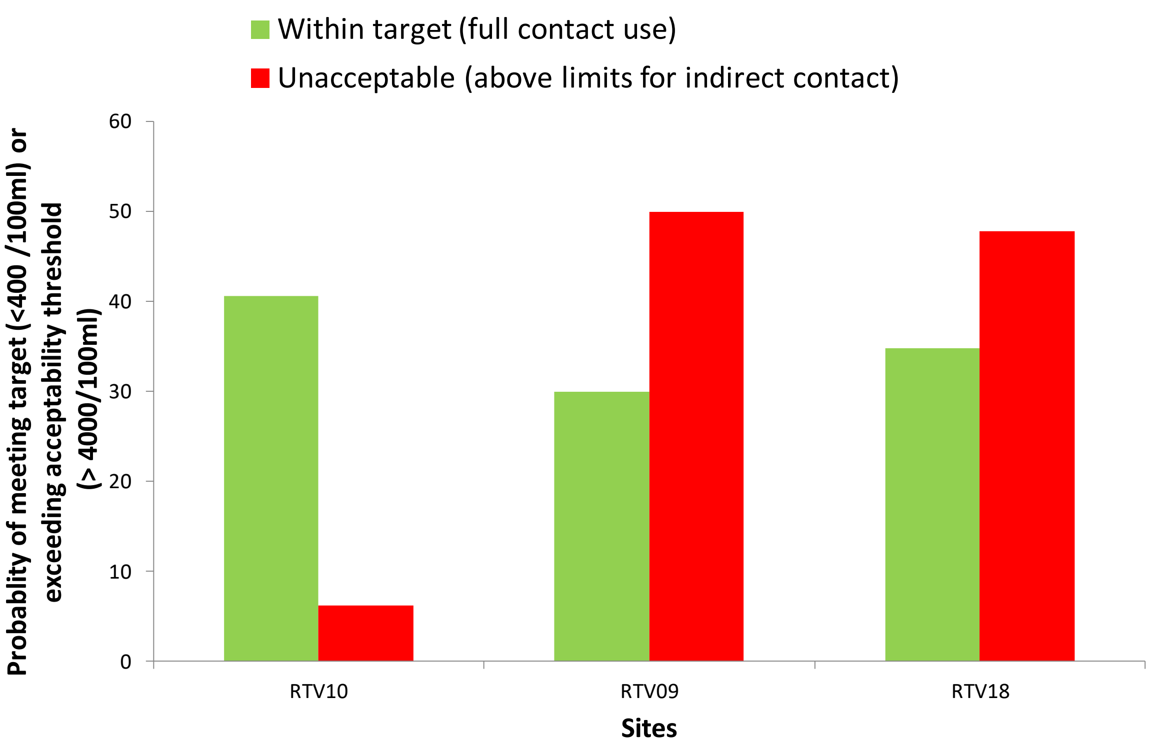


Figure 4. Return interval curves for summer *E. coli* measurements at three sampling sites for Milnerton Lagoon, Cape Town area (2015-2019), plotted in relation to the target for full contact recreation and the threshold of unacceptable risk for intermediate contact recreation. Accompanying bar graph shows the probability of meeting the target (green bars) or exceeding the risk threshold (red bars) in each season (as derived from the return intervals) (Source: Day et al. 2020).

3.2.2 Industrial and military effluents

This category includes oil spills, seepage from mining (including acid mine drainage), and industrial/ military effluents. While this category is almost exclusively a point-source pollutant, where the impacts on biodiversity would best be understood through the lenses of narrow-range endemic species and sensitive ecosystems in close proximity to spills, it is also the pollution category with the highest level of uncertainty for defining hotspots. This is on the premise that at any one time, there are significant volumes of a range of industrial and military chemicals being transported around South Africa. The degree of complexity of the supply chain, and its vulnerability to disruptions, were illustrated during the civil unrest experienced in parts of South Africa in July 2021.

The volume of industrial chemicals being transported by road is disproportionately larger than the volume transported by rail, with the gap becoming larger with time due to the demise of South Africa's rail network dating back to the 1980s. This means that the potential exists for effluent spills from a wide range of chemicals along any of the major roads in South Africa. This is further exacerbated by the deterioration of roads across South Africa which increases the chances of accidents. Spatially representing this category would thus need to incorporate a statistical analysis to map hotspots and return intervals (probability of a spill) for spills.

Understanding this category of pollution requires an understanding of historical legacies, current economic context, and future energy trajectories. A report from 2009 from South Africa's Department of Mineral and Energy stated that 5906 abandoned mines required rehabilitation (Auditor-General 2009). Based on available information from 2009, the concentration of abandoned mines is highest in the Witwatersrand, West Coast and Orange/Vaal River areas (Auditor-General 2009; Figure 5). This results in, *inter alia*, major environmental impacts on surface water and groundwater systems through pollution by acids, salts and metals. Inadequate closure of old mines that were not rehabilitated, coupled with the lack of an integrated information system, a lack of accountability, and inadequate policies and procedures for budgeting on rehabilitation projects, all compound the challenges in addressing this category of pollution (Auditor-General 2009). In particular, waste from gold mines is described as one of the largest single sources of pollution in South Africa, and is a major contributor to acid mine drainage as a serious environmental and socio-economic issue (Chetty et al. 2021). Here, due to the network of karst aquifers in mining areas of the Witwatersrand, point source pollution results from water from mine shafts and boreholes contaminating groundwater, and entering streams, negatively impacting aquatic biota (Hobbs 2017). This excludes currently active mines which are non-compliant in terms of their Water Use License (WUL) requirements, with 118 mines listed as non-compliant, and 87 of these being less than 50% compliant (DWS 2018).

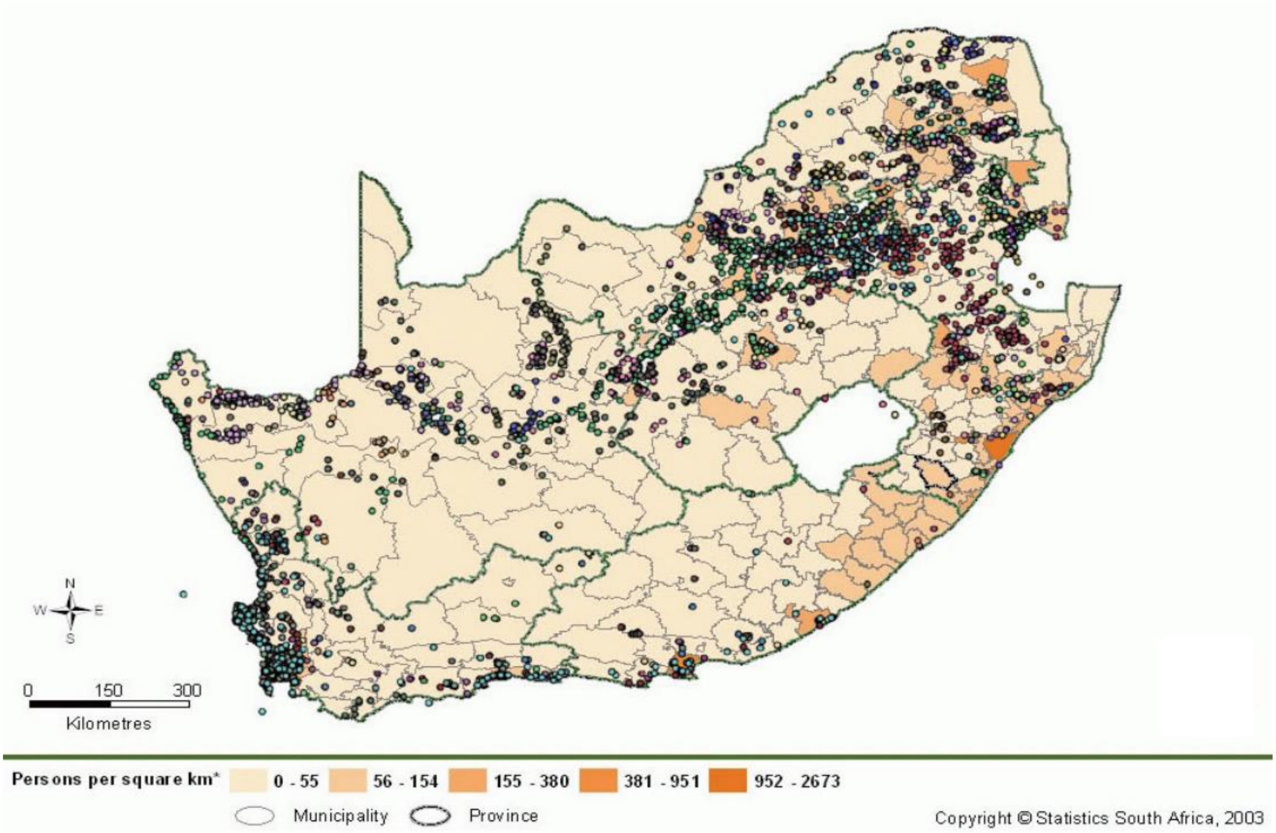


Figure 5. Spatial pattern of abandoned mines in South Africa versus population density (Source: Auditor-General 2009).

Current impacts include a strong stochastic element in terms of spills. Within a six month period between July 2021 and January 2022, for example, three major spill incidents occurred in three different parts of South Africa, all for different reasons, involving different chemicals, and with different environmental impacts. In the first case, a chemical warehouse near Durban storing thousands of tons of pesticides was set alight during the July 2021 social unrest[7]. In addition to the air pollution problems caused by the fires, chemical run-off into the Umhlanga Lagoon impacted water quality and caused fish fatalities. The post-fire cleanup presents a potentially informative insight into the loopholes in legislation for chemical warehouse zoning and rental agreements, private sector accountability and government intervention that warrants further investigation[8]. In the second case, a coal mine slurry dam burst on 24th December 2021, releasing some 1.5 million litres of acidic water containing toxic chemicals into the surrounding landscape, and ending as a plume of polluted water in the Umfolozi River[9]. Here, the impacts on aquatic biodiversity are yet to be documented. In a third example, a fuel pipeline fire at the

[7] https://www.dailymaverick.co.za/article/2022-02-13-upl-cornubia-catastrophe-highly-toxic-cocktail-of-chemicals-in-smoke-plume-finally-identified/

[8] https://www.dailymaverick.co.za/article/2021-12-10-government-no-longer-trusts-upl-after-cynical-attempt-to-delay-cornubia-chemical-directives/

[9] https://www.dailymaverick.co.za/article/2022-01-11-river-turns-black-after-coal-mine-dam-collapse-next-to-rural-communities-and-hluhluwe-imfolozi-game-reserve/

Waterkloof Airforce Base near Pretoria on Sunday 23rd January 2022 resulted in a hydrocarbon spill into the surrounding landscape[10].

A latent future source of industrial pollution that could pose biodiversity risks in the central Karoo region of South Africa exists in the form of shale gas development (Scholes et al. 2016). While this is not current, a change in South Africa's energy policies could re-activate this initiative, resulting in chemical pollution of surface water and groundwater resources, as well as a range of other pollution problems including air and noise, for which potential biodiversity impacts have already been assessed (Scholes et al. 2016).

3.2.3 Agricultural and forestry effluents

This category includes nutrient loads, soil erosion and sedimentation, herbicides and pesticides, and other agricultural and forestry effluents. The overview in this section assesses pollutions impacts on biodiversity from this category in terms of a holistic picture, focusing on turnaround times of harvesting of plantations versus agriculture, the land cover transformation that accompanies these activities, and the use of pesticides (here including herbicides, larvicides, insecticides and fungicides) and fertilizers to maximize yields.

In South Africa, as with many other Western countries at the least, a so-called "green revolution" occurred following on from the end of the Second World War. The combination of modified seed varieties, availability and increased use of fertilizers and pesticides, all enabled an exponential increase in agricultural production that reflected the growth in the global human population. However, following on from a boom in agricultural profits and production was a growing realization that this also brought considerable environmental costs (Carson 1962).

Through a combination of eight seasonal rainfall types across three climatic zones (mediterranean, temperate and sub-tropical), and varied topography over elevation ranges from sea level to > 2500 m, the landscape is suitable for extensive afforestation and cultivation of a wide range of agricultural crops (Schulze 2007). The main species of plantation trees in the forestry industry are gums (*Eucalyptus* spp.: poles and mine structures), pine trees (e.g. *Pinus patula:* timber and pulp industries) and wattle (e.g. *Acacia mearnsii*: leather tanning industry) (Brink and Janes 2017). Rotation intervals for forestry and agriculture are a useful indicator of the likely frequency of application of pesticides, fertilizers and sediment loads. Many of the major agricultural crops are annual crops, while rotational intervals for forestry range from approximately 8-20 years (Brink and Janse 2017). Intermediate to these timeframes are orchard crops such as citrus and vineyards, where crops are harvested annually but the standing crop will have a rotation age similar to forestry plantations. The implication of this is that pollution impacts on biodiversity for this category will need to be assessed in terms of frequency of chemical applications, and that this is likely to be significantly lower for forestry than for agriculture. Also of relevance in terms of regulation is that forestry is the only gazetted streamflow reduction activity in terms of the National Water Act (Chapter 4, Part 4, Section 36 of 1998), which in turn relates specifically to regulation in terms of the issuing of WULs by the Department of Water and Sanitation.

One of the major direct impacts of agriculture and forestry on biodiversity is as a result of changes in land cover and disturbance to natural energy pathways, which in turn may result in reduced carrying capacity of the landscape (McLaughlin and Mineau 1995). Impacts of

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[10] https://www.iol.co.za/news/south-africa/gauteng/still-no-word-on-what-started-the-fire-at-waterkloof-air-force-base-6d1f29ee-4478-461b-9bdb-aa895bd87e9a

pesticides and fertilizers on biodiversity are another secondary pathway resulting from the wider impacts of agriculture and forestry in general. The effects of pesticides on biodiversity can be categorized based on a number of factors including application concentration; specificity and toxicity; and frequency and timing of application, particularly with respect to timing of life cycle events of impacted species (McLaughlin and Mineau 1995). For example, insecticides often used to control pest blackfly are often highly target-specific and less damaging to ecosystems (Palmer and Rivers-Moore 2008), while broad spectrum insecticides are less discriminate and cause greater mortalities in non-target species. In contrast, herbicides are typically aimed at controlling all plants except the crop species (McLaughlin and Mineau 1995). Pesticides may be toxic to beneficial insects, birds, mammals and amphibians, as well as soil organisms (Isenring 2010). Pesticides enter the food chain, either through direct application, or as run-off or drift into adjacent ecosystems such as rivers, and typically accumulate in higher trophic levels (Isenring 2010). Indirect impacts of pesticides thus include trophic impacts, such as the availability of plants and insects for food, unintentional impacts on bird populations through the use of insecticides, or changes in habitat structure through the indiscriminate use of herbicides (McLaughlin and Mineau 1995).

One of the most useful tools for assisting with assessing impacts of pesticides on biodiversity in South Africa is a recently completed study by Dabrowski et al*.* (2022) for the Water Research Commission. This was a national scale study aimed at identifying hotspots of agricultural non-point source pollution from pesticides. Pesticide risk maps were created to identify potential risks to algae, fish and aquatic invertebrates (*Daphnia magna*) per quaternary catchment. Quaternary catchments are fourth-level catchment divisions and are the principal water management units in South Africa and are based on a standardized runoff measure per unit area (Midgley, Pitman, & Middleton, 1994). A second tool, known as the Automated Land-based Activity Risk Assessment Method (ALARM; DWA 2014), also a national spatial tool using quaternary catchments in South Africa, allows users to interactively assess risk for a wide range of point and non-point pollutants to surface water and groundwater quality, as well as including paths of entry based on catchment morphometry and rainfall region.

3.2.4 Garbage and solid waste

Solid waste in South Africa is defined in terms of the National Environmental Management: Waste Act (Act 59 of 2008), and can be broadly classified as general waste (17 sub-categories including domestic and commercial waste, and building and demolition waste) or hazardous waste (21 categories including batteries, waste oils and electronic equipment) (DEA 2012). Four national waste information baseline reports have been undertaken in South Africa to date (1991, 1997, 2011 and 2018: DEA 2018). For each baseline, volumes and trends in waste streams in South Africa have been quantified. However, baseline data between years are not directly comparable due to changes in the definitions of waste and incorrect classification, as well as poor record keeping of solid waste across municipalities (DEA 2012).

Driving variables of solid waste generation include population size and growth, income levels, urbanization and economic growth, all as internal mechanisms. Extraneous drivers include the global recyclable market and economic incentives for countries to accept foreign waste[11]. Solid waste is associated more typically with urban areas, and in South Africa, the urban population has been growing by 2% per annum since 2008 (DEA 2018).

By way of volumes of solid waste, the 2011 baseline study estimated that 108 million tonnes of waste were generated for that year, of which 90.7% were disposed of at landfill sites. Of this total, the breakdown of waste categories was estimated as 59 million tonnes for general waste (10% recycled), 48 million tones as unclassified waste, and 1 million tones as hazardous waste (DEA 2012). Despite the 2011 assessment showing a growth trend of 2-3% per annum increase in waste volumes, figures from the 2018 baseline survey seem to be slightly anomalous against the 2011 survey. Here, the volume of general waste was 55.6 million tonnes (34.5% recycled), and 52 million tonnes of hazardous waste (DEA 2018). The largest component of hazardous waste pollution in 2018 was from coal burning (75.2%: 63.9% as fly ash and 11.3% as bottom ash), followed by industrial waste (16.7%: 11.1% as brine from industrial activity, and 5.6% as slag from smelting) (DEA 2018). Fly ash presents a specific problem for human health, causing respiratory disorders as an air pollutant. Data on waste in South Africa is available via the South African Waste Information Centre as a resource to government, business, industry and the public on waste management.

The national auditing of solid waste, assessment of trends, and management thereof is strongly linked to the effective functioning of local municipalities. According to the 2018 baseline survey, 59% of solid waste was collected and disposed of by local authorities (DEA 2018). While the majority of landfill sites cater for general landfill, there are also facilities that cater for hazardous materials, recycling and treatment. Landfill sites not only receive urban waste, but, to varying degrees, will have been receiving increased volumes of personal protective equipment (PPEs, as a sub-category of hazardous waste), since late 2019 with the start of the COVID pandemic. Sub-Saharan Africa has seen a considerable increase in the volume of discarded single-use masks, protective gear, needles and syringes informally disposed of[12]. While not unique to Africa, other lower income countries such as Bangladesh have reported similar problems, where microfibers, microplastics and elastics from masks can impact biodiversity and ecosystems (Abeden et al. 2022). This is occurring against an existing background of some 3.5 billion soiled nappies annually entering landfills in South Africa[13]. Waste not being disposed of at official landfill sites is likely to end up in the environment through illegal dumping (Figure 6). Families living in informal housing are more likely to dump waste in the street, or near rivers, with impacts on aquatic ecosystems potentially identifiable as a distance decay function between households and ecosystem (Quayle et al. 2015; Haywood et al. 2021).

Further compounding factors include the importation of general and hazardous waste for recycling or disposal at landfill sites. One potential case in point is that as wealthier economies progressively ban plastic waste, this may in turn be externalized to poorer African countries, with Africa becoming a dumping ground for plastic waste. Weakening economies and high unemployment rates increase the chances of this happening as it can

[11] https://www.news24.com/news24/africa/news/africa-faces-tough-job-not-to-become-worlds-plastic-dustbin-20220226

[12] https://www.dw.com/en/africa-groans-under-the-weight-of-covid-19-waste/a-60804723

[13] https://gbcsa.org.za/tackling-the-environmental-impact-of-disposable-nappies/

generate revenue and taxes[14]. In a recent study on single use plastic bottles and containers collected along the South African coast (Ryan et al*.* 2021), the sources of solid waste was found to be a mixture of local bottles and waste illegally dumped from ships (Ryan et al*.* 2021).

A relatively new source of solid waste, categorized as the fastest growing waste stream globally – including South Africa – is waste from electronic products, or "e-waste". Contributing factors to this are the increased access to electronic products, improvements in technology that results in fast rates of redundancy in older equipment, and decreasing production costs. It is estimated that 5-8% of South Africa's solid waste consists of e-waste[15]. E-waste's inherent toxicity in its electronic components is also a factor in resolving this issue, because of the economic benefits of recycling components. There is an existing private sector initiative for recycling e-waste that is based in Durban but operates nationally through a network of 1 000 e-waste collection points (e-Waste Association of South Africa). It should also be mentioned that a number of pollutants released via the dismantling and/or burning of discarded electronic items are entering natural habitats through illegal/informal 'recyclers', particularly within and around urban slums and informal settlements throughout the country and continent (Orisakwe et al. 2019).

