INTEGRATING WATER QUALITY – HEALTH IMPACTS INTO AN INTEGRATED WATER RESOURCES MANAGEMENT DECISION-SUPPORT SYSTEM (INWARDS) FOR EARLY WARNING IN THE INKOMATI BASIN

Report to the
WATER RESEARCH COMMISSION

by

SHARON POLLARD[1], HUGO RETIEF[1], BETTINA GENTHE[2] AND EMILY NICKLIN[1]

with inputs from

Karen Kotschy (AWARD), Marlene van der Merwe-Botha (WaterGroup: Green Drop Assessment), Lethabo Makgoba (Research assistant: AWARD)

and work on Endocrine Disruptor Contaminants co-funded through GIZ-SA

Christoff Truter (Stellenbosch University), Albert Myburgh (iThemba Labs), Shaskia John (Tshwane University of Technology), Jan Myburgh (University of Pretoria), Annelize van der Merwe (University of Mpumalanga), Angelica Kaiser (University of Mpumalanga)

Julia Williams[1] (Finances)

[1] Association for Water & Rural Development (AWARD)
[2] Private consultant

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Water Research Commission
Lynnwood Bridge Office Park, Bloukrans Building
4 Daventry Street
Lynnwood Manor
PRETORIA

hendrickm@wrc.org.za or download from www.wrc.org.za

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EXECUTIVE SUMMARY

This work covers a two-year period from 2021 to March 2023. The study area comprises the Crocodile River Catchment which forms part of the Inkomati-Usuthu Water Management Area (WMA) and the transboundary Inkomati River Basin shared with Mozambique and eSwatini. The study area also considered the City of Mbombela, which reflects the shared functions regarding water quality and health and disaster management.

BACKGROUND and RATIONALE

Given that water quality decline and pollution are of increasing global and local concern, this aim of this work is to capacitate water resources managers and staff to understand, communicate and manage biotic and human health risks arising from poor water quality in the Inkomati Catchment through

1) the collaborative development of a pilot Water Quality-Health System (WQHS) with the managers, staff, other experts and stakeholders;
2) piloting the integration of a Water Quality-Health Module into the INWARDS decision-support system (being developed for the Inkomati-Usuthu Catchment Management Agency) for early warning; and
3) rendering and communication of time and location-specific risk profiles for key water quality constituents under various scenarios including climate change.

The work responds to a need of water resource managers and partners in the Inkomati River Catchment to understand the implications of non-compliance with select water quality standards (such as Resource Quality Objectives or RQOs and the Reserve) for risks to human health. This is because water resource and disaster managers have to make complex decisions regarding water use licences, actions for Compliance Monitoring and Enforcement (CME) and disaster preparedness within the context of understanding what risks this might pose downstream. To this end they are provided with gazetted standards developed by specialists with which to comply. *However, these standards have little meaning or value if not understood in conjunction with the potential risks associated with non-compliance* especially for vulnerable communities. For example, for the IUCMA board and staff, answers to the following questions are regularly sought:

- *What are the priorities in terms of acting on non-compliant, unlawful water-use activities?*
- *If this water use licence is approved, what are the likely consequences downstream*?
- *If there is non-compliance with water quality standards, what are the potential implications thereof*?

Making decisions and responding to such questions without an understanding of what the downstream or cumulative impacts might be on human or biotic health is very difficult without the ability to integrate multiple information sets. This requires a decision support system that can quickly integrate data (social, biophysical) to allow water resources managers to plan and act appropriately. AWARD has developed an integrative platform, the Integrated Water Resources Decision Support (INWARDS) system to support IWRM, principally water resource protection, licencing, compliance monitoring and enforcement and longer-term decision-making, particularly under climate change. This work aimed to strengthen the INWARDS DSS, which is being tested by the IUCMA, through the addition of a Water Quality Health System which supports managers to interpret benchmarks for water quality in terms of potential risks to human health. To give value to benchmarks such as RQOs and drinking water quality standards, this project has piloted an approach that integrates a risk profile and "risk narrative" associated with an exceedance of these benchmarks. This has involved selecting a number of priority water quality variables in the Crocodile River Catchment and developing easy-to-understand narratives for inclusion in the INWARDS DSS. Ultimately, this will allow a water resource manager to rapidly interpret new or historical monitoring data in the context of the potential impact and importantly, to share this with other stakeholders. In the Inkomati-Usuthu WMA, this is done through various operations committees and forums.

It is important that the development and testing of a decision-support system be done within an environment of strong governance and management because it is through this that decision-making and action are enabled. The Inkomati-Usuthu CMA (IUCMA) has assumed relevant functions since 2016, including a commitment to compliance with gazetted benchmarks, water quality monitoring, and the mitigation and regulation of non-compliance within the context of IWRM. It has also established strong stakeholder networks and forums, including with the DWS Provincial Office and the municipality. Equally SANParks, through the Kruger National Park river manager and staff has developed strong competency for river health through monitoring and tracking of compliance against benchmarks as well as strong networks with partners. Given this, the WQHS has therefore been co-developed and tested principally with the IUCMA and SANParks. Other key partners include the municipality with the City of Mbombela (CoM) as the Water Services Authority and Ehlanzeni District Municipality (EDM) responsible for disaster management and early warning, including public health risks; the Department of Health, Silulumanzi (some water services provision and the management of wastewater treatment works (WWTW)). Given the projected impacts of climate change on water resources, partners in this field include DARDLEA and the municipality. Water users and those impacted by water quality challenges are critical partners.

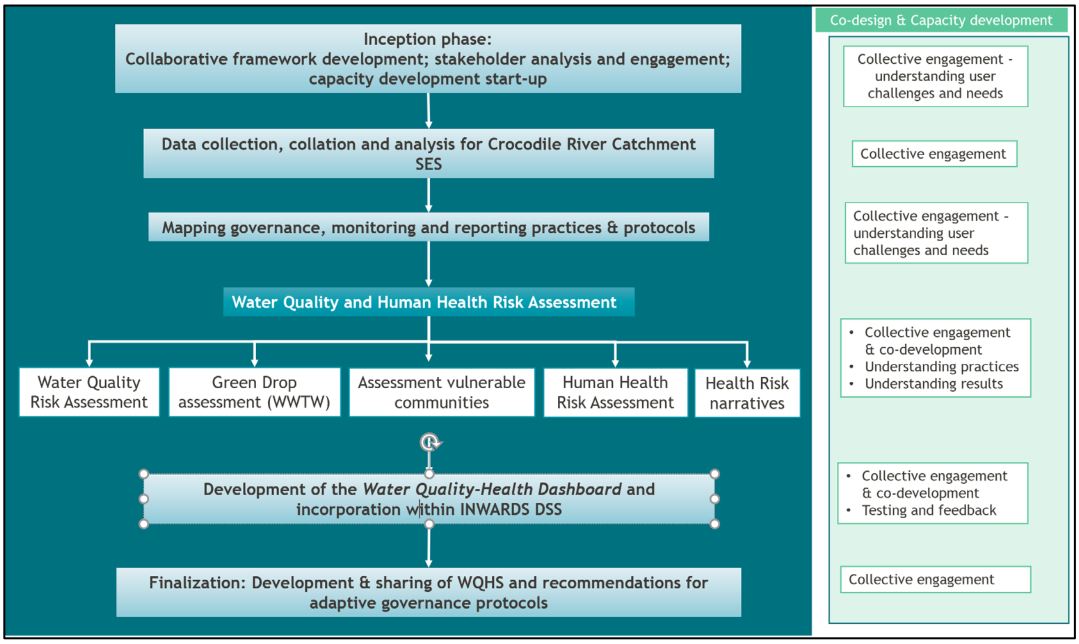
The Water Quality-Health System refers to three broad components, namely

1) A technical component, namely the Water Quality-Health Dashboard as part of the INWARDS DSS. This includes a number of risk assessments (water quality, human health and potential communities at risk)
2) The human health risk narratives included in the dashboard
3) The governance, practices and protocols (i.e. management) needed to support a range of actions and to enact an early-warning system. This is limited to a broad overview with a focus on the IUCMA and the municipality given the resource constraints.

METHODOLOGY

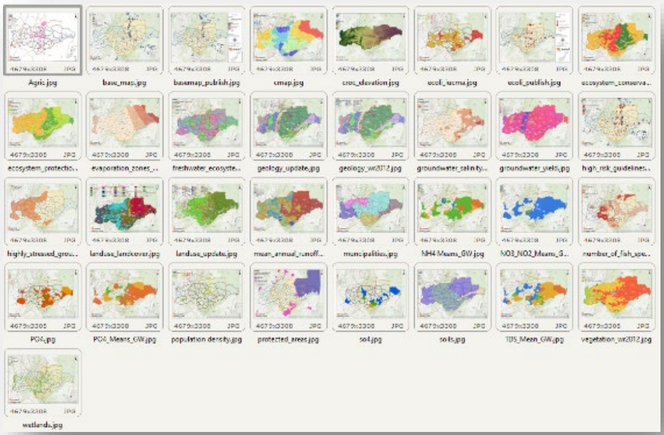
We have adopted a systemic, social learning approach as detailed in Chapter 1. Key partners have been involved in a social learning process of co-design and co-development throughout the project. Given the need to understand the state of the resource (water), the underlying drivers and pressures as well as the impacts and potential responses, the work was organized according to a modified risk assessment framework known as the DPSIR (drivers, pressures, state, impact and response) or DPSEEA.

The overall project tasks are summarised in the figure below.



A stakeholder analysis was undertaken and key partners were identified. As part of the scoping phase, data collection was undertaken which focused on two components:

I. Data analysis of biophysical, environmental and social characteristics of CRC viewed as a socio-ecological system (SES).
II. Data analysis of governance, institutional arrangements and practices that relate to water quality in some manner.



A large amount of socio-economic and environmental data were collected, cleaned, analysed, represented spatially and included within the INWARDS DSS (see Deliverable 2). This included the collection and analysis of social data (census and demographic data), climate change and the impacts on water resources, infrastructure, biophysical data, hydrology and water quality data, and data on land and water use and changes in these. This also involved the collection of all relevant benchmark data. The analysis and synthesis of data related to the state of water-quality and trends over time, and potential drivers of change, linked to land and water uses in the catchment. Land use practices and an assessment of WWTWs (Green Drop assessment for 2021) were examined in terms of potential contribution to water quality constituents. Also, additional funding sourced during the project enabled work on governance and a study on Endocrine Disrupting Chemicals (EDCs) to complement the work herein which faced resource constraint challenges.

Given the links between land use and water resources, a number of key water quality variables were selected for a detailed analysis and for use in the Water Quality-Health System. The water quality variables included antimony, arsenic, cadmium, chrome, iron, lead, manganese, mercury, *nitrites + nitrates, orthophosphates,* ph, *sulphates*, *suspended solids*, TDS, *temperature*, total phosphorus and *E. coli*. Some of these variables are important indicator species (italicised).

An overall risk assessment was developed as part of the WQHS and comprising a Water Quality Risk Assessment, a Human Health Risk Assessment (HHRA) and a Community Vulnerability Assessment.

1) The water quality assessment used water quality data available from two sources: DWS until 2018 and from the IUCMA from 2016 to present. These data were cleaned and incorporated into the initial modelling process. The water quality data have been integrated into a Water Quality Systems Assessment Model (WQSAM) and into the INWARDS system. Through this a water quality risk assessment was undertaken for key variables. Water quality risks were also enhanced through Green Drop assessment of wastewater treatment works (WWTW).in the Crocodile River Catchment (CRC).
2) A Human Health Risk Assessment: The Human Health Risk Assessment (HHRA) was undertaken on a number of selected variables, A literature review of potential human health risks was then undertaken for each of these variables The HHRA was contingent on data availability. Only the IUCMA water quality data (2016-2022) were available until very recently and hence were used for the HHRA analysis. This was deemed appropriate since the focus is on recent and emerging risks. Narratives for constituents of concern were also developed. (A related, ongoing study on EDCs includes heavy metals, pesticides and herbicides see Trutter et al., 2022).
3) Community vulnerability assessment: Census data (StatsSA 2011) were analysed for riparian communities and water dependencies on untreated water.

This composite risk assessment is a key component of the Water Quality Health dashboard within the INWARDS DSS.

In terms of governance and practices related to water quality management, and in order to ensure that the DSS is responding to managers' needs, institutional arrangements, roles and responsibilities and current management practices and procedures were analysed. Data were also collected on key management challenges.

Co-development and institutionalisation

To ensure responsiveness to managers and stakeholder needs, a process of co-development was used throughout the project with key partners. This 'demand pull' is central to the institutionalisation of new tools and practices. The requests made from users included a WQHS that supports:

- Reporting to the IUCMA board, especially regarding compliance against their obligations (the Reserve and RQOs) and potential implications of non-compliance;
- Reporting on progress to stakeholders;
- Supporting municipalities and response interventions;
- Support for Compliance Monitoring and Enforcement;
- The use of loads to incorporate system dynamics (and hydrology) and so as to move away from static concentrations;
- Early warning systems in which physical drivers could be used for various warnings regarding pathogens, e.g. bilharzia and low flows;
- The need to incorporate effluent data from WWTWs (DWS and IUCMA) and an update on their Green Drop status;
- Collation and analysis of data needed for the water use licence application process based on use of INWARDS

RESULTS AND DISCUSSION

Governance and management and shared practices

In terms of governance and management, each of the six units comprising Water Resources Management within the IUCMA have bearing on water-quality related issues, most notably Resource Quality Management which manages water quality monitoring, data collection and analysis. The key partners within the IUCMA include Resource Quality Management and Resource Planning & Operations. Water quality data have been collected in-house since 2016. These are shared with stakeholders through various forums and are used for river operations, Water Use Authorisations and Compliance Monitoring and Enforcement and reporting.

The CoM has various departments which intersect with water quality management, both through the Environmental Management and Planning Unit (EMPU) and Water Services Compliance Monitoring. Responsibility for climate change also sits with the EMPU, who liaises with DARDLEA. Key functions related to Environmental Health and Disaster Management are held at the district level, as is oversight and support for environmental management.

Silulumanzi is a private company delivering water and sanitation services to a concession area around Mbombela (on behalf of the CoM) under a public-private partnership contract (with 10 years remaining).

SANParks through their focus on water resources within the Kruger National Park plays an important 'watchdog' role, monitoring compliance and supporting multiple networks.

It is clear that a number of different partners are involved in areas of overlap and their key functions and areas of overlap are detailed in Chapter 5. For example:

- Water quality monitoring: IUCMA, Silulumanzi, CoM, SANParks.
- Community engagement: IUCMA, Silulumanzi, CoM, EDM., Department of Health
- Disaster management & Early Warning: EDM, IUCMA
- Climate change: DARDLEA, CoM, IUCMA.

The inclusion of the Provisional Department of Health as well as the clinic committees which would represent local-level concerns and information on water quality and health requires further work.

<u>Water quality and human health risks</u>

Water quality

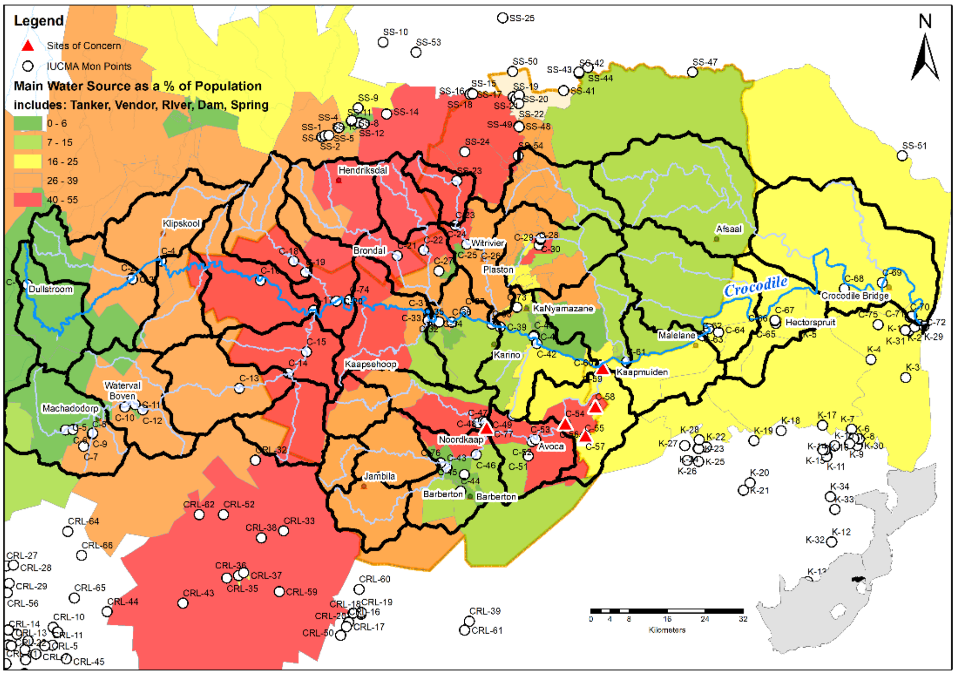
- Trends in the Elands River indicate that sulphates are becoming more of a concern with a shift from Ideal to Acceptable. The Kaap River was long seen as the biggest contributor of sulphates to the system, however the most recent data suggests that the median loads contributed by the Elands River have now surpassed that of the Kaap River.
- Sulphate loads are being transported down the main stem of the Crocodile evident by loads observed at downstream at Karino, Rivers View and Tenbosch.
- Orthophosphates are elevated across the catchment. However, the highest levels are found downstream of major settlements and wastewater treatment works. These sites also have high levels of *E. coli*.
- The Crocodile River Catchment topography is steep with fast flowing rivers only levelling out near Mbombela and the Kruger National Park. Consequently, residence times are low as there is little to no attenuation. While sulphates are not a constituent of concern they are a good indicator of the system's ability to transport other possible toxins, with the potential of transferring risks far downstream.
    - For example, arsenic, a toxin of concern particularly as a carcinogen has been detected at concerning levels in the Kaap River system. Upstream of a mine along the Suid Kaap River levels are below the detection limit; however below the mine and

the confluence of the Kaap River all the way to the confluence with Crocodile River, levels are elevated and categorized as *hazardous* with an increased carcinogenic risk if untreated water is consumed.

- The lower Crocodile River is unique as we see a decrease in loads of both orthophosphates and sulphates. This is presumed to be as a result of irrigation (sugar cane fields) along the main stem of the Crocodile River. While reducing water quality loads is a benefit to the ecosystem, the concern would be that if sulphate loads have made their way this far, this may also be the case for other toxins as well. This would mean that the crops being irrigated would be accumulating the toxins transferred from the Kaap. In addition, the same area is sequestrating orthophosphates which are primarily contributed by WWTWs. This would mean that *E. coli* levels or other pathogens which are also high would transferred to the crops being irrigated.

Communities at risk (Dependency on run-of-river/ untreated water for livelihoods)

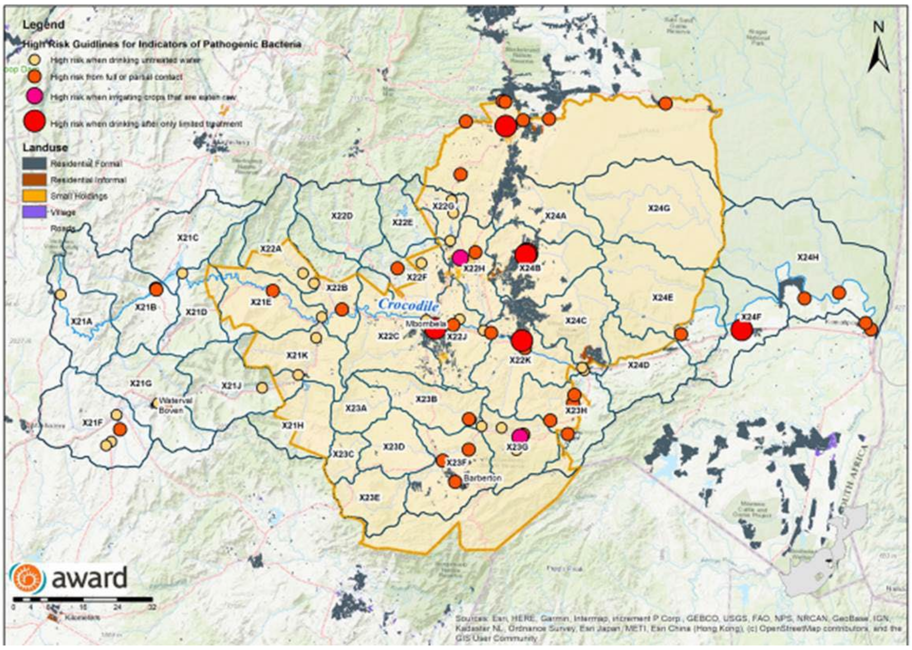
The highest direct dependency, namely of 40-50% of their water needs is a band that incorporates the foothills of the escarpment of the region, including Hendriksdal, Brondal and areas west of Kaapsehoop. Concerningly given the health risk assessment also an area in the Kaap River Catchment.



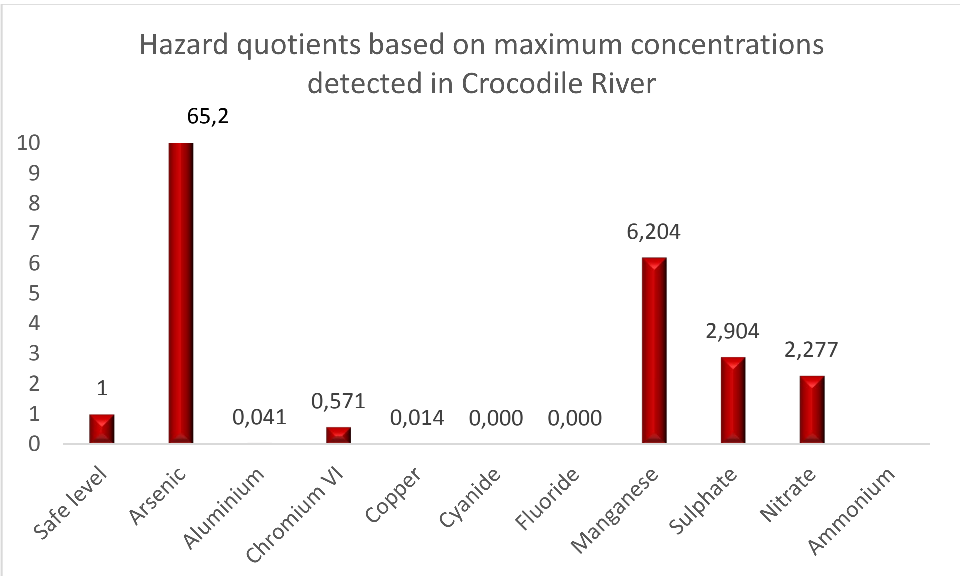
Map of the Crocodile River Catchment indicating location of people that are dependent on run-of-river to meet some or all of their water resource needs (based on Census 2011 data)

Potential Human Health Risks related to water quality

In terms of the human health risks, the results highlighted arsenic, chromium VI and manganese as compounds that present potential health risks to communities making use of river water if not treated to safe levels. Both cancer and toxic risks are anticipated, requiring action from water authorities to ensure that public health is protected. An analysis of *E. coli* data (Figure 48) indicates additional concerns regarding *E. coli* both as being problematic in itself but also as an indicator of other pathogens and pointing to dysfunctional WWTWs. Additionally, the analysis, as summarised below, suggests that arsenic is problematic in the Kaap River and poses a significant health risk. It is also an area with a high dependency on run-of-river.