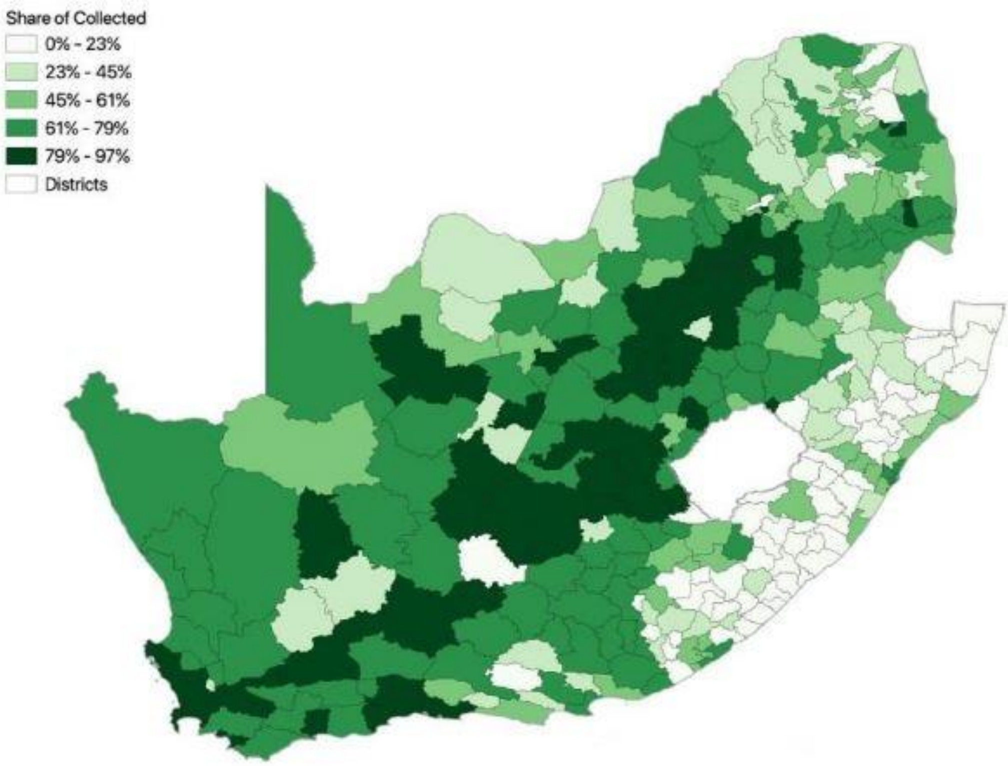
Tourist camps in protected areas generate solid waste, although the management and disposal of solid waste generated in rest camps is a function of reserve size, distance from municipal landfill sites, cost of transport as a component of limited conservation budgets (Hatton 2002). Here, it was found that protected areas less than 5-10 000 ha, and less than 30-40 km from a municipal landfill site, would use municipal landfills (Hatton 2002). The implication of this is that larger, more isolated game reserves are likely to represent localized point-sources of solid waste in important conservation areas.

Species impacts from solid waste are likely to negatively affect individual organisms in affected areas, thereby raising overall population mortality rates. Pathways of influence include ingestion of plastics and other foreign bodies and entanglement causing suffocation or maiming. Hazardous chemicals from landfill sites may leach out into rivers and water bodies, negatively affecting water quality. This can result in the loss of sensitive and/ or endemic aquatic macroinvertebrates and fish, and common, poor water quality-tolerant taxa such as Chironomid larvae dominating. A build-up of solid waste in rivers may impact on channel functioning and loss of hydraulic biotopes. The net result of both of these impacts is a reduction in beta-diversity at the landscape level, and homogenization of environments in terms of biodiversity (Socolar et al. 2016).

[14]https://www.news24.com/news24/africa/news/africa-faces-tough-job-not-to-become-worlds-plastic-dustbin-20220226

[15] https://www.golegal.co.za/e-waste-treatment-facilities/

(A)



(B)

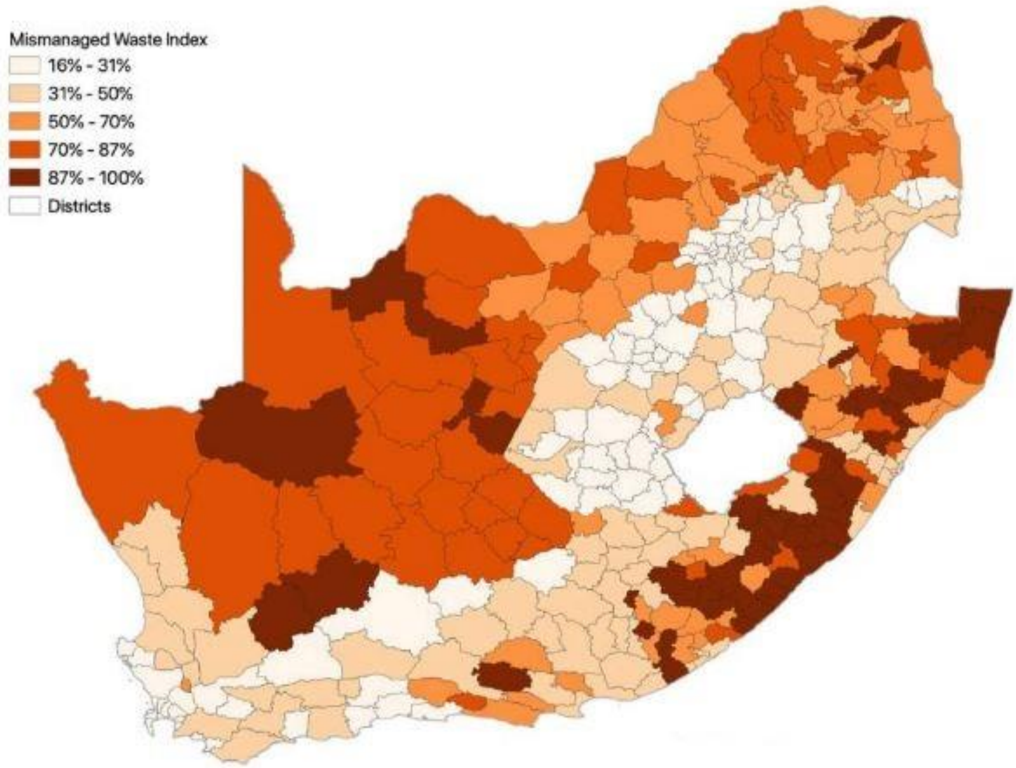


Figure 6. (A) Pattern of waste collection effort across provinces and (B) Mismanagement Waste Index, typically lower around big cities (Source IUCN-EA-QUANTIS, 2020).

3.2.5 Air-borne pollutants

This category includes the sub-classes of acid rain, smog and ozone as pollutants. While sources of airborne pollution are classified as points, they quickly become diffuse regional issues as chemicals are dispersed through air currents. This is also a cross-cutting pollution category, as many airborne pollutants eventually dissipate into water or soil. Airborne pollutants may also be secondary pollutants from primary pollution sources in other categories, e.g. gold mining and coal burning power stations.

In South Africa, ambient air quality monitoring focuses primarily on levels of exposure to the human population. Monitoring is typically limited to metropolitan and industrial areas, with few stations in rural areas; number and location of monitoring sites are calculated according to SANS 1929 (2005) guidelines. Priority pollutants monitored are limited to sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), lead (Pb), nitrous oxides (NO_x), and particulate matter for particles < 10 μm diameter (PM10 and dust). An additional toxic global pollutant – total gaseous mercury (TGM) – is also now routinely monitored in the Highveld region of South Africa (Beliele et al. 2019). As far as can be ascertained, there is no coordinated approach to ambient air quality monitoring either provincially or nationally, with monitoring undertaken by 35 agencies through approximately 430 stations in 2006 (DEAT 2006; Figure 7). In addition to this is a regional-scale passive air quality monitoring programme consisting of 37 sites for the Eastern portion of South African, which has been in operation since 2006. This was initiated as a joint venture between academic institutions and para-statal organizations (Council for Scientific and Industrial Research and the South African Environmental Observation Network) to characterize spatial variation in selected pollutant concentrations (DEAT 2006).

Ambient air quality impacts on human health include respiratory and cardiovascular problems and carcinogens (Wright et al. 2011). Other impacts may include raised mortality as a result of Covid-19 infection in poor air quality areas (Bourdrel et al. 2021), and potential impacts on sperm motility[16]. In terms of human health impacts on South Africa, poorer nutrition in low-income areas promotes increased susceptibility to acute and chronic health issues linked to airborne pollution, with major problem areas located in the Vaal Triangle and Highveld (Highveld Priority Area: Wright et al. 2011).

Limited impacts of air pollution on biodiversity were described in the 2006 National air quality management programme report. Of the impacts described, these included chronic problems such as acid rain affecting the pH of rivers, deposition of particulate matter on plant leaves, and impacts of high levels of ozone on plant function and productivity (DEAT 2006). In the case of birds, air pollution in the form of sulphonates, which act like a detergent, can be transported in fog; a consequence is decreased water repellence in plumage (Kylin et al. 2011). Amphibians have been viewed as a taxon that is particularly susceptible to the negative impacts of airborne pollutants as a result of their permeable skins and bi-phasic life-histories (Alton and Franklin 2017). In a meta-analysis study, impacts of pollutants and chemicals on amphibians were assessed (Egea-Serrano et al. 2012). Findings were that airborne pollutants posed a concentration-dependant threat to amphibians, with impacts quantified as reductions in size and survival rates, and most markedly in terms of frequencies of abnormalities within affected populations. However, these impacts were most likely to be the result of a number of interacting factors including pollution, climate change and alien invasive species (Alton and Franklin 2017).

[16]https://www.theguardian.com/environment/2022/feb/17/air-pollution-may-affect-sperm-quality-says-study

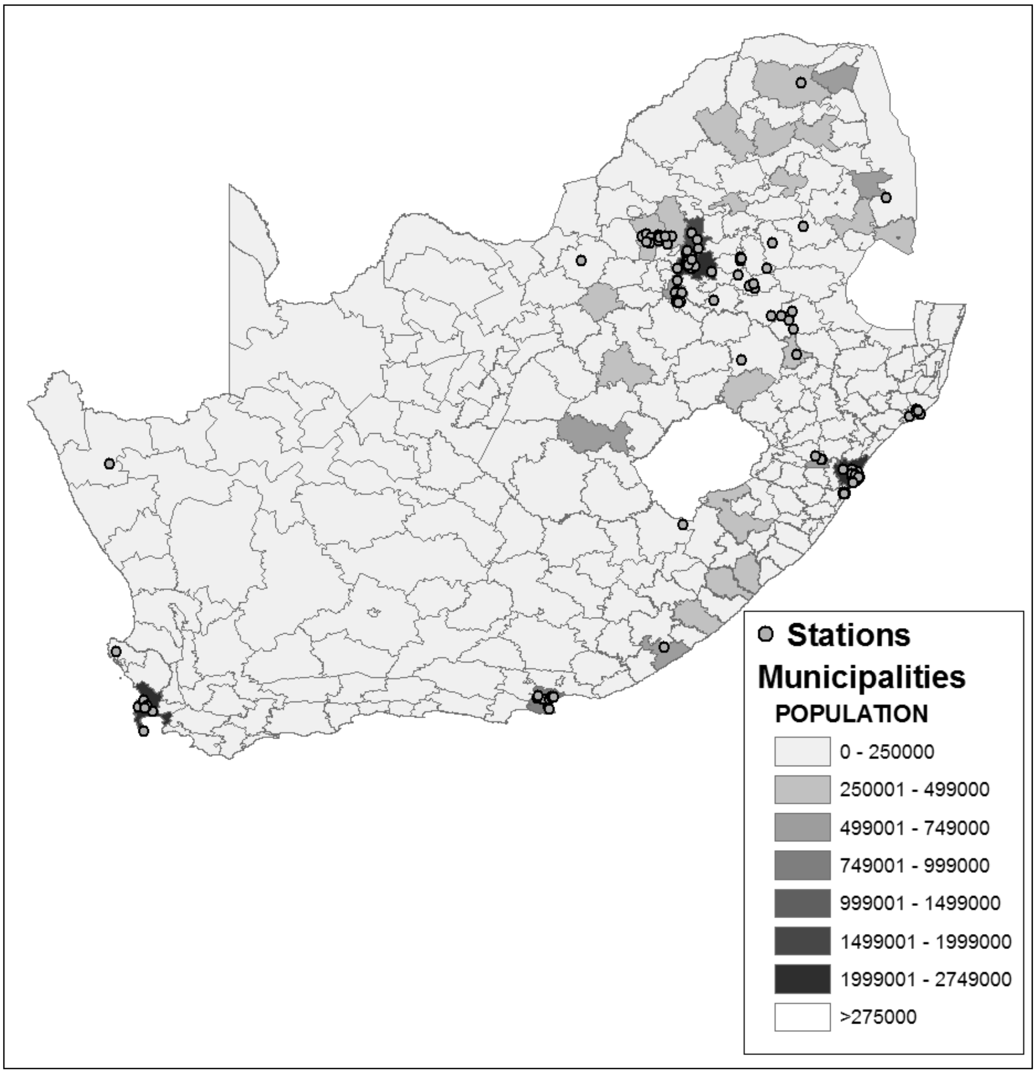


Figure 7. South African population distribution and the relative location of the ambient air quality monitoring stations (Source: DEAT 2006).

3.2.6 Excess energy

The category of excess energy includes the following sub-components: light, thermal, and noise pollution. While the other pollution categories can be categorized in terms of volume and concentration, this category is less easily defined because it is less visible. Although excess energy pollution could be considered a silent polluter, its categories are measurable, with light and noise being measured based on their wave patterns (candelas and decibels respectively), and thermal pollution can be defined in terms of heat units. Nevertheless, these pollutants can be linked to biodiversity losses, either as a result of chronic or acute stress, based on exceedances of defined thresholds.

Light pollution is something that would typically affect crepuscular or nocturnal species, and/ or species with diurnal life history cycles. While most prevalent around high-density urban areas, many many rural settlements that either occur within or surround natural/wild areas are now being electrified as part of Government's developmental strategy, which is likely to have an impact on the resident fauna (Meyer and Overen 2021). An example of this would be bat populations in close proximity to urban areas. Bats typically live as large populations that depend on a small number of caves. In South Africa, a study on two species of bats linked their populations to 47 important caves and found that the quality of the natural environment within a 5 km radius of a cave was critical for the survival of these populations (Pretorius 2021). However, the study noted increasing rates of land cover transformation and urban encroachment in the vicinity of the caves. Impacts on bat populations can impact whole ecosystems because of the importance of bats as pollinators and in controlling insect populations. Amphibians, because they are often nocturnally active with many of their natural rhythms regulated by light intensity, are another example of where light pollution impacts on specific taxa[17].

A second form of point-source light pollution is due to the polarizing effect of solar panels on ambient light. Where solar farms occur near water bodies, the polarized light can confuse aquatic insects that mistake solar panels for water bodies, resulting in them ovipositing on solar panels (Száz et al. 2016). This polarizing effect of light also confuses migrating birds. While South Africa's Green energy revolution is still in its infancy, a number of large-scale renewable energy solar farms are currently built, or either being built or planned for the near future. These include a number of sites in the Northern Cape Province, such as Sonplaas near the town of Douglas, and a 100 Mw Redstone concentrated solar thermal power plant under construction near Postmasburg (Figure 8). These solar farms form part of a growing network of independent power suppliers to the national energy supplier, ESKOM, with the site at Postmasburg being affiliated with the South African Renewable Energy Independent Power Producers (REIPP). The highest density of solar farms is likely to be in the arid regions of South Africa, such as the succulent karoo, where solar radiation levels are highest. These regions are habitat to thousands of species of endemic and red-listed succulent plants, where unemployment is also high. Aside from the threats of habitat destruction through changes in land use, there is also the threat of intensified illegal harvesting of these plants for international trade to collectors[18].

[17] https://cescos.fau.edu/observatory/lightpol-Amphib.html#Wise_Amphibians

[18] https://www.dailymaverick.co.za/article/2022-03-07-northern-capes-rare-succulents-are-being-stolen-for-the-international-illegal-market/

Figure 8. Solar farms in the Northern Cape Province of South Africa (Source: AfriGIS (Pty) Ltd, Google, 2022).

Thermal pollution is most marked in aquatic ecosystems, either as downstream heat plumes in rivers due to industrial activity, or cold-water plumes downstream from dams with hypolimnetic release valves (Marshall et al*.* 2016). As a result of thermal stress and changes in dissolved oxygen levels, not only are species of fish and aquatic macroinvertebates differentially negatively affected, but natural rates of species turnover with downstream distance are disrupted. While a river has the capacity to reset itself within a certain downstream distance, the actual reset distance is a function of stream order and relative discharge volumes (Palmer and O'Keeffe 1989). The effects of such point-source thermal pollution can be measured and monitored using biologically defined thermal thresholds. In South Africa, there is a growing body of research on thermal thresholds for aquatic macroinvertebrates and fish (for example, Dallas and Rivers-Moore 2012; Olsen et al. 2021; Dallas et al. 2019). These can be integrated into ecological models to predict the effects of thermal stress on abundances (Rivers-Moore et al*.* 2021). Recently published research also ranks sub-catchments in South Africa for their relative levels of resilience to thermal stress (Rivers-Moore and Dallas 2022; Figure 9). This provides not only a tool to assist in prioritizing river systems for conservation action and identifying river systems sensitive to climate change, but also has the potential to identify vulnerable taxa (such as narrow range endemic fish or aquatic macroinvertebrates) by overlaying this with the resilience map.

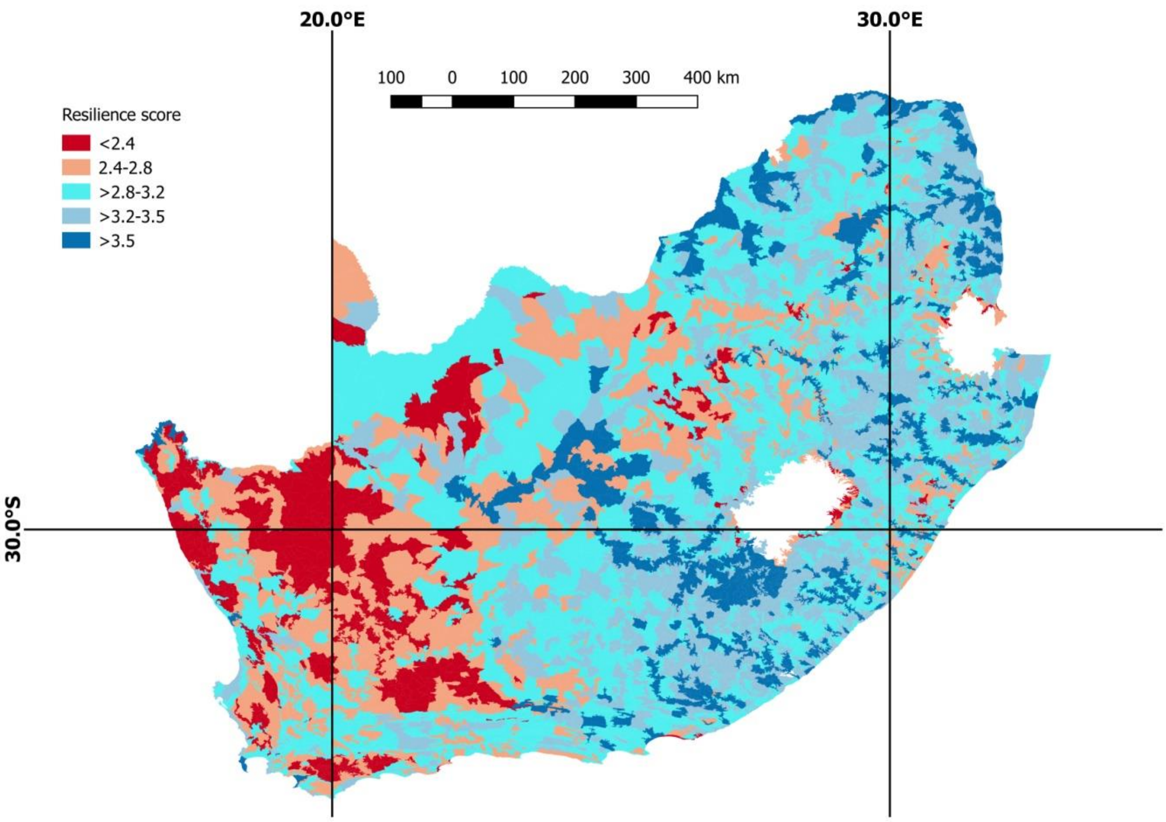


Figure 9. Thermal resilience map for aquatic ecosystems for South Africa, where higher scores indicate higher potential resilience (Rivers-Moore and Dallas 2022).

Noise pollution occurs as a chronic stressor to terrestrial biodiversity, particularly around urban areas. This is most likely to affect breeding populations of birds, such as those near to airports. In marine ecosystems, in contrast, noise pollution can be either chronic, in the form of propeller noise from cargo ships, or acute stress caused by high-intensity sound blast in seismic surveys. The latter has been circumstantially linked to deaths of sharks and cetaceans (whales and dolphins), and has recently been an issue along South Africa's west coast (le Roux et al. 2022).

3.3 Policy review

Environmental rights are protected in the South African Constitution, coupled with a wide range of environmental laws at a national, provincial, and municipal (local government) level (Bowman 2020). As such, environmental matters are highly regulated in South Africa. This review focuses on the overarching National Acts that regulate pollution and the use of pollutants (Table 2).

Table 2. Summary of national legislation in South Africa that deals with the protection of threatened species, and with pollution in water, air, and soil (after Hutton 2002; Dabrowski et al. 2016; Edwards et al. 2018; Bowman 2020).

National Legislation	Summary
The Constitution of the Republic of South Africa Act 108 of 1996	Section 24 of the South African Constitution guarantees everyone the right to a clean and safe environment that is not harmful to their wellbeing or health. It further states that this includes the prevention of pollution and ecological degradation.
National Environmental Management Act (No. 107 of 1998) (NEMA)	NEMA is the principal environmental statute, which guides the management of the environment in South Africa. It includes environmental principles which must form an integral part of all decision-making that affects the environment. NEMA also specifies that a person or company has a duty to take reasonable measures to prevent significant pollution or degradation of the environment from occurring, continuing, or recurring. If the pollution or degradation is authorised in terms of other legislation, or cannot reasonably be avoided, section 28 of NEMA requires that it be minimized or rectified.
National Water Act (Act 36 of 1998) (NWA)	The NWA requires a licence or other form of entitlement, such as a general authorisation, for undertaking water uses, which include: abstractive water uses, various effluent discharge and waste-related activities that may impact on water resources, as well as activities entailing physical impacts on, or in proximity to, water resources.
National Environmental Management: Waste Act (Act 59 of 2008) (the Waste Act)	The Waste Act requires licensing of listed waste management activities or compliance with norms and standards for certain other listed activities. It regulates residue deposits and residue stockpiles in the context of mining, production, and related operations. It imposes obligations relating to the reporting, handling, and remediation of contaminated land. Contaminated sites may need to be reported to the environmental authorities and are potentially subject to remediation orders, being declared as remediation sites and recorded on the South African contaminated land register, and with the Deeds Registry.
National Environmental Management: Air Quality Act (Act 39 of 2004) (the Air Quality Act)	The Air Quality Act requires the licensing of listed activities that result in atmospheric emissions, with specific minimum emission standards being prescribed for such activities. The Act requires the reporting of emissions, which includes mechanisms for air pollution control (e.g. creating 'Priority Areas' around the country where air quality management plans are required to be in place). The requirement for reporting emissions also includes dust control

	regulations and establishing categories of controlled emitters. A recent focus has been on establishing mechanisms for registration; measuring and reporting regarding greenhouse gas emissions in light of a carbon tax regime that applies in South Africa in terms of the Carbon Tax Act, 15 of 2019; and other anticipated tighter climate change-related regulatory controls, including through a pending Climate Change Act.
National Environmental Management: Biodiversity Act (Act 10 of 2004) (NEM:BA)	NEM:BA provides various measures for the protection of biodiversity, including the control of activities affecting threatened or protected species and ecosystems and activities involving alien and invasive species. Various planning tools are provided for, including bioregional plans and biodiversity management plans.
National Environmental Management: Integrated Coastal Management Act (Act 24 of 2008) (the Coastal Management Act)	The Coastal Management Act includes compliance obligations and restrictions with respect to activities within the coastal zone, or that may impact on the coastal zone, as well as marine and coastal pollution control (e.g. the requirement to obtain a permit for dumping at sea).
National Environmental Management: Protected Areas Act (No. 57 of 2003) (NEM:PAA)	The NEM: PAA's purpose is to affect a national system of representative protected areas to preserve the country's biodiversity, natural landscapes, and seascapes, and manage such areas in a sustainable manner.
Mineral and Petroleum Resources Development Act (Act 28 of 2002) (MPRDA) in the context of mineral prospecting and mining, and oil and gas exploration and production-related activities	The MPRDA provides for the regulation of the prospecting for and extraction of mineral and petroleum resources. In particular, the MPRDA provides regulations for environmental management, pollution control, and waste management for all phases of mining activities. In this regard, impacts on terrestrial and aquatic ecosystems are required to be identified, assessed, and adequately mitigated prior to issuing mining permits and rights.
Water Services Act (No. 108 of 1997)	The Act is underscored by the following principles: Recognizing the rights of access to basic water supply and basic sanitation necessary to ensure sufficient water and an environment not harmful to health or well-being. Acknowledging that there is a duty on all spheres of government to ensure that water supply services and sanitation services are provided in a manner that is efficient, equitable, and sustainable. Recognizing that the provision of water supply services and sanitation services, although an activity distinct from the overall management of water resources, must be

	undertaken in a manner consistent with the broader goals of water resource management.
Health Act (Act 63 of 1977)	In terms of the Health Act, every local authority is required to take all necessary and practical measures to ensure that its area of responsibility is maintained in a clean and hygienic condition. They must prevent the pollution of clean water, and purify any polluted water.
Municipal Systems Act (Act 32 of 2000)	The Act transfers the responsibility of provision and management of waste services and facilities to local and district municipalities. This must be in compliance with the prevailing national and provincial waste management legislation.
Conservation of Agricultural Resources Act (No. 43 of 1983) (CARA)	To protect natural agricultural resources, the CARA promotes the conservation of soil, water resources, and vegetation situated on agricultural land. Permission is required to undertake specific activities. Control measures must be complied with by land users. One of the control measures relating to water is the protection of water resources against pollution because of farming practices.
Marine Living Resources Act (Act 18 of 1998) (the Marine Living Resources Act)	The Marine Living Resources Act intends: • To provide for the conservation of the marine ecosystem, the long-term sustainable utilization of marine living resources, and the orderly access to exploitation, utilization, and protection of certain marine living resources; • For these purposes to provide for the exercise of control over marine living resources in a fair and equitable manner to the benefit of all the citizens of South Africa; and • To provide for matters connected therewith.
Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act 36 of 1947)	Pesticide registration in South Africa is regulated by the Fertilizers, Farm Feeds, Agricultural Remedies, and Stock Remedies Act. The Act states that a fertilizer, farm feed, agricultural remedies, or stock remedies shall be registered if: • It is suitable and sufficiently effective for the purposes for which it is intended; • That it is not contrary to the public interest that it be registered; and • The establishment where it is manufactured is suitable for such manufacture.

There is extensive National legislation in South Africa that deals with pollution in water, air, and soil. The country has even received international praise for some of these policies (e.g. the NWA) (Schreiner 2013). However, even with this extensive legislation, there are still significant challenges. These can largely be summarised into two broad categories. The first, and probably more concerning, is that while South Africa has much of the legislation needed to regulate pollution, the reality is there is limited capacity and resources to implement compliance and enforcement of the legislation. This challenge is further compounded by governance failures. The second of these challenges, is that some legislation is outdated. In particular, the Fertilizers, Farm Feeds, Agricultural Remedies, and Stock Remedies Act, which is considered to be behind what would be regarded as best practice throughout the rest of the world (Dabrowski et al. 2016). According to Dabrowski et al. (2016), the current risk assessment process used for the registration of pesticides in South Africa is largely focused on human health effects, and there are no guidelines prescribed for predicting environmental exposure and the potential risks that pesticides could pose to aquatic and terrestrial organisms.

4 Analysis of findings

This section presents a comprehensive analysis of information based on a synthesis of findings from the workshop, post-workshop questionnaires, key informant interviews, and supported where necessary by relevant literature. The outcomes of this analysis are to provide a clearer understanding of the local analysis of pollution for South Africa in the context of the pollution category framework in terms of (i) adequacy of species data; (ii) evaluation of and specific comments on each pollution category's maps and gaps; (iii) identified pollution problems specific to South Africa.

4.1 Workshops and post-workshop questionnaires

The full narrative results from the workshop are available as a separate report (Appendix 5), with the main outcomes summarised in this section. A total of 29 stakeholders attended the two workshops on the 10th of December 2021. The participants represented a wide variety of sectors, including all levels of government (national, provincial and local), and the NGO, academic, and private sectors (Figure 10). Dominance of the public/government sector was evident. All the workshop participants completed the workshop questionnaire which was administered during the workshop. When asked which South African provinces exhibit pollution hotspots and/or pollution threats to biodiversity, most participants answered KwaZulu-Natal and Gauteng (77.8% and 66.7%; Figure 11), while zero participants answered Northern Cape. However, there is a strong correlation between provinces exhibiting pollution hotspots and provincial representation, where KwaZulu-Natal and Gauteng were the best represented provinces, followed by Western Cape.

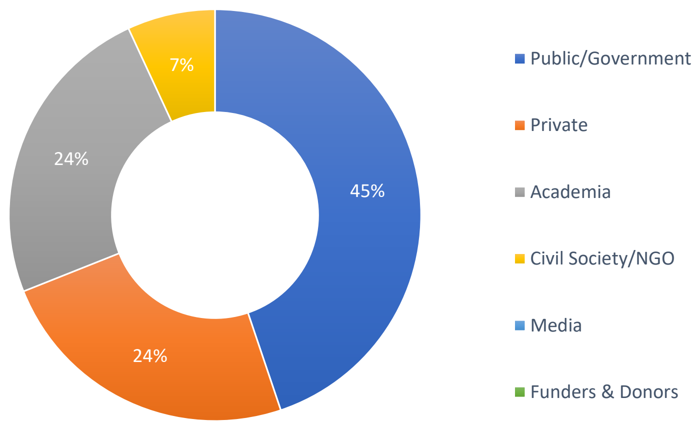


Figure 10. Sector representation of the attendees at the Local Sense Workshops (n = 29).

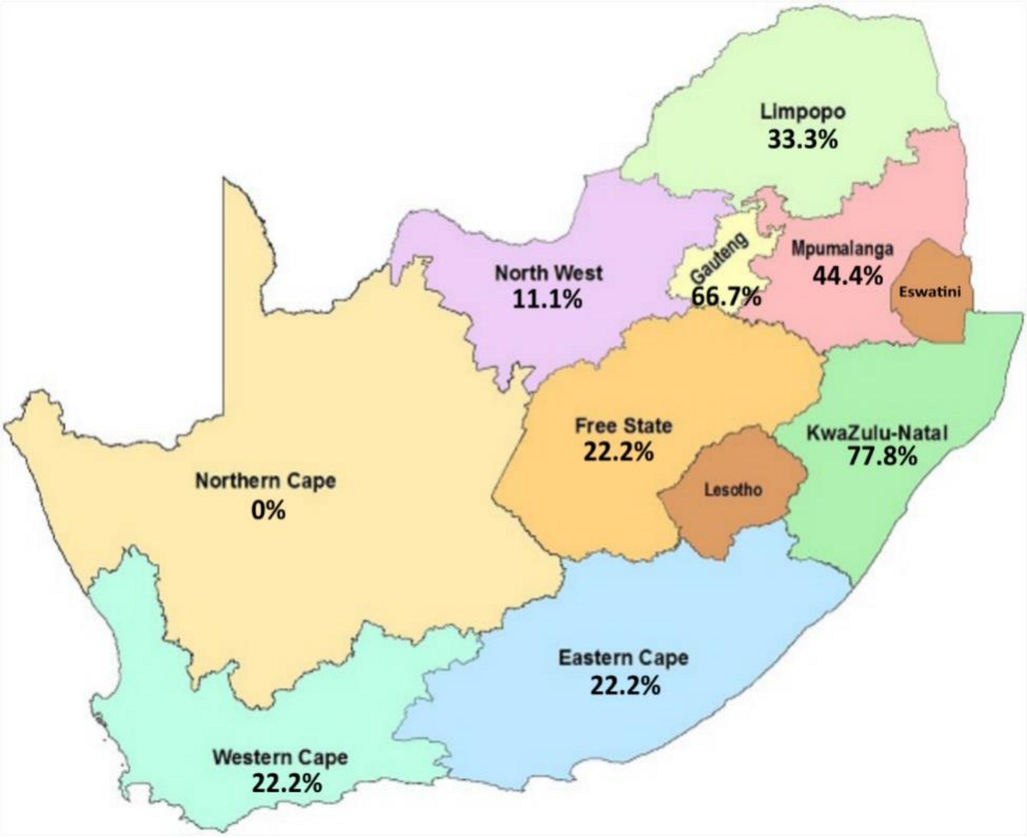


Figure 11. Provincial representation of participants' responses when asked 'Which province(s) exhibit pollution hotspots and/or pollution threats to biodiversity' in the PWQ (%; n = 9; multiple responses permitted).

The majority of the participants (68%) agreed that the results were a realistic reflection of the proportions of species threatened by pollution in South Africa, while 32% disagreed with this (n = 28). Importantly, 8 out of 29 participants highlighted (see comments below) the importance of the study and recognised that it is a great starting point.

The majority (59%) of the respondents indicated that the data was moderately reflective of the current situation while 34% indicated that the data was largely (to very largely) reflective of the situation in the country. It was encouraging to note that just 7% of participants thought the results reflect the current situation very little. However, comments by participants that the analysis did not always accurately reflect flora and fauna threatened by pollution in South Africa should not be ignored (see below) since they allude to the possibility that key taxonomic groups could have been overlooked/given more attention. More specifically, participants called for the inclusion of a number of important freshwater species, cryptic taxonomic groups such as diatoms, and invertebrate species.

A dominant concern from attendees at the workshop was the lack of monitoring of pollutants, and more specifically the lack of compliance monitoring to ensure the industry conforms to environmental laws and regulations. This could also point to poor tracking of emerging pollutants. This motivated a set of questions that were designed to gain an insight into the emerging pollutant threats in South Africa. Insights into emerging pollution threats gained from workshop attendees can be used to guide researchers when considering the JNCC pollution hotspot maps. Participants were asked if they knew of any major and/or emerging pollution threats in South Africa that were not included in the analysis. From the answers received, four major threat categories emerged, namely:

- Thermal Pollution (associated with climate change and anthropogenic activities);
- Microplastics;
- Traffic pollution; and
- Pharmaceuticals and endocrine disrupting compounds.

Microplastics were raised as an emerging pollutant on several occasions during the stakeholder workshops. Attendees expressed that they are increasingly abundant in South African ecosystems, particularly aquatic (freshwater, estuarine, and marine) ecosystems. For example, a recent study showed that microplastics were found in more than half the juvenile fish sampled in four mangroves on the east coast of South Africa (Naidoo et al*.* 2020). In terms of the impacts of microplastics on aquatic organisms, there are studies that show that microplastics can result in genotoxicity, oxidative stress, changes in behaviour, reproductive impairment, mortality, and altered population growth rate (Barboza et al*.* 2020). This remains mostly unstudied in the South African context and requires further investigation (Naidoo et al*.* 2020) but there are reports of significant levels of ingestions for some organisms that inhabit the county's shores (e.g. mussels: Sparks et al. 2021).

Pharmaceuticals and EDCs emerged strongly as a pollutant threat category in the workshops. Global pharmaceutical consumption is rising with the growing human population, and increased access to western medicine; South Africa is no different (Arnold et al*.* 2014). Many middle to low income countries, including South Africa, do not have regulations pertaining to pharmaceutical traces as pollutants in aquatic systems (Ngqwala and Muchesa, 2020). This absence of 'prescribed limits' has resulted in very little or no environmental monitoring of these chemical stressors (Ngqwala and Muchesa, 2020). Elsewhere in the world, studies have found pharmaceuticals in a wide range of ecosystems and organisms, including synthetic oestrogen in freshwater fish populations downstream of a WWTW in Ontario, Canada, which resulted in the feminization of young male fish (Kidd et al*.* 2007).

Workshop attendees expressed concern about the lack of pollution control and long-term monitoring, while highlighting the need for additional research to be done in these areas. Research needs to focus on how these emerging pollutants impact the fauna and flora, at an individual level and at an ecosystem level. The comments received in the post-workshop questionnaire supported the concerns expressed during the workshops around the extent to which the results reflect the current situation in the country and were particularly useful in identifying areas/ways in which the analysis could be improved going forward, i.e. made to be a more a realistic reflection of the proportion of species threatened by pollution in South Africa. Importantly, many of these comments alluded to the use of other datasets that exist for the country and the inclusion of specific taxonomic groups that may be under-represented in the IUCN database used for the present analysis.

4.2 Key informant interviews

This section synthesizes the comments and feedback from interviews with eight high-level decision-makers and/or experts, where the global and country analysis reports were discussed in terms of the main pollution categories. These experts were drawn from key organisations/groups represented across the core pollution categories targeted for the interviews (Figure 12). Results from all interviews were synthesized and collated into sections according to each of the questions asked.

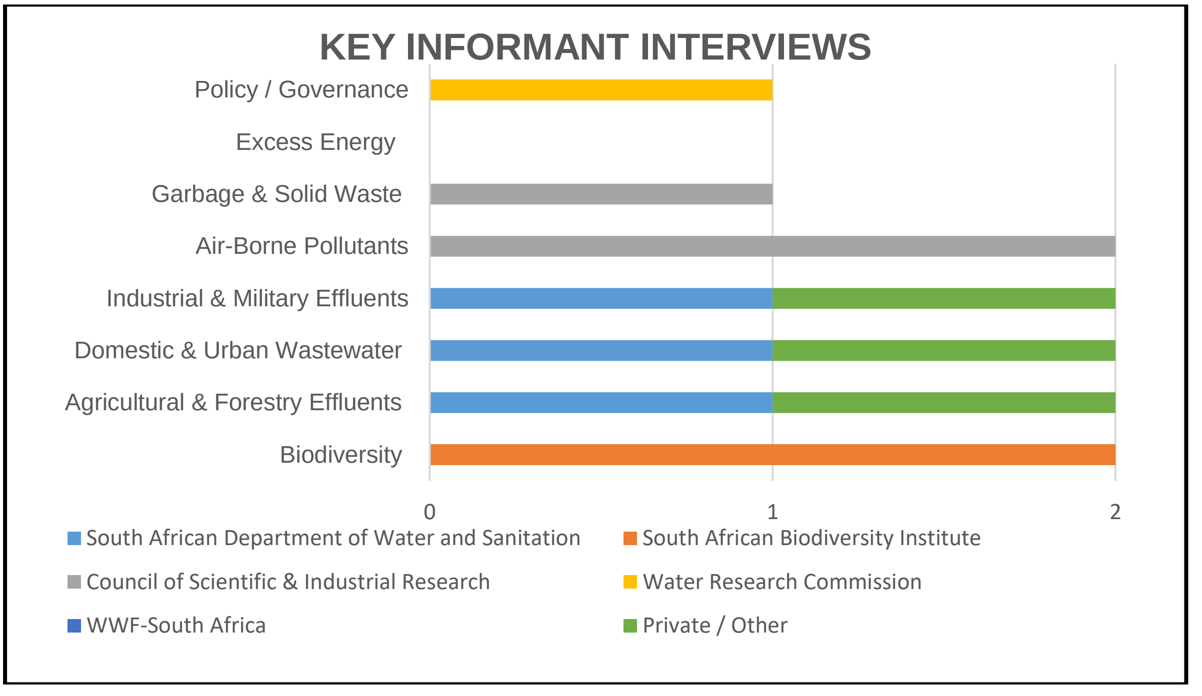


Figure 12. Key informant interview representation across sectors and by organisation representation.

4.2.1 Main pollution threats in South Africa/globally not included in the Global Analysis

In general, the interviewees were of the opinion that all of the important pollution threats are in some way covered under the broad IUCN pollution categories used for the global analysis. Several interviewees raised the possibility of expanding some of the sub-categories. Examples of these included: sedimentation and turbidity could be added as a separate pollution category given the prevalence and importance of this form of pollution; sub-categories of garbage and solid waste could include: plastics, builders rabble, and garden waste (plastic pollution in particular was considered a critical pollution threat, which is linked to the emerging threat of endocrine disruptor hormones from plastic bottles); country specific air quality issues may be worth considering, for example domestic fuel burning; smog is a complex of pollutants including sulphur dioxide (SO_2), nitrogen oxide (NO_x), aerosols, and other compounds, and while there may not be sufficient data for this level of detail for all components (i.e. sub-categories), there are some data that should be considered; an emerging concern is mercury in the atmosphere, produced from a variety of sources but primarily coal burning, and while there are no models in place to simulate this South Africa is participating in a global study through the South African Weather Service (SAWS) research programme to understand dispersion of mercury in air, soil and water (It is worth noting that South Africa is a signatory of the Minamata convention on mercury[19]; the inclusion of Solar PV shade pollution/disruption as a sub-category under excess energy; and finally while there is limited data on certain pollutants (EDH, heavy metals, POPs, chemicals of emerging concern), it was highlighted that these pollutants should not be overlooked.

In conclusion, while there was agreement amongst the experts interviewed that adding more detail to the pollution threat categories may be of value, the consensus was that the broad categories were appropriate for the global analysis. Should further investigations be undertaken, the South African Biodiversity Institute (SANBI) pollution categories should be taken into consideration, as they use an additional level of classification to that of the IUCN.