E. coli **concentrations in the Crocodile River Catchment**



Hazard quotients based on maximum concentrations in Crocodile River

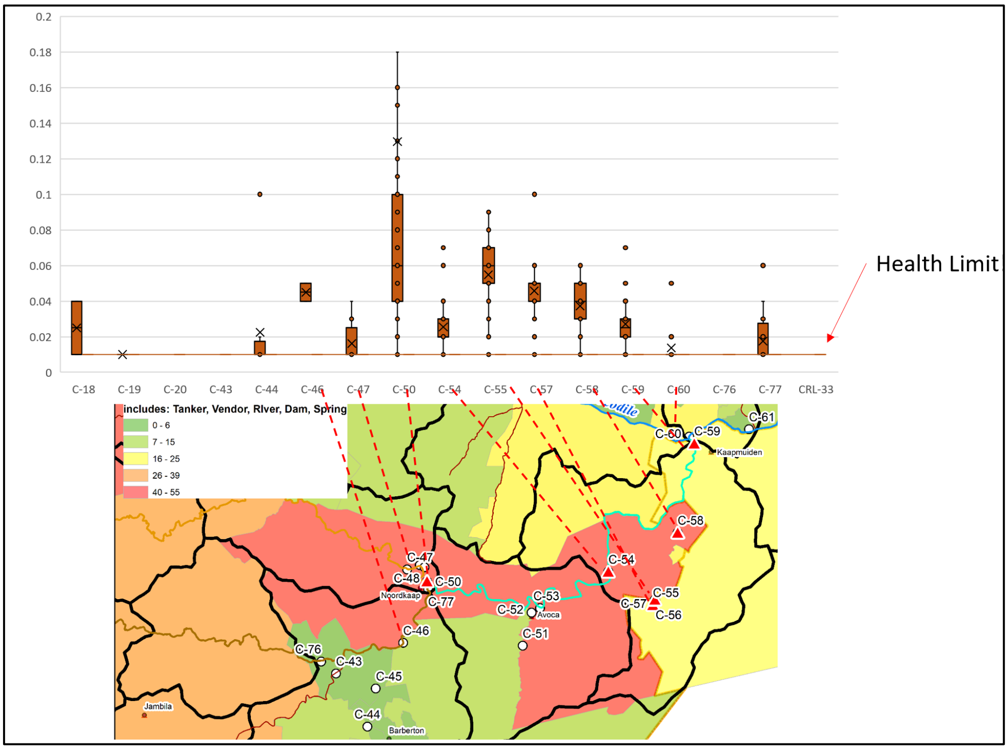


Figure summarising arsenic-related health (hazard quotient) risks along the length of the Kaap River

Water Quality Health Dashboard

The WQH dashboard has been completed and successfully integrated into the INWARDS DSS. This has included user control and registration, security controls, a registration module, an admin module, a backend datasets and models, and steps for building the analysis through input selection.

Overview of the Water Quality Health dashboard indicating dashboard panels

REFLECTIONS AGAINST AIMS

In terms of the aims and objectives of the project, all of these were successfully met. This was enabled through additional co-funding. However, a number of constraints including Covid-imposed limitations and staff changes meant that the inclusion of public health staff was less comprehensive than hoped.

CONCLUSIONS AND RECOMMENDATIONS

The Crocodile River Catchment was used as a pilot site to explore water quality health risks and their incorporation into both a decision support system for IWRM and as an approach to raise awareness and shared actions regarding pollution-related risks. From the analyse, water quality poses potential health risks particularly in terms of arsenic, chromium, manganese and *E. coli*. Subplate and orthophosphate loads are also concerning indicators of other pollution sources. The collaborative approach has enabled key partners to co-design a system and dashboard that captures such risks and in ways that can respond to their various needs. This has greatly strengthened water governance functions, as noted by the IUCMA and SANParks. Nonetheless some gaps and challenges are noted below as recommendations for future work.

Recommendations

The recommendations discussed in Chapter 10, are as follows:

Expansion of the WQHS

- The WQHS needs to be expanded to the entire Inkomati-Usuthu WMA if their functions regarding compliance monitoring against the Reserve and RQOs is to be strengthened.

Monitoring

- The lack of reference sites for long-term heavy metal data (toxins) is a constraint in examining relationships between indicator species and contaminants of concern, e.g. sulphates and heavy metals. Full spectrum monitoring is needed at an identified long-term site(s) that is minimally impacted such as at Montrose (would include physico-chemical, biological and toxins).

Understanding water quality risks

- The Elands River has shown an increase in salinization which is likely to impact on irrigated agriculture and soil health and requires further examination.
- At Montrose Falls orthophosphates appear to be a problem during high flows. The source of this needs to be examined
- Given the rapid transfer of water quality risks downstream and the changes in indicator water quality species before and after the sugar-cane agriculture, additional research and toxic screening may be needed to examine the potential accumulation at this point.

Impact practices and pathways

- Indicator water quality species have indicated the high level of risk transfer due to the nature of river channel. This needs to be further explored.
- It is recommended that changes in practices be explored in depth at a number of sites.
  - At Ngodwana in order to understand the higher levels of sulphates that have been recorded. It was noted that they were moving from gum to pine processing with implications for water use and impacts.
  - The increasing trends in arsenic from about 2017 near the new Consort mine (gold) in the Kaap River (as part of the Barberton mines) need to be understood particularly in terms of the potential to transfer risks downstream.

Communities at risk

- Updated census data from 2021 is needed to provide a more up-to-date understanding of communities at risk since 2011. Furthermore, a more holistic approach that includes additional determinants of vulnerability is needed.
- Vulnerable communities need to be appraised of potential health risks from pollution.

Dashboard development

- Currently a limited analysis of the array of variables has been included but these can be expanded should users require further inclusion of variables.
- In the future, additional datasets on water quality standards covering each user (domestic, industry, agriculture and so on) should be included
- A key recommendation is to update the data capture process for the IUCMA into a more structured procedure to limit the inclusion of erroneous comments or data and to support the submission process to RQIS, which has their own clear submission requirements.

Stakeholder engagement and capacity development of affected communities

- Resource constraints meant limited engagements with the local structures regarding community health and information sharing (clinic committees) and, as noted, this remains an important area of work in taking forward outputs and community capacity development. This should be linked to building resilience for climate change
- In terms of stakeholder networks and community capacity development, further work is needed (Provincial Department of Health and bottom-up through the clinic committees).
- Based on the inclusion of visuals and a narrative, further work is still required to track the communication of results: to the IUCMA board and other stakeholders.

Capacity Development: The project focussed on capacity development for work-based competency and for young professionals (Chapter 2 and Table 5).

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Reference Group	Affiliation
Dr Eunice Ubomba-Jaswa	WRC – Research Manager
Ms Penny Jaca	WRC – Project Co-ordinator
Dr Caradee Wright	South African Medical Research Council (SAMRC)
Dr Danny Govender	South African National Parks (SANParks)
Mr Marcus Selepe	Inkomati-Usuthu Catchment Management Agency (IUCMA)
Prof. Abraham Addo-bediako	University of Limpopo
Prof. Gunnar Sigge	Stellenbosch University
Dr Gordon O'brien	University of Mpumalanga
Prof. Wilmien Luus-Powell	University of Limpopo
Ms Zamokuhle Mntambo	National Department of Health (Environmental Health)
Mr Jurgo van Wyk	Department of Water and Sanitation (DWS) (Water Quality Planning)

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ACRONYMS & ABBREVIATIONS

AMDR	Annual maximum daily rainfall
ARC	Agricultural Research Commission
AWARD	Association for Water and Rural Development
CBA	Critical Biodiversity Areas
CEC	Cation exchange capacity
CMA	Catchment Management Agency
CME	Compliance Monitoring & Enforcement
CoC	Constituents of Concern
CoGTA	Department of Cooperative Governance and Traditional Affairs
CoM	City of Mbombela
CRC	Crocodile River Catchment
CROCOC	Crocodile River Operations Committee
CSIR	Centre for Scientific and Industrial Research
DARDLEA	Department of Agriculture, Rural Development and Environmental Affairs
DFFE	Department of Forestry, Fisheries and the Environment
DMM	Deputy Municipal Mayor
DPSIR	Drivers, pressures, state, impact and response
DSS	Decision support system
DWS	Department of Water and Sanitation
EbA	Ecosystem-based Adaptation
EDC	Endocrine disrupting Chemicals
EDM	Ehlanzeni District Municipality
EMPU	Environmental Management and Planning Unit
EWR	Ecological water requirements
GCM	General Circulation Model
GHG	Greenhouse gas
IDP	Integrated Development Plan
IHA	Indicators of Hydrologic Alteration
INWARDS	Integrated Water Resources Decision Support
IUCMA	Inkomati-Usuthu Catchment Management Agency

IWAAs	Integrated Water Availability Assessments
IWRM	Integrated Water Resources Management
KNP	Kruger National Park
LM	Local Municipality
LUMS	Land Use Management System
MAE	Mean annual potential evaporation
MAR	Mean annual runoff
MEGA	Mpumalanga Economic Growth Agency
MTPA	Mpumalanga Tourism and Parks Agency
NGO	Non-Governmental Organisation
NICD	National Institute of Communicable Diseases
NWA	National Water Act (Act 36 of 1998)
RCM	Regional climate modelling
RCPs	Representative concentration pathways
RDM	Resource Directed Measures
RESILIM-O	Resiliency of the Limpopo River Basin-Olifants
RQO	Resource Quality Objectives
SAEON	South African Environmental Observation Network
SALGA	South African Local Government Association
SAM	Strategic Adaptive Management
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks
SDF	Spatial Development Framework
SES	Socio-ecological system
TDS	Total Dissolved Solids
WCR	Water Control Room
WMA	Water Management Association
WQSAM	Water Quality Systems Assessment Model
WRC	Water Research Commission
WSA	Water Services Authority
WTW	Water Treatment Works
WUA	Water User Association
WUL	Water use licences

WULA	Water Use Licence Authorisation
WWTW	Wastewater Treatment Works

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION AND THEORY OF CHANGE

The focus of this project is on exploring and clarifying the links between declining water quality and human and biotic health and making this information available to managers and stakeholders in an easily accessible format for decision-making and action. This builds on – and is enabled by – previous work that AWARD and partners have undertaken in the lowveld rivers through the Shared Rivers Programme, funded through the Water Research Commission (WRC) (Pollard & du Toit 2011) and the RESILiM-Olifants (funded through USAID). This background is summarised below.

In Integrated Water Resources Management (IWRM), integrated systems and approaches are needed to meet the increasingly complex needs of water resources management in catchments under stress (Pollard et al., 2020; 2023). Water resources staff must make complex decisions regarding water use licences (WUL), actions for Compliance Monitoring and Enforcement (CME) and early-warning systems for disaster management. Approving a WUL without understanding what the downstream or cumulative impacts might be for example, is proving exceedingly difficult without the ability to integrate multiple information sets (Pollard & Retief, 2020). Indeed, access to information that supports this in a format that is easy to understand and use, is vital. Our work in the Olifants River Catchment and other areas, where declining water quality and flows threaten biotic and human health both in South Africa but also downstream in neighbouring Mozambique at risk (increasingly under climate change) has highlighted the difficulties of dealing with various water resource management needs (e.g. water use licence applications and unlawful use) in the absence of integrated information and governance systems to support this.

In response, AWARD has developed the Integrated Water Resources Decision Support (INWARDS) system platform to support IWRM (see www.award.co.za[1],) and in particular Resource Directed Measures (RDM), Water Use Licence Authorisation (WULA) process and Compliance Monitoring & Enforcement (CME) and longer-term decision-making. The strength of this platform is in the ability to integrate multiple data sets including biophysical, socio-economic and technical data (e.g. hydrology, water quantity and quality, resource protection, community vulnerability, risks, climate change) at a catchment scale. Through this the following actions are being facilitated: i) Tracking flow and water quality in real-time; ii) Tracking compliance against benchmarks in real-time (such as water quality RQOs); iii) Early-warning, such as flow cessation or drought; and iv) Water-use allocations and potential impacts.

Moreover, it is open source and “user-friendly”, thereby supporting the quick acquisition of information by staff with limited capacity. It has been used to maintain flows in the drought in the Olifants Catchment (Pollard & Retief, 2020) and is now being further developed for use in the Inkomati-Usuthu Water Management Area where the Inkomati-Usuthu Catchment Management Agency (IUCMA) is interested in developing and testing a similar system.

However, a key component that remains to be co-developed, tested and used is a Water Quality-Health System which is the focus of this proposal. This is regarded as critical to supporting decision-making so that managers can anticipate the potential negative impacts of certain water uses on human and

[1] https://award.org.za/index.php/focus-areas/water/the-inwards-decision-support-for-integrated-water-resources-management-in-the-olifants/

biotic health. Water resources managers are often provided with standards to comply with, which are developed by specialists and captured in reports which *have little meaning or value if not understood in the broader context of the implications and potential risks associated with non-compliance*. The outputs need to have meaning for water resources managers, staff and stakeholders and these need to be readily available. For example, in our work with the Catchment Management Agency (CMA) and Department of Water and Sanitation (DWS) staff, answers to the following questions are regularly sought:

- *What are the priorities in terms of acting on non-compliant, unlawful water-use activities?*
- *If this WULA is approved, what are the likely consequences downstream*?

Through this project, the IUCMA has also asked the question "*If there is non-compliance with water quality standards, what are the potential implications thereof*?".

The use of the INWARDS system can quickly and partially contribute to answering these critical questions but would be greatly strengthened by the ability to consider the impacts on biotic and human health. For example, increasing loads of arsenic in domestic and irrigation water poses a public health threat including short-term vomiting and diarrhoea; whilst long-term exposure can cause cancer (WHO, 2018). Understandably, this would be vital information for any water resources manager as well as others such as public health and disaster management staff and would support difficult decision-making in the face of competing uses. Such easily accessible information would be of major benefit, especially within the context of South Africa where water resources managers lack resources such as capacitated staff and budget.

The proposal has national applicability. It is well known for example, that inadequate regulation regarding the compliance of water toxins is a major issue in South Africa. In terms of water-borne diseases, many pathogens are released into rivers and other water sources if water is inadequately treated. In the case of dysfunctional wastewater treatment works (WWTW) with poor treatment efficiency, there is a high probability that active pathogens remain (WHO, 2020) and hence are discharged into rivers (or recirculated to water treatment plants). This places communities who are directly dependent on water-related ecosystem services at the greatest risk. This is particularly relevant given a) the high percentage of WWTW in South Africa that have scored poorly on the Green Drop assessment scores and b) the level of communities still reliant on run-of-river to meet their domestic, cropping or livestock watering needs.

It is important that the development and testing of a decision-support system be done within an environment of strong governance because this is where decision-making and action are enabled. We therefore co-developed and tested the Water Quality-Health System together with the IUCMA who has been monitoring and putting action systems in place and are already positioned to test and use the INWARDS system. Whilst progress has been made by the IUCMA in terms of real-time monitoring and the integration of data sets for planning within the Water Control Room (WCR), one key component that requires development within INWARDS system is the quantification and spatial representation of human and biotic health risks to declining water quality and quantity. As noted, water resources managers need to be able to interpret the risks associated with the exceedance of standards in both the short and medium term (such as under climate change, see below). And to communicate these to partners. Therefore, the Water Quality-Health System is designed to integrate the potential risks associated with these standards in a user-friendly manner to support water resources managers in the decision-making and communication process. For example, in rural areas where people may have a direct dependence on run-of-river for drinking water, exceedance of a benchmark (such as arsenic or *E. coli*) will pose a risk to human health.

To give value to various benchmarks such as RQOs and drinking water quality standards, we piloted the integration of a risk analysis and narratives of potential risks to human health that would be associated with an exceedance of these benchmarks in the Crocodile River Catchment (CRC). By selecting a number of priority water quality variables that are of concern to water resource managers and partners in the Catchment and developing easy-to understand narratives for inclusion in the INWARDS system, water resource managers and staff will be able to rapidly analyse and interpret new or historical monitoring data in the context of the potential risks and impacts and importantly, to share this with other stakeholders. In the Inkomati-Usuthu Water Management Association (WMA), this is done through various operations committees such as the Crocodile River Operations Committee (CROCOC) for the Crocodile River Catchment (CRC) and the Disaster Management Forum.

At a temporal scale, risks over time also need to be considered. Such risks are likely to increase under climate change which is projected to reduce surface water flow increasingly in an easterly direction between 20-60% in the near future (Sawunyama and Mallory, 2014; Schulze and Davis 2019). Such alarming impacts – which will affect dilution capacity (amongst other things) – need to also be considered in the assessment of risks. Thus, integrating climate change impacts is also a core consideration.

Another advantage enabled by the work is that a module for INWARDS has been developed that supports the Water Quality Systems Assessment Model (WQSAM[2]) currently set-up for the CRC. The module will accommodate both the analysis of WQSAM data outputs as well as a suite of processing tools, which will streamline the data population of the WQSAM. This will significantly bolster the analytical capacity of the WQSAM as well as reduce the human capital cost associated with manually updating WQSAM datasets on a continuous basis. In addition, this project will endeavour to equip WQSAM with the data models required to simulate water quality loads based on three-day flow and rainfall forecasts. This allows for proactive rather than reactive water quality management.

1.2 PROJECT AIMS

The aims of the project are as follows:

1) To capacitate water resources managers and staff to understand, communicate and manage biotic and human health risks arising from poor water quality in the Inkomati Catchment.
2) To collaboratively develop a pilot Water Quality-Health System with managers, staff, experts and stakeholders.
3) To pilot the Integration of this Water Quality-Health System into a highly appropriate platform, the INWARDS decision-support system (being developed for the Inkomati-Usuthu WMA) for early warning.

1.3 INTENDED OUTCOMES

The direct outcomes of this work in this proposal will be

1) A pilot Water Quality-Health System is developed and tested within INWARDS for use at a site in the Inkomati WMA.
2) Key staff of the IUCMA, including one post-graduate student, have engaged, and been capacitated in the potential risks associated with declining water quality and are motivated to further develop and use the module.

[2] See https://www.ru.ac.za/iwr/resources/software/wqsam/

The work is sufficiently beneficial to catalyse further support (resources). If successful, this project aims to contribute to the following broader outcomes

3) The development and use of an integrated and systemic decision support system (DSS) for water resources management in the Inkomati WMA;
4) Capacitated water resources managers and staff to manage both biotic and human health risks arising from poor water quality in the Inkomati Catchment (regulation of water use, mitigation of potential risks and disasters, future planning); and
5) Improved disaster preparedness – through the early-warning provided by the proposed Water Quality-Health System – for planning and action for health risks associated with poor or declining water quality (e.g. water-borne diseases).

Contingent on stakeholder engagements which are an important component of IWRM and Disaster Risk Reduction in the Crocodile River Catchment and the City of Mbombela, this work will also contribute to increased capacity of stakeholders to interpret and act on the risks associated with non-compliance, unlawful use, new water use and climate change from an "impact on health" lens.

1.4 THE RESULTS FRAMEWORK

The results framework is provided below (Figure 1).

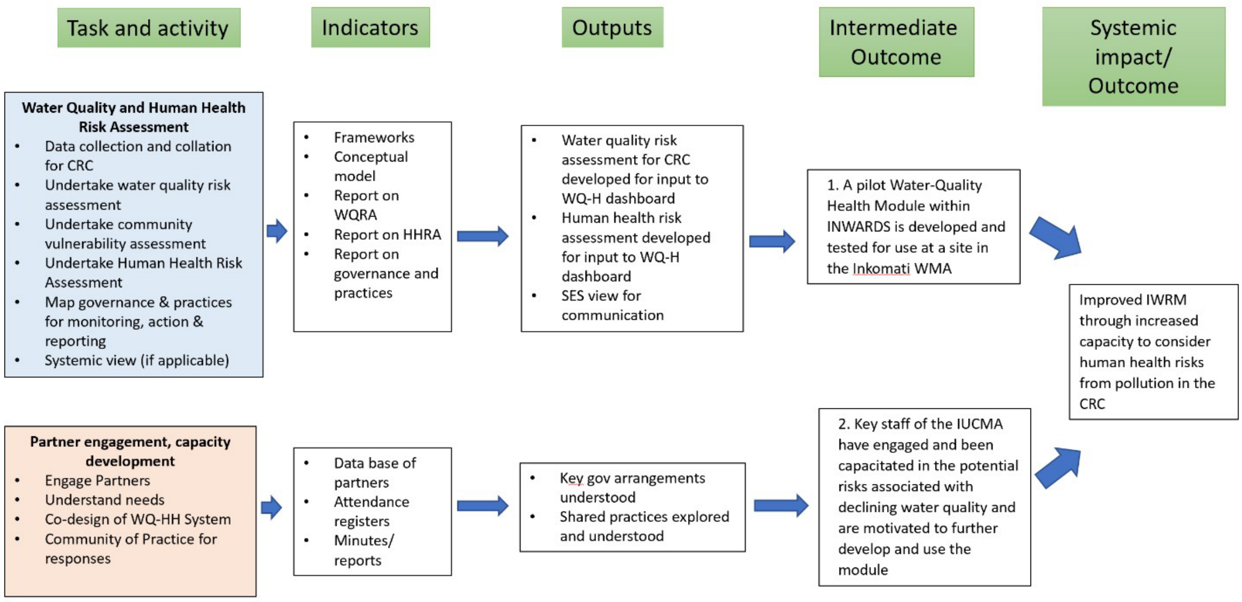

Figure 1 Results Framework

1.5 SCOPE AND LIMITATIONS

The scope of the project spatially is the CRC which is part of the broader transboundary Inkomati Basin (Figure 2). In terms of conceptual scope, the project adopts a strongly systemic, social learning approach as described below. Thus, the **Water-Quality Health System** refers not just to the technical component but also to capacity development, and support for governance through strengthened practices and institutional arrangements. The system therefore refers to

- Databases
- Technical components, namely a Water Quality-Health Dashboard
- Evidence-based narratives included in the dashboard

- The practices and protocols (i.e. management) needed to enact an early-warning system.

In terms of partners, the institutionalisation of the **Water-Quality Health System** depends on careful and considered work with multiple partners.