4.2.2 Information from the South African pollution heatmaps

The consensus from the interviewees was that the heatmaps do not provide an accurate or reasonable indication of pollution across South Africa. While the approach taken was considered to be acceptable, in most cases there were too few taxa coded for a threat for the heatmap to be useful. In addition, the lack of data to identify sources of pollution and the cause-and-effect linkage to threatened species was considered a limitation. The interviewees highlighted a range of omissions and/or anomalies, and also provided recommendations of potential data sources to consider:

- Pollution is unlikely to have an impact on any species across its entire distribution range, except for narrow-range endemic species. Consequently, the use of widespread species to define pollution threats dilutes point-specific pollution threats;
- The reliance on a low number of species provides a potentially skewed output, and the use of local data would provide a statistically and more robust approach through the use of bigger samples;
- There is a general lack of data for aquatic species, both freshwater and estuarine, and invertebrates; and there is limited data included for endemic and range-restricted species;
- A number of inadequacies were identified for pollution-specific category heatmaps:
    - the heatmaps for nutrient loads and seepage from mining are not accurate (the top two polluted rivers in South Africa are the Upper and Lower Crocodile River, followed by the upper Olifants River in the vicinity of Emalahleni, and neither are coming out as pollution hotspots);
    - the garbage and solid waste hotspot maps were also not accurate, resulting in no clear pathways for management or intervention for the specific pollution impact; the domestic and urban wastewater heatmap detects some areas but were not accurate for other areas;
    - the heatmaps for pesticides probably over-estimate the extent of pollution; some pollution hotspots may be emerging based on the intensity of data collection in certain areas;
    - sewage and run-off are major concerns in South Africa and these issues are not adequately reflected; the east rand grasslands have been exposed to decades of acid rain and coal fall out pollution, and there was little evidence reflecting these impacts; air-borne pollutants on the highveld plateau is a seasonal problem, which is not adequately reflected;
    - industrial and military effluents, and fuel spills in particular were considered to be a big issue that is not reflected adequately; petrochemical and leather tanning industries, the paper industry, and the essential oil industries were

[19] https://www.epa.gov/international-cooperation/minamata-convention-mercury

also considered major polluters in parts of South Africa that should not be overlooked;

- Legacy pollution issues from old abandoned mines are of particular concern in South Africa.

Recommendations of potential data to identify sources of pollution and the cause-and-effect linkage to threatened species included: South Africa has a national Red List database, and while there is still a lot of work to be done, the national database could be used to complement the global dataset (e.g., there is good data on plants and associated threats, which are currently not part of the IUCN database); hotspot maps for plastic pollution are available for the city of Johannesburg, and there is also less detailed national data; a possible mapping method for detecting sources of solid waste could include the mapping of informal urban and rural settlements as surrogates for solid waste hotspots (Note that one of the contributing factors to these hotspots relate to service delivery protests, in response to the provision of services not meeting the requirements of the communities. Additionally, rivers intersected with high density areas with poor service delivery, can indicate waste management problem hotspots); there is available research, both published and unpublished, looking at waste management in National Parks near tourist camps (e.g., Setara, Skukuza and Shingwedzi as main camps in the Kruger National Park), and private nature reserves, as these sites attract scavengers (monkeys, baboons, warthog and birds); Plastics South Africa is an organisation that provides litter booms for rivers in the major metropolitans across South Africa, and this could be useful in detecting source areas of solid waste pollution; there are gridded regional datasets of SO_2, Nitrogen dioxide (NO_2), ozone and particulate matter (PM), which are derived from modelling and satellite data; there is also satellite data for NO_2, which has been widely used globally and in South Africa; the use of spatial data generated for the country's Greendrop reports, which shows the distribution of Waste Water Treatment Facilities across the country, could be used to identify potential sources of domestic and urban wastewater pollution (This data is publicly available through the National Integrated Water Information System (NIWIS) on the Department of Water and Sanitations (DWS) website (both Greendrop and Bluedrop reports)); the DWS has project data for Water Quality Planning, which includes water quality pollution hotspots; the DWS also has data on eutrophication of inland water bodies; there is data on the sedimentation of reservoirs, which can be sourced through the Water Research Commission (NatSil Project); port regions and industrial areas could be used to reflect pollution hotspots; air pollution hotspots could be deduced from point source locations (e.g. Eskom) as well as ground level emission sources (e.g. vehicles and domestic fuel combustion); some data on deposition zones (modelling of hotspots compounded by dynamics of air quality pollutants, with deposition into water systems) is collected from the flux towers at the South African Earth Observation Network (SAEON) long-term research sites; air-borne pollutant hotspot refinement is possible, even without the CSIR models, there is global model outputs and satellite data that could be used; and finally the use of surrogate datasets such as "global burden of disease maps", or other census-based proxies for human health risk and vulnerabilities should be considered.

4.2.3 Most important pollutant threats to species

In general, interviewees found it difficult to choose. Some pollutant threats are particularly severe but, from a national perspective, cover a relatively small spatial area (e.g., mine seepage). Others may be less severe (e.g., in terms of toxic effect), but cover a much larger spatial area and may have a greater impact on water resources (and general water use by different sectors) as opposed to species (e.g., nutrient pollution). Some pollutants are more specific to aquatic ecosystems (e.g., domestic and urban wastewater, nutrients and mining seepage), while others affect both terrestrial and aquatic ecosystems (and associated species). This is a key consideration for defining the objectives of the next phase of the study.

Pollutant threats differ per realm as summarized in the South African National Biodiversity Assessment (NBA). For example, for Estuaries, it is clear that nutrient pollution from wastewater treatment plant failure, plus deliberate or accidental sewage outfall into rivers, is the main pollution pressure, which substantially affects ecosystem function and species populations. Similarly, nutrient pollution for the same reasons is a major issue in the freshwater realm. An overarching message stemming from the NBA is that rivers and estuaries are exposed to a huge concentration of pollutants (i.e., the way drainage systems work, it is inevitable that rivers and estuaries are the big losers when it comes to pollution).

A key recommendation provided was to undertake a prioritization of the different pollutants in terms of their threats to species and this should consider factors including the spatial extent of the pollutant, and the risk the pollutant poses to species (i.e., in terms of toxicity/alteration of food webs/ alteration of habitat quality/etc.)

In summary, the common response for the pollutant with the greatest threat to species was pollutants that impact water. This was followed by air-borne pollutants. Excess energy was considered to have the least impact (Note - excess energy specialists were not interviewed, and therefore this is considered a gap in the findings from the interviews).

4.2.4 Additional species or specific ecosystems where pollution poses a major threat either currently or in the future in South Africa

Aquatic ecosystems were considered the primary ecosystems threatened by pollution. This is largely the result of pollution manifesting mostly in South Africa's rivers and wetlands. Freshwater fish are of particular concern (Barnhoorn and van Dyk 2020). Some key species threatened include Barrydale Redfin, Knysna Seahorse, Estuarine pipefish, etc. Amphibians are also a concern (Note, there are working groups for specific groups of taxa that can be engaged with beyond the scoping stage). Species loss and conservation of aquatic species is a far greater challenge than for terrestrial ecosystems. Invertebrates were highlighted as a specific taxonomic group that is at risk from pollution.

4.2.5 Socio-economic, climatic, political, or other important information missing from the global analysis

Other factors that influence pollution in South Africa, identified by interviewees, and hence should be considered for the next phase of the analysis for South Africa included the following:

- The South African mining heritage, i.e., the legacy issues causing insidious pollution, which other countries typically do not have.
- South Africa's energy dependence on coal. This creates air pollution problems (NO_2 associated with power plants) in areas such as Mpumalanga.
- Governance failures at various levels of government, and particularly around the failures of local government (e.g., sewage, where accountability should be enforced for effluent failures).
- Changes in or levels of management dysfunctionality, at a local government level and the inability of the national government to intervene.
- Issue of pollution promoting the spread of alien species in water resources.
- Lack of species monitoring data, which provides trends in abundance. Typically, data is available for species occurrence and distribution.
- The IUCN species Red List approach could be enhanced by looking at the ecosystem integrity or ecological condition data used in ecosystem assessments (e.g., estuarine ecosystem assessments use Present Ecological State (PES) data that includes pollution information, or marine ecosystem assessments use

cumulative pressure mapping (from which pollution could be extracted) to map pressures such as pollution spatially (and in some cases assign intensity/level of impact)).

4.2.6 Additional data (besides threatened species)/approaches that could be potentially useful for guiding decision-making

The interviewees identified additional sources of data and methodological approaches that could be used to guide decision-making around pollution mitigation in country:

- Land cover (or land use) would be useful, and in many instances could be a more useful indicator of pollution than threatened species, or at least it could be used to improve the current maps by providing a better resolution of where pollution sources are expected to occur.
- Not additional data, but a method that focuses on the prioritization of pollutants would be useful for guiding management.
- National monitoring data (e.g., water quality monitoring data collected by the DWS).
- SANBI geographic information system (GIS) coverages – for example, the National Biodiversity Assessment 2018 could potentially be used to determine whether the PES of rivers could be an indicator of pollution (although this might be difficult to separate from habitat alteration which also has a clear effect on the PES).
- Data from the South African Department of Forestry, Fisheries, and the Environment (DFFE) 'Coastwise' project on plastic waste on the coast, which threatens marine and coastal species (especially birds and turtles). This is supplemented by programmes focused on the source, such as fishing boat programmes where they reward fishers who return from sea with black bags, to prevent them from throwing refuse overboard. Many more initiatives are implemented and could be identified through an investigation in the next phase.
- Human health impact and cost thereof, which is often seen as a driver of decision making, with co-benefits for threatened species. This is particularly relevant in developing countries that need to prioritize resources for pollution management.

4.2.7 Pollution intervention projects of relevance in South Africa

A number of sources of data that could be useful to supplement the current heatmap analyses were highlighted in the interviews. Further information on these is provided in Table 5:

- National Dam Siltation Management Plan (WRC project) is of relevance to tackling sediment pollution in South Africa.
- Greendrop status reports (the programme has been reinstated by the DWS), indicate wastewater pollution issues at a municipal scale.
- Mine Water Atlas which is a WRC Project.
- Pesticide Use and Risk Maps (WRC project).
- Plastics in the Environment project by the Fitzpatrick Institute at the University of Cape Town.
- WRC projects which focus on various aspects of nonpoint source pollution.
- Waste Discharge Charge system, which is a current WRC project being piloted in the Inkomati-Usuthu catchments.
- The State of Environment reporting for South Africa carried out by the Department of Fisheries, Forestry and the Environment, which includes sections on air pollution and solid waste.
- All provinces and municipalities are mandated to develop air quality management plans. These cover the region of interest (i.e., the municipality or province) and contain implementation plans for mitigation actions. The plans are the responsibility

of each province or municipality but are eventually guided and approved by the national DFFE. There are also designated Air Quality Priority Areas (three in South Africa so far: Vaal Triangle, Waterberg, and the Highveld), and the national DFFE have developed overarching air quality management plans for these regions.

4.2.8 Published data on pollution in South Africa that should be incorporated into the analysis for the country

- The DWS Monitoring data from the National Chemical Monitoring Programme (nutrients, salts, some metals: http://dwa.gov.za/iwqs/wms/data/000keyasp).
- The National Eutrophication Monitoring Programme provides information on the trophic status of dams throughout the country and is, therefore, a good indicator of nutrient pollution.
- The DWS has data on bathymetric surveys of dams which indicate the level of sedimentation in dams and is, therefore, a good indicator of sediment pollution from the catchment.
- Many of the metropolitan and priority area management plans contain a baseline assessment using air quality modelling. This data could be used to inform a spatial assessment of risk to species.

4.2.9 Suitability/effectiveness of the current legislation in South Africa

- In general, it was agreed by the experts interviewed that legislation that deals with pollution in water, air and soil is quite good. The issue is mostly, not that there is not adequate legislation, but that compliance and enforcement of the legislation is a major problem. Compliance and enforcement of the legislation is the biggest challenge and is probably related mostly to our socio-economic challenges and the lack of resources dedicated to ensuring compliance and/or monitoring and enforcement.
- With regards to pesticides specifically, the legislation handling the registration of pesticides in South Africa is outdated and is way behind what would be regarded as best practice throughout the rest of the world.
- Legislation for the Waste Discharge Charge System was promulgated in 1999, but it is still not currently implemented.
- Air quality legislation is driven by science and is regarded as adequate to excellent and improving all the time. The focus is on human health impacts (primary objective) with ecosystems as a secondary objective (e.g., air quality as a co-morbidity factor in foetal deformation). The main problem relates to inadequate implementation. This could be facilitated through:
    - Internalizing costs to human health and ecosystems (i.e., account for threats to ecosystems and ecosystem services), but
    - This could be hampered by air quality regulations being controlled across multiple departments, not just DFFE, but also the Treasury and the Department of Mineral Resources and Energy.

4.2.10 Priority pollutants that will need to be mitigated in South Africa to tackle species loss

Some of the interviewees considered plastics, mining seepage, and pesticides to be the highest priority, with plastics and pesticides affecting both terrestrial and aquatic species. Mining seepage is likely to mostly affect aquatic species. Wastewater, solid waste, and other persistent pollutants like oil, mining, and industrial chemicals were also considered priorities due to the concentration of these pollutants in watercourses. Air pollution and acid rain were also considered priorities in the eastern highveld, where mine related dust pollution is a major issue. Mercury was flagged as a priority as well. However, the overarching response from the interviewees was that a more in-depth analysis is required to justify the selection of priority pollutants in South Africa.

4.2.11 Next steps to inform a pollution intervention programme

- An exercise that prioritizes pollutants would be a useful start. Low and middle-income countries will generally have limited budgets and expertise in tackling pollution. Given that multiple pollutants are likely to be problematic within each country, a process which prioritizes the risks of each pollutant to species (e.g., species loss) would be helpful in terms of targeting which pollutants to tackle.
- Link causes to effects, by linking species known to be affected by the specific pollution category to known pollution hotspots/major source areas.
- Focus on translating the identified issues and pollution impacts into costs. This helps roleplayers such as industry and government departments to link the costs to their budgets, and is potentially where one could focus to try and direct change/monitoring/mitigation.

4.3 Adequacy of species data

The South African National Biodiversity Institute (SANBI) curates a list of threatened and endangered species in South Africa, which is aligned with the assessment criteria of IUCN's Red List. The SANBI list of threatened species is frequently updated using input from the country's experts and includes additions from the SANBI Threatened Species Programme and the 2018 National Biodiversity Assessment (NBA). The NBA is SANBI's primary tool for monitoring and reporting on the state of biodiversity in South Africa. It is used to inform policies, strategies and actions for managing and conserving biodiversity more effectively. The NBA 2018 made use of the Threatened Species Programme which assessed over 2900 plant species in South Africa over three years making South Africa the first megadiverse country to fully assess the status of its entire flora (SANBI 2019).

South Africa has 3024 threatened terrestrial indigenous taxonomic groups, 13% of the 22 667 indigenous terrestrial taxa assessed by SANBI and the IUCN (Figure 13). South Africa has very high levels of endemism (64%) with 19% of these endemic species being threatened with extinction.

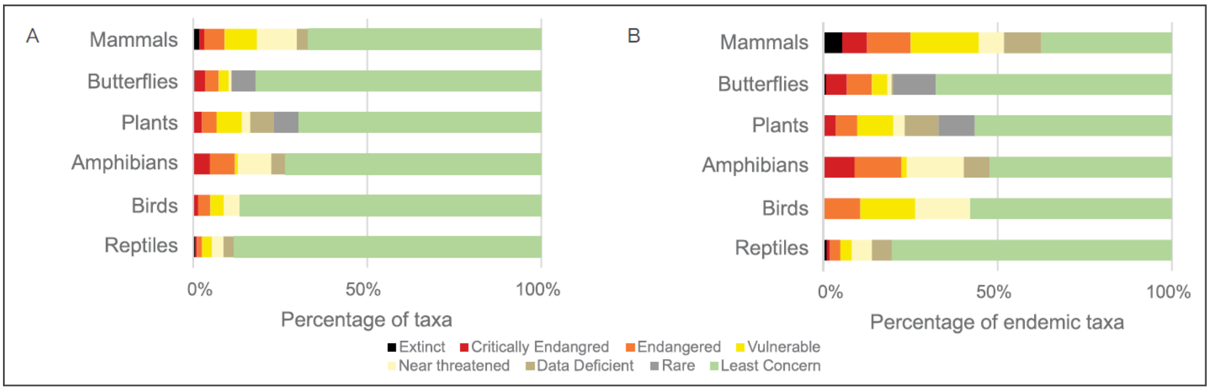


Figure 13. The proportion of indigenous taxa (A) and endemic indigenous taxa (B) in each of the IUCN conservation threat categories for terrestrial ecosystems (Source: Figure adapted from SANBI NBA 2018 Technical Report, SANBI 2019).

Based on the assessments in the IUCN database, there are 809 threatened species in South Africa, compared with the assessments done by SANBI which puts this at 3146 threatened species (Table 3; Figure 14). Making use of the additional assessments made by SANBI in the NBA 2018 and the Threatened Species Programme increases the number of species on the threatened list from 809 to 3146.

Table 3. Comparison between SANBI and IUCN threatened species lists for South Africa (Source: adapted from data in SANBI Red List and IUCN Assessment).

Class Common Name	SANBI Threatened Species	IUCN Threatened Species
Fish	65[20]	153[21]
Amphibians	16	16
Insects	87[22]	138
Sea cucumbers	N/A	3
Snails	N/A	24
Crustaceans	N/A	16
Reptiles	24	20
Sea anemones and corals	9	9
Velvet worms	N/A	4
Hagfish	N/A	1
Mammals	57	36
Birds	84	60
Millipedes	N/A	11
Plants	2804	318
TOTAL	3146	809

[20] SANBI assessed only freshwater fish, seabreams, and linefish

[21] IUCN assessments included all Chondrichthyes (cartilaginous fish) and Actinopterygii (bony fish)

[22] SANBI assessed only butterflies, dragonflies and damselflies

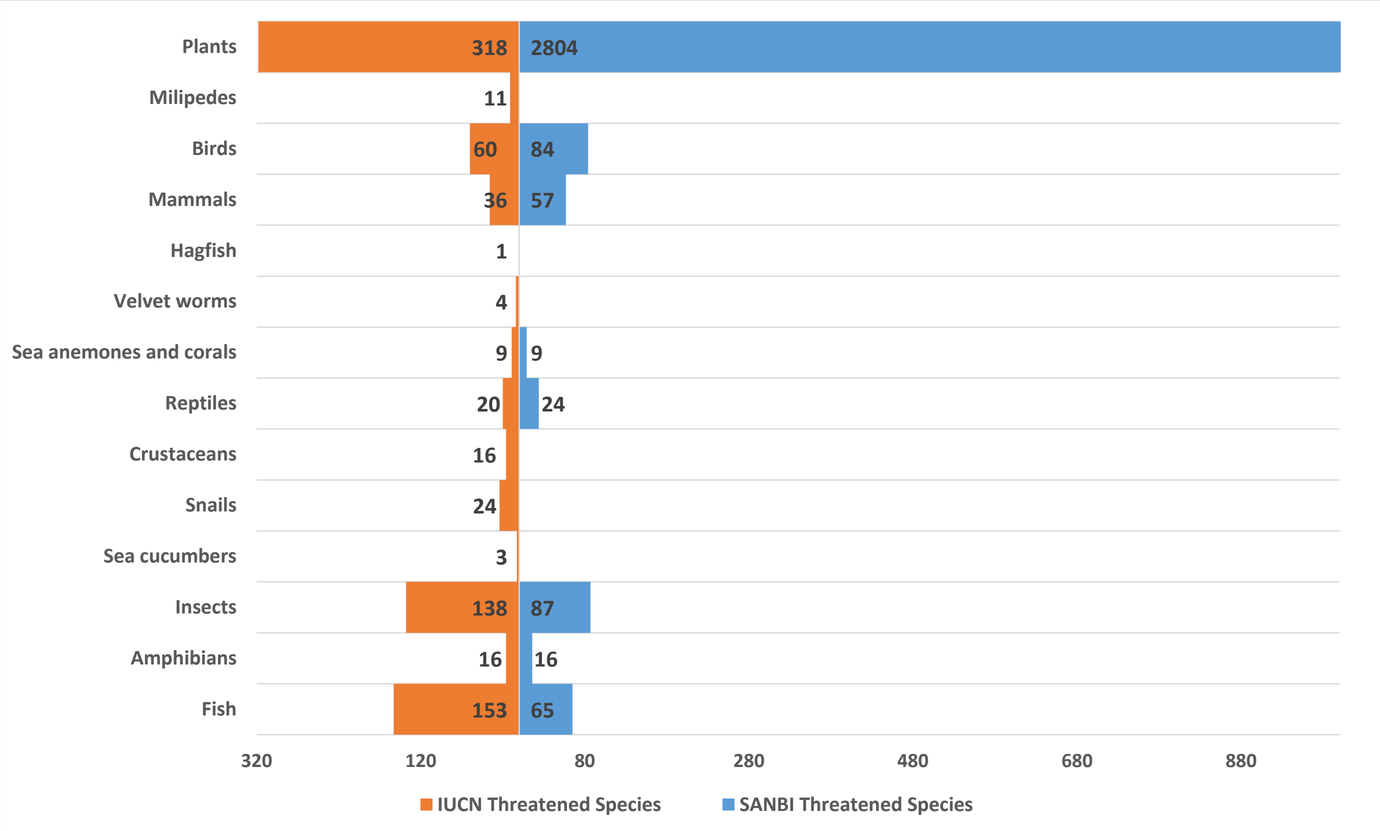


Figure 14. Graphical comparison between SANBI and IUCN threatened species lists for South Africa (Source: adapted from data in SANBI Red List and IUCN Assessment).

SANBI assessed the key pollution pressures for threatened species in the terrestrial, inland aquatic, and marine realms (Figure 15). Their analysis found that of the pollution types considered, agricultural and forestry effluents had the largest impact on the terrestrial realm, particularly amphibians, birds, mammals and reptiles. Furthermore, the assessment found that the impact of agricultural and forestry effluents has the biggest impact on the inland aquatic realm of all of the pollution types considered in the assessment. The impacts of agricultural and forestry effluents in the inland aquatic are most evident in birds, freshwater fishes, and reptiles. However, the SANBI analysis showed that all types of pollution had significant impacts on Taxa of Conservation Concern, with marine mammals and reptiles being amongst the most impacted groups. Combining threatened species data into numbers of taxa expressed spatially shows where hotspots of threatened taxa occur, such as most notably in the Cape Floristic region (Figure 16).

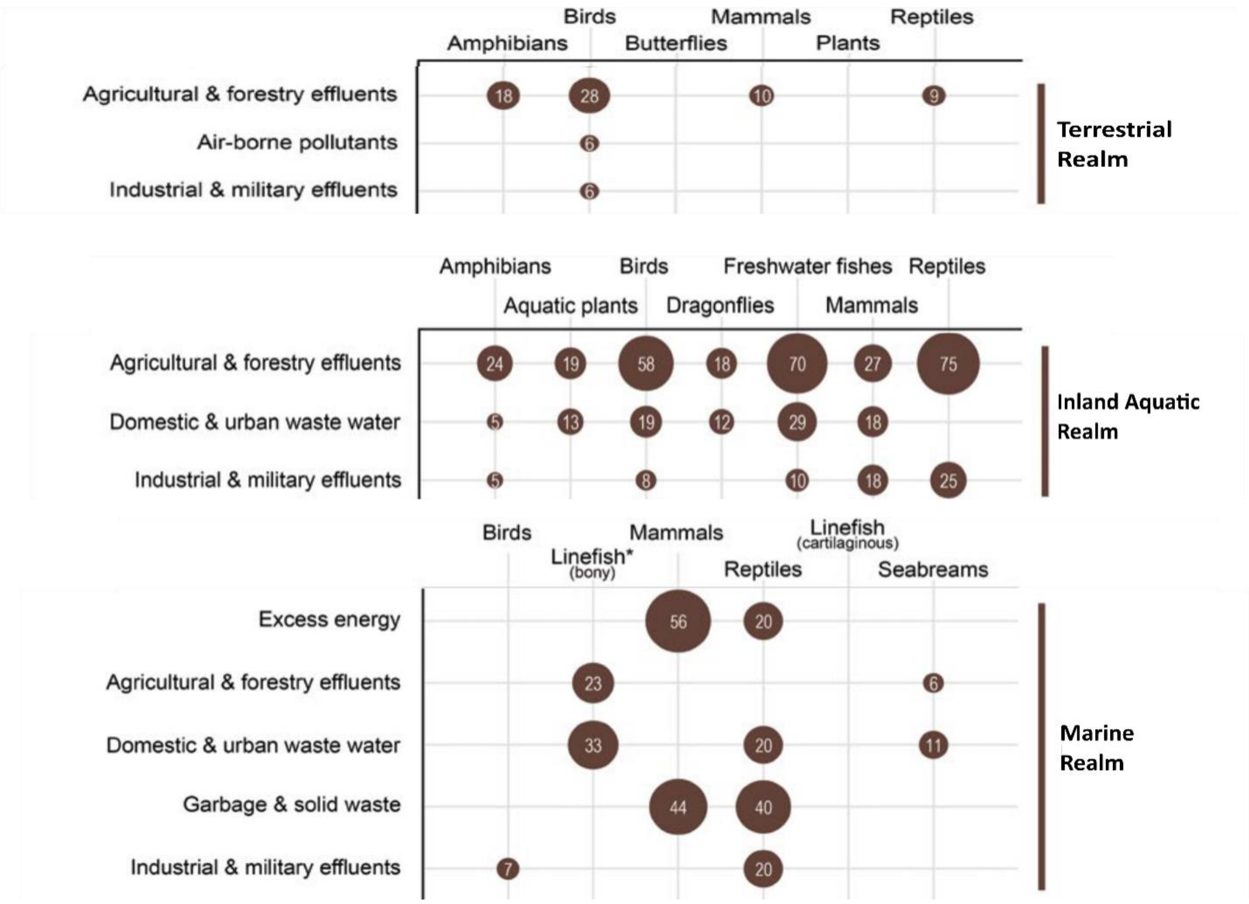


Figure 15. The key pollution pressures for Taxa of Conservation Concern (ToCC) in the terrestrial, inland aquatic, and marine realms based on a meta-analysis of the South African Species Red List Database. The size of the bubble and label number is the percentage of ToCC in the taxonomic group that is subject to each pressure. The 'pressures' categories follow the IUCN threat classification system (Source: Figure adapted from SANBI NBA 2018 Technical Report).

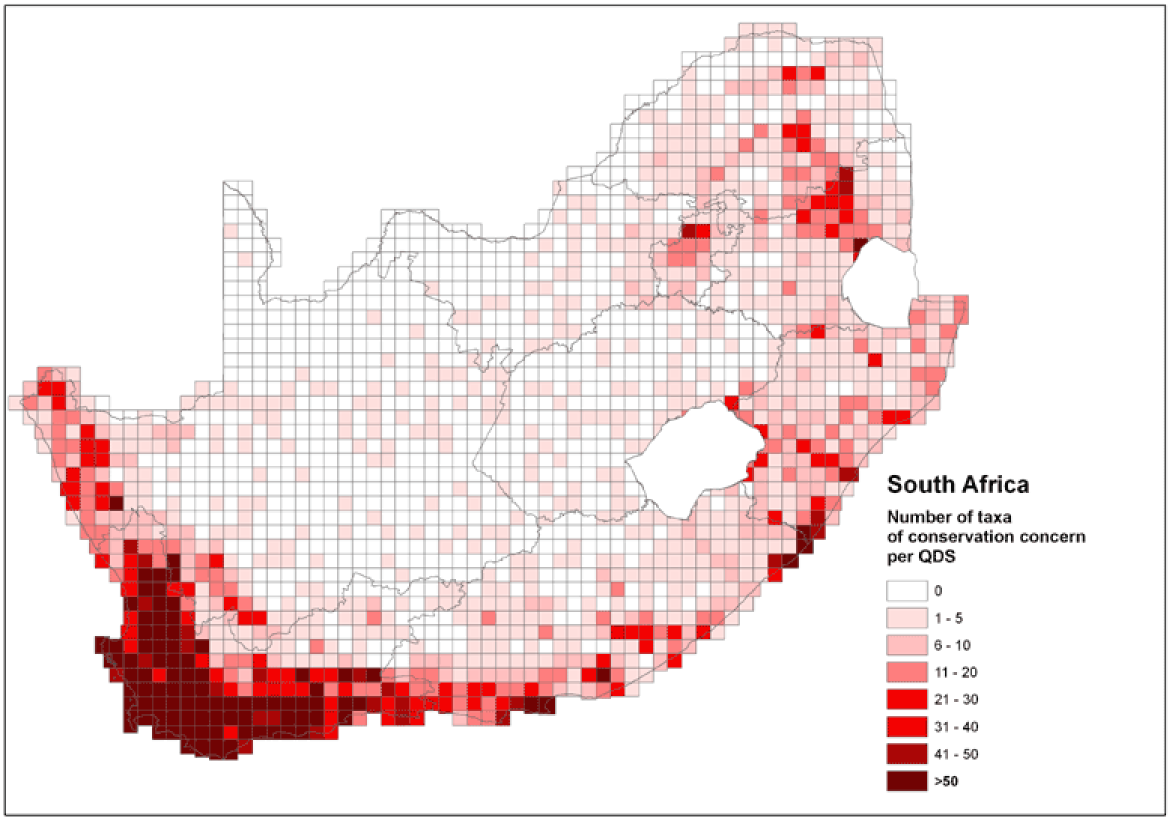


Figure 16. A map of South Africa, showing areas of high concentrations of taxa of conservation concern (Source: SANBI Red List website - http://redlist.sanbi.org/stats.php).

4.4 Evaluation and specific comments on each pollution category's maps and gaps

Based on the feedback received from the stakeholders participation processes (workshop and key informant interviews), as well as the literature reviews for pollution impacts on biodiversity in South Africa, key points were highlighted for each of the pollution category hotspot maps relative to the species lists (Table 4). These findings, listed below, are supported in terms of alignments between taxa represented in the analyses versus relative rankings of taxa impacted per pollution category for South Africa (Figure 17).

Table 4. Key points on country analysis maps and potential avenues for improvements for pollution categories in South Africa.

Pollution Category	**Key points on country analysis maps**	**Potential avenues for improvement**
Domestic and urban wastewater	The domestic and urban wastewater heatmap detects some areas but were not accurate for other areas. Sewage and run-off are major concerns in South Africa and these issues are not adequately reflected	Refine domestic waste hotspots by combining informal residential/urban settlement spatial data with the national rivers coverage (i.e., a rivers coverage that highlights free-flowing rivers and/ or rivers with high levels of fish endemism (e.g., Cape floristic region)). These layers could be used as a proxy for identifying hotspot areas from a solid waste perspective. In addition to this, estuaries and ports could also be included to highlight key source areas from a marine perspective.
Industrial and military effluents	The heatmap for seepage from mining is not accurate (the top two polluted rivers in South Africa are the Upper and Lower Crocodile River, followed by the upper Olifants River in the vicinity of Emalahleni, and neither are coming out as pollution hotspots). Industrial and military effluents, and fuel spills in particular were considered to be a big issue that is not reflected adequately. Legacy pollution issues from old abandoned mines are of particular concern in South Africa.	
Agricultural and forestry effluents	The heatmap for nutrient loads is not accurate (the top two polluted rivers in South Africa are, as per above, are not coming out as pollution hotspots).	Refine the agricultural runoff using the WRC pesticide risk zones map by James Dabrowski versus the national landuse map for commercial irrigated agriculture, and overlay it with relevant species data (Note, this could also be undertaken for forestry).

Pollution Category	Key points on country analysis maps	Potential avenues for improvement
	The heatmaps for pesticides probably over-estimate the extent of pollution.	Spatial data that is generated for the countries Greendrop reports through the NIWIS. The DWS project data for water quality planning, and the eutrophication of inland water bodies. The WRC NatSil project data on the sedimentation of reservoirs.
Garbage and solid waste	The garbage and solid waste hotspot maps were not accurate, resulting in no clear pathways for management or intervention for the specific pollution impact.	Hotspot maps for plastic pollution are available for the city of Johannesburg, and there is also less detailed nationally data. There is available research looking at waste management in private reserves, and waste dumps in National Parks near camps. Plastics South Africa's litter boom programme.
Air-borne pollutants	Air-borne pollutants on the highveld plateau is a seasonal problem, which is not adequately reflected.	The gridded regional datasets of SO_2, NO_2, ozone, and PM. Satellite data for NO_2. Air pollution hotspots could be deduced from point source locations (e.g. Eskom). SAEON research site deposition zone data. CSIR air quality modelling data. Alternatively, air quality global model outputs and satellite data.
Excess energy		Add layers for excess energy pollution by cross-referencing taxa such as bats with light pollution, and rare and endemic succulents with solar panel farms in arid areas.
General		Refine the threatened species maps by using local threatened species data (SANBI data). For

Pollution Category	Key points on country analysis maps	Potential avenues for improvement
		example, there is good data on plants and associated threats, which are currently not part of the IUCN database. Very few countries have a national Red List database. South Africa has one, and while there is still a lot of work to be done the national database could be used to complement the global dataset. Investigate the possibility of collating provincial conservation plans to pick out key conservation areas and overlay them with pollution hotspot areas. Surrogate datasets such as “global burden of disease maps”, or other census-based proxies for human health risks and vulnerabilities. National land cover (or land use) datasets. National DWS monitoring data. SANBI spatial data used for the National Biodiversity Assessment 2018. The DFFE Coastwise project data. Data depicting human health impact and costing thereof

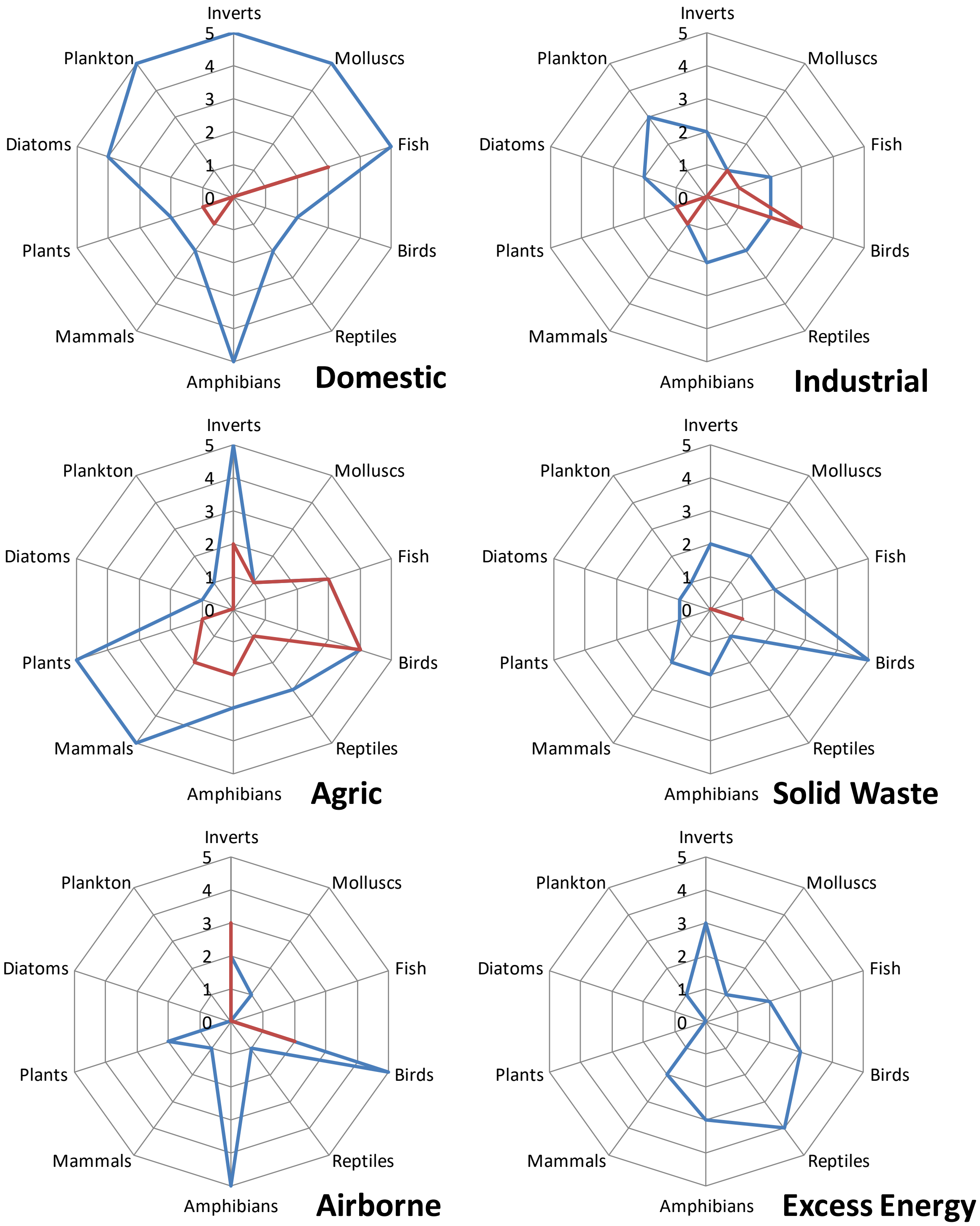


Figure 17. Signatures of relative impact of pollution category per major taxonomic group (blue line) versus current representation of taxa in the Country analysis (red line) (adapted from non-marine species numbers in JNCC Reducing Pollution through Partnership Project, Document E, November 2021, and SANBI NBA 2018 Technical Report, SANBI 2019).

5 Additional sources of data to strengthen the country analysis

This chapter provides the sources of data identified that could be used to help design a wider pollution programme for South Africa. The available data have been provided in a table that includes the relevant data, where it can be sourced, any limitations worth noting, and potential methods for how it could be used in the development of a wider pollution programme (Table 5).

Table 5. Pollution and biodiversity databases and data sources recommended by workshop attendees for decision-making.

Pollution Category/Type	Database / Sources of Data	Update Frequency	Notes
Species	South African National Biodiversity Institute (SANBI) Red List data. Data to be sourced from SANBI's Threatened Species Programme Manager	Variable	• Use to complement the IUCN global dataset. • SANBI uses IUCN pollution categories to a third level of classification.
Ecological	miniSASS	Regularly	
Ecological	Freshwater Biodiversity Information System	Occasionally	
Ecological	Virtual Museum	Frequently	
Ecological	Southern African Bird Atlas Project 2	Frequently	
Ecological	Coordinated Waterbird Counts	Unknown	
Various	Specialist reports and academic papers. For example: • Research looking at waste management in National Parks and private reserves. • The DWS has project data for Water Quality Planning, which includes water quality pollution hotspots. The department also has data on the eutrophication of inland water bodies. • Waterberg Air Quality Priority Area may include studies on some species (particularly birds). • Data from the DFFE Coastwise project on plastic waste on the coast that threatens marine and coastal species.	Unknown	
Garbage & Solid Waste	South African Waste Information Centre	Unknown	

Pollution Category/Type	Database / Sources of Data	Update Frequency	Notes
Garbage & Solid Waste	CSIR Pollution tracking	Unknown	E.g., through the use of a Chemistry Transport Model for air quality simulations. This is a state-of-the-art model that includes recent advances in full chemistry and atmospheric models.
Garbage & Solid Waste	Hotspot maps for plastic pollution are available for the City of Johannesburg. IUCN plastic pollution maps are available for South Africa (i.e., the MARPLASTICCs initiative)	Unknown	The IUCN plastic pollution maps are based on course / limited data.
Garbage & Solid Waste	South African 2020 national landcover and rivers data. This spatial data can be used to map informal urban and rural settlements as a surrogate for solid waste hotspots.	Occasionally	These areas are commonly associated with poor or no service delivery. Additionally, because a lot of solid waste ends up in rivers (people see rivers as disposal points), rivers that intersect with high-density areas with poor service delivery can indicate waste management problem hotspots.
Garbage & Solid Waste	The organisation Plastics South Africa's litter boom programme across metropolitans in South Africa.	Unknown	The organisation's records could be used to detect source areas of solid waste pollution.
Air-borne	South African Air Quality Information System	Daily	

Pollution Category/Type	Database / Sources of Data	Update Frequency	Notes
Air-borne	Modelled and satellite gridded regional datasets of SO_2, NO_2, ozone and PM. There is also satellite data for NO_2, which has been widely used globally and in South Africa.	Unknown	
Domestic & Urban Waste Water	Spatial data generated for South Africa's Greendrop reports, which shows the distribution of Waste Water Treatment Facilities across the country. These could be used to identify potential sources of domestic and urban wastewater pollution. Data is publicly available through the National Integrated Water Information System (NIWIS) on the Department of Water and Sanitation (DWS) website.	TBC	It was noted that the last public report was published in 2012. However, the Greendrop status reporting programme has been reinstated by the DWS.
Soil Erosion, Sedimentation	There is data on the sedimentation of reservoirs, which can be sourced through the Water Research Commission (NatSil Project). The National Dam Siltation Management Plan (WRC) is of relevance to tackling sediment pollution in South Africa.	Unknown	
Various	Port regions and industrial areas could be used to reflect pollution hotspots	Unknown	This would only indicate where likely pollution hotspots occur.
Air-borne	• Air pollution hotspots could be deduced from point source locations (e.g., Eskom) as well as ground-level emission sources (e.g., vehicles and domestic fuel combustion). • Modelling of hotspots compounded by dynamics of air quality pollutants, with deposition into water systems. Some data on deposition zones are collected from the flux towers at SAEON research sites.	Unknown	SAEON encompasses seven Research Nodes throughout South Africa
Air-borne	Air quality modelling is undertaken at ~6 km^2 grid resolution by the CSIR. The air quality models model atmospheric concentrations. The atmospheric concentrations are what are used to estimate human/ecological impacts. Hence, airborne pollutant hotspot refinement is possible.	Unknown	Note - even without the CSIR models, there are global model outputs and satellite data that could be used.