However, given the budgetary constraints, there are a number of limitations and caveats to the work that were noted at the outset:

1. Understanding the practices and protocols of multiple partners will only be possible should further funding be secured.
   Some additional funding was secured through BZM Germany (also known as GIZ) and the IUCMA which supported understanding some of the practices and protocols of a number of partners.
2. In terms of partners, and despite the recognition of the importance of working with multiple partners (see Table 6), this work focussed mainly to the IUCMA as the principal partner, as well as SANParks. The CoM, EDM and Climate Change Department of DARDLEA were also engaged to some extent but further engagements are required with additional partners such as the Department of Health. These engagements were also somewhat limited by Covid-19, but attempts were made to address this via virtual engagements.
3. Capacity development options through formal post-graduate support have been severely constrained by the budget. However, some additional budget was secured for an MSc student and AWARD adopted innovative approaches focussing on IUCMA staff professional development, as described below.

1.6 STUDY AREA

The study area is part of the Inkomati-Usuthu transboundary Basin (Figure 2) and covers a footprint that includes the Crocodile River Catchment (CRC) and the City of Mbombela (CoM) (Figure 4). This was described in detail in Deliverable 2 and is further elaborated in Chapter 3.

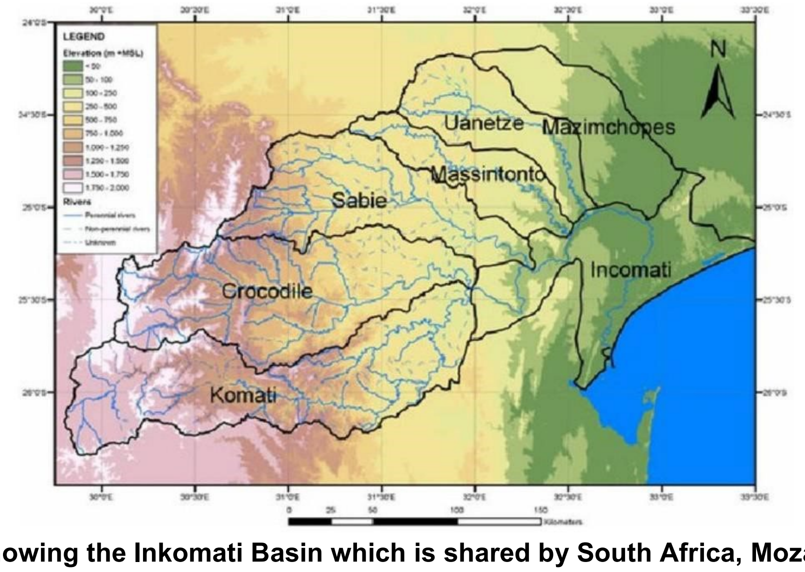

Figure 2 Map showing the Inkomati Basin which is shared by South Africa, Mozambique and Eswatini in the south

CHAPTER 2: OVERALL APPROACH AND METHODOLOGY

2.1 INTRODUCTION

AWARD has a long history of adopting a systemic, social learning approach to programmes and projects and to working strongly in the implementation space whilst being strongly supported by robust conceptual and methodological frameworks (e.g. Pollard et al., 2014; and see Pollard et al., 2020). The adoption of a different way of working – that of systemic, social learning – emerged from experiences over the years when it became apparent that natural resource management – and especially water resource management – is complex and beset by uncertainty and surprise. The technicist 'hydraulic mission' of the 1960s and 70s, where dams and infrastructure were seen as 'the solution', is no longer tenable in a rapidly changing world. Indeed, these linear approaches, based on a simplistic paradigm of 'cause-and-effect' have failed to deliver long-term sustainability (see Ison, 2014 for example). This is because as socio-political, economic and environmental factors come into play – especially in a more connected and water scarce world – solutions are often more complex than technical responses alone can deliver. Climate change, the recent pandemic and the emergence of endocrine disruptors are all examples of unanticipated system drivers that have impacted on socio-ecological systems and that require flexibility and adaptability within governance and management. The emergence of systems thinking and complexity theory together with Strategic Adaptive Management have all offered innovative approaches to address these shortfalls (see Pollard et al., 2011; Mcloughlin et al., 2021) through a new praxis (theory-informed practice).

2.2 KEY PRINCIPLES

Many of the key principles have been captured under the Theory of Change. In summary these focus on the adoption of a **systemic, social learning approach** which is foundational to the work since it is better placed to deal with complex socio-ecological systems where the relationships between socio-economic, environmental technical and political variables result in **uncertainty and emergence**. This is guided by the overarching systemic framework as shown in Figure 3 and described below.

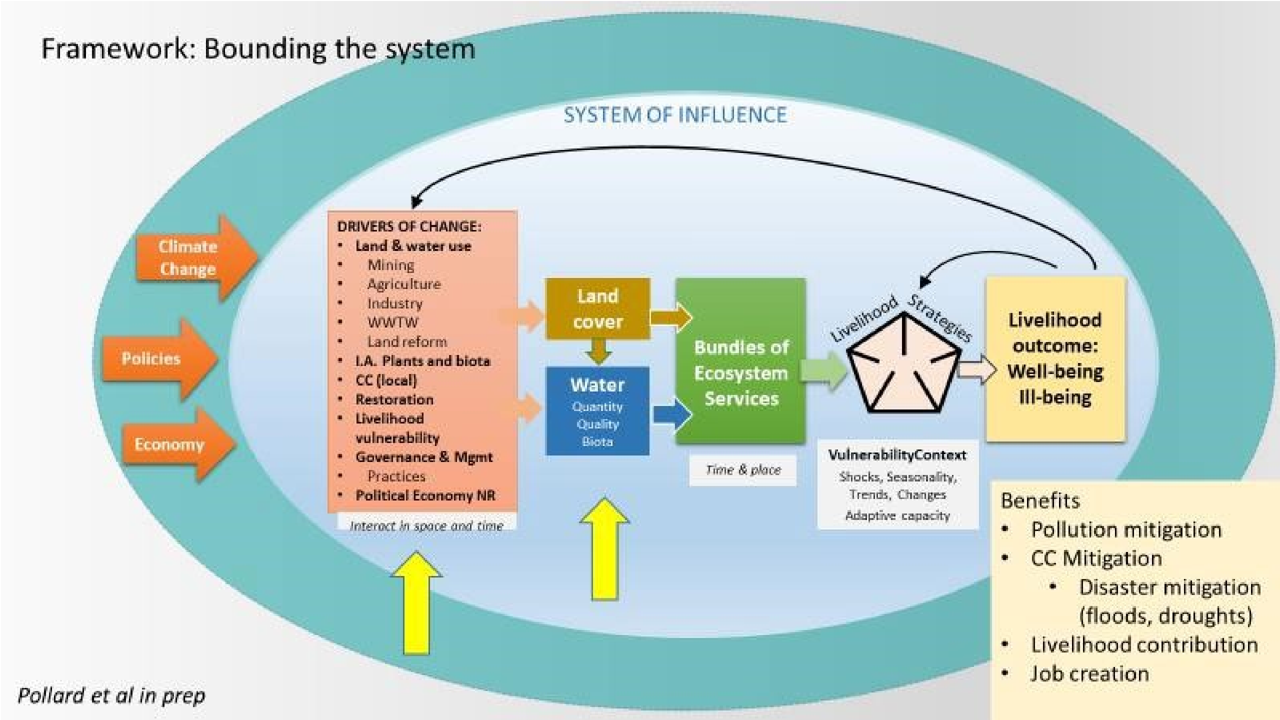

Figure 3 Systemic framework for understanding pollution dis-benefits and risks to human and biotic health (from Pollard et al., in prep)

In addition, there are a number of additional principles elaborated below.

- *The adoption of user-centred, collaborative approach for institutionalisation*

A central principle as part of institutionalisation was to ensure partner engagement from the onset so as to develop a "demand-pull" for the work. Water resources and pollution control management is profoundly cross-cutting and a cross-sectoral endeavour and **developing a collaborative process is essential** to ensure that there is understanding of the need for compliance and the risks of non-compliance. Indeed, a key focus in the development of the WQHS was to build stakeholding within partners: principally the IUCMA and SANParks whose mandate it is for water resources management, as well as partners involved in climate change and health.

The theory of change holds that by engaging key stakeholders from the start understanding would be deepened and guidance on how to build and strengthen collaboration around pollution impacts and management, sought. Unfortunately, within the timeframe of the project, the limitations imposed by reduced funding and Covid-19 meant less stakeholder engagement than planned. Nonetheless a combination of virtual engagements, one-on-one meetings and in-person workshops when constraints were lifted, allowed for some stakeholder engagement, albeit less than planned. However, the Water Quality-Health System should be seen as Version 1 and a dynamic system that is revised as stakeholders engage more deeply and as learnings come to the fore. The IUCMA needs to extend engagement more broadly to all stakeholders, including the CoM, EDM and the DoH together with local committees and civil society, traditional leaders and representatives of business, industry and agriculture.

The other important considerations were that, given the time frame and limited resources, the project should see to consider the following.

- *The adoption of an approach of requisite simplicity*

  Whilst water resources management and water quality in particular are in themselves complex fields, all partners recognised the need for adopting an approach of requisite simplicity. The purpose of the work was to pilot an approach that would broadly identify potential human health risks that would strengthen the IUCMA and partners role in taking appropriate action. Thus, for example, it is recognised that interactions between certain water quality constituents may occur, that travel times and environmental fate may differ for each constituent of concern and that communities-at-risk is far more nuanced that simply identifying a broad riparian area based on outdated-census data. However for the purposes of co-developing a pilot risk-based system, these constraints have been made explicit and are acknowledged. Further work would be needed to address these and refine the system as the first version of the Water Quality-Health System is put into use. This was designed to add as little extra resources and time to already over-stretched departments.

- *To support and integrate this work into current work.*

  This project tied in well with existing efforts to track the legal obligations for compliance on the part of a number of partners, particularly the IUCMA and SANParks as well as with another project which developed an action plan for ecosystem-based adaptation for the CoM (Pollard et al., 2023). This also has implications for transboundary commitments to both Mozambique and eSwatini.

2.3 KEY ELEMENTS OF THE WATER QUALITY-HEALTH SYSTEM

2.3.1 Overview

The Water Quality-Health System refers to three broad components; namely

1) A technical component, namely the Water Quality-Health Dashboard as part of the INWARDS DSS. This includes a number of risk assessments (water quality, human health and potential communities at risk)
2) The human health risk narratives included in the dashboard and in more detail in this report
3) The governance, practices and protocols (i.e. management) needed to support a range of actions and to enact an early-warning system. This is limited to a broad overview with a focus on the IUCMA and the municipality given the resource constraints.

The key methodological components of the project included a 1) governance and management component, 2) a technical component and 3) a capacity development component which are highlighted throughout the report.

2.3.2 Governance and management component

As stressed previously, it is important that the development and testing of a decision-support system be done within an environment of strong governance and management because it is through this that decision-making and action are enabled (Pollard et al., 2023). Given commitment to compliance with gazetted benchmarks, the focus on water quality monitoring, and the mitigation and regulation of non-compliance within the context of IWRM, the Inkomati-Usuthu CMA has assumed such functions since

2016 and has established strong stakeholder networks and forums, including with the DWS Regional Office and the municipality. Equally SANParks, through the Kruger National Park river manager and staff has developed strong competency for river health through monitoring and tracking of compliance against benchmarks as well also strong networks with partners (see Pollard et al., 2023). Given this, the Water Quality-Health System has therefore been co-developed and tested principally with the IUCMA and SANParks and to some degree, with the EDM and CoM as key partners (Chapter 4). Through the risk analysis and narratives the IUCMA and SANParks are better positioned to communicate risks to human health which can then be used as the basis for planning and with other partners.

2.3.3 Technical component

The technical component has, wherever possible, worked with or built on what is available, seeking to integrate data, evidence and specialist understanding into a Water Quality-Health risk model. Technical activities have included conceptual framing, software development and testing, accessing biophysical and socio-economic data, and incorporating best-available data related to the water quality and health.

i. **Software development and testing**: The approach piloted and tested the development of the Water Quality-Health Dashboard as a component of the INWARDS DSS. The dashboard integrated various data types (hydrology, water quality, spatial and social) for identifying vulnerable communities and the potential risks of water-borne health risks.
ii. **Data acquisition, analysis and integration**: Data availability is one of the key issues for the effective management of water quality in South Africa and thus for identifying potential biotic and human health risks. The project has accessed, analysed and integrate data related to hydrology, water quality, waste-water treatment works (including Green Drop Status) and biotic and community vulnerability.
iii. As can be appreciated, water quality comprises multiple variables and hence the project has used a number of proxy **indicators** for estimating risk associated with different land and water-uses.
iv. The profound **effects of climate change** have been integrated into the INWARDS DSS (through WQSAM which has been developed in a previously funded WRC project) and hence into the Water quality Health Dashboard. This has been based on downscaled data which were modelled for this work. Consideration has been given to impacts via different scenarios and impacts on dilution capacity (amongst other things) – which can move risks into higher risk categories.

2.3.4 Capacity Development:

The WRC and AWARD have shared priorities regarding capacity development. We focussed on both professional capacity development (work-placed) and of young graduates in the field. In order to ensure that the WQHS responded to managers' needs, we adopted a social learning approach (see earlier) to the co-development of the WQHS as well as to understanding current and future shared management practices and procedures and with key stakeholders from the start. Such an approach highlights professional capacity development within the project. We have also included new graduates (from public health and water resources studies) as junior researchers and interns.

This component is further elaborated in Chapter 4.

2.4 FRAMEWORK FOR UNDERSTANDING WATER QUALITY RISKS AND HUMAN HEALTH

As noted, the focus of the work has been on the Inkomati WMA (Figure 2,) and principally on the Crocodile River which, as a pilot site, captures a range of the water quality health issues related to different land- and water-use drivers that are similar to the rest of the Inkomati WMA. There is emerging evidence of increasing pressures and risks on surface waters of the WMA as demand for water increases, populations both increase and urbanise and land and water use changes with concomitant impacts on both surface water flows and water quality. These conditions and the development of the WQHS place the work squarely within the field of risk assessments and particularly those that recognise the links between social and environmental 'systems'.

The field of risk-based methodologies and assessments has grown immensely over the last two decades and whilst a detailed review is beyond the scope of this project, a range of examples within the broad fields of socio-environmental risks are noted. For example, there are those that focus on environmental and/ or social assessments (EIAs, SIAs, SEAs), livelihood risk assessments, Health Risk Assessments, economic or monetizing assessments (e.g. RiVamp), Disaster Risk Assessments, Integrated risk and vulnerability assessments, Climate Change Risk assessments for various natural resources or for rural or urban environments, Community-Based Disaster Risk Reduction Assessment and Solution-focused Sustainability Assessment. Within each of these broad 'categories' are more focussed risk assessments such as a hydrological or water quality risk assessment. This indicates the importance of focussing attention on the purpose at hand.

The overall approach is guided by a systemic conceptualization developed by AWARD (Figure 3) of the Crocodile River Catchment as a dynamic SES. More specifically for this work, the objective was to explore <u>water quality risks</u> on the <u>health of communities at risk</u>. Underlying the changes in water quality, are a range of drivers including land- and water-use as well as climate change and broader socio-economic pressures. Communities at risk comprises society at large but in this case is limited to those people directly dependent on run-of-river (untreated) water to meet their livelihood needs. Given this need to understand the state of the resource (water), the underlying drivers and pressures as well as the impacts and potential responses, ultimately the work was organized according to a modified risk assessment framework known as the DPSIR (drivers, pressures, state, impact and response) or DPSEEA (Box 1).

In the broad field of socio-environmental assessments and the impacts of human activities on environmental resources, the DPSIR framework (Driver-Pressure-State-Impact-Response, developed by the OECD and EEA) is widely used. Despite its flexibility and guidance in providing a means to organise data from multiple disciplines, its use has not been without criticism and to address these, the framework has been used in combination with other analytical methods and models[3], One criticism has been the lack of attention to human welfare which, given the emphasis on human health in this project, has been addressed through a focus on a Human Health Risk Assessment and the narratives that have been included in the WQHS dashboard (see Chapter 6). This would thus be commensurate with proposals for a DPSIRW to consider human welfare[4]. Although the DPSIR framework links environmental degradation to human health (impacts), it has been criticised for the lack of social, economic, and behavioural factors that contribute to human health risks. One response has been the addition of *Welfare* (as noted above), although an alternative to the DPSIR Framework is the Driving

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[3] See also comments https://i2insights.org/2022/10/25/extending-dpsir-framework/comment-page-1/#comments

[4] Other frameworks have also been developed known as the DPSEEA to account for human health risks

force-Pressure-State-Exposure-Effect-Action (DPSEEA) framework. DPSEEA has been widely used in European and international health assessments (Corvalán et al., 1999). Nonetheless, criticisms of the de-emphasis on natural capital which lies at the heart of sustainability has also led to the development of so-called 'integrated models'.

Box 1: Elements of the DPSIR / DPSEEA conceptual frameworks

- Drivers – Social, demographic and economic factors and changes in society which the effect consumption and production patterns. These drivers cause pressures on the environment which are mediated through human activities. These pressures lead to changes in the State of the ecosystem (unintentional or intentional).
- Changes in ecosystem health (the quality and functioning of the ecosystem) impact on the provision of ecosystem services which in turn, impact of human well-being (including human health).
- Society then responds (intentionally or unintentionally) in response to the impacts on ecosystem services or their perceived value.
- Exposure to the pressure is influenced by behavioural and 'lifestyle' choices

Another recommendation has been the need to focus on locally-specific attributes which when aggregated can have a substantial impact. This has been addressed through various modelling techniques especially those focussed on water quality modelling and the compound, catchment-wide impacts that a decline in water quality variable may have.

A key criticism of the framework is that it fails to capture the dynamic nature of real-world problems, which cannot be expressed by simple causal relations. This has been widely acknowledged in our work in the past and has led to the used of Systems Dynamic Models (SDM) to address dynamics in complex situations. Whilst this was beyond the scope of this project, a number of focussed causal-loop diagrams were developed to explore the use of nature-based solutions to mitigate some of the water quality challenges. Whilst the limitations of the DPSIR were taken into account by the team and addressed as outlined above, it was used principally as an organising framework for data collection and analysis.

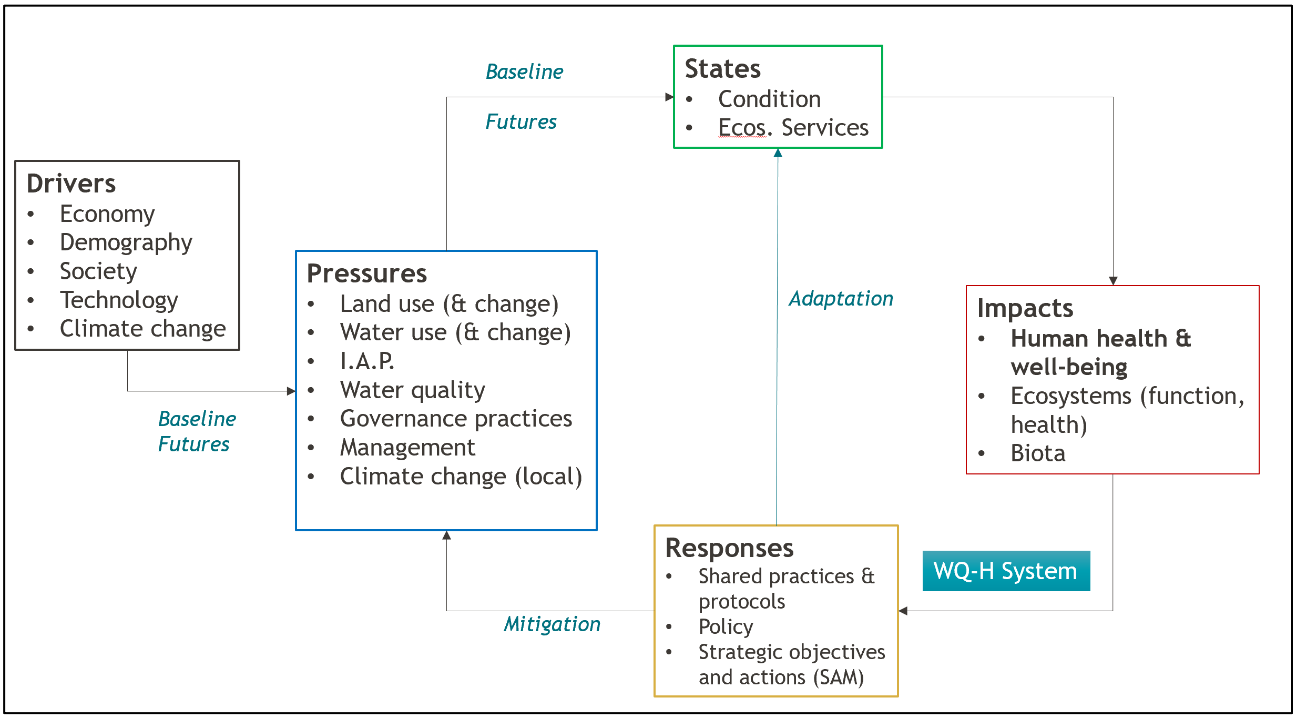

Figure 4 The modified DPSIR framework used to guide the co-development of the risks assessment and Water Quality Health System. I.A.P. – Invasive Alien Plants

2.5 OVERVIEW OF APPROACH AND METHODOLOGY

The project spanned two years and comprised a number of key steps as summarised in Figure 5, including conceptualisation, stakeholder engagement, data collection and analysis, risk assessments as components of the overall Water Quality-Health Risk Assessment, and the development of the Water Quality Health Dashboard and narratives as a key component of the INWARDS DSS. Importantly, key partners were engaged from the outset in a process of collaborative enquiry and co-design as part of a social learning approach to capacity development. Thus, the entire process comprises 'implementation' and institutionalisation (embedding) rather than the conventional approaches of product development and hand-over towards the end of project finalisation.