Pollution Category/Type	Database / Sources of Data	Update Frequency	Notes
Air-borne	The use of surrogate datasets such as "global burden of disease maps", or other census-based proxies for human health risk and vulnerabilities should be considered.	Unknown	
Various	Land cover (or land use) spatial data (e.g., mapped in 2008, 2014, 2018, and 2020).	Occasionally	Land cover data could provide valuable information about where pollution sources are expected to occur.
Water Quality / Quantity	National monitoring data (e.g., water quality monitoring data collected by the DWS).	Frequently	
Ecological	SANBI GIS coverages – e.g., the National Biodiversity Assessment 2018 could potentially be used to determine whether the Present Ecological State (PES) of rivers could be an indicator of pollution.	Occasionally	
Seepage from mining	Mine Water Atlas	Unknown	WRC Project
Agricultural & Forestry Effluents	• Pesticide Use and Risk Maps: Dabrowski et al. (2022) • The Water Research Commission has invested considerable funds in various aspects of nonpoint source pollution research over the years.	Unknown	WRC are an important stakeholder for the next phase in the development of the reducing pollution programme.
Garbage & Solid Waste	Plastics in the environment project by the Fitzpatrick Institute at the University of Cape Town.	Unknown	
Various	The state of Environment reporting done by DFFE (e.g., There is an air pollution section and solid waste section, etc.)	Occasionally	

Pollution Category/Type	Database / Sources of Data	Update Frequency	Notes
Water Quality	DWS Monitoring data from the National Chemical Monitoring Programme (nutrients, salts, some metals).	Unknown	
Water Quality	National Eutrophication Monitoring Programme	Unknown	Provides information on the trophic status of dams throughout the country and is, therefore, a good indicator of nutrient pollution.

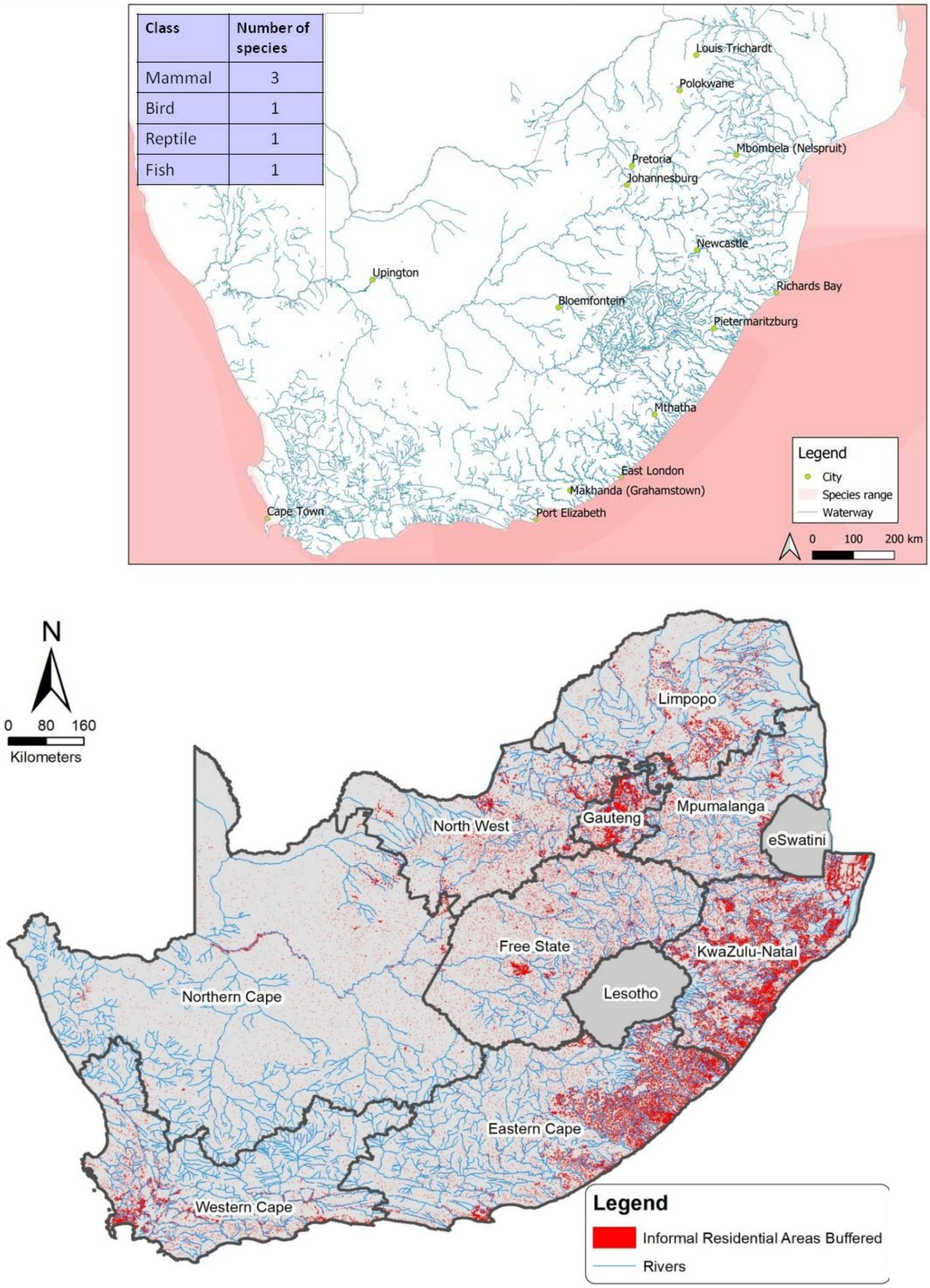
6 Case studies

Case studies have been included in the evidence report to demonstrate examples of how some of the identified locally available data could be used to inform a wider pollution programme for South Africa. Three case studies are proposed:

Case study 1 - Solid waste: The Global Analysis for South Africa for garbage and solid waste showed very few inland impacts of this pollution category on biodiversity. Impacts were primarily predicted to be for marine areas (Figure 18). However, based on the information gathered in this study, hotspots for this category are most likely to occur around informal residential areas where service delivery is less likely to be making use of landfill sites. The information gathered suggests that birds are the most likely taxonomic group to be impacted by garbage and solid waste.

We suggest that the prediction of hotspots could be refined through an approach where informal residential areas are mapped, with a second step being to overlay this with species maps such as Important Bird Areas. The South African landcover spatial assessment from 2020 allows for the identification of informal residential / urban areas, which typically have poor or no service delivery (i.e. collection of solid waste for disposal at landfill sites). Additionally, rivers are known to be dumping sites for solid waste. Therefore, spatial data of major rivers and informal residential areas can be used as a proxy for identifying hotspot areas from a solid waste perspective. In addition to this, estuaries and ports could also be included to highlight key source areas from a marine perspective.

9.4 Garbage & Solid Waste



Class	Number of species
Mammal	3
Bird	1
Reptile	1
Fish	1

Figure 18. Solid waste impact hotspots on biodiversity for South Africa (top) versus a potential refinement using reclassified National Landcover data for South Africa showing informal residential areas which typically receive poor service delivery.

Case study 2 – Catchments at risk to water quality problems: Freshwater ecosystems, despite their relatively smaller size compared to terrestrial ecosystems, contain a disproportionately high species richness and phylogenetic diversity (Román-Palacios et al. 2022). However, these ecosystems are also at higher risk of species losses because rivers assimilate pollutants from catchment-based activities, which further accumulate with downstream distance. Freshwater conservation programmes and associated interventions benefit from tools that assist with prioritizing catchments where risks to biota are high. The Automated Land-based Activity Risk Assessment Method (ALARM) is a national risk assessment method based on GIS and Excel spreadsheets which was developed for the Department of Water and Sanitation (DWA, 2014b). This tool is aimed at identifying likely diffuse or point source water quality impacts on water resources, and assesses the relative risks to vulnerable ecosystems and downstream users at a quaternary catchment scale (Figure 19).

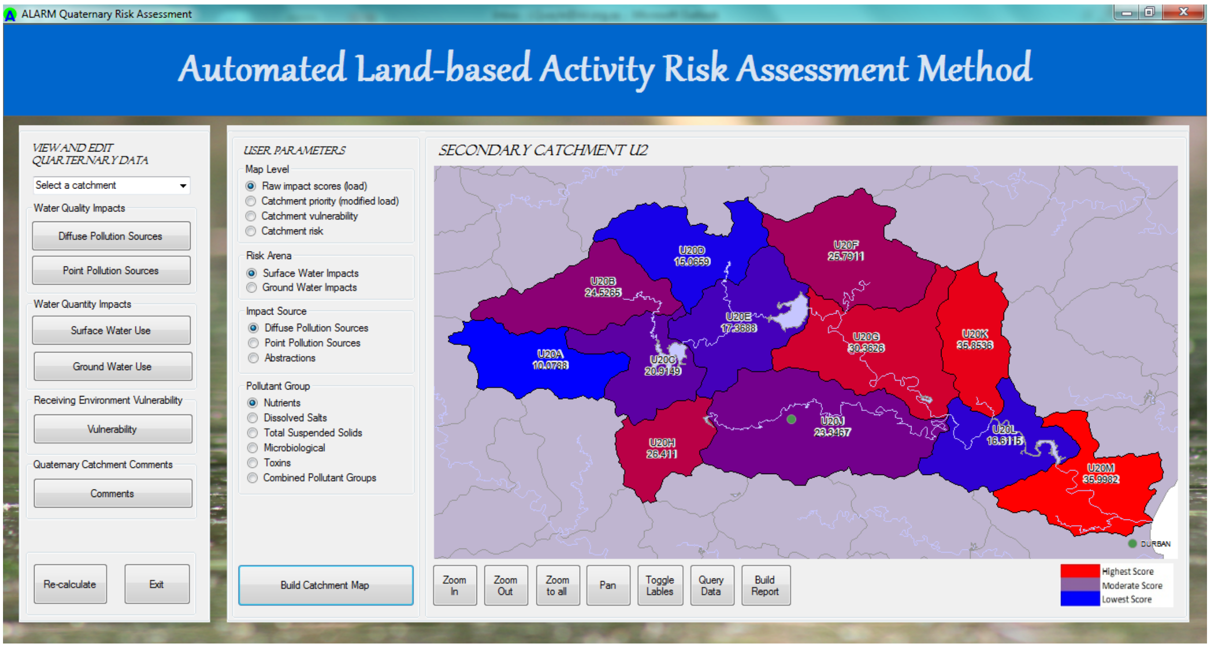


Figure 19. The Automated Land-based Activity Risk Assessment Method (ALARM) tool (Source: DWA 2018).

Case study 3 - Domestic wastewater: South Africa's deteriorating water quality has again been identified as a major threat to its freshwater biodiversity in this study. A major contributor to this problem is through untreated sewage entering rivers due to non-compliant or poorly managed wastewater treatment works. The Integrated Regulatory Information System (IRIS) is an online interactive spatial tool that allows users to obtain information on wastewater treatment system compliance at the district municipality scale (Figure 20). This is a national database that shows levels of compliance and associated monitoring levels reflected through microbiological, chemical, physical and operational risk metrics. When overlayed with suitable species distribution layers, this is potentially a simple tool to refine the identification of sewage pollution hotspot maps for South Africa.

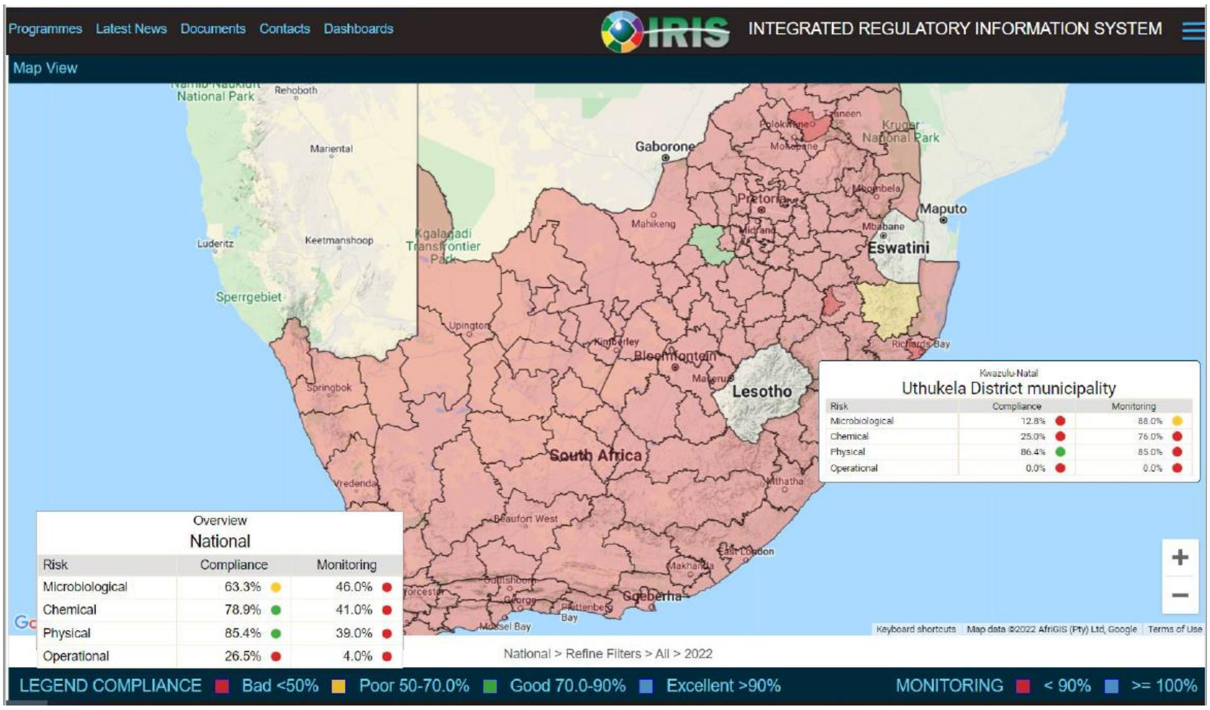


Figure 20. Integrated Regulatory Information System (Source: screenshot from https://ws.dws.gov.za/IRIS/mywater.aspx).

7 Discussion

This chapter provides an overall synthesis based on information collated from all information sources described in Chapter 4. Based on this, key recommendations have been made for refining the accuracy and resolution of the local and global analysis, which includes comments on an overall pollution programme, adequacy of data, and gaps in terms of knowledge, policy, etc., Based on this, recommendations are suggested about the way forward in terms of mitigating pollution impacts on biodiversity in South Africa, including monitoring and reporting risks posed to biodiversity. We include a synthesis of emerging threats and pollutants, and how climate change may exacerbate pollution impacts on species.

Information assessed in this study indicates that many of the pollution types, and their impacts on biodiversity losses, are cross cutting. For example, agricultural pesticides may be assessed in terms of its primary impacts, but through runoff it also affects water quality, which is in turn also impacted by domestic sewage. Air-borne pollution may also be a primary source of pollution, but through circulation patterns and rainfall, potentially toxic chemicals enter soil and water ecosystems.

Nevertheless, tackling these issues remains complex. For example, there has been a long history of paired-catchment studies on these systems, and what these studies have highlighted is that there is often a failure in the application of knowledge to improve the water quality status of many rivers. This has been an ongoing problem for more than 20 years, for a number of reasons. A number of relevant studies previously undertaken on aspects of pollution in South Africa relate specifically to relationships between land use and water quality (DWA 2014; Dabrowski et al. 2013). Such studies explored relative contributions of various parameters to water quality problems within a Bayesian network framework (Quayle et al. 2015; Rivers-Moore 2016). There have also been extensive risk assessments undertaken on the impacts of fracking on groundwater and surface water, largely based on expert opinion and supporting studies [Scholes et al. 2016].

7.1 Emerging threats and potential future optimism

7.1.1 Sector threats

The fundamentals for addressing pollution impacts on biodiversity already exist within the South African context. A strong constitution with a good legislative framework enables and supports pollution mitigation programmes and prosecution of polluters. There is a history of public involvement by individuals, private sector pressure and vibrant cross-sector networks of non-governmental organizations. There is also a comprehensive body of knowledge in terms of baseline data studies and species status data to support a pollution programme. Based on our findings, it is also clear that there is excellent human resource capacity within the scientific community. To add to this, there is the real prospect of two major game-changers for pollution control to enter the landscape:

- Movement toward a legally binding “end plastic pollution” treaty led by the United Nations[23], with this initiative endorsed by 175 nations including South Africa in

[23] https://www.bbc.com/news/science-environment-60590515

March 2022. The aim of this treaty is to regulate pollution from single use plastics, with the timeframe to reach agreement set for the end of 2024[24];

- Climate finance of $8.5 billion has been pledged by five countries (UK, US, Germany, France and the EU) to facilitate the South African economy in retiring coal-fired power plants, and moving towards renewable energy sources[25] Under the current dispensation, 83% of South Africa's electricity supply is met through generation from coal-fired power stations (DoE, 2019).
- An extended producer responsibility policy for a number of industries (paper and packaging; electrical and electronic; and lighting) came into effect in South Africa 2018, which offers some optimism in the context of improved waste management in South Africa (Packaging SA 2018).

However, such a trajectory would need to be protected against emerging threats. In a recent update of the rankings of 164 countries on equality of its citizens, South Africa again ranked as the most unequal country on this list[26]. With an official current unemployment rate of 47%, and an economy increasingly under strain after the economic and social impacts of two years of lockdown in response to the COVID-19 pandemic, South Africa is at a crossroads where it is also having to negotiate a path through an era of corruption as highlighted in the Zondo Reports and factionalism with the ruling African National Congress. There is also the emerging knock-on effect on fuel and grain prices from the Russia-Ukraine conflict that began in February. According to a recent World Economic Forum (WEF) Global Risks report[27], five key areas of risk have been identified:

- Prolonged economic stagnation;
- Employment and livelihood crises;
- State collapse;
- Failure of public infrastructure;
- Proliferation of illicit economic activity.

In addition, South Africa is listed as one of 31 countries with risks around erosion of social cohesion. This poses not only problems for a lack of accountability in abiding by and enforcing pollution regulations, but also in terms of business growth. This is because, as highlighted by the current Chief Executive Officer of Nedbank, it is "difficult to run a business in an unsuccessful society – and for society to be successful - greater equality levels are essential". He further adds that to address this and to fight corruption, better education outcomes, sustained growth and strong leadership are key ingredients to reverse this trend[28]. The Institute of Risk Management South Africa (IRMSA) has recently highlighted that unless there is action to bolster economic growth led by ethical and decisive leadership, South Africa increasingly risks becoming a "failed" state. This is likely

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[24] https://www.unep.org/news-and-stories/press-release/historic-day-campaign-beat-plastic-pollution-nations-commit-develop

[25] https://mybroadband.co.za/news/energy/436152-eskom-must-use-r130-billion-clean-energy-loan-to-retire-coal-power-plants.html

[26] https://www.news24.com/fin24/economy/sa-is-still-the-most-unequal-country-in-the-world-according-to-the-world-bank-20220310

[27] https://businesstech.co.za/news/business/550154/state-collapse-and-other-risks-threatening-south-africa-over-the-next-two-years-wef/

[28] https://businesstech.co.za/news/banking/563522/south-africa-is-out-of-runway-nedbank-ceo/

to be accompanied by a continued breakdown of ethical and legal principles, social unrest and a breakdown in the "rule of law"[29].Declining quality in governance is reflected in the "hard" data on the state of the South African economy[30]. Findings in this report identify a declining Gross Domestic Product (GDP); a declining investment in State-Owned Enterprises (SOEs) and in the private sector; government overspending including an inflated wage bill but accompanied by a declining investment portion; and a declining public perception of government handling of the economy between 2002 and 2018.

7.1.2 Climate change threats and impacts on pollution and biodiversity loss

Climate change represents an additional and synergistic stressor on species and ecosystems (Cabral et al. 2019; Zandalinas et al. 2021). Pollution impacts on biodiversity should thus be assessed in conjunction with pollution impacts. Such chronic stressors have the potential to cause rapid declines in populations and local extinctions, in the absence of direct lethal effects. This has recently been demonstrated in populations of the yellow-billed hornbill *Tockus leucomelas*, where a combination of increased air temperatures and drought has drastically reduced breeding success (Pattinson et al. 2022).

Climate change predictions for South Africa are that the western portion of the country is likely to become drier and warmer, while the eastern portion is likely to become wetter and experience more regular severe flooding (as reported in Dallas and Rivers-Moore 2014). One of the implications of this is that in the drier areas, there will be reduced flows in rivers, which in turn is likely to reduce the dilution capacity of rivers for buffering water quality. There is also likely to be an increase in water temperatures, promoting increased mobilization of certain toxins and resulting in higher parasite loads in organisms such as fish (as reported in Dallas and Rivers-Moore 2014).

Impacts of global climate change on species is likely to differ, with indications that pest species may benefit while high-conservation value species are more likely to decline (Rivers-Moore et al. 2013). The capacity for species to adapt to environmental stress from pollution and climate change is increasingly constrained in both terrestrial systems and aquatic systems. In the former case, this is a consequence of ongoing catchment transformation and land cover change, including ongoing fragmentation and loss of natural movement corridors (Skowno et al. 2021). In the latter case, the loss of river connectivity prevents organisms from migrating upstream or downstream to avoid chronic stress.

Future studies will need to include a wider range of taxa: Cowie et al. (2022) highlight that the IUCN Red List is heavily biased towards birds and mammals, and that only a small fraction if invertebrates are included. To quantify the true rates of extinctions, a wider range of taxa need to be included in analyses. Recent studies highlight major reductions in abundances and numbers of species for insects due to the interacting effects of agriculture and climate change pressures (Outhwaite et al. 2022). Despite this, insects have been shown to be useful to monitor in terms of their abundance, distribution and diversity to reflect ecosystem responses to multiple stressors (Wilson and Fox 2020).

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[29] https://businesstech.co.za/news/business-opinion/563512/south-africa-at-risk-of-becoming-a-failed-state-says-professional-body/

[30] https://www.dailymaverick.co.za/article/2022-02-08-what-the-hard-data-reveals-about-the-true-state-of-the-nation-spoiler-alert-not-good-at-all/

7.1.3 Pollution category risk overview

Information from this study were summarized using the qualitative risk framework of Scholes et al. (2016), where activities are ranked in terms of their severity of impact, and the likelihood of impact. A third dimension was added to this, with the relative importance of each pollution category as a contributor to biodiversity loss was scored (Figure 21). On the basis of the information received from this study, it is our considered opinion that domestic waste, primarily in the form of unmanaged sewage, represents the greatest risk pollution category to biodiversity for South Africa. This is followed by solid waste in terms of risk and importance. However, we also recognize that the impacts of pollution on biodiversity cannot be viewed in isolation, and that the overall challenge of mitigation pollution impacts on biodiversity requires a holistic approach.

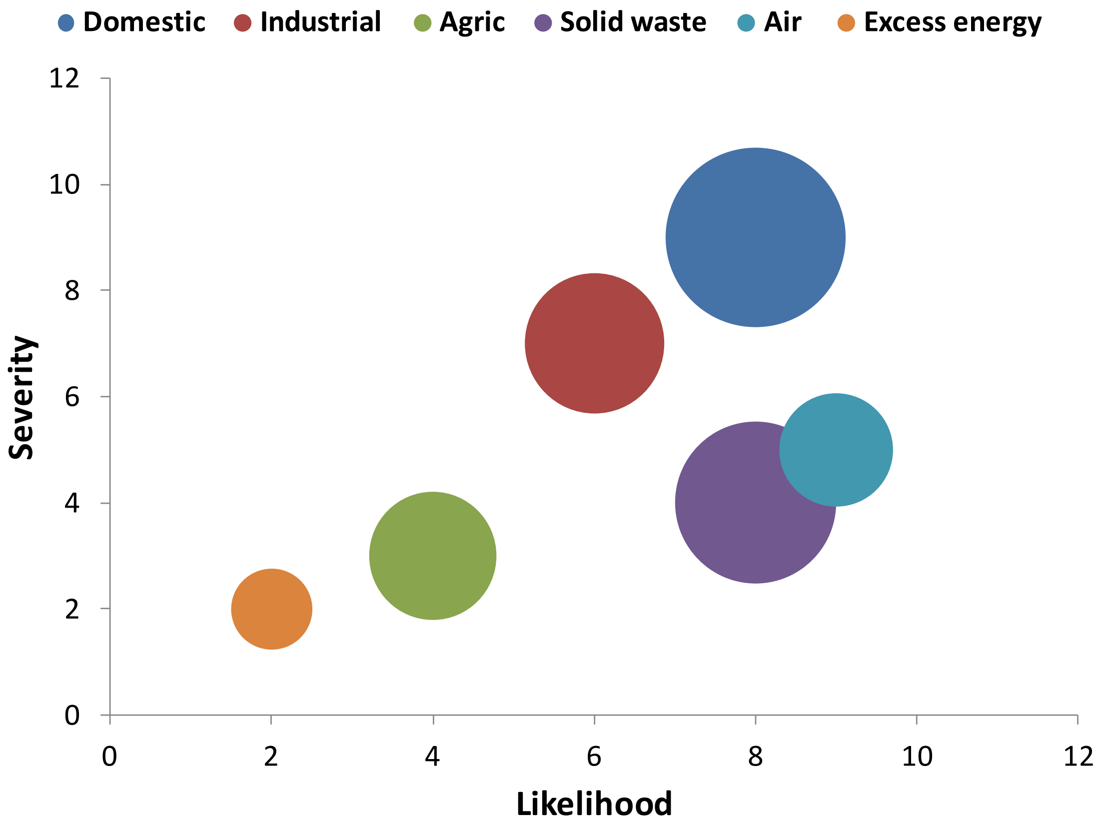

Figure 21. Risk framework of impacts of major pollution categories on biodiversity, ranked according to likelihood and severity of impacts. Bubble size reflects relative importance (Source: Pollution categories were scored from 1-10 for relative likelihood, severity and importance based on the information gathered in this report, and verified by key informant interviewees).

7.2 Overview with scenarios

While pollution is a global problem, its manifestations may be local, affected by culture and climate (for example: salting on roads versus the legacy issues of abandoned mines). It is therefore critical to understand sources of pollution, their potential and actual impacts on biodiversity, and the development and application of solutions. Underpinning all of this is that solutions must be based on scientific knowledge, an awareness of current problems, and buy-in from both the relevant private and government sectors. Here, the scientific literature will provide the objectivity and mechanisms to inform on pollution problems, while direction and incentives will be more easily driven by perspectives from the media (Figure 22). In taking generic lessons from water reforms globally, Richter (2014) identifies a few key elements that could just as easily be applied to reducing the impacts of pollution on biodiversity:

- Change may happen gradually, or is prompted by catalytic events (either positive or negative);
- A foundation of active dialogue and debate necessarily precedes initiation of implementation of changes.

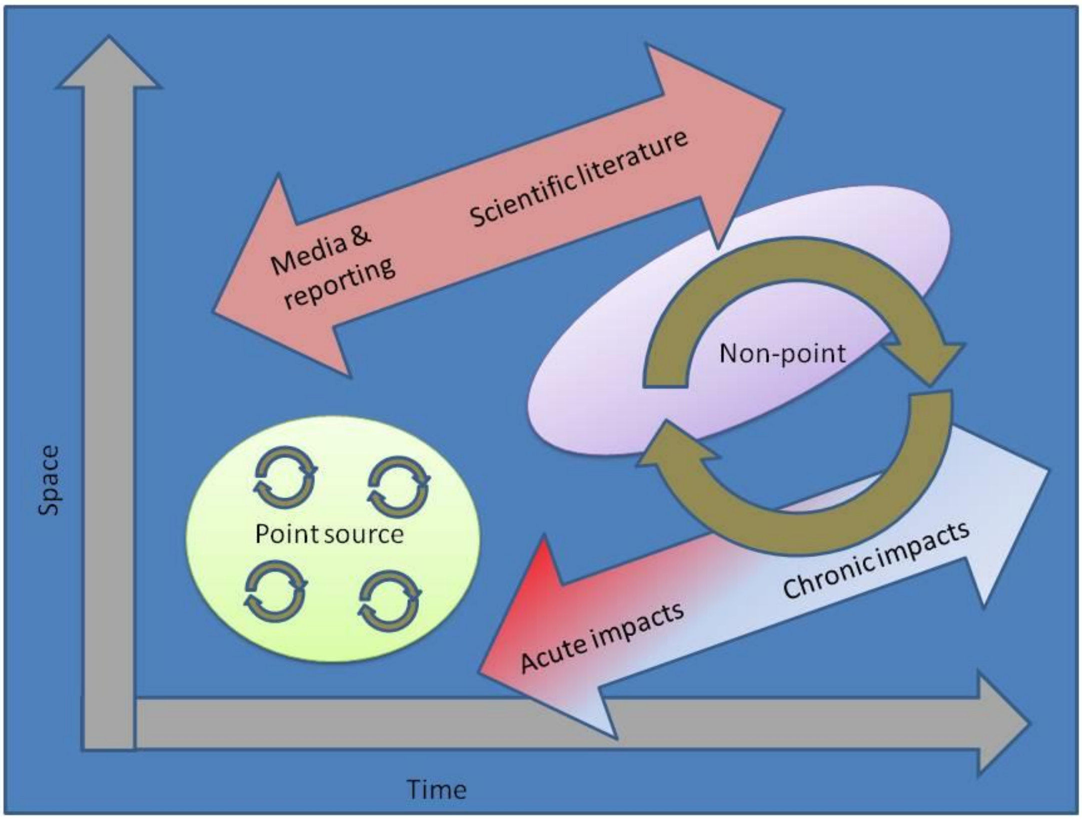

Figure 22. Relative spatio-temporal scales of point source versus non-point source pollution events. In this conceptual diagram, point source pollutants are likely to have a more rapid but localized negative impact on biodiversity, caused by acute stress and mortality. Knowledge on these events is more likely to be reported in the media and drive public perceptions. Conversely, non-point source pollutants, with a larger spatial footprint, are more likely to cause chronic stress that negatively impacts on biodiversity over longer periods of time as reflected in increased parasite loads, reduced fecundity, and invasions of alien species. Public perceptions are likely to be less affected by media reports, while this field is likely to have a greater presence within the scientific literature.

That pollution has a cost is provided by a recent example from the Black River in the Cape Town metropolitan area: R10 million to dredge 5000m^3 (650 truckloads) of solid waste – sediment, invasive water plants, litter and solid waste – for disposal at local landfill sites[31]. Such costs are typically not borne by the manufacturers of pollutant products or by polluters themselves, but by society at large. While direct intervention costs, which in themselves

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[31] https://www.iol.co.za/news/south-africa/western-cape/650-truckloads-of-dried-material-including-mattresses-found-in-black-river-during-dredging-process-8880f2de-f587-410b-a089-1c1ad0c4fef3

represent lost opportunity costs for better service delivery, this figure does not reflect internal costs of biodiversity losses and reduced system resilience and ecosystem services.

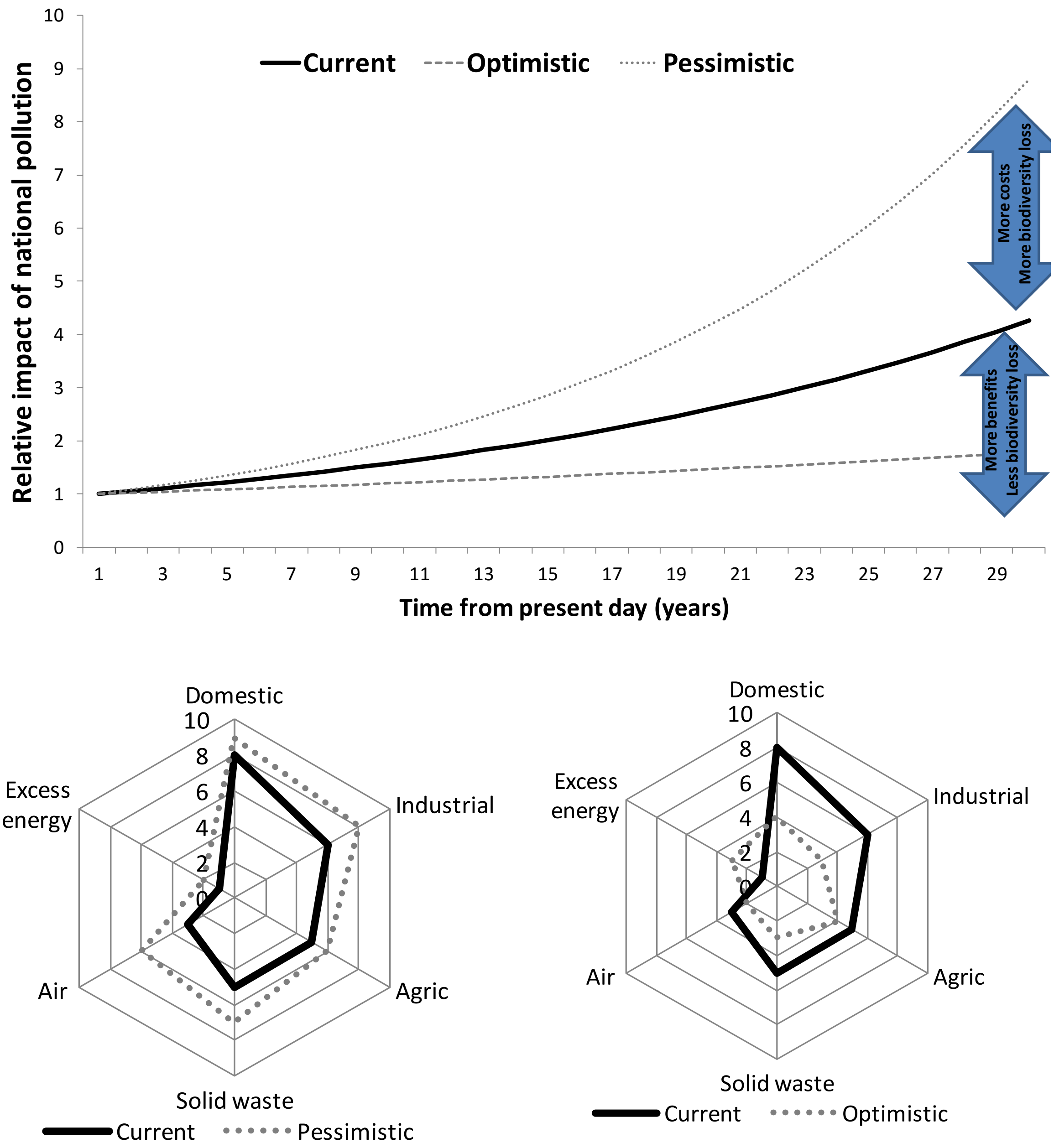

Figure 23. Theoretical demonstration of relative trendlines under current, pessimistic and future pollution scenarios (top), while radar plots below show changes in national pollution signatures based on potential changes for each pollution category under pessimistic and optimistic scenarios.

Based on the collated information from the scoping exercise, the relative impacts of pollution categories on biodiversity loss rates were ranked from 1-10. Incorporating the major threats in relation to this, three broad scenarios have been proposed as possible future outcomes (Table 6). These are described as a ‘business-as-usual’ trendline based on current trends continuing without directed interventions; a pessimistic scenario, and an optimistic scenario. Trendlines were projected from current with a 30 year time horizon, based on the assumption that pollution volumes will increase exponentially tracking human population growth trends. At this stage, this data is purely speculative and not based on hard data, with this exercise used to demonstrate the conceptual value of pollution interventions. All three scenarios have been plotted to start from a value of unity = 1.

In the current scenario, impacts from pollution are projected to increase exponentially at the present rate (Figure 23). Under a pessimistic scenario, the rate of relative impact from current is faster, and demonstrates that the longer the delays in mitigation and intervention, the greater the economic costs and the greater the loss of biodiversity. Conversely, under the optimistic scenario, the rate of relative impact declines so that the impacts of pollution in the future are reduced from current. This scenario implies that benefits accrue and costs decline, and the rate of biodiversity loss is reduced. For example, under an optimistic scenario, the overall pollution footprint is likely to decrease, but gains in one pollution category may also be offset by increased pollution levels in other categories. For example, reduced air pollution in response to a shift to a 'greener' economy could result in increases in excess energy pollution as the surface area of solar farms increases.

However, it is also important to break this down further according to the relative impacts of the different pollution categories based on each scenario, as it is likely that gains in one pollution sector may result in changes in other categories (see radar plots, Figure 23). For example, reductions in air-borne, industrial and solid waste pollution may result in increased local impacts from solar farms (increased footprint of excess energy).

Table 6. Outline of current, optimistic and pessimistic future scenarios for pollution in South Africa.

Current scenario	Optimistic scenario	Pessimistic scenario
This represents a "business as usual" situation; where no active intervention to reduce pollution impacts on biodiversity occur, beyond what is currently happening.	Under an optimistic scenario, South Africa's energy generation shifts from a coal-based one to a greener energy sector. Here, solar power becomes dominant. As a signatory and active participant of the global treaty to control use of single-use plastics, solid waste declines (noting that single-use plastics only make up 13% of solid waste: DEA 2018). The railway network is revitalized.	Under a pessimistic scenario, reliance on a coal-based economy continues, supplemented by natural gas from fracking.

7.3 Mitigation

Mitigation of pollution impacts on biodiversity requires identifying how each of the major pollution categories differs in terms of its 'signature' as reflected by suitable metrics, as a means of identifying intervention priorities. Based on the assessments from this report, each major pollution category's impacts on biodiversity were ranked on a scale of one to five for seven metrics reflecting different avenues of pollution intervention. These metrics were: adequacy in legislation and policy; degree of successful enforcement; perceived management capacity within relevant government departments; existence of a national monitoring programme; perceived level of public compliance in refraining from polluting activities; level of understanding of the pollution category; and level of local/ global knowledge and research on the impacts of pollution by category on taxa and ecosystems (Figure 24). This approach shows that each pollution category has its own 'signature'. In our opinion, the major shortfalls for all pollution categories relate to public sector problems; viz. lack of enforcement and a lack of management capacity, either at national or municipal level. Thus, in many instances, finding solutions to address biodiversity impacts on pollution is not limited by a lack of available literature on the topic, but rather seemingly through issues around enforcement, management capacity and public compliance. This requires decisive regulatory action to take the crisis seriously[32]. Another aspect that seems to require further research is around directed research that establishes more rigorous cause-and-effect relationships between species or ecosystem responses to specific pollutants, as measured at different toxicity thresholds.

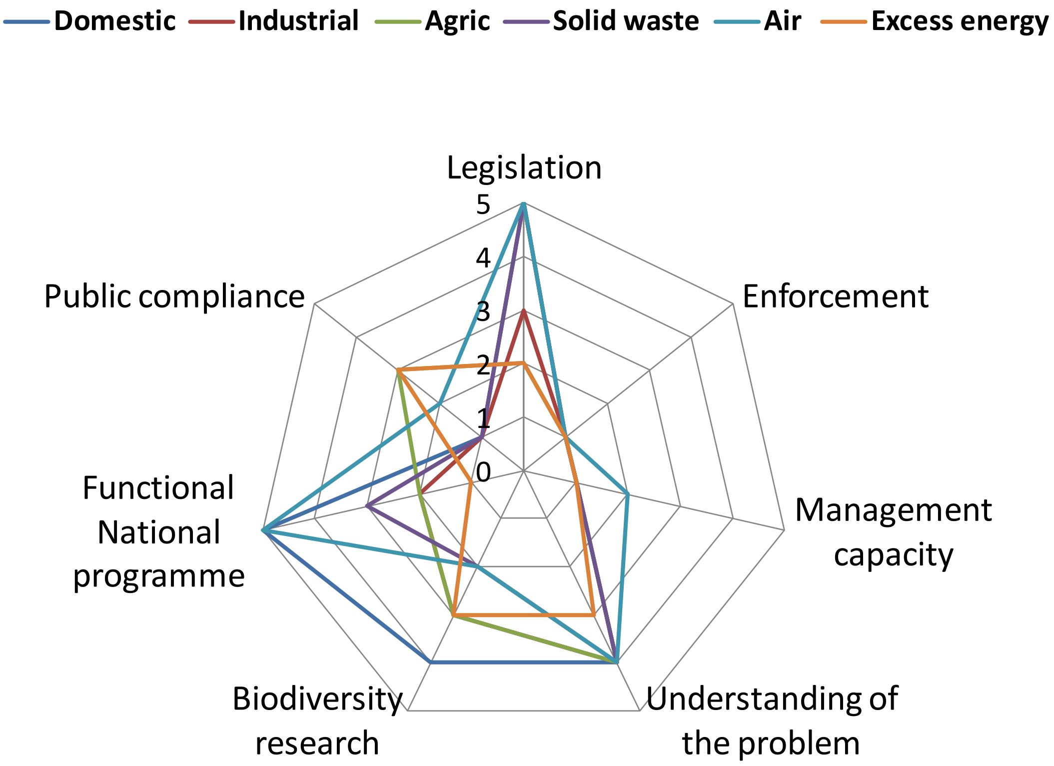

Figure 24. Radar plot representing signatures of pollution categories in terms of eight metrics as potential measures of success of a future pollution programme in reducing impacts on biodiversity (Source: Pollution categories were scored from 1-5 for perceived level of effectiveness across performance metrics based on the information gathered in this study, and partially verified by key informant interviewees; note: we did not distinguish between public and private sector compliance).