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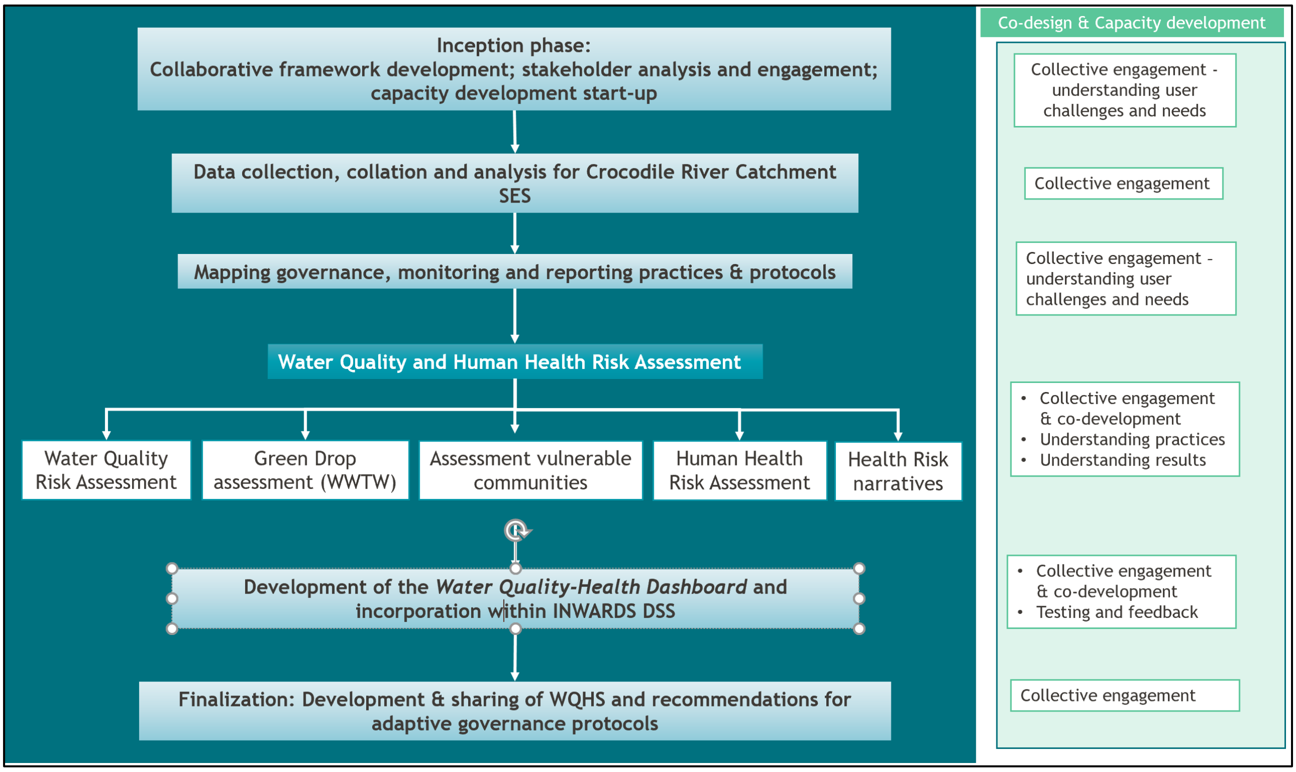

Figure 5 Overview of the approach and key steps indicating the embedded process of co-development and institutionalisation

Each step is summarised below and further detailed in corresponding chapters. The overall frameworks have been discussed above including the systemic, social learning approach and the DPSIRW framework for organising data and understanding potential risks of water quality on human health.

2.5.1 Stakeholder analysis and identification of key partners

A stakeholder analysis was undertaken as part of the inception phase of the project. Based on this and previous work on IWRM, this project was undertaken within the governance framework and management practices of a) the Inkomati-Usuthu Catchment Management Agency with the mandate for water resources management and b) the City of Mbombela and Ehlanzeni District Municipality, which, together with Silulumanzi with responsibilities related to water services, including waste-water treatment water quality monitoring and disaster management, The DoH is also an important partner with which the district municipality engages around matters of public health and disaster management. SANParks (through the Kruger National Park (KNP) is also a key stakeholder with water resources management functions for rivers traversing or bordering the KNP.

2.5.2 Mapping governance arrangements and practices for monitoring, reporting and action

As noted, it is important that the development and testing of a decision-support system be done within an environment of strong governance because this is where decision-making and action are enabled. The Water Quality-Health System has therefore been co-developed and tested principally with the Inkomati-Usuthu CMA and SANParks and to some degree with the EDM and CoM as key partners (Chapter 4). The key activities have included

1) Mapping key stakeholders (see above), institutional arrangements including organisational structure, rules, protocols and procedures followed. Under the current project this has been limited to the functions of IWRM (IUCMA) and of the WSA (City of Mbombela).
2) Co-analysis of the main practices related to management of water resources, water quality and water pollution (monitoring). Under the current project this has been limited to the practices of the IUCMA and of the municipality (City of Mbombela & EDM).

2.5.3 Data collection and analysis for the Crocodile River Catchment: Drivers, pressures and ecosystem state

A large amount of socio-economic and environmental data were collected, cleaned, analysed, represented spatially and included within the INWARDS DSS (see details in Deliverable 2). This included the collection and analysis of social data (census and demographic data), climate change and the impacts on water resources, infrastructure, biophysical data, hydrology and water quality data, and data on land and water use and changes in these). This also involved the collection of all relevant benchmark data. The analysis and synthesis of data related to the state of water-quality and trends over time, and potential drivers of change, linked to land and water uses in the CRC.

2.5.3.1 Selection of water quality variables for analysis

Given the links between land use and water resources, a number of key water quality variables were selected for a detailed analysis and for use in the Water Quality-Health Dashboard which also includes narratives.

Table 1 presents a list of water quality variables selected as potential contaminants of concern based on an analysis of land-use (see Figure 13), together with a specialist understanding of the catchment and from available literature.. However, most of these variables are not routinely monitored – if at all – and therefore proxies or indicators have been selected which, if evident in samples, are indicative of potential water quality challenges and concerns. The potential health impacts of each of the variables or parameters are given in the literature reviews (see below) and in the Human Health Risk Assessment (HHRA).

Table 1 Water quality variables selected for this study in relation to the land-use in the Crocodile River Catchment. Yellow – relevant; blue – proxy variable

Variable			Land use			
	Coal mining	Gold Mining	Chrome Mining	WWTWs	Irrigated Agriculture	Industry
Antimony						
Arsenic						
Cadmium						
Chrome						
Iron						
Lead						
Manganese						
Mercury						
Nickel						
Nitrites + nitrates					Nitrites + nitrates	

Variable			Land use			
	Coal mining	Gold Mining	Chrome Mining	WWTWs	Irrigated Agriculture	Industry
Orthophosphates				Orthophosphates	Orthophosphates	
pH						
Sulphates	Sulphates	Sulphates	Sulphates			Sulphates
Suspended Solids	Suspended Solids					
TDS						
Temperature						Temperature
Total phosphorus						
Groups						
EDCs						
Heavy metals						Industry dependent
Pesticides						
Water-borne pathogens						
Cholera (*Vibrio cholerae*)						
E. coli				*E. coli*		
Total coliforms						
Malaria						
Schistosomiasis						

Indicator parameters:

1. Sulphates: The presence of sulphates (SO_4) is regarded as a very good parameter for detecting the effects of coal mining (Rickard & Kunckle 1990) and is a more sensitive indicator ahead of acidity and pH.

2. Orthophosphates: The presence of orthophosphate is important in water quality monitoring since this compound is regarded as the best indicator of the nutrient status of natural waters. Levels of orthophosphate are indicators of phosphorus levels in the water. Phosphorus is an essential nutrient for all plants and animals but in excess, results in nutrient-rich waters (eutrophication), causing changes in the types of plants and animals and algal blooms which themselves may be a) toxic to biota and humans and b) cause oxygen depletion, impacting fish and other organisms. Phosphorous is a common ingredient in commercial fertilizers. High concentrations of phosphorus may result from poor agricultural practices, runoff from urban areas and lawns, leaking septic systems or discharges from sewage treatment plants[5].

3. Nitrite and nitrate: Like phosphorus, nitrite and nitrate are common ingredients in commercial fertilizers. As a nutrient, the impacts are similar to the phosphates above. Together with phosphorus, excess nitrates can accelerate eutrophication (see above). This, in turn, affects dissolved oxygen, temperature, and other indicators. Excess nitrates also result in human health risks.

[5] https://www.epa.gov/national-aquatic-resource-surveys/indicators-phosphorus. Some aquatic resources, such as wetlands, naturally serve as sinks for phosphorus found in sediments or dissolved in water.

4. *Escherichia coli (E. coli)*: Bacterial contamination in fresh water is measured using indicator organisms, notably *E. coli* (Enterococci in marine water) rather than the total coliforms present (Price and Wildeboer 2017). Most strains of *E. coli* are harmless but some compromise human health especially of the vulnerable (youth, elderly, immune compromised). *E. coli* is one of the most commonly adopted indicators for the determination of the microbiological quality in water and treated wastewater. Their presence provides direct evidence of faecal contamination from warm-blooded animals. Although most *E. coli* strains cause only mild infections, their presence is indicative of the potential presence of other more hazardous, pathogenic organisms. In cases of water treatment, WWTW should remove *E. coli*. If their presence is detected in the locale of a WWTW, it is an indicator of inadequate treatment and a cause for concern both because of direct impacts and because it indicates potential treatment problems more broadly. The acceptable levels of indicator organisms are defined in legislation and are set for drinking, river and groundwater and various uses.

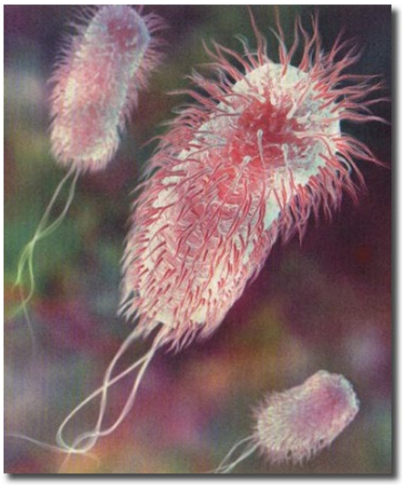

Figure 6 *Escherichia coli*
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2.5.4 Assessing impacts: Risk assessments

The overall considerations regarding risk assessment approaches was summarised above (Section 2.4). A review of risk assessment approaches was undertaken and a modified DPSIR model guided much of the work. Within the overall framework a number of specific risk assessments were undertaken comprising:

1) Water Quality Risk Assessment
2) Green Drop Risk Assessment for WWTWs
3) Human Health Risk Assessment
4) Communities-at-risk (vulnerability to water pollution) Assessment

Detailed methodologies are described in the previous deliverables and a summary is provided below. Further details are also provided in each chapter. Essentially, the Water Quality Risk Assessment, and the Human Health Risk Assessment share many commonalities particularly regarding hazard identification, exposure and potential impacts. They also share many of the same steps outlined in Box 3. It is also noted that the University of Mpumalanga are also developing an Ecological Risk Assessment model known as *Relative Risk Model – Bayesian Network* (RRM-BN) using a probability modelling approach. Linkages can be made once both projects are complete.

The overall risk assessment for the CRC comprised the development of a Water Quality Risk Assessment, a Human Health Risk Assessment and a Community Vulnerability Assessment.

Box 1 Steps in Risk Assessments being used Blue indicates key area of linkage	
Water Quality Risk Assessment (e.g. Skivington 1997	Human Health Risk Assessment
• Description of the intention; • hazard identification; • identification of consequences; • estimation of magnitude of consequences; • estimation of probability of consequences; • risk estimation; • risk evaluation; • risk assessment; • risk management	• Hazard identification; • Dose response assessment • Exposure assessment & dose calculation • Risk characterisation

2.5.4.1 Water quality risk assessment

Key water quality variables were collaboratively selected for analysis and inclusion in the WQHS based on land-use, water use and data availability (Table 1). Whilst a significant amount of data on water quality has been collected for the CRC by DWS, this was not available until the last quarter of the project. The IUCMA took over water quality monitoring in 2016 and much of the early analysis was based on these data. Another consideration is that of benchmarks or limits for water quality variables and sites for which these are available (see later). For example, not all sites have gazetted Reserve or Resource Quality Objectives (RQOs).

1) A *water quality risk analysis* (see Box 1) to determine key risks was undertaken according to compliance with benchmarks that have been set.
2) Compliance and mitigation assessment: The next step (as part of the WQRA) will be to identify pollutant pathways based on a water-quality load analysis (using indicators) using WQSAM.
3) Explore risks under climate change scenarios.

2.5.4.2 Green Drop Assessment for water-water treatment works for the CRC

The discharge of untreated- or partially treated wastewater has been identified as a major contributor to the deterioration of natural waters. South Africa has adopted the Green Drop Certification Programme forms of Incentive-based Regulation (IBR) pioneered by the South African Water Sector since 2008. It assesses capacity management, environmental management (risk abatement), financial management, technical management and quality compliance.

The Green Drop audit provides a comprehensive overview of the wastewater management in the country and includes the Mpumalanga Green Drop Report. It offers a vital benchmark for assessing the functionality of WWTW and discharge effluent water quality, as well as to track trends. Unfortunately, South Africa's assessment process suffered a hiatus after 2013 when no assessments were done. Fortunately, these resumed in 2021. As part of this project (co-funded through BMZ (GIZ-SA), a report on the WWTW of the CRC, prepared by WaterGroup (also responsible for the Green Drop Assessment) was undertaken.

Data were analysed for those WWTWs within the study area and data from the latest report (2022) were compared to the last data in 2018 following a gap where no assessment was undertaken in 2020.

2.5.4.3 Human Health Risk Assessment

Once the water quality variables were selected, these were then used for a detailed Human Health Risk Assessment (Chapter 8; the HHRA followed a stepwise process outlined in in Box 1). This together with the community vulnerability assessment (water supply) were used to understand potential communities-at-risk

2.5.4.4 Communities-at-risk (vulnerability to water pollution) Assessment

This analysis provided some of the social context in understanding community vulnerability in terms of water-related pollution and the identification of communities-at-risk. This comprised the identification and analysis of households with direct dependencies on untreated water or water that is potentially polluted. Based on census data (2012), those communities whose primary source of water included non-treated run-of-river or surface water for some or all of the time to meet a variety of needs were identified (see Chapter 8).

Water use included:

- water for domestic purposes – risks from drinking and washing;
- small-scale crop production – risks from irrigation water and bioaccumulation; and
- recreational and spiritual purposes which includes contact with water sources.

2.5.5 Development of the Water Quality-Health Dashboard and human health risk narratives

This involved: mapping potential risks in the Crocodile River Catchment CRC (human and biotic), embedding potential health impacts within the INWARDS DSS; developing and coding the narratives and spatial model into INWARDS DSS and designing a user-friendly interface. The output is a multi-layered spatial model, depicting areas of potential risk for biotic and human health within the CRC. Details are provided in Chapters 6.

2.5.6 Testing, feedback and finalisation

This involved the collaborative consultation with stakeholders and various iterations to test and assess the dashboard in terms of the managers'' needs and in terms of the communication potential.

CHAPTER 3: CATCHMENT OVERVIEW AND DRIVERS OF CHANGE

3.1 OVERVIEW

The study area covers a footprint that includes the Crocodile River Catchment (CRC) and the City of Mbombela (CoM) (Figure 7). It lies in the Mpumalanga Province, with an area of 10 440 km^2. The Crocodile (East) River is the major river system of the broader transboundary Inkomati Basin which is shared between South Africa, eSwatini and Mozambique. The river is ±320 km in length and flows west to east across the centre of the catchment draining 35 quaternary catchments (Deksissa et al., 2004).

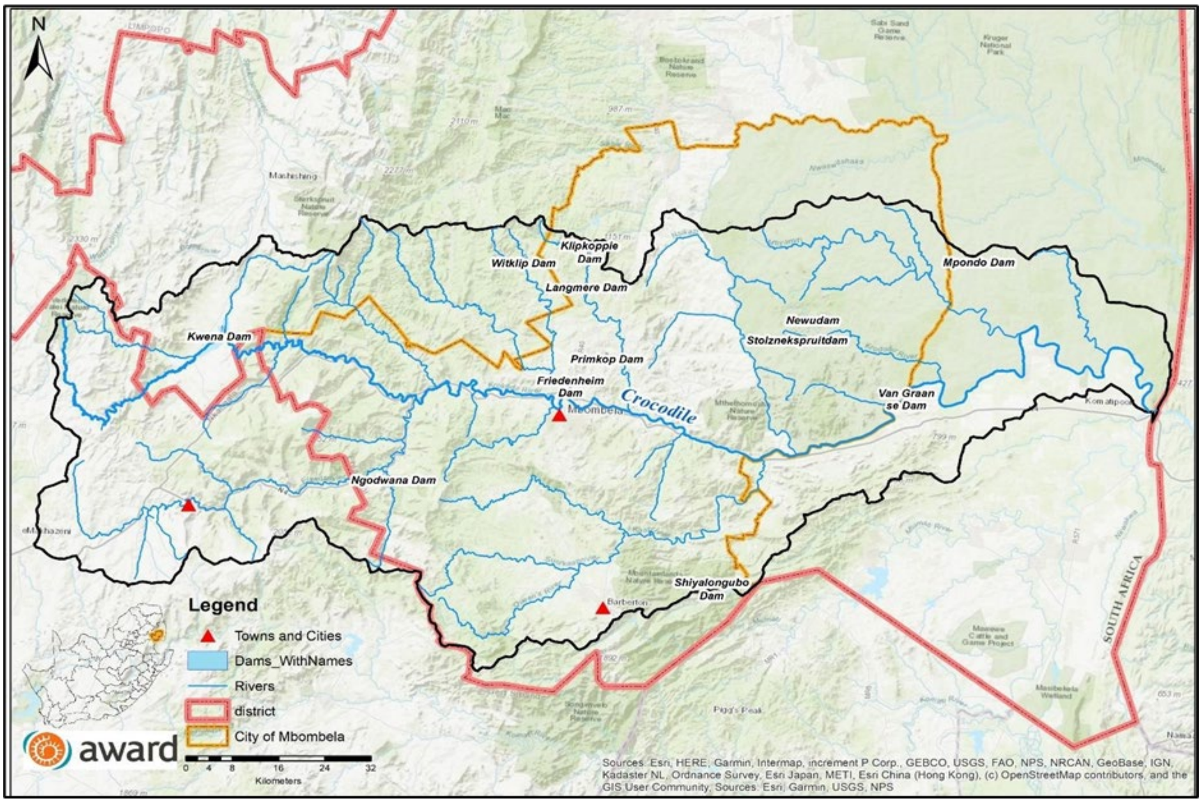

Figure 7 Study area showing the boundaries of the Crocodile River Catchment and the City of Mbombela Local Municipality

Mbombela is the administrative capital of Mpumalanga Province and houses various provincial departments. From a governance perspective and as the main administrative and service delivery node within the CoM Local Municipality (LM), it is an important focus as it serves as both the Water Services Authority as well as holding responsibilities for various functions related to environmental and human health. Four LMs are either partially or fully located in the study area: Mbombela LM, Nkomazi LM, Thaba Chweu LM and Emakhazeni LM. The Bushbuckridge LM falls within the EDM and lies in the adjacent Sabie-Sand Catchment (Figure 8).

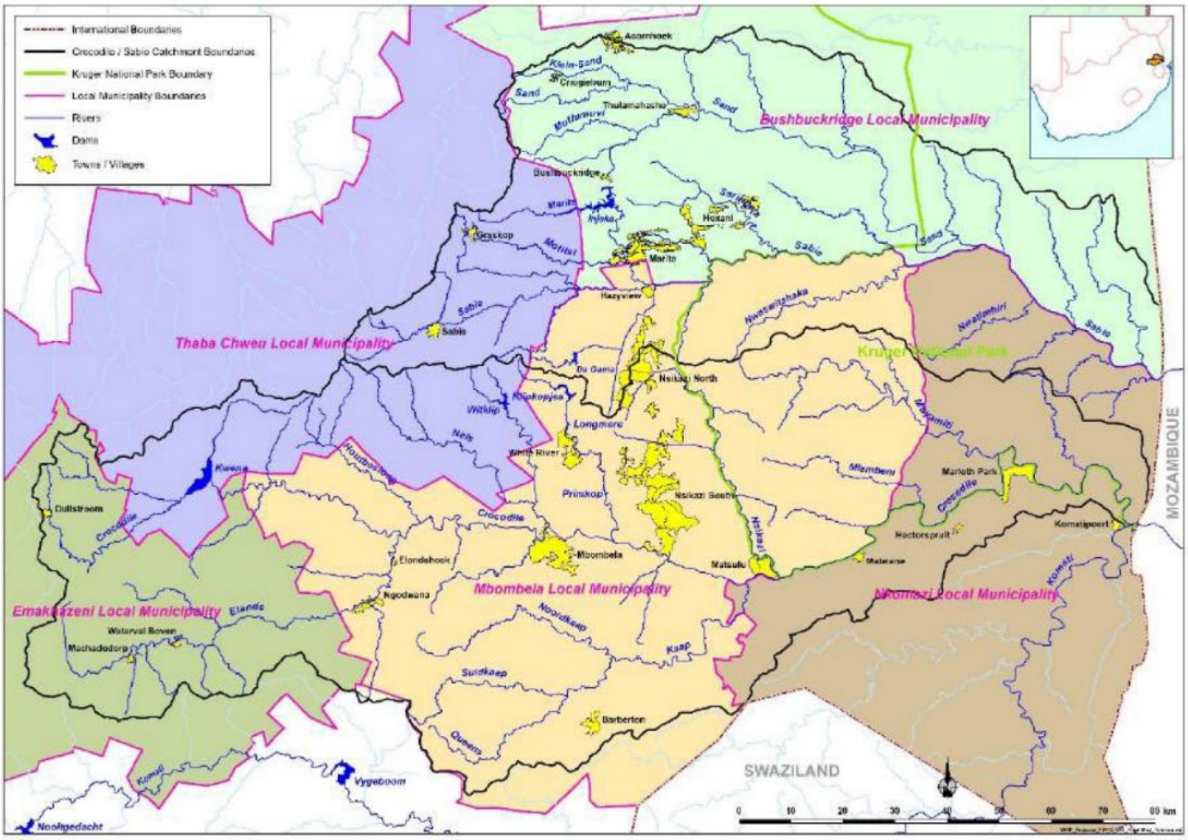

Figure 8 Location of local municipalities and urban areas within the study area

3.2 BIOPHYSICAL FEATURES

3.2.1 Geology and topography

The CRC is located within the eastern escarpment which bisects the catchment (N-S). Altitudes vary from 1400 m.a.s.l in the West (highveld) to 100 m.a.s.l. in the East (the lowveld). The western upper reaches are underlain predominantly by sedimentary rocks belonging to the Transvaal Super Group which includes the Pretoria Group. This area's lithology is dominated by shale, andesite, arenite, quartzite and hornfels. The remaining areas comprises less weatherable lutaceous arenite, arenite, dolomite, gneiss and granite. The outlet of the catchment is underlain by sedimentary rock formations of the Lebombo Group belonging to the Karoo Super Group, comprising of arenite, rhyolite and basalt.

3.2.2 Climate

The CRC has a sub-tropical climate over most of its area with warm, wet summers (October-March) and cool, dry winters (April-September). The western highveld experiences cold winters, while the eastern lowveld experiences extremely hot summers with temperatures exceeding 38℃. Mbombela and surrounds experience drought at roughly 7-year cycles although this may be altering under climate change. They also experience extreme high annual maximum daily rainfall (AMDR) events resulting in flood hazards (Masereka et al., 2018).

3.2.3 Rainfall, temperature and evaporation

Mean Annual Precipitation (MAP) varies from 1 200 mm in the western regions to 600 mm in the lower eastern parts of the catchment (Figure 9). The highest rainfall is found in the middle catchment over the escarpment foothills (900-1300 mm). The overall MAP across the catchment is about 880 mm, with most of the rainfall received during the hot summer months of November-April.

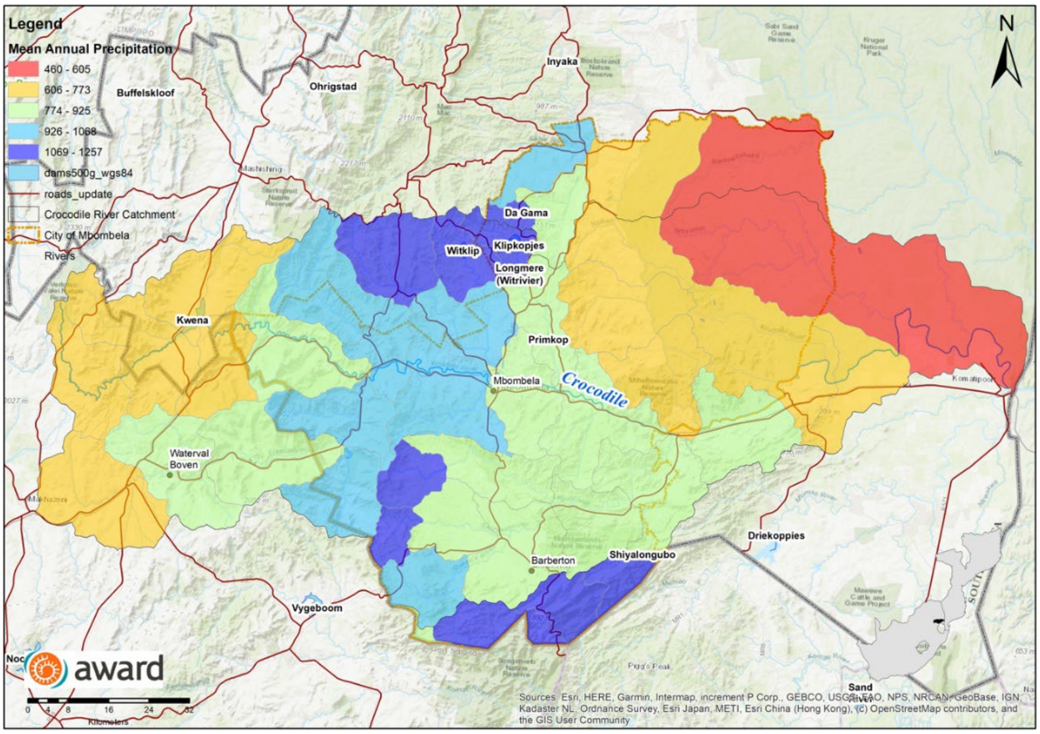

Figure 9 Rainfall

The mean annual runoff (MAR) for the CRC is 1 446 x 106 m^3 (Figure 10, Deksissa et al., 2003). Mean annual potential evaporation (MAE) losses for the CRC range from 1300 to 1700 mm, which greatly exceeds the MAP over the entire catchment and particularly in the drier areas of the upper and lower regions of the catchment (Figure 11, Deksissa et al., 2003). Average annual temperatures vary from the cooler upper catchment (13.2-16.1°C) to the warmer, lower region (20.2-22.7°C).

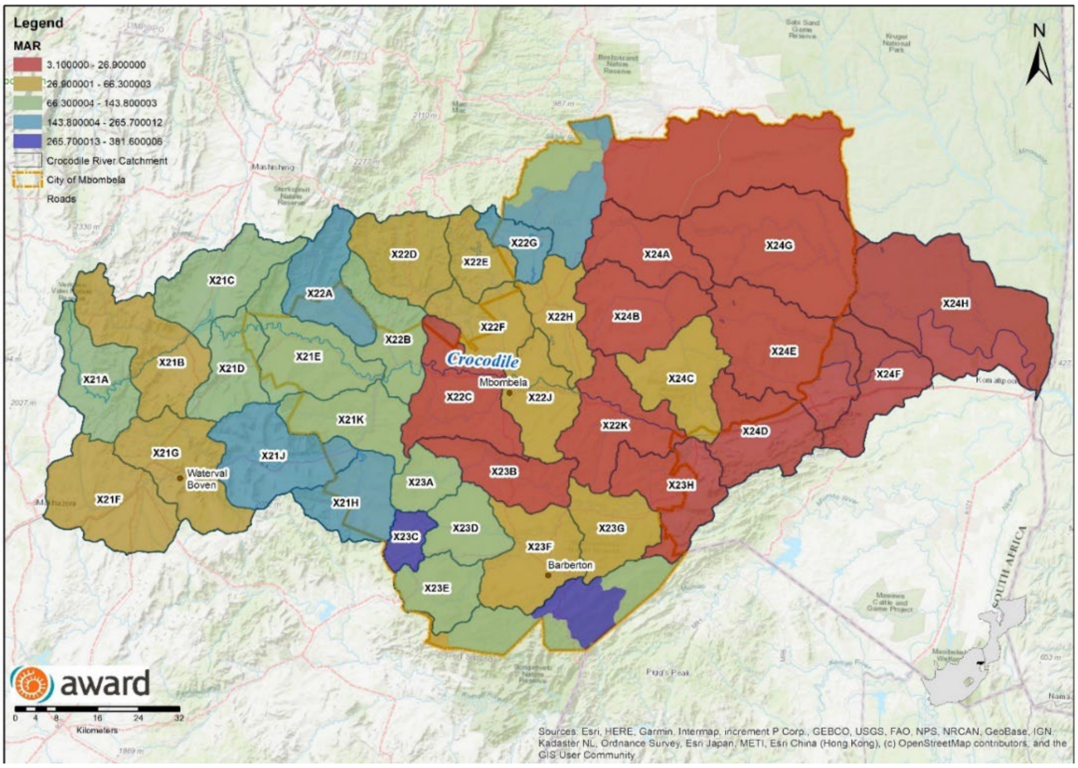

Figure 10 Mean annual runoff (MAR)

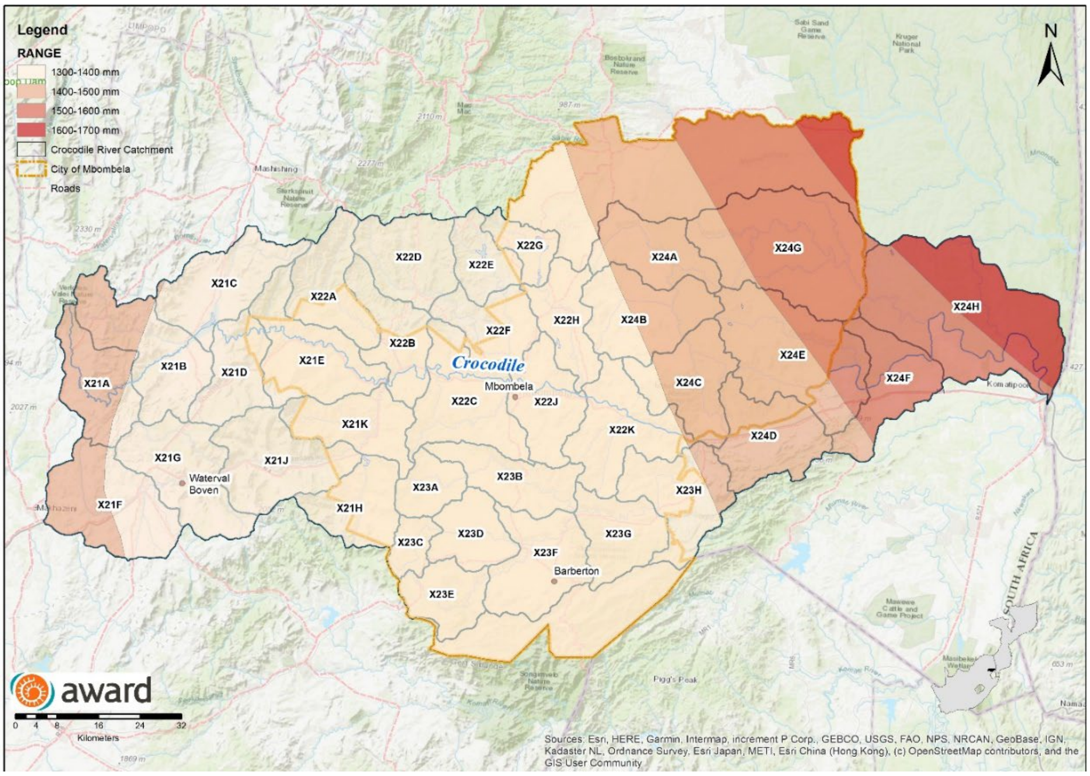

Figure 11 Mean annual evaporation

3.2.4 Vegetation

Three biomes are found in the catchment: forests, grasslands and savannah, with savannah being the predominant biome. These biomes support Lydenburg Montane Grassland in the western regions, Legogote Sour Bushveld in the mid-region and the Granite Lowveld in the eastern regions.

3.3 WATER RESOURCES

3.3.1 Water availability and balance

An understanding of water resources availability is ongoing. At the municipal scale, the current water balance presented in the updated CoM reconciliation study (DWS, 2021) shows the CRC in a severe deficit. The White River Catchment still has a surplus whilst the Witklip Dam is in a deficit.

3.3.2 Flow regime

The Crocodile River is highly seasonal with high flows tracking summer rainfall. However, a reversal of seasonality has been noted in the past below Kwena Dam where dam operations have led to above-normal flows in winter (Jackson, pers. comm. 2014). Changes to the flow regime have only been described relatively recently (see Riddell, 2013; Saraiva Okello et al., 2015), with significant alterations of the natural flow regime in the Crocodile basin being observed over the past 40 years (Riddell, 2013). Irrigated agriculture, forestry and urbanisation were the most important anthropogenic drivers. Based on an analysis of long-term rainfall and streamflow records in the Indicators of Hydrologic Alteration (IHA) method, the most significant changes in flow regime were noted in the Komati and Crocodile systems (Saraiva Okello et al., 2015), which are also the most stressed sub-catchments. A striking trend is the "significant increase in the number of reversals[6] at almost all stations. The observed increased number of reversals is likely due to the effect of flow regulation and water abstractions". These changes have important implications for meeting the Reserve (or environmental flow requirements), RQOs and minimum cross-border flows. Analyses a decade ago indicated that flows in the Crocodile River (outlet) did not comply with environmental flow requirements during most of the dry season (Pollard & du Toit, 2011a; Riddell et al., 2013) although this is improving (see Pollard et al., 2023).

3.3.3 Water quality

Water quality in the CRC is influenced by climate and geology as well as anthropogenic activities. Human activities include (DWAF, 2003b; DWAF, 2008; DWAF, 2009; DWAF, 2010):

- Discharge of wastewater effluent;
- Agricultural return flows (especially during low flow conditions) from farmland used for intensively irrigated sugar cane and subtropical fruits;
- Pollutant inputs from urban areas; and
- Pollutant inputs from old gold mining activities and other mining activities.

According to the DWS literature over a decade ago (DWAF, 2010; DWA, 2011), the water quality in the upper CRC was relatively good but then deteriorates in the lower regions of the catchment below the Kaap River confluence with the Crocodile River and its tributaries, showing unacceptable salt values (electrical conductivity or EC), turbidity, pH, nitrates, ammonia, phosphates and the presence of heavy metals. In the slower flowing reaches of the CRC, water hyacinth (*Eichhornia crassipes*) and algae populations were noted to be spreading rapidly, due to escalating anthropogenically-induced nutrient levels in the water, and resulting in increased pH levels of surface waters (DWA, 2011).

Later work indicated that water quality in the Crocodile River remained a challenge (Retief, 2014), with the previous three decades being characterised by a marked increase in physical, chemical and microbial

[6] Reversals are calculated by dividing the hydrologic record into 'rising' and 'falling' periods, which correspond to periods in which daily changes in flows are either positive or negative, respectively. The number of reversals is the number of times that the flow switches from one type of period to another.

pollutants because of point source inputs (from industrial and waste-water treatment plants), as well as from diffuse source runoff and return flows (from agriculture and mining). Water quality in the main stem of the Crocodile River is regularly non-compliant with orthophosphates in the upper and lower reaches although there has been a decline most notably in the reference sites in the upper reaches. Other tributaries such as the Kaap (near Barberton) and the Elands (flowing through Machadodorp) have been marked by a decline in certain water quality parameters including orthophosphates and sulphates, for example.

3.3.4 Groundwater

A detailed analysis of groundwater is not part of the scope of this project due to resource constraints. Nonetheless, groundwater areas of stress are evident, and salinities are high in the eastern regions. Yields are highest at the foothills of the escarpment.

3.4 SOCIO-ECONOMIC CHARACTERISTICS

The most up-to-date demographic information is that for the CoM area which is provided in the updated Mbombela Reconciliation Strategy (February 2021) based on a demographic study completed in 2018 (DWS, 2018a). The projected population at the local municipal level at 5-year intervals from 2010 to 2040 for realistic and high growth scenarios are given in Table 2. It is important to note that this does not include the entire CRC. The best available estimate is given for a decade ago as 1.6 million (Wangusi, 2013). The population density ranges from 0-5 people/ km^2 to over 2000 p/km^2 (Figure 12). The heavily populated areas correspond to the CoM followed by the former Bantustans of Apartheid South Africa. These areas are frequently classified as rural but have characteristics commensurate with poorly serviced peri-urban areas (Pollard et al., 2014). Understanding these population distributions and densities is important in terms of implications for risks to human health both in terms of direct use and for small-scale cropping which is often undertaken within the boundaries of the household.

Table 2 Municipal projected population per 5 years per growth scenario, 2010 to 2040 (from DWS, 2021)

Municipality	Scenario	2010	2015	2020	2025	2030	2035	2040
Mbombela LM (former) excl. rural	Realistic	570 446	611 228	647 312	681 604	716 484	750 755	784 628
	High	570 958	625 675	682 826	733 699	783 528	831 715	882 311
Umjindi LM (former) excl. rural	Realistic	62 779	69 517	73 565	77 617	81 866	86 304	90 922
	High	62 778	72 397	79 961	85 420	91 072	96 842	102 925
Bushbuckridge LM excl. rural	Realistic	528 388	538 801	546 244	553 638	561 102	568 632	576 233
	High	528 388	548 854	569 644	590 126	610 294	630 120	649 579

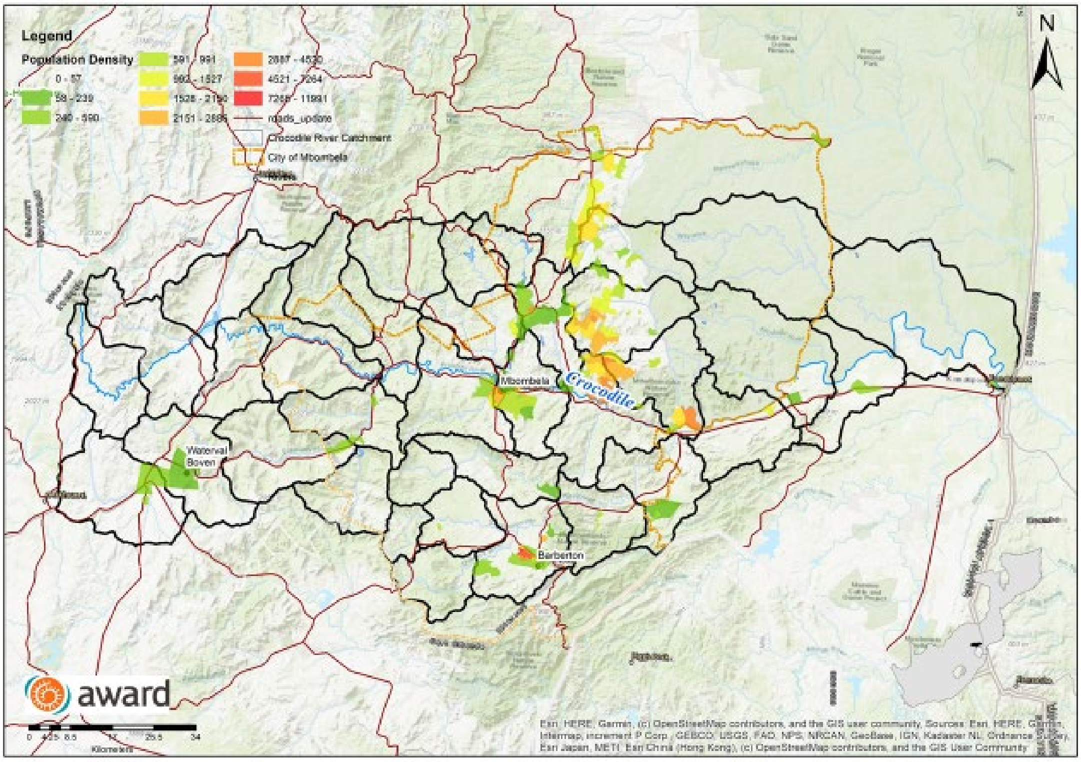

Figure 12 Population density

3.5 DRIVERS OF CHANGE

3.5.1 The links between land and water use

As emphasised in the Inception Report, land use and water use comprise critical drivers in the system because of their role as sources of water quality contaminants. Therefore, a large focus has been on ensuring the production of an up-to-date land-use map and data set as the basis for providing the links to potential water quality contaminants of concern. These are further described below.

3.5.1.1 Land use

Agricultural activities within the CRC range from forestry, wheat and maize farming in the western regions to cattle, game farming and sugar cane cultivation in the eastern regions (Figure 13). Some 20 years ago, the CRC supported one of South Africa's largest irrigation area (±42 300 ha, DWAF, 2004), with farmers and industries abstracting large quantities of water to support extremely water-intensive crop species and industrial applications (Roux et al., 1994). Water flow is further decreased by extensive afforestation (19% of the catchment), and a low precipitation to evaporation ratio, leading to significant decreases in flow in the Crocodile River and the eastern (lower) tributaries during the winter months. Apart from the agricultural economic importance, the Crocodile River also forms the southern boundary of the internationally renowned Kruger National Park.

Land use activities in relation to EDCs is described in Section 6.2.

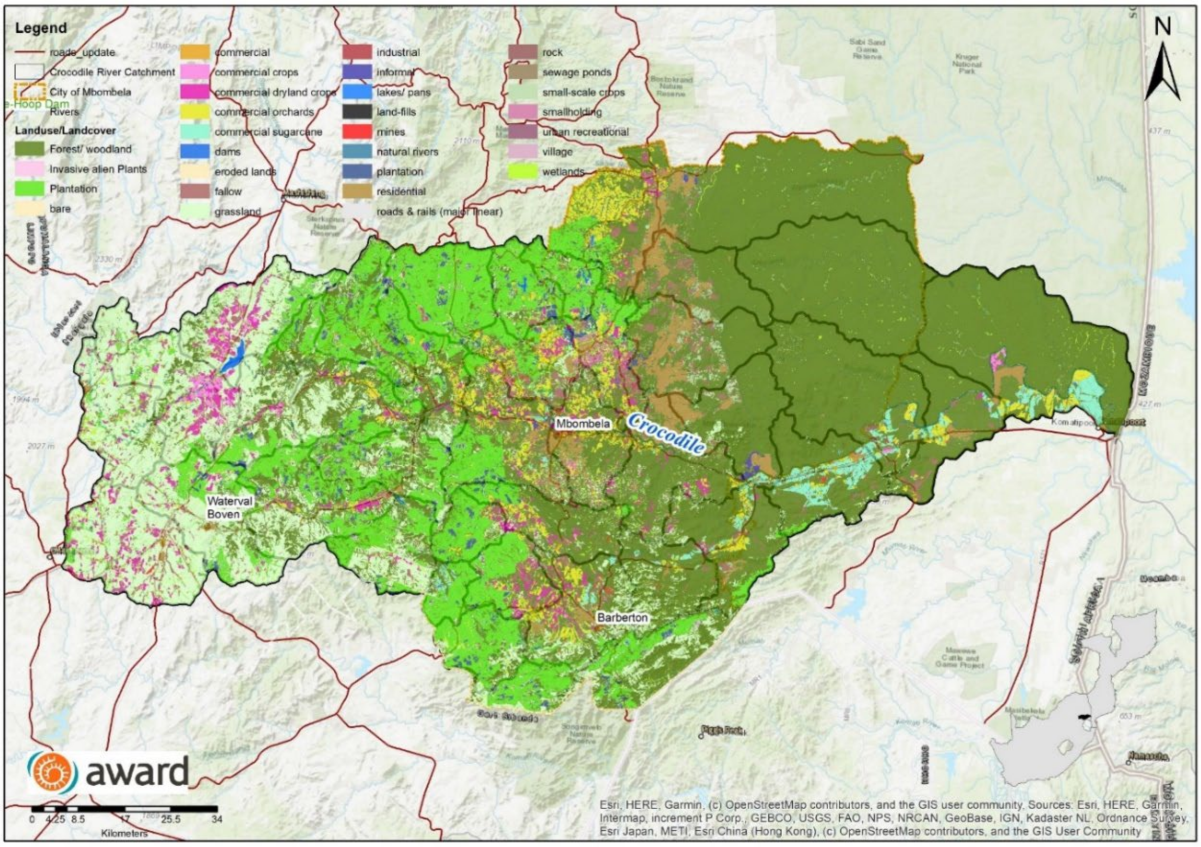

Figure 13 Map of land use/ land cover in the Crocodile River Catchment

3.5.1.2 Water use

i. Irrigation

The largest water user in the CRC is the irrigation sector (467 mm³/annum), followed by commercial afforestation (158 mm³/annum). Sugarcane is the most common crop grown in the CRC, followed by vegetables and citrus. Various irrigation boards are located along the river, all sharing the water resources of the Kwena Dam.

ii. Industrial use

The Sappi Ngodwana Mill is a major industrial water user which abstracts water from the Ngodwana Dam, on the Ngodwana River, and obtains additional water supply from former irrigation licenses. Other major industrial water users are the TSB sugar mill at Malelane in the Nkomazi LM in the Lower Crocodile (East), and smaller mining operations in the former Umjindi LM.

iii. Afforestation, invasive alien plants and streamflow reduction

There are large areas of forestry within both the Crocodile (and Sabie) River catchments including exotic plantations such as Pine, Eucalyptus and Wattle which reduce the amount of water that would otherwise flow in the rivers. A study by van Eekelen et al. (2015) found that streamflow reduction due to forest plantations may be two to three times more than that allowed by the Interim IncoMaputo Agreement. There have been some recent land-use changes from forestry to macadamia production to meet the growing global demand.

iv. Water transfers

There are water transfers in from the neighbouring Lomati Catchment to support the towns of Barberton and Shiyalongubo. There is a transfer from the Sabie Sub-Catchment to the CRC to support the Nsikazi North demand centre. Some inter-catchment transfers occur within the study area and some from catchments outside the study area. These are as follows:

- Transfer from Sabie River (Hoxane WTW) to Nsikazi North (CRC), Mbombela portion of Hoxane WWTW capacity is 36 Ml/d (13 million m^3/annum).
- Transfer from neighbouring Inkomati Catchment (Lomati Dam) to Barberton-Umjindi, approximately 4 million m^3/annum.
- Transfer from neighbouring Inkomati Catchment (Shiyalongubu Dam) to Louws Creek Irrigation Board, approximately 4.6 million m^3/annum.

v. Environmental Water Requirements and International Obligations

The National Water Act (Act 36 of 1998) (NWA) requires that sufficient water must be left in rivers to sustain their ecological functioning (the Reserve): where the Ecological and Basic Human Needs Reserve are the only water uses with the right to water, and as such must be given the highest priority. The ecological water requirements (EWR) for the CRC has been determined and gazetted as part of the Classification process (DWS, 2014a). The EWR represents 16.4% of the MAR.