[32] http://award.org.za/index.php/2019/02/01/south-africa-is-drowning-in-its-own-waste-are-our-regulators-taking-this-crisis-seriously/

8 Recommendations and conclusion

As discussed in the previous section, key recommendations for refining the accuracy and resolution of the local and global analysis, which includes commenting on an overall pollution programme, the adequacy of the data, and identifying potential sources of additional data, has been identified. This chapter provides recommendations on improving the local and global analysis, and suggestions for way forward including key principles for monitoring and reporting risks. The recommendations outlined below provide a potential way forward for mitigating pollution impacts on biodiversity in South Africa, and other low to middle-income countries. In addition, the recommendations also provide a possible way forward for monitoring and reporting on pollution risks posed to biodiversity.

The recommendations for improving the local and global analysis, improving the analysis for South Africa specifically, and for the next steps to informing a programme to tackle pollution in low and middle-income countries are outlined in the subsequent sections.

8.1 Recommendations for improving the local and global analysis

- Undertake a gap analysis on how hotspots relate to conservation areas by engaging with national/ regional conservation departments/organisations.
- Source information across a range of resources including research reports and media reports (i.e., “grey literature”).
- Identify and target suitable data sources: real-time data; monitoring data, etc.
- Rank pollution and species loss hotspots by the level of risk (defined as severity of impact X likelihood of pollution), and then undertake a focused threat analysis for the country’s biodiversity hotspots.
- Spatial analysis of hotspots linked to the level of ecosystem connectivity and movement corridors.
- Based on the identified taxa, expand the understanding of the mechanisms of pollution impacts by directly linking to their effects on organisms.
- Classify selected species by the level of mobility and life-history traits (e.g., amphibians have threats in freshwater and terrestrial habitats because of their biphasic life cycle).
- “Super-hotspots” could be identified by overlaying all heatmaps.
- Relate hotspots to specific ecosystems and catchments/ rivers for “whole system” protection.
- Provide more detail on methods used to produce maps.
- Use suitable modelling tools to identify or predict cumulative impacts of pollutants on species or ecosystems.
- Expand the impacts of pollution and ecosystems by documenting secondary impacts/benefits, such as alien species, and link back to impacts on threatened species.

8.2 Recommendations for improving the analysis for South Africa

The evidence gathered in this scoping phase identifies that there is scope for building on existing hotspot maps and iteratively refining these using available data sources. Targeted data collection would increase the chances of success in identifying more direct causal links between pollution and biodiversity impacts. Examples of available data that may improve the analysis include:

- Prioritizing the different pollutants in terms of their threats to species. This would be a valuable exercise and should consider factors including the spatial extent of the pollutant, and the risk the pollutant poses to species.
- Continuing to build on the networking undertaken in the scoping phase. Ongoing networking will promote to a greater understanding of pollutants and their impacts on biodiversity.
- Taking note of the interconnectedness and complexities of pollution categories.
- Using the outputs from proposed postgraduate studies, which will focus on adapting a global-scale contaminant fate model to identify high-risk river reaches likely to be impacted by emerging pollutants such as pharmaceuticals.
- Investing in citizen science programmes, which are likely to provide valuable feedback through the use of 'pollution monitors'; stakeholders engaged as part of a nappy waste pollution case study in South Africa embedded within the present project indicate that this should include citizen-science based solid waste pollution monitoring within riparian zones.
- Exploring the concept of a 'circular economy' including life cycle analysis of products applied at the beginning of product initiation.

8.3 Recommended next steps to inform a programme to tackle pollution in low and middle-income countries

The various stakeholder engagements and the review of best practice in terms of mitigating pollution impacts on the environment, emphasise the value of awareness-raising. Stakeholders indicated that this was urgently needed in the South African context. We believe that a selection of diverse communication platforms will be useful, and a target group-based approach is suggested. Of particular value will be a provincially-based approach which forms part of a National Awareness Campaign on the effects of pollution. Other considerations include:

- Careful attention must be paid to using the right language, selecting culturally sensitive and context-specific messages and delivering these using appropriate platforms when disseminating the findings of the project;
- There is a need to engage with citizens (stakeholders) early in life either directly or indirectly (ensuring prior learning) possibly through schools. There is a need to build public awareness on the links between pollution and ecosystem impacts, and to collect real-time data on these impacts using citizen science programmes;
- There is a need to supplement the data used for the local analysis with existing databases and future research focused on established pollutants that pose a major threat (example those within the 'industrial and military effluents' and the 'domestic and urban wastewater' categories), emerging pollutants (endocrine disruptors and light pollution) and taxa (e.g. plants) that are under-represented in the IUCN Red List database.

While the workshops focused largely on the environmental and public sectors, this project presents an opportunity to encourage a country-wide approach to mitigate pollution impacts. It is hoped that the findings and recommendations of the project will inspire multiple sectors to buy-into the goals of a National Pollution Mitigation Strategy (and embedded awareness campaign) as recommended. Finally, the data collected during the workshops provide strong motivation for capacity building initiatives around pollution mitigation, particularly at the community level.

- Start with prioritizing pollutants for the respective country, since low- and middle-income countries will generally have limited budgets and expertise in tackling pollution. Given that multiple pollutants are likely to be problematic within each country, a process which prioritises the risks of each pollutant to species (i.e., species loss) would be helpful in terms of targeting which pollutants to tackle.

- Include the spatial dimension of the pollution source data, which could be used as a filter to determine the level of accuracy of the data (i.e., global/regional/local).
- Link causes to effects – link species known to be affected by the specific pollution category to known pollution hotspots/major source areas.
- Consider translating the issues/impacts into costs. This helps governments and industries to link the costs to their budgets. This could potentially lead to direct change/monitoring/mitigation. In South Africa, a legislative framework already exists in the water sector – the waste discharge charge system – but this has never been implemented.
- Investigate opportunities for linking species distribution data with evidence of actual exposure to the pollutants. For example, the exposure fields for air pollution are available through modelling and satellite data. Available measurement data should be able to provide localized exposure estimates.
- Aligning appropriate land uses with important biodiversity areas. For example, limited use of pesticides in regions identified as 'important bird areas' (McLaughlin and Mineau 1995).

The design of the next phase of the project in South Africa should be guided by the Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis of the Global and Country reports which was based on a combination of comments from the workshop participants and inputs from the project team. The "Opportunities" represent pathways for addressing the "Weaknesses", while the "Threats" represent the wider country-specific landscape that have the potential to erode future pollution mitigation projects targeting identified species conservation measures.

Table 7. Strengths, Weaknesses, Opportunities, and Threats analysis of hotspot analysis of pollution category impacts on inland biodiversity for South Africa.

STRENGTHS	*WEAKNESSES*
• Useful high-level approach for identifying specific pollution threats and geographical focal areas (i.e. hotspots for pollution impacts on species). • Pollutant categories appear to be extensive and reflective of the pollution profile of South Africa. • Hierarchical classification of pollution categories is useful for the linked meta-analysis component. • Heatmaps are useful as an approach readily understood by the public (This representation has become more familiar since early 2020 with COVID hotspots reported in the media). • The use of restricted-range species is a practical way for targeting specific areas for further focus. • Highlighting taxonomic groups that are threatened is useful for targeting areas for further consideration. • Identifying species threatened by climate change and pollution is essential for prioritising focus areas. • Useful process for building a pollution-biodiversity impact network of colleagues and community of practice.	• The limitations of using the IUCN threatened species list, e.g. invertebrates currently form only 32% of all animal assessments on The IUCN Red List (as many as 1 in 5 invertebrates may be considered threatened). • The Global and Country Analysis may be underplaying certain pollution categories, e.g. water quality problems in many of South Africa's rivers. • The analysis does not explicitly separate terrestrial and freshwater systems by hotspots. • Further inputs are required to prioritize specific systems for interventions. • There is a need to re-analyse using the same data, but excluding marine species – this was alluded to in the Global Analysis for South Africa but not addressed in the Country Analysis. (see Figs. 3-4)* • Habitat loss is equally or more important than climate change for restricted-range species but this has not been factored into the analysis. • Correlation between pollution category and species may be misleading: (i) limited species associated with solid waste, downplaying this issue (Category 9.4, Figure 18 and Table 11); (ii) avifauna not emerging as an impacted group for sewage and runoff impacts (Categories 9.1.1-2; Figs. 9-10; Tables 4-5)*. • Chemical spills, which are common occurrences in South Africa, are not listed as a pollution category under Category 9.2*. • Category 9.6* dealing with Excess Energy is not currently mapped, e.g. light pollution that impacts nocturnal species such as birds and glow worms. • Maps for specific categories (9.3 Agriculture & Forestry effluents: Figure 14; 9.3.3 Herbicides & Pesticides: Figure 17)* appear to be too general for targeting all areas of impact. • Some concerns were expressed about maps not capturing the complexities and synergies of pollution impacts on species.

OPPORTUNITIES	THREATS
• Undertake a gap analysis on how hotspots relate to conservation areas by engaging with national/ regional conservation departments/organisations. • Rank pollution and species loss hotspots by the level of risk (defined as severity of impact X likelihood of pollution). • Classify selected species by level of mobility and life-history traits (e.g. amphibians have threats in freshwater and terrestrial habitats because of biphasic life cycle) • "Super-hotspots" could be identified by overlaying all heatmaps. • Spatial analysis of hotspots linked to the level of ecosystem connectivity and movement corridors. • Relate hotspots to specific ecosystems and catchments/ rivers for "whole system" protection. • A focused threat analysis for the country's biodiversity hotspots should be considered. • Enhance uptake of maps by providing more detail on methods used to produce maps. • Sourcing information across a range of resources including research reports (e.g. Water Research Commission) and media reports ["grey literature"]. • Document secondary impacts of pollution, such as alien species benefitting from pollutants. • Identification and targeting of suitable data sources: real-time data; air pollution monitoring groups, etc. • Based on the identified taxa, expand the understanding of the mechanisms of pollution impacts by directly linking to their effects on organisms. • Use of modelling tools to identify cumulative impacts. • Expand the impacts of pollution and ecosystems by documenting secondary impacts/benefits, such as alien species, and link back to impacts on threatened species.	• The uncertainties around the evolving socio-economic and political landscape may hamper the future development of an effective programme to reduce pollution. • Conservation agencies in South Africa are under severe financial strain. • Emerging threats not captured, e.g. sonic boom surveys along coastal areas by SHELL, mutagens (heavy metals and endocrine-disrupting hormones) and pharmaceutical products that accumulative downstream, microplastics. • The level of landscape fragmentation impedes natural adaptation processes and system resilience. • Many pollution problems are linked to failing municipalities; which may not have the capacity or resources to introduce interventions. This includes a lack of service delivery especially in rural areas, a lack of waste management, and a lack of relevant policy and enforcement thereof. • Other challenges such as SA's growing unemployment problem and WASH (water, sanitation and health) needs may represent more urgent priorities than mitigating pollution. • Ageing infrastructure and poor management is leading to the failure of many of the country's wastewater treatment plants. • Stability in IUCN data versus not capturing new threats = time lags in identifying threats. • Not all species databases are feeding into the IUCN database. • Lack of societal awareness, and non-compliance including littering. • Pollutants may show different mobility levels of toxins at different temperatures. This has relevance in the face of climate change impacts.

[*]These items relate specifically to the Pilot Country Pollution Analysis report for South Africa (JNCC Reducing Pollution through Partnership Project, Document E, November 2021).

8.4 Conclusion

The overarching aim of the project was to contribute to the reversing of biodiversity loss, strengthening ecological resilience, and improving human health. The research team is confident that saturation was reached in the workshop, key informant interviews and literature review, and that the information/data gathered is adequate and of sufficiently good quality to have been used to inform the future of the project. The success of the workshops was based on a high level of engagement between the research team and JNCC. While the Information Package was extremely useful, it required inputs from a multi-disciplinary team to ensure that the content was presented to the participants in a digestible format. Participants displayed informed levels of awareness of climate change and understanding of pollution and were highly appreciative of JNCC's and the South African research team's decision to engage them. It was clear that a number of sectors affected by/interested in pollution are concerned about its impacts but they are also facing other challenges, most recently the COVID-19 pandemic. Nevertheless, the project, and more importantly the Global Analysis, were viewed as having value and considered an urgent initiative. The role of national government and industry in implementing the recommendations that emerge from the project was highlighted by participants in several instances.

The evidence presented in this report details the effectiveness of the pollution Global Analysis to guide the setting of appropriate mitigation measures to achieve the overarching aims. In the absence of local data, a global analysis may provide a useful baseline analysis. However, in South Africa, we are fortunate to have a wide range of data options to draw on and there is clear evidence to demonstrate that the use of these datasets, monitoring, mitigation activity, existing networks (technical, community or other), will likely lead to an enhanced ability to manage chemicals and to reduce air, chemical, and waste pollution. The recommendations outlined above should be taken into consideration for guiding the development of a wider pollution programme for South Africa, and where relevant other low to middle-income countries. There is also a need to ensure wider participation of experts from the public, civil society and private sectors in the next phase of the project to ensure evidence-based decision-making around mitigation and adequate buy-in in terms of the implementation of interventions.

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10 Hyperlinks

Descriptive text	Link
SciVal	https://www.scival.com/
South African Waste Information Centre	http://sawic.environment.gov.za/
E-Waste Association of South Africa	https://www.ewasa.org/about-ewasa/
WRC Project	https://wrcnatsilt.org.za
Mine Water Atlas	http://wrc.org.za/programmes/mine-water-atlas/
Plastics in the Environment project	http://www.fitzpatrick.uct.ac.za/fitz/research/programmes/maintaining_global/plastics_ocean
The State of Environment reporting for South Africa	https://soer.environment.gov.za/soer/
miniSASS	www.minisass.org
Freshwater Biodiversity Information System	www.freshwaterbiodiversity.org
Virtual Museum	https://vmus.adu.org.za/)
Southern African Bird Atlas Project 2	www.sabap2.birdmap.africa/
Coordinated Waterbird Counts	www.cwac.birdmap.africa/
South African Air Quality Information System	https://saaqis.environment.gov.za/
NatSil Project	https://wrcnatsilt.org.za
Research Nodes	https://saeon.ac.za/nodes/
Global burden of disease maps	https://ourworldindata.org/burden-of-disease
Mine Water Atlas	http://wrc.org.za/programmes/mine-water-atlas/
DWS Monitoring data	http://www.dwa.gov.za/iwqs/wms/data/000key.asp

Appendices

Appendix 1 - Workshop schedule and questionnaire

Workshop Schedule

1. Introductory definition slides loop for first 3-5 minutes
2. Google form for Workshop Questionnaire emailed to all participants
3. Welcome and introduction to project, data protection measures and data collection methods for workshop
    - Start recording meeting
4. Trial for polls and Polly emailed to all participants
5. Introduction to local sense video
    - Local sense video will be played for you now (video is 26 minutes long)
    - Provide YouTube link for video in chat box (After video is complete, allow 2 minutes for YouTube people to finish watching)
6. Open floor for questions, clarifications etc.
7. Commence with questions (administered via Polly/Chatbox/Google Form, or posed verbally by facilitator where participants can answer verbally or via the chatbox):
8. Open floor for any questions/comments/suggestions from participants.
9. Thank participants and alert them to post-workshop questionnaire that they will be receiving.

Workshop Questions

1. What other projects in South Africa are you aware of that are looking at pollution threats to biodiversity? Please provide details.
2. Are there any other factors in South Africa that should be considered when assessing pollution e.g., socio-economic, climatic, political?
3. Are the results of the analysis a realistic reflection of the proportion of species threatened by pollution in South Africa? If no, please explain.
4. To what extent does the data reflect the current situation in terms of the types of flora and fauna threatened by pollution in South Africa?
5. Are there any major and/ or emerging pollution threats in South Africa that weren’t included in the analysis?
6. How much effort is being put into pollution mitigation/characterization in the country? For which pollutants and by whom?
7. What degree of investment is being made by funders/donors in pollution-related research?
8. What degree of investment is being made by funders/donors in pollution mitigation?
9. Are the data analyses applied suitable/useful? Please explain
10. What types/sources of data are presently guiding decision-making around pollution in the country?
11. What pollutants in your opinion need to be mitigated in South Africa and how?

Appendix 2 – Post-workshop questionnaire

1. What would you say your level of expertise in pollution is? (Include examples of your involvement in pollution management and whether you have a general or specific area of knowledge of pollution.)
2. Which province(s) do you think exhibit pollution hotspots and/or pollution threats to biodiversity? Provide details.
3. Are there any other factors in South Africa that should be considered when assessing pollution? e.g., socio-economic, climatic, political.
4. From the categories below, which pollutant threats do you think pose the greatest threat to species? (Use the following scale: 1 = lowest threat to species, 6 = highest threat to species) [Agriculture and forestry effluents]
5. Please identify the three main organisations/entities responsible for managing pollution in South Africa.
6. Are the results of the analysis presented a realistic reflection of the proportion of species threatened by pollution in South Africa? Please provide details.
7. Is your opinion based on experience or published data? If data – please include references of information sources. (e.g. article, database, report etc.).
8. Are there any major and/ or emerging pollution threats in South Africa that weren't included in the analysis?
9. Is the interaction between pollution and climate change reflected for South Africa in terms of threat to species a realistic representation? If no, please explain.
10. To what degree can reducing pollution affect the South African economy and livelihoods in the country?
11. What information should be made available to decision-makers to mitigate pollution?
12. Which organisations/entities should champion the mitigation of pollution in South Africa?

Appendix 3 – Key Informant semi-structured interview questions

Data collection method 3 will target high-level decision makers and/or experts in the fields of pollution management/monitoring, biodiversity management or climate change who have been identified during the stakeholder engagement process and via snow-ball sampling. The questions posed in the interviews are similar to those posed in DCM1 and 2 but will be probed in more detail. Some questions featured here, particularly those related to the Global Analysis and SWOT are, however, unique to this DCM.

Platform for interview: Online, Zoom/MSTeams

Mode: Administered

Format: Semi-structured Questionnaire

Duration: 40 minutes

Schedule:

- Interviewer provide background on project and context for interview:
    - I. *Generate a situational analysis for pollutant prevalence, threats and management in South Africa.*
    - II. *Local sense check results of global analysis to ensure appropriate mitigation measures are included and discussed so that relevant and correct information is taken into account when designing the wider programme.*
    - III. *To scope and help design a wider pollution programme to enhance ability of low to middle-income countries to manage chemicals and to reduce air, chemical, and waste pollution.*
    - IV. *Overall main aim - to reverse biodiversity loss, build ecological resilience in face of climate change and improve human health.*
    - V. *Priority during this scoping year is to engage with pilot countries to understand how better deliver a fit for purpose pollution programme in the future.*
- Interviewer confirms that respondent agrees to be interviewed before recording meeting and inform them that their private information will be protected based on the INR's POPIA compliance framework.
- Interviewer confirms that interviewee has received information pack (Local and Global sense presentations and written reports) and has had time to engage with the material.
- Interviewer commences with interview based on questions below.

Section 1: Introduction

1. Are there any main pollution threats in South Africa/globally that weren't included in the Global Analysis?
2. Does the information shown in the pollution heatmaps, based on the distribution of species threatened by specific pollution threat types reflect your understanding and experience for South Africa? Is your opinion based on experience or published data? If data – please include names of information sources. Please highlight any omissions and/ or anomalies that occur to you.

3. Which pollutant threats do you think pose the greatest threat to species:
    i. Agricultural and forestry effluents;
    ii. Industrial and military effluents;
    iii. Domestic and urban wastewater;
    iv. Garbage and solid waste;
    v. Excess energy and air-borne pollutants (Interviewer should be prepared to expand if interviewee requests information on these as separate pollution threat categories)

    Please explain your answer.

4. Are there any additional species or specific ecosystems that you are aware of, where pollution poses a major threat either currently or in the future in South Africa.

Section 2: Pollution controls

5. Is there any important information missing from the global analysis provided which could help us understand the sources, types, locations and impacts of pollutants in South Africa/globally? (e.g. socio-economic, climatic, political, etc.).
6. What other data (besides threatened species), not presented in the global analysis, would be useful for guiding decision-making around pollution in a future pollution reduction programme?
7. Are there pollution intervention projects of relevance in South Africa that aim to tackle (directly or indirectly) the sources of pollution identified in the Global Analysis? Please provide information about which organisations are responsible, or in your opinion, should be responsible.
8. Is there published data on pollution in South Africa that should be incorporated into the analysis for the country? (Examples of data types: time series of data; event logs of spills; species distribution data, etc.)
9. What are your thoughts on the suitability/effectiveness of the current legislation in place in South Africa regarding pollution.

Section 3: Next steps

10. What pollutants, as a priority, will need to be mitigated in South Africa in order to tackle species loss?
11. What do you think our next steps should be to make this analysis useful in informing a programme to tackle pollution in low and middle-income countries in general?
12. Are you comfortable providing any names of key informants for future interviews?

Thank respondent and ask if we could provide them with any further information regarding the project.

Appendix 4 – SciVal Report

Document available upon request.

Appendix 5 – Workshop report

Please see document linked on JNCC webpage.