EWR structures are based on the cumulative natural flow that occurs from the catchments upstream of the EWR site. There are seven EWR sites in the Crocodile River (Figure 14).

1. EWR1 Valyspruit
2. EWR2 Goedehoop
3. EWR3 Poplar Creek
4. EWR4 KaNyamazane
5. EWR5 Malelane
6. EWR6 Nkongoma
7. EWR7 Honeybird

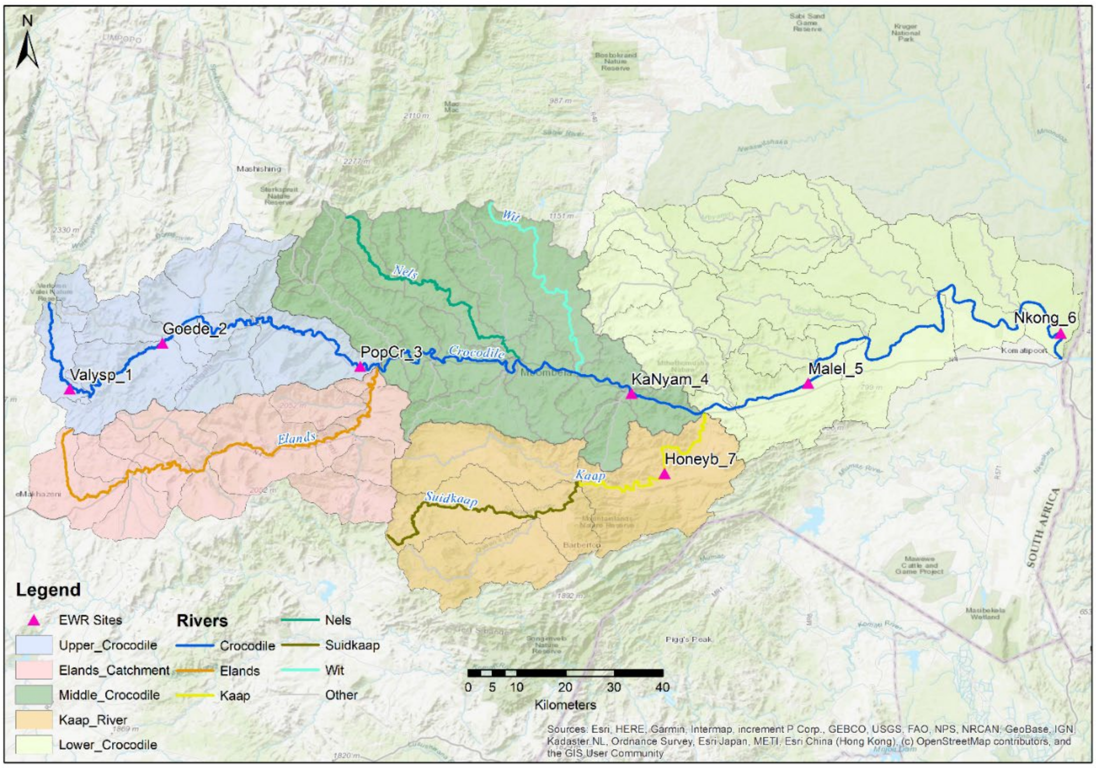

Figure 14 Map of the Crocodile River Catchment, showing the seven EWR sites

vi. International water sharing and obligations

The shared watercourses with Mozambique are regulated by an international water sharing agreement (IIMA, 2002). International Obligations exist for the Crocodile and Sabie Rivers. The requirements are stipulated in the Interim IncoMaputo Water Use Agreement (TPTC, 2002), as a minimum flow of 2.6 m^3/s at Ressano Garcia. This is assumed to be split 55% and 45% between the Komati and Crocodile Rivers, respectively (DWAF, 2009). This results in a minimum requirement of 37 million m^3/annum (1.17 m^3/s) to cross the border into Mozambique. Furthermore, 0.6 m^3/s is the required minimum flow from the Sabie River to cross the border.

3.5.2 Water-related infrastructure

i. Dams

The major dam is the Kwena Dam in the Thaba Chweu LM. It is used to improve the assurance of the supply of water for irrigation purposes in the catchment. The Montrose gauge (X2H013) lies a few kilometres downstream of the dam. There are several smaller dams such as Witklip Dam, Longmere Dam, Klipkopje Dam, Primkop Dam and Da Gama Dam.

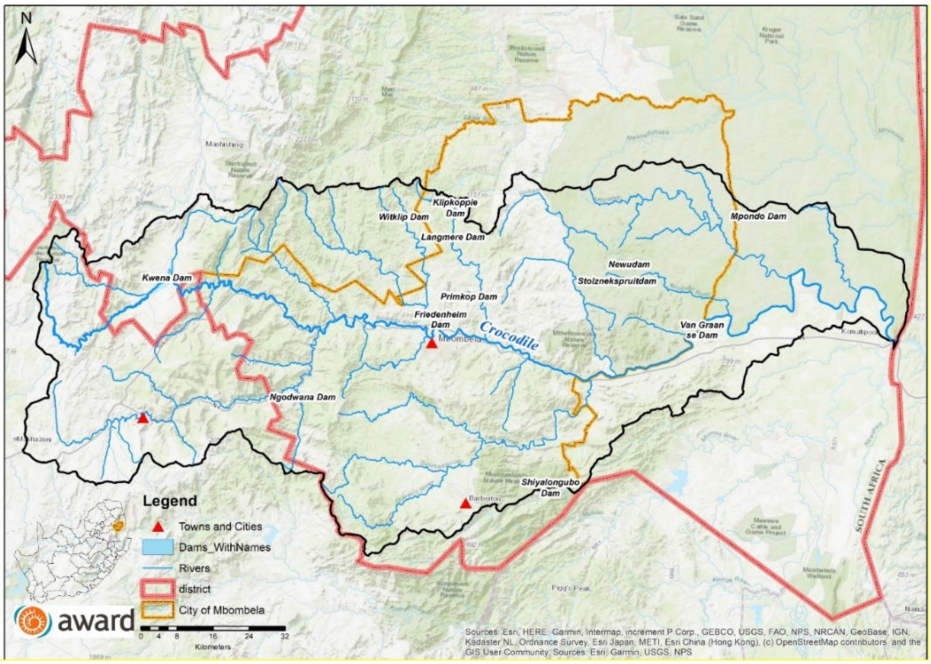

Figure 15 Study area showing the boundaries of the Crocodile River Catchment and the City of Mbombela Local Municipality

ii. Gauge stations and water quality data

Water quality data from both DWS and IUCMA are integrated into the human health dashboard and are used in the various risk assessments.

There are an estimated 88 flow gauge stations and 83 water quality monitoring sites in the CRC. A large proportion of these includes those installed by the IUCMA.

Water quality gauging was taken over by the IUCMA in 2016.

Data stopped being verified after 2018 but DWS is now dealing with the backlog.

While the IUCMA data received only spans from 2016-2023, hard copy records predating this exist as well. Currently the IUCMA has 83 active water quality monitoring points in the Crocodile River Catchment, with the variables being collected and analysed varying according to the site and monitoring purpose. Thus, some sites have toxin and/or biological data whereas others only cover the basic physicochemical parameters (e.g. pH, sulphates). The DWS datasets obtained from RQIS show a consistent growth in active monitoring stations with a steep decline in data received from stations around 2015. Most of the long-term monitoring sites are still active as they are part of the National Chemical Monitoring Programme. Whilst the physico-chemical parameters are well represented in the DWS data, the toxin and biological data are sparse and outdated.

iii. Inter Basin Transfers (IBTs)

IBTs have been described above under water transfers.

iv. Wastewater Treatment Works (WWTWs)

Understanding the numbers, status and management authority for WWTW in the CRC is essential for understanding the risks for biotic and human health since, in theory, water treatment would render effluent water of acceptable standards for different uses, with drinking water being the most stringent. As noted, as part of this project an assessment of the Green Drop Status was undertaken and results are summarised in Table 3, which includes a comparison to the previous assessment (Table 3). A full report is available upon request.

Table 3 WWTWs and Green Drop Status in the CRC (prepared from analysis by WaterGroup 2022)

	Treatment Plant	Receiving River	Management Authority	Municipality	2013 Green Drop Score and State	2021 Green Drop Score and State
1	Kabokweni	Gutshwa River	Silulumanzi	Mbombela	29% (Critical)	48% (Very Poor)
2	Kanyamazane	Crocodile River	Silulumanzi	Mbombela	93% (Excellent)	84% (Good)
3	Kingstonvale	Crocodile River	Silulumanzi	Mbombela	90% (Excellent)	88% (Good)
4	Matsulu	Crocodile River	Silulumanzi	Mbombela	90% (Excellent)	86% (Good)
5	Rocky's Drift	Sand River	Silulumanzi	Mbombela	76% (Average)	52% (Average to Poor)
6	White River	White River Stream	Silulumanzi	Mbombela	68% (Average)	52% (Average)
7	Baberton-Umjindi	Sand River	Silulumanzi	Mbombela	54% (Average)	42% (Very Poor)
8	Baberton Prison	Queen's River	DPW	Mbombela		25% (Critical)
9	Mthlati Plaas/ Malelane	Crocodile River	Nkomazi Municipality	Nkomazi	38% (Very Poor)	78% (Average)
10	Hektorspruit	Crocodile River	Nkomazi Municipality	Nkomazi	29% (Critical)	75% (Average)
11	Mthlatikop	Crocodile River	Nkomazi Municipality	Nkomazi	27% (Critical)	67% (Average)
12	Komatipoort	Crocodile River	Nkomazi Municipality	Nkomazi	30% (Very Poor to Critical)	78% (Average)
13	Emthonjeni (Machadodorp)	Leeuspruit River	Emakhazeni Municipality	Emakhazeni	45% (Very Poor)	45% (Very Poor)
14	Emgwenya (Waterval Boven)	Elands River	Emakhazeni Municipality	Emakhazeni	49% (Very Poor)	48% (Very Poor)
15	WPS	Sand River	SANParks	Kruger Park	N/A	53.7% (Average)
	No Green Drop Assessment					
16	Milly's (Privately owned plant)	Elands River	Emakhazeni Municipality	Emakhazeni	N/A	N/A
17	Ngodwana Pulp Mill	Elands River	Emakhazeni Municipality	Emakhazeni	N/A	N/A
18	Pretoriuskop Rest Camp	Guthawa River	SANParks	Kruger Park	N/A	N/A
19	Berg-en-Dal Rest Camp	Matjulu River	SANParks	Kruger Park	N/A	N/A
20	Malelane Rest Camp	Crocodile River	SANParks	Kruger Park	N/A	N/A
21	Crocodile Bridge Rest Kamp	Crocodile River	SANParks	Kruger Park	N/A	N/A

As noted, the Green Drop Assessment offers a vital benchmark for assessing the functionality of WWTW and discharge effluent water quality, as well as to track trends. The analysis revealed a diversity in results, with WWTW in the middle and lower catchment scoring above 65%, whilst those in the upper catchment, and the Kaap and White River area performing at 52% or lower. Of the 14 WWTWs with comparable data, five had improved (all in the Nkomazi LM), three had remained the same (albeit at low scores) and six had declined. The worst score and designated as critical, was that of the Barberton Prison (Kaap River sub-catchment). The WWTW falling under the Nkomazi Municipality had all improved significantly since 2013. Nonetheless, an examination of the breakdown of the assessment revealed areas of concern (see Chapter 6).

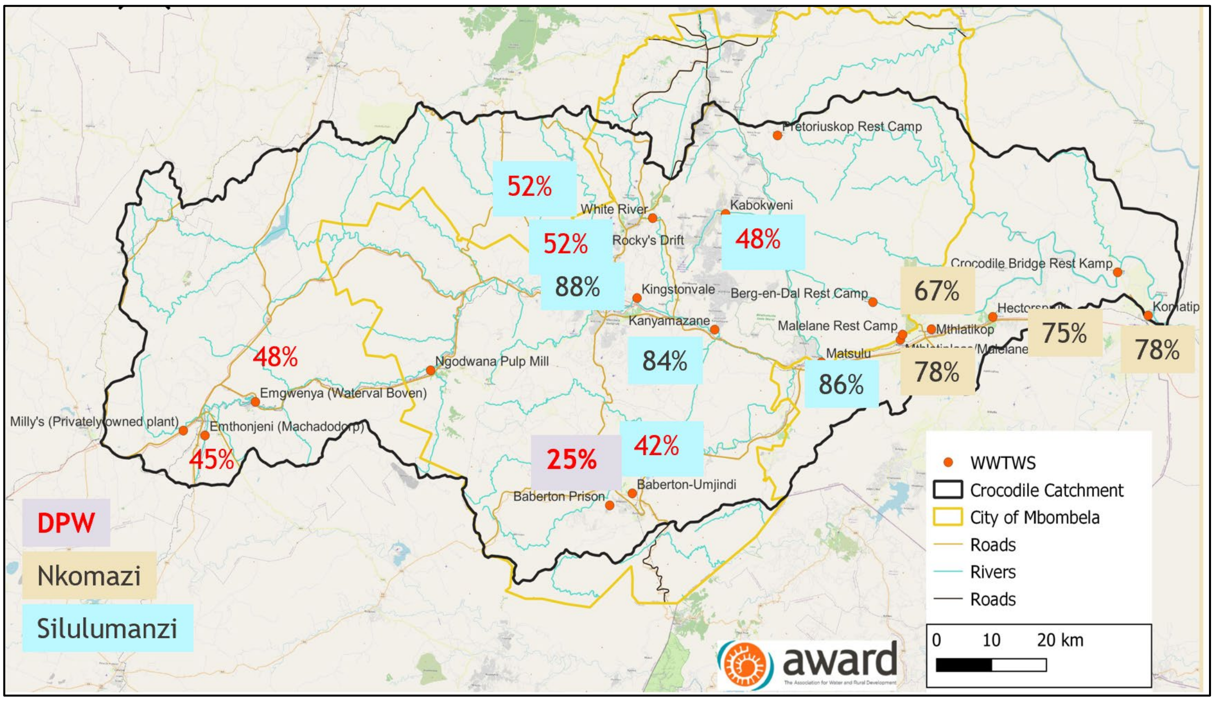

Figure 16 Summary of the overall Greed Drop status (2021) of WWTW and management authority in the CRC.

CHAPTER 4: STAKEHOLDER ENGAGEMENT AND CAPACITY DEVELOPMENT

4.1 INTRODUCTION

As noted earlier, the project has adopted a strongly systemic, social learning approach. This is because experience shows us that despite good efforts and the development of sophisticated tools, many of these remain unused because they are socially and institutionally dis-embedded; in other words they have not been responsive to practitioners needs and co-designed and tested throughout the project but rather delivered as a final 'product' with the assumption that engagement at this late stage of the project will result in uptake. Working with partners from the outset and being responsive to their needs is what we refer to as the process of institutionalisation. In order to ensure that the DSS is responding to managers' needs, means understanding current management practices and procedures and working with key stakeholders to build on these as part of the Water Quality-Health System which thus includes support for governance through strengthened practices and institutional arrangements (Chapter 5).

4.2 STAKEHOLDER ANALYSIS

Information on stakeholders and stakeholder roles was gathered from the following sources:

- The project team's existing knowledge about stakeholders and stakeholder networks in the region.
- Internet searches and organisations' websites.
- AWARD meetings and workshops with the primary contacts from the IUCMA, CoM and EDM, Silulumanzi and National Institute for Communicable Diseases (NICD).
- AWARD workshops
- Detailed analysis of organograms
- Attendance at the Compact of Mayors and Administrators and Provincial Climate Change Information System workshop (9-10 December 2021), which included a wide range of stakeholders.
- Sharing of information with consultants undertaking a stakeholder analysis for CoM at the same time.
- A compilation of information about other relevant projects which have been and are being implemented.

The above sources were first used to produce a broad scoping/identification of stakeholders, represented in the form of a stakeholder diagram ("map"), as detailed in Deliverable 2. Stakeholders were then categorised, broadly, according to the expected level and nature of their involvement with water quality management and practices. The next step was to look at stakeholder roles in more detail, and – importantly – to relate these roles to potential 'types' of action:

- Water resource operations management
    - Authorisation and enforcement
    - Policy influence
    - Stakeholder engagement and awareness-raising
- Ecosystem protection with a focus on water-related ecosystems (RDM)
    - Monitoring –
        - Status monitoring of water quality, aquatic biota, and human health
        - Compliance monitoring
    - Ecosystem restoration and EbA
    - Invasive alien plant control
- Water supply

- Operation and management of wastewater treatment works
- Drinking water supply
- Disaster management and disaster risk reduction
- Local government climate change support
- Research

A database of stakeholder contact details was compiled and is available on request.[7]

4.2.1 Stakeholders scoping and categorisation

An initial broad scoping of stakeholders (Figure 17) where stakeholders are grouped according to their “sector” (different levels of government, NGOs, sector organisations, private sector, etc.) revealed the following.

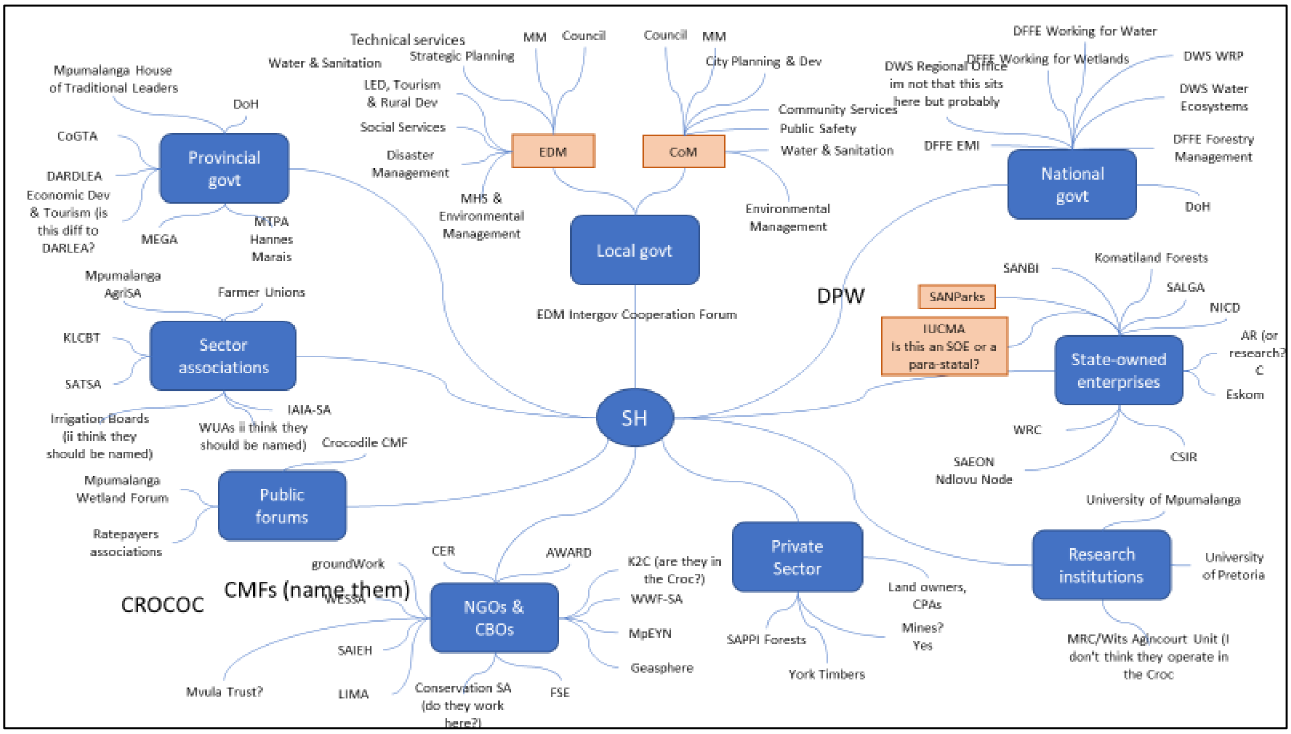

Figure 17 Schematic summarising initial stakeholder scoping

The key stakeholders were categorised and are summarised below

- <u>IWRM and water resources monitoring</u>: The IUCMA has a major role in both water quantity water quality monitoring and reporting. They have established additional hydrological gauge stations to those of DWS and assumed responsibility for water quality monitoring from 2016. In terms of compliance, their mandate is to work towards compliance with the Reserve (both the Basic Human Needs and Ecological components- or Ecological Water Requirements) and, in terms of water quality to both monitor and ensure compliance with the gazetted Resource Quality Objectives (RQOs).Water quantity and quality monitoring takes place at various sites throughout the CRC including the EWR sites for flow and sites established to track water quality including sites above and below WWTWs. Other agencies such as Silulumanzi and SANParks also monitor water quality.
- <u>Water services, health and disaster management</u>: Several different municipal departments have a stake including a number of departments in CoM (plus one public-private partner – the water service provider Silulumanzi), and about three departments in EDM.

[7] Due to the requirements of the Protection of Personal Information (POPI) Act, email addresses and telephone numbers are not reproduced here.

- Provincial government entities or departments include the Department of Agriculture, Rural Development and Environmental Affairs (DARDLEA), the Department of Economic Development and Tourism (EDT), the Mpumalanga Economic Growth Agency (MEGA) and the provincial Department of Health. The latter appears to be weak and understaffed, and there is no mention at all of environmental health issues on its website or in any of the publicly accessible documents. HIV/AIDS and Tuberculosis are current focus areas.
- There are several important sector organisations including tourism bodies, agricultural unions, irrigation boards, and the International Association for Impact Assessment (IAIA-SA) representing Environmental Impact Assessment practitioners. Public forums include the well-functioning Crocodile Catchment Management Forum (CMF), the Crocodile Operations Committee (CROCOC), the Mpumalanga Wetlands Forum and ratepayers' associations.
- A large number of NGOs and CBOs are active in the area. The Federation for a Sustainable Environment (FSE) and the Mpumalanga Environmental Justice Network (MEJN) operate primarily on the Mpumalanga Highveld but have strong links with stakeholders in the lowveld. The South African Institute for Environmental Health is based in Kwa-Zulu Natal but was included because it is one of the few organisations focusing specifically on environmental health. GreenCape is based in Cape Town but has worked closely with the provincial department of Economic Development and Tourism on the Mpumalanga Green Economy Cluster.
- Private sector stakeholders include forestry and mining companies, organisations providing water quality testing and consulting services (Zamangwane Water Tech and Water Group), and landowners – including Communal Property Associations.
- Research organisations: include the universities of Pretoria, Stellenbosch and Mpumalanga, along with several state-owned research entities: the Water Research Commission (WRC), Agricultural Research Commission (ARC), South African National Biodiversity Institute (SANBI), Centre for Scientific and Industrial Research (CSIR), and the South African Environmental Observation Network (SAEON). Numerous other research organisations, both national and international, are involved in relevant research in the area including AWARD.
- Besides the research entities mentioned above, state-owned entities/enterprises include the South African National Parks (SANParks) and the Mpumalanga Tourism and Parks Agency (MTPA) focused on tourism and biodiversity conservation, the Inkomati-Usuthu Catchment Management Agency (IUCMA), Komatiland Forests – a forestry company, power generation entity Eskom, the National Institute for Communicable Diseases (NICD) and the South African Local Government Association (SALGA) which provides support around climate change to local government.

National government departments or entities include the Department of Water and Sanitation (DWS), National Department of Health, Department of Forestry, Fisheries and the Environment (DFFE), the natural resource management programmes Working for Water and Working for Wetlands, and Department of Public Works.

4.3 PARTNERS: ROLES AND RESPONSIBILITIES FOR WATER QUALITY, PUBLIC HEALTH AND EARLY WARNING

Once this scoping was complete, partners were categorised to reflect the level of engagement in the use of the Water Quality-Health System (WQHS) (Figure 18). This differentiation was important because not all of the partners will host the INWARDS DSS to which the WQHS is linked, and many partners require outputs in different formats for different purposes whilst others may be interested on a more 'ad hoc' basis. Conceptually this was discussed and agreed on as follows:

- Host institutions running the INWARDS and WQHS analytics and direct response and action would be the IUCMA and potentially SANParks. Both have the mandate for water quality monitoring, analysis and reporting and a direct interest in tracking compliance with the Reserve and water quality
- institutions with whom they would share the outputs and with whom they would engage in collective action (see Chapter 5 for more details), such as

- Monitoring and reporting on compliance with the Reserve. This would include the IUCMA who reports to their board and to stakeholders through various forums such as the WUAs and the CROCOC as well as to neighbouring states. The SANParks (through the KNP staff) and DWS also have a responsibility towards tracking environmental health, of which rivers and other water ecosystems are part
- Monitoring and reporting on compliance with RQOs. This function relates more directly to water supply and sanitation issues and water use licence conditions and includes the IUCMA, the Water Services Authority (CoM) and the Water Services Providers including institutions such as Silulumanzi and the municipality. In the event of public health concerns both the district and the Department of Health would be informed as well as the Disaster Management Committee of EDM.

Given this, partners were categorised, identified and linked to action as follows (Figure 18; see table 4 for details):

1) First Level: **Primary users** of the Water-Quality Health System for action. These are users who are directly responsible for monitoring water quality, regulation, disaster management and early warning (public health). Specifically, the IUCMA and SANParks have been engaged in the
    a. co-research and co-design, and conceptual issues;
    b. the design of the User-Interface; and/or
    c. research on governance and practices.
2) Second level: **Secondary users** who may not use the model directly for action but will use the outputs. Some of these partners have been engaged in conceptual issues and in research on governance and practices.
3) **Third level: Stakeholders** who are interested or affected by the results and practices of the project such as other research programmes, NGOs and organisations tracking implementation, and community-based initiatives.

    Any future work would engage further particularly those partners listed under 2) and 3).

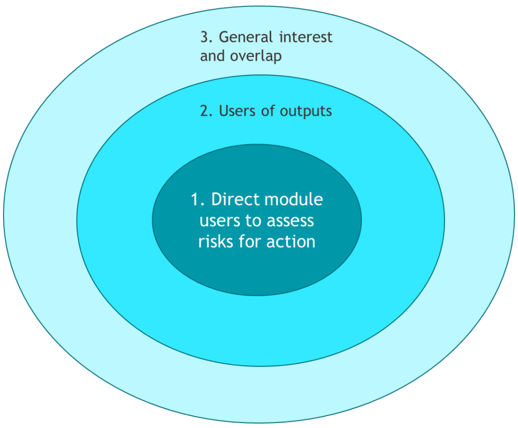

Figure 18 Schematic indicating partner categories

Table 4 Identified partners and responsibilities related to water quality and human health

Partners	Description
Primary Users	
1. Inkomati-Usuthu Catchment Management Agency	Responsible for IWRM of the Inkomati-Usuthu Basin (South Africa) and liaison with and cross-border flows with neighbouring states (Mozambique and eSwatini).
2. District Government (EDM) –	Mandates for disaster management and core mandate for municipal health (including water quality monitoring, environmental management aspects).
1. Disaster management	Disaster Management & Early Warning
2. Municipal health	Includes water quality monitoring in response to identified problems
3. City of Mbombela	Water Services Authority (WSA) responsible for water services. Environmental Management Unit with monitoring functions
4. Department of Health	Public Health, Disaster Management & Early Warning
5. SANParks	Monitoring compliance with the Reserve, RQOs, Disaster Management & Early Warning
Secondary users	
6. NICD National Institute for Communicable Diseases)	Disaster Management & Early Warning. NICD is a national public health institute, providing reference to microbiology, virology, epidemiology, surveillance and public health research to support the government's response to communicable disease threats
7. Clinic committees	Governance structures legislated by the National Health Act. Each primary health care facility should have a committee. They have an oversight function for quality of care at clinics (requires a broad purview, i.e. social determinants including early warning). Comprised of community members and facility manager and local government ward councilor.
8. Silulumanzi	Water Services Provider (WSP) – provider of quality water and wastewater services in the Mbombela city area
9. WUA and operations committees	Collaborate in certain IWRM functions especially in monitoring water use of users within the WUA
10. DWS Provincial Office	Monitoring functions for REMP
11. University of Mpumalanga	Undertaking Risk Study in the Crocodile Catchment
12. SA MRC	Strategic objective to help strengthen the health systems of South Africa. Address inequity by conducting and funding relevant and responsive health research, capacity development, innovation and research translation
13. Climate change practitioners Department of Agriculture, Rural Development & Environmental Affairs (DARDLEA)	Advocating and mainstreaming climate change and environmental issues for a better, cleaner and healthier Province and beyond. Focus on the development of climate response tools, education and awareness, demonstration and job creation in the environmental sector. Sharing and communication of information
14 General users/ interest	
• COGTA • other government agencies (DEA, SANBI, DMRE) • volunteer organisations	Involvement of municipalities Monitoring and policy development for natural resources and biodiversity May include “Friends of” and other volunteer groups (in future, potentially citizen science groups)

For this project, the IUCMA and SANParks have been the primary focus because of their direct role on monitoring water quality compliance. Despite severe limitations imposed by Covid as well as budgetary constraints which limited ongoing engagements with the full range of stakeholders, engagement with all stakeholders was possible at the project’s inception workshop. Ongoing collaboration was held over the course of the project with primary users including the IUCMA, SANParks and the municipality – both the City of Mbombela and Ehlanzeni District Municipality.

4.4 CAPACITY DEVELOPMENT

The WRC and AWARD have a shared priority of capacity development. AWARD has a long history of strengthening in-house capacity through a focus on work-based competency as well as through the provision of specific training. The primary pathway for capacity development has been ongoing commitment through building work-based competency, including support to one post-graduate student from the IUCMA. Unfortunately, under a reduced budget we have had to limit capacity development to that of the IUCMA staff (estimated at eight), staff from SANParks and the employment of three research assistants at AWARD.

Strengthening institutional, work-based competency

Capacity development is conceptualised in a number of ways. Firstly, the Water Quality-Health System must be embedded in a context so as to be useful (fit-for-purpose). Secondly, both the users and stakeholders need to be engaged in such a way that strives to build partner engagements where appropriate but that avoids stakeholder fatigue. Since the system is designed to strengthen governance and management practices (under different scenarios including climate change), the concept has been to explore which practices are likely to be enabled. The system was therefore be co-designed together with these primary partners so as to understand user needs in a process where both the R&D team (AWARD) and partners are learning as the process unfolds. This approach also leads to greater institutionalisation outcomes.

The IUCMA staff members involved were identified through an understanding of governance and institutional arrangements as well as management practices at the project inception. As a pilot project focussing geographically on the Crocodile River, staff from the IUCMA and SANParks (with inputs from EDM), have been the focus. This is because the WQHS will be housed by the IUCMA as the water resource managers, with the technical components being overseen and managed by their staff. They will then share and report on outputs in different formats for different users. Equally the river manager within SANParks (KNP) will also have the capacity to run the INWARDS model and report of water quality compliance.

Junior R&D staff development

Another aspect of capacity development has been the employment of interns or junior R&D staff[8]. This has included a range of post-graduate students as outlined in Table 5 (and see capacity development report)

Table 5 Student capacity development and current positions

Name	Background on joining project	Capacity Development support	Current studies/ position
Caroline Tlowana	IUCMA: Scientist Water Resource Management: Resource Quality Monitoring	Support for Resource Quality Monitoring, tracking of Reserve and RQO compliance	Master of Environmental Management (specialising EWR Institution): University of Limpopo. on hold since 2022
Lethabo Makgoba	Student completing her MSc in Public Health University of Cape Town	review of the potential health impacts of water quality variables	Council for Geoscience as an occupational health/ hygiene intern
Emily Nicklin	Recent MSc post-graduate student University of Cape Town Environmental Science	Engaged across the broad spectrum of SES dimensions, including systems thinking	Registered for a PhD at UCT on nature-based solutions to water pollution. Dr Kevin Winters
Shaskia John	Tshwane University of Technology; Department of Nature Conservation	literature review and tracking analysis of potential endocrine disruptors in the Crocodile River Catchment	Registered MSc (Dr Xander Combrink (TUT) – Co-supervisor: Dr Christoff Truter (SAUN), Mr Albert Myburgh (UKZN)

[8] This post have been enabled through co-funding from BMZ-SA.

CHAPTER 5: MAPPING GOVERNANCE ARRANGEMENTS AND PRACTICES FOR MONITORING, ACTION & REPORTING

5.1 INTRODUCTION

As noted in Chapter 1, the 'WQH System' refers to the a) technical components, namely a Water Quality-Health Dashboard, b) the narratives included in the dashboard and c) the practices and protocols (i.e. management) needed to enact an early-warning system. This chapter deals with c).

Resilience in the water sector also requires new collaborations for the planning and management practices of water supply, water resources and their ecosystems. Such complex challenges can only be addressed through collaborative approaches and integration; this cannot be done by a single sector, stakeholder group or government agency. Dealing better with external shocks and stresses further requires a functioning, vertically and horizontally integrated governance approach (to include all stakeholders, not just government). Certainly, within government, much needs to be done to build capacity for better integration and governance.

Whilst the Water Quality Health Dashboard integrates data and narratives to explore risks, such tools and actions are only as good as the governance system within which they are embedded (Pollard et al., 2023). Thus, it is important that the development and testing of a Water Quality-Health System – as part of a Decision Support System – is embedded within an environment of strong governance because this is where decision-making and action are enabled. As noted in Chapter 4, we therefore proposed to co-develop and test the WQHS together with the IUCMA and other partners. The activities have included:

I. Mapping out key stakeholders (Chapter 4)
II. Mapping institutional arrangements, including organisational structure, rules, protocols and procedures followed. Under the current project, this will be limited to the functions of IWRM (IUCMA) and of the WSA (City of Mbombela).
III. Co-analysis of the main practices related to the management of water resources, water quality and water pollution (monitoring). Under the current project, this was limited to the practices of the IUCMA and of the municipality (City of Mbombela & Ehlanzeni District Municipality).

In order to really build capacity and strengthen governance and IWRM, a detailed understanding of governance and practices (planning, monitoring and responding) of each institution was needed. These need to be analysed for points of synergy (as identified by partners themselves) so as to develop a shared practice or a common understanding of each others' practices to avoid duplication and to ensure alignment and coherence. As noted above, such details would only be possible subject to further funding. Some of this funding has been secured through a sister project funded through BMZ which explored the potential for Ecosystem-based Adaptation (EbA) to mitigate water quality problems.

5.2 APPROACH ADOPTED FOR MAPPING GOVERNANCE ARRANGEMENTS AND PRACTICES

Whilst improved governance can be supported in part by information, understanding the institutional arrangements is key for exploring key roles and responsibilities and practices of each stakeholder in order to develop a shared practice (if appropriate). These may be for planning (what is the scope, what is the framing adopted), and action (monitoring, regulation, reporting and response to disasters) and exploring points of synergy (realised or potential).

In terms of water resources management, the governance framework of the Inkomati-Usuthu CMA is central. Additionally, whilst the focus has been on the IUCMA who holds overall responsibility for IWRM, it is important to examine which other stakeholders need to be considered in the overall system, based on the stakeholder analysis (Chapter 4). Additionally, a collaborative understanding of the institutional arrangements (policies, plans, protocols and practices) and structure (organogram) was also developed so as to identify points of synergy and gaps. In terms of domestic water supply and disaster management, important institutions included the local and district municipality, namely the City of Mbombela and Ehlanzeni District Municipality, together with Silulumanzi for water services, including the management of some waste-water treatment works. Thereafter, an in-depth analysis of the roles and functions pertaining to water quality and the practices related directly or indirectly to IWRM, monitoring and regulation as well as disaster management and climate change within the IUCMA, the City of Mbombela (CoM), Ehlanzeni District Municipality (EDM) and Silulumanzi was undertaken.

The following outlines the key steps

1) A stakeholder analysis of those involved in water-related management, in particular water quality, as well as in municipal health, disaster management and climate change adaptation and mitigation.
2) Map institutional arrangements of major partners.
    a. Within institutional arrangements, related policies and plans were examined (such as classification and the RQOs), and in particular, practices related to planning, monitoring, regulation and disaster management.
    b. Understanding functions, roles and responsibilities that directly or indirectly related to water quality, health, disaster and risk.
3) Understand practices around the above.. An emphasis on practices is made because synergy and integration can be enabled through collaborative practices around a common goal (such as improvement in water quality or enhanced preparedness).
4) Ongoing stakeholder/ partner workshops with the IUCMA and various directorates from EDM, CoM, Silulumanzi and others was also undertaken over the course of the project as a means for institutionalisation.

5.2.1 Findings:

The following section outlines the main partners and their roles and responsibilities.

5.2.1.1 Governance linkages between IWRM and water supply

It is important to note that IWRM follows catchment and WMA boundaries whilst water services fall under municipalities and therefore follow administrative boundaries. This poses certain challenges for planning and management that need to be considered throughout. The main local municipalities within the study area have been indicated in Chapter 3

As a first step, the project has examined the organisational arrangements with respect to WRM and water supply – the IUCMA and CoM respectively – so as to start to explore practices and responsibilities with regard to water quality and human health.

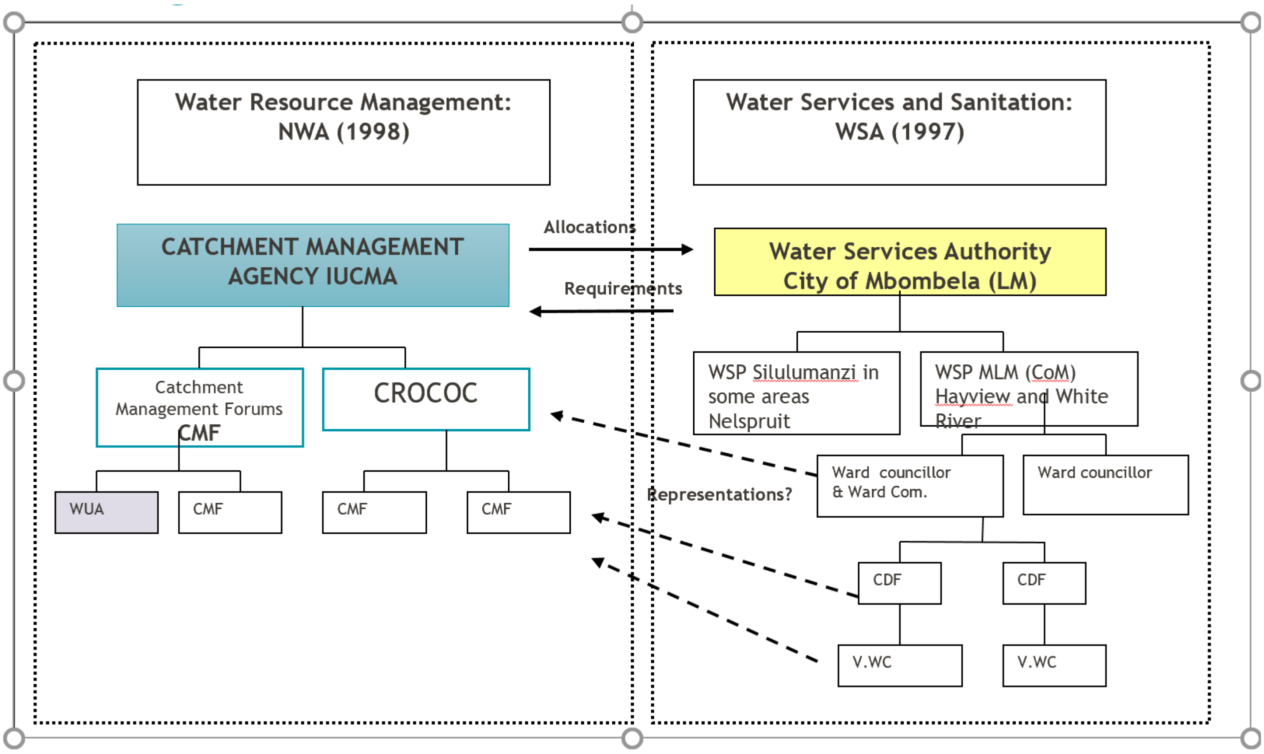

Figure 19 Draft schematic of the institutional arrangements for IWRM and water services in the Crocodile Catchment (CROCOC – Crocodile Ops Committee; VWC – village water committee)

5.2.1.2 Organisational structure of key partners

A number of functions related to IWRM and water services are shared between the local and district municipality and are more easily understood when detailed against the organisational structure. For this reason, these are elaborated first before looking at functions, roles and responsibilities.

1) IUCMA

Each of the six units comprising WRM within the IUCMA have bearing on water-quality related issues, most notably is that of Resource Quality Management which manages water quality monitoring, data collection and analysis. Water quality data have been collected in-house since 2016. These data are held and shared with stakeholders through various forums (see below) and are used for river operations, as well as for Water Use Authorisations and Compliance Monitoring and Enforcement. Resource Planning & Operations deals with a hydrological monitoring and analysis thereby informing river operations.

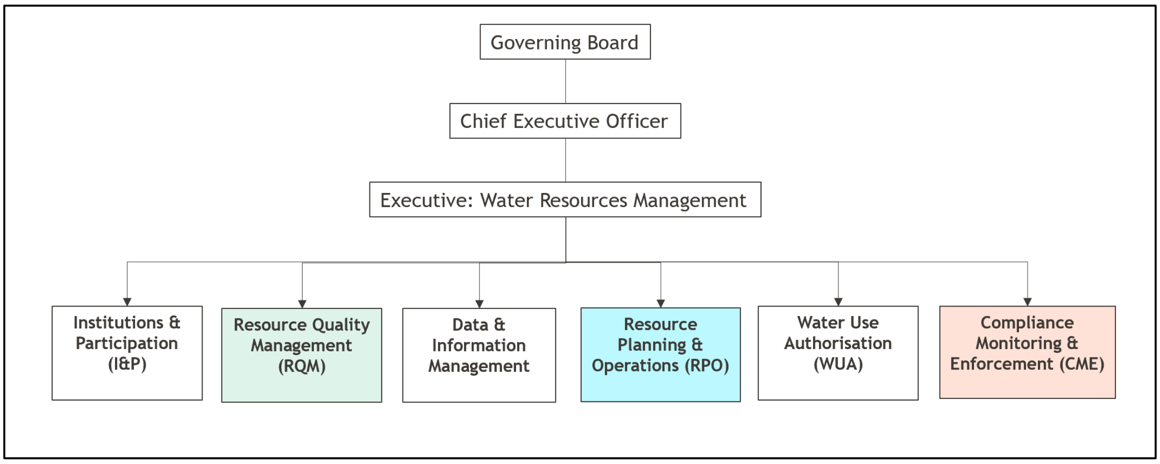

Figure 20 Water Resources Management Department within the IUCMA. Key units for this work are highlighted (adapted from IUCMA 2022)

2) City of Mbombela

The CoM has various departments which intersect with water quality management (Figure 21; however this structure has changed and is due to be approved in April 2023). Both Environmental Management and Planning Unit (EMPU) and Water Services Compliance Monitoring are of importance. The responsibility for climate change also sits with the EMPU.

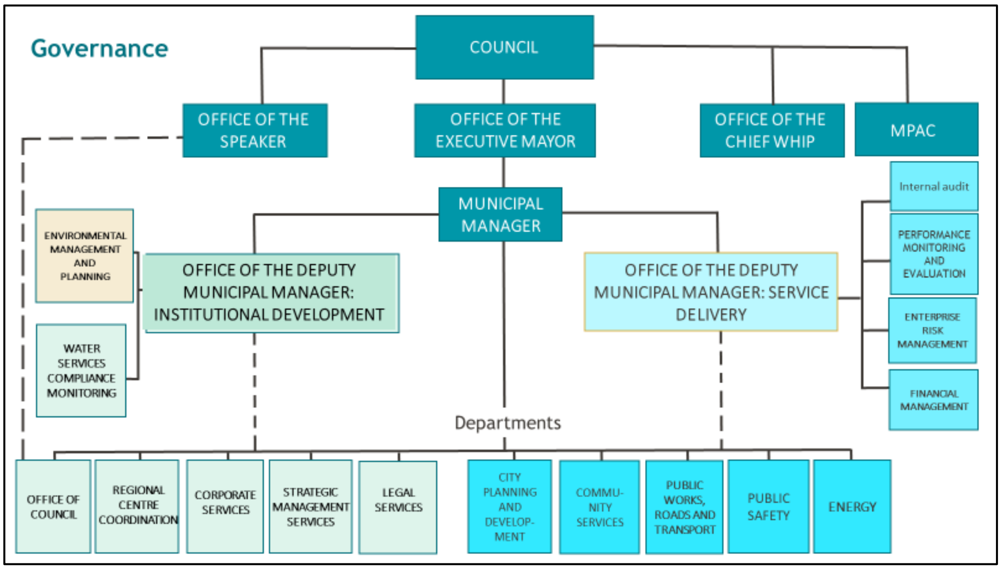

Figure 21 Organogram for the CoM. Note that this has changed new ratified structure to be approved April 2023

3) EDM

Key functions related to Environmental Health and Disaster Management are held at the district level (Figure 22). Oversight and support for environmental management are also held at this level.

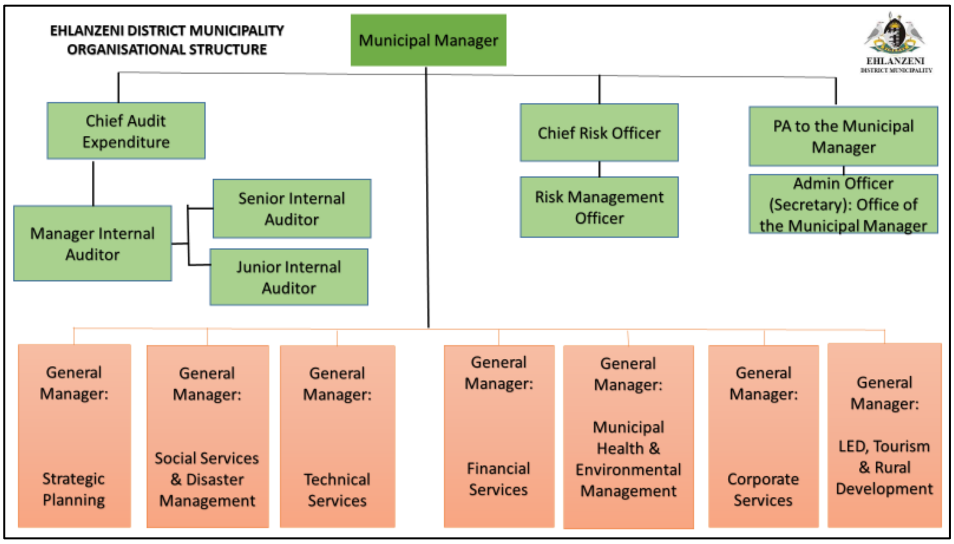

Figure 22 High-level organogram for EDM

Other important core stakeholders are indicated in Table 6.

5.2.2 Primary/ core partners and key functions

These stakeholders actively participate in practices regarding water quality, human health and disaster management. They include the IUCMA, various departments from the CoM Local Municipality, the CoM water service provider Silulumanzi, SANparks, DARDLEA, the Department of Health and the NICD.

The key partners within the IUCMA include **Resource Quality Management** and **Resource Planning & Operations**.

The key partner within the CoM is the **Environmental Management and Planning Unit**, although a new organogram is awaiting approval in April 2023 (Figure 21). It was recognised that environmental management cuts across all units. The **Water Services Compliance Monitoring Unit**, manages the contract with Silulumanzi. There is only one person in this unit currently, and only limited water quality monitoring is performed. **Silulumanzi** is a private company delivering water and sanitation services to a concession area around Mbombela (on behalf of the CoM) under a public-private partnership contract (a 30-year concession with 10 years remaining).

SANParks through their focus on water resources within the Kruger National Park plays an important 'watchdog' role, monitoring compliance and supporting multiple networks (Pollard et al., 2023).

Key functions are elaborated in Table 6. From this initial analysis, it is clear that a number of different partners are involved in areas of overlap. For example:

- Water quality monitoring: IUCMA, Silulumanzi, CoM, SANParks.
- Community engagement: IUCMA, Silulumanzi, CoM, EDM.
- Climate change: DARDLEA, CoM, IUCMA.

Table 6 Summary of key functions of primary or core partners

Organisation and Unit	Overview of functions
IUCMA	
Resource Planning & Operations	Responsible for • Development of the Catchment Management Strategy • Development of Water Allocation Plan • Verifying existing lawful water use • Performing integrated planning and operations of river systems • Stakeholder-cantered progressive implementation of the Reserve.
Resource Quality Monitoring	• Undertake monitoring, data collection and analysis. Water quality data available on the Water Resources Information Management Dashboards (pH, EC, nitrite/nitrate, phosphates, *E. coli*, COD, SS, sulphates, and many other metals and elements). • Issues annual water quality and river eco-status reports.
Compliance Monitoring & Enforcement	• Monitors and enforces compliance as part of the IUCMA's mandate.
Institutions & Participation	• Community/ stakeholder engagement, education and awareness and public liaison.
CoM	
Environmental Management and Planning Unit	• To monitor adherence to all environmental statutes and ensure protection and sustainable use of natural resources. • To restore, maintain and conserve biological diversity. • To monitor ambient air quality and adherence to national air quality standards. • To build sustainable communities by **improving their climate adaptive capacity** and improving climate resilience. • To create **environmentally conscience** communities by providing continuous environmental education and awareness. • To continuously conduct scientific environmental research to improve the knowledge base. **Subunits** :undertake • Environmental Education and Awareness • Biodiversity Management • Air Quality Management • **Impact Management and Compliance Monitoring** • Climate Change Program
Water Services Compliance Monitoring Unit	• Manages contract with Silulumanzi (WSP) • Does limited water quality monitoring.
WSP	
Silulumanzi	• Subsidiary of South African Water Works, a South African utility company delivering water and sanitation services on behalf of the City of Mbombela under a PPP (a 30-year concession, 10 years remaining). • They operate the Nelspruit Water Treatment Works, Matsulu Water Treatment Works, Matsulu Sewer Treatment Works and Kingstonvale Sewer Treatment Works.
EDM	
EDM Municipal Health & Environmental Management	• Monitoring, sampling, bacteriological & chemical tests for quality control purposes as well as monitoring and evaluation of Local Municipalities' performance with regard to waste, sewerage, and landfill sites. They note that they have insufficient staff
EDM Disaster Management, Social Services & Public Safety	• EDM has a broader mandate for disaster management than CoM. • Responsible for applying for municipal disaster relief funding.

SANParks (Kruger National Park)	
Conservation Management: Water Resources	• Ensuring adequate environmental flows are maintained in rivers originating outside of the KNP, and that water quality remains within acceptable limits. This requires close cooperation with the IUCMA and DWS.
Scientific Services: Aquatic Ecology	• Integrated bio-monitoring of freshwater ecosystems within the KNP. • Produces an annual report which includes hydrology and biodiversity data and aims to highlight significant changes
DWS	
	• Provincial Office: Engage at CMF meetings and sit on IUCMA governing board • National Office: Data acquisition from RQIS (Resource Quality Information System). RQIS provides national water resource managers with aquatic resource data, technical information, guidelines and procedures that support the strategic and operational requirements for assessment and protection of water resource quality.
DARDLEA Environmental Affairs:	Climate change Adaptation & Mitigation
Chief Directorate – Climate Change (reports to Environmental Policy Planning Coordination)	Responsible for • Policy Development on Climate Change Adaptation and Mitigation, recently added Just Transition • Mainstreaming Climate Change and Just Transition into municipal and provincial Sector Plans • Climate Change and Just Transition Training and Capacity Building • Facilitating climate change development policies to municipal and provincial departments and other stakeholders • Developing Climate Change information and other systems • There is a *Climate Change Coordinator*, assisted by a colleague from EPPC when available
Health-related	
DoH	• Primary health care services through the District Health System Model
National Institute for Communicable Diseases (NICD) is the national public health institute of South Africa,	• The National Public Health Institute of South Africa • Provides reference microbiology, virology, epidemiology, surveillance and public health research and training to support the government's response to communicable disease threats • Assists in the planning of policies and programmes to support communicable disease control and elimination efforts, • Provides numerous specialised diagnostic services. • A critical role is to respond to outbreaks through the Outbreak Response Unit and the Emergency Operations Centre (EOC).

The inclusion of the Provisional Department of Health as well as the clinic committees, which would represent local-level concerns and information on water quality and health, requires further work. Clinic committees are governance structures legislated by the National Health Act. They have an oversight function for quality of care at clinics. Each primary health care facility should have a committee comprised of community members and a facility manager and local government ward councillor. Health requires a broad purview including social determinants so early warning would be in their scope. However resource constraints limited project engagements in this regard and this remains an important area of work in taking forward outputs.

5.2.3 Practices: Integration through a common vision and shared practices

Despite policy intentions supporting cooperation and integration, collaborative governance remains a challenge. Our experience is that integration is more likely through a focus on shared practices since it is the practices that mediate the relationship between policies, action plans and the resource in question. We suggest that greater emphasis should be placed on understanding practices and the challenges and enablers for a shared practice, guided by a common vision. Practices are an important component of governance, and most practices are shared between a number of organisations and partners even when led by one organisation (see Table 7 and Table 8). For example, a number of agencies and partners undertake monitoring for different purposes and a shared understanding of these practices is essential. Understanding these and seeking collaboration and coherence between them can greatly enhance responsive and appropriate actions but is very rarely recognised or examined. These issues can be partially addressed by adopting a systemic, social learning approach for building shared practices around a common focus. The common focus in this work is the management and protection of water quality and water-related health as part of a suite of measures that seek to contribute to water security in the longer term.

A range of practices that relate to the planning, monitoring and mitigation of health risks imposed by water quality challenges include Planning and policy development, Water quality monitoring (status and compliance, Early-warning systems, Disaster management, Regulation, Sharing of information, Community engagement (Table 7). For this project two key collaborative responsibilities were detailed, namely for monitoring (Table 8) and for early warning (

Table 9).

Table 7 Summary of practices related to ensuring compliance with water quality guidelines for beneficial health outcomes

Practice	Detail
• Planning	Different plans are developed within the IUCMA and municipalities which pertain to water resources and each of which requires understanding. For example, Catchment Management Strategy, Water Resources Reconciliation (planning and implementation), the Integrated Development Plan (IDP), the Water Services Development Plans, Water Resources Classification. Health – under review
• Monitoring (compliance and status)	Regulation of unlawful activities is preceded by the need to monitor the status of the resource and compliance with conditions of use. Status monitoring of the resource against benchmarks such as the class of the resource. Compliance monitoring against benchmarks set in general authorisations or the conditions of a water use licence. There are also land-use activities that impact water resources that require regulation (e.g. invasive alien plant control).
• Regulation	This requires procedural action against unlawful use but is supported by data showing transgressions.
• Water Use Authorisation	The issuing of Water Use Licences through water use authorisations includes limits and benchmarks such as RQOs.
• Early Warning Systems and disaster risk reduction	This generally falls under Disaster Management but is also included in operational practices for water resources management and water services as well as climate change preparedness.
• Research (baseline and action-research)	Research is needed to understand water quality-health links regarding legacy contaminants, current risks and emerging contaminants of concern. This then feeds into the establishment of benchmarks, guidelines and policies. Action research with stakeholders embeds such research within a social context.

Practice	Detail
• Stakeholder engagement and education	Stakeholder engagement in understanding plans, guidelines and potential risks is essential. Stakeholders should be actively involved in regulation especially 'internal', self-regulation within a sector.
• Establishment of guidelines	See above.
• Policy development	Policies that guide and regulate harmful practices are a key part of the strategies to mitigate negative impacts. This can include bylaws.
• Transboundary engagements	In the case of transboundary catchments such as the CRC, engagement with riparian states is key.

The key monitoring practices related to water quality and human health is summarised in Table 8.

Table 8 Summary of monitoring practices of key partners

Organisation	Type of Monitoring	Location(s)	Schedule	Sampling Period	Variables
City of Mbombela	Status (Rivers)	To be confirmed	1 x per month		Iron, manganese, conductivity, turbidity and *E. coli.* Sulphate is monitored in upper reaches of the catchment only.
	Compliance (WWTW)	5 WWTW in total 7 purification works in total	2 x per month Responds to an event/ complaint within 5 days		Set by the conditions of the license. Includes some parameters from the Green Drop Assessment.
	Compliance (Drinking)	To be confirmed	2 x per month Full SANS 1 x per year		pH, conductivity, phosphate, nitrogen and *E. coli* SANS standards
IUCMA	Status (Rivers)	80 sites in total	1 x per month (within first 2 weeks)	2016-current	Aluminium; Ammonia N; Arsenic; Calcium; COD; Chloride; Chromium; Copper; EC; *E. coli*; Faecal coliforms; Fluoride; Iron; Magnesium; Manganese; Nickel; Nitrate + Nitrite N; Orthophosphate; pH; Potassium; Sodium; Sulphate; Suspended solids; TDS; Total Nitrogen. Variables differ across different sites.
	Compliance (WWTW)	Milly's (Elands); Emthonjeni (Leeuspruit); Waterval Boven (Elands); White River (White); Rocky's Drift (Sand); Kabokweni (Croc); Kingstonvale (Croc); Kanyamazane (Croc); Barberton; Matsulu (Croc); Mhlatikop (Croc); Hectorspruit (Croc); Komatipoort (Croc); Mhlatiplaas (Croc), Thekwane, New Consort Mine, Louieville.	1 x per month (within first 2 weeks)	2016-current	
Department of Water and Sanitation (DWS)	Status (Rivers)	To be confirmed	Effluent is sampled 4 x per year and sumps are monitored 1 x per month. Responds to an event/ complaint within 5 days.	1970-current	Aluminium; Ammonium N, Ammonia N; Antimony; Arsenic; Barium; Boron; Cadmium; Calcium; COD; Chloride; Chromium; Cobalt; Copper; Dissolved Major Salts; EC; *E. coli;* Faecal coliforms; Fluoride; Hardness; Iron; Kjel Total N; Langl Index; Lead; Magnesium; Molybdenum; Manganese; Nickel; Nitrate + Nitrite N; Orthophosphate; pH; Potassium; Selenium; Silicon; Sodium; Sulphate; Suspended solids;

Organisation	Type of Monitoring	Location(s)	Schedule	Sampling Period	Variables
					Titanium; Total Alkalinity; TDS; Total Nitrogen; TP; Vanadium; Zinc.
	Compliance (WWTW)	To be confirmed	To be confirmed	1970-current	To be confirmed
	Compliance (Drinking)	To be confirmed	To be confirmed	1970-current	To be confirmed
Ehlanzeni District Municipality (EDM)	Compliance (WWTW)		1 x per year and in response to an event	2016-current	Monitor compliance in accordance with Section 24(2A) of NEMA
	Compliance (Drinking)		2 x per month	2016-current	Full SANS 241
Silulumanzi	Compliance (WWTW)	Kabokweni (Crocodile); Kanyamazane (Crocodile); Kingstonvale (Crocodile); Matsulu (Crocodile); Rocky's Drift (Sand); White River (White); Barberton-Umjindi (Suid-Kaap).	1 x per month	To be confirmed	To be confirmed

Table 9 An example of responsibilities of different partners in early-warning related to pollution events

Subjects	Responsibilities
Department of Health (DOH) Incident management team (nurses, doctors, health department officials).	Identifying possible point source for outbreak, supply services to manage, risk assessment and advising the municipalities on informant dissemination and disease management.
IUCMA Resource Quality Monitoring scientists and Compliance, Monitoring and Enforcement.	The IUCMA is responsible for water quality monitoring and investigating any possible outbreak and reporting back to the local and District Municipality. In a case where a W/WT plant is identified as the potential source of the outbreak, a directive is issued to the Local Municipality responsible for WWTW and WTW management to remedy the breakout.
Local municipality Ward councillors, WWTW and WTW technical staff	Information dissemination on disease prevention and management, clean water supply, treating water in WWTW and WTW.
District Municipality	Water testing and reporting to national government.
NICD (The National Institute for Communicable Diseases)	• Provide support to the department to the Department of Health. • Incident assessment and patient testing. • Report outbreak to WHO.
Local Clinic and hospital staff Who: Nurses, Doctors, Homebased caregivers.	• The technical and clinical task teams are responsible for recording cases and updating cholera states and providing health services to affected individuals in the community. • Collecting diarrhoea states for Cholera indicator.

5.3 REMARKS

Compliance with water quality standards (benchmarks) relies not just on the act of regulating but rather on a bundle of practices which collectively contribute to compliance (Pollard et al., 2023). Nonetheless, engagements with stakeholders persistently raised concerns regarding the regulation or the lack thereof, noting that – despite good policies and guidelines – regulation was problematic. At the workshop in October 2021, it was noted that the IUCMA has taken over much of the regulatory activities and whilst making progress was facing the challenge of substantial backlog in cases.

Whilst the IUCMA and SANParks, both with key practices related to water resources and compliance, were a key focus of this project, this does not imply that there are no other key partners who should be engaged. Rather, this reflected the limitations imposed by funding and Covid-19 for ongoing stakeholder engagements for the work and the fact that the INWARDS system is already under development with the IUCMA. Indeed, there are a range of other partners within the water supply, health and disaster management domains (see above) who would need the outputs of the Water-Quality Health System. Thus, it is emphasised that a detailed understanding and the development of shared practices would be subject to further funding, some of which we are delighted to note has been secured (see below). This would include the stakeholders identified above and most importantly, the vulnerable communities whose rights to a healthy environment and water are enshrined in the constitution.

CHAPTER 6: REVIEW OF POTENTIAL WATER POLLUTION IMPACTS ON HUMAN HEALTH AND THE DEVELOPMENT OF NARRATIVES FOR HUMAN HEALTH RISKS

6.1 INTRODUCTION

As noted, water resource managers are often provided with standards to comply with, which are developed by specialists and captured in reports. ***These standards have little meaning or value if not used in conjunction with the potential risks associated with non-compliance***. For example, in rural areas where people may have a direct dependence on run-of-river for drinking water, exceedance of a benchmark (such as arsenic through mining) will pose a risk to human health. The outputs need to have meaning for water resource managers, staff and stakeholders and these need to be readily available. For example, in our work with the CMA and DWS staff, answers to the following questions are regularly sought:

- *What are the priorities in terms of acting on non-compliant, unlawful water-use activities?*
- *If this water use licence application is approved, what are the likely consequences downstream?*
- *If there is non-compliance with water quality standards, what are the potential implications thereof?"*

Moreover, the value of identifying risks is enhanced if supported by narratives. In consultation with the users (principally the IUCMA), narratives explaining potential health impacts have been integrated with the potential risks associated with these standards, as a user-friendly manner to support water resource managers in the decision-making process. For example, increasing loads of arsenic in domestic and irrigation water poses a public health threat including short-term vomiting and diarrhoea whilst long-term exposure can cause cancer (WHO, 2018). Understandably, this would be vital information for any water resources manager and would support difficult decision-making in the face of competing uses. Such easily-accessible information is of major benefit especially within the context of South Africa, where water resource managers lack resources such as capacitated staff and budget.

6.2 METHODOLOGY

In order to derive narratives a number of key steps were followed:

1. Development of principles and framework
2. Identification of water quality variables (see Chapter1)
3. Identifying standards, data and detection limits
4. Undertake a literature review (including EDCs)
5. Development of draft narratives
6. Review with IUCMA staff
7. Finalisation

6.2.1 Principles and framework

In addition to the a systemic, social learning approach a number of key factors were considered.

Climate change: At a temporal scale, risks over time were considered. Such risks are likely to increase under climate change which is projected to reduce surface water flow increasingly in an easterly direction between

20-60% in the near future (Sawunyama and Mallory 2014; Schulze and Davis 2019). Such alarming impacts – which will affect dilution capacity (amongst other things) – need to also be considered in the assessment of risks. Thus integrating climate change impacts was a core consideration.

Current models in South Africa: Another advantage enabled by the work proposed herein is that a module for INWARDS is being developed that supports the Water Quality Systems Assessment Model (WQSAM, see Section 1.1) currently setup for the Crocodile catchment. The module will accommodate both the analysis of WQSAM data outputs as well as a suite of processing tools, which will stream line data population of the WQSAM. This will significantly bolster the analytical capacity of the WQSAM as well as reducing the human capital cost associated with manually updating WQSAM datasets on a continuous basis. In addition, this project will endeavour to equip WQSAM with the data models required to simulate water quality loads based on three-day flow and rainfall forecasts. This allows for pro-active rather than reactive water quality management.

International recommendations

The WHO notes that it is important to take account of the impact of the proposed intervention on overall rates of disease. For some pathogens and their associated diseases, interventions in water quality may be ineffective and may therefore not be justified. This may be the case where other routes of exposure dominate. For others, long experience has shown the effectiveness of improving drinking-water supply and quality management in the control of waterborne diseases such as typhoid and dysentery.

Progressive realisation and transitional targets

The IUCMA has the responsibility to manage against the Reserve and RQOs (see below). Once these are gazetted they are legally binding and, within effective IWRM, form benchmarks against which management is enacted. For example, the IUCMA reports regularly on non-compliance to their Board and to stakeholders. South Africa recognises that achieving compliance may take time and the legalistic notion of progressive realisation is important (Pejan et al.; 2007; 2011). For this, it may be important to establish stringent transitional targets supported by sound risk management systems which track incremental improvements of water quality (WHO, 2022).

6.2.2 Identification of water quality variables

Given the land use (Figure 13), land-use changes and the associated links to water resources, a number of key water quality variables were selected for a detailed analysis and for use in the Water Quality-Health Module and narratives were then developed for each of these. These are shown in Table 1.

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6.2.3 Standards, benchmarks and establishing limits

The Water Quality-Health Dashboard is reliant on trigger values for displaying the severity of risk as well as for running analyses against the observed data (see also Chapter 10). The human health risk calculations provide maximum and average values which are static and need to be translated into a suite of algorithms applied to observed data and predefined parameters. This enables site-specific risk assessments where the data requirements are met.

In addition, to gain a spatial representation of risk, a model is required. In this case, the WQSAM model has been used to fill in the gaps where observed data does not exist for a few of the parameters of concern, particularly those defined in the RQOs. To this end, a wide range of benchmarks have been utilised for determining the potential risks to biotic and human health. The following more formal/ legislated limits provide the DSS with the limit ranges to trigger an exceedance flag and the subsequent risk and provide a narrative with the potential health impacts.

Biotic Health:

- Resource Quality Objectives (RQOs) for EWR sites
- Generic National Resource Quality Objectives for Non-EWR sites
- Department of Water Affairs and Forestry (DWAF). 1996c. South African Water Quality Guidelines (second edition). Volume 7: Aquatic ecosystems.

Human Health:

- South African National Standard (SANS) 241 Drinking Water Specification (SANS 241:2015)
- World Health Organization. 2011. Guidelines for Drinking-water Quality. WHO. 4TH edition.
- Department of Water Affairs and Forestry (DWAF). 1996a. South African Water Quality Guidelines (second edition). Volume 1: Domestic Use
- Department of Water Affairs and Forestry (DWAF). 1996b. South African Water Quality Guidelines (second edition). Volume 4: Agricultural Water Use: Irrigation.
- The United States Environmental Protection Agency (EPA). 2003. Fact sheet: National secondary drinking water standards, Office of Water. US EPA. European water standards
- Government of British Columbia. 2006. British Columbia approved water quality guidelines. Ministry of environment. Canada. GBC.

6.2.3.1 Protocols for the use of limits

The IUCMA follows a number of protocols in using a variety of benchmarks. Whilst RQOs are normally the most stringent and therefore would cover all other users limits, not all sites that are monitored have (a) RQO values/ limits established for that site and (b) RQOs have not been established for all water quality variables. It follows therefore that the IUCMA have developed an approach that takes into account the need for compliance with RQOs and the Reserve at sites (through progressive realisation) and that is appropriate for users. Thus, a range of benchmarks are used in the protocol used by the IUCMA (Figure 23).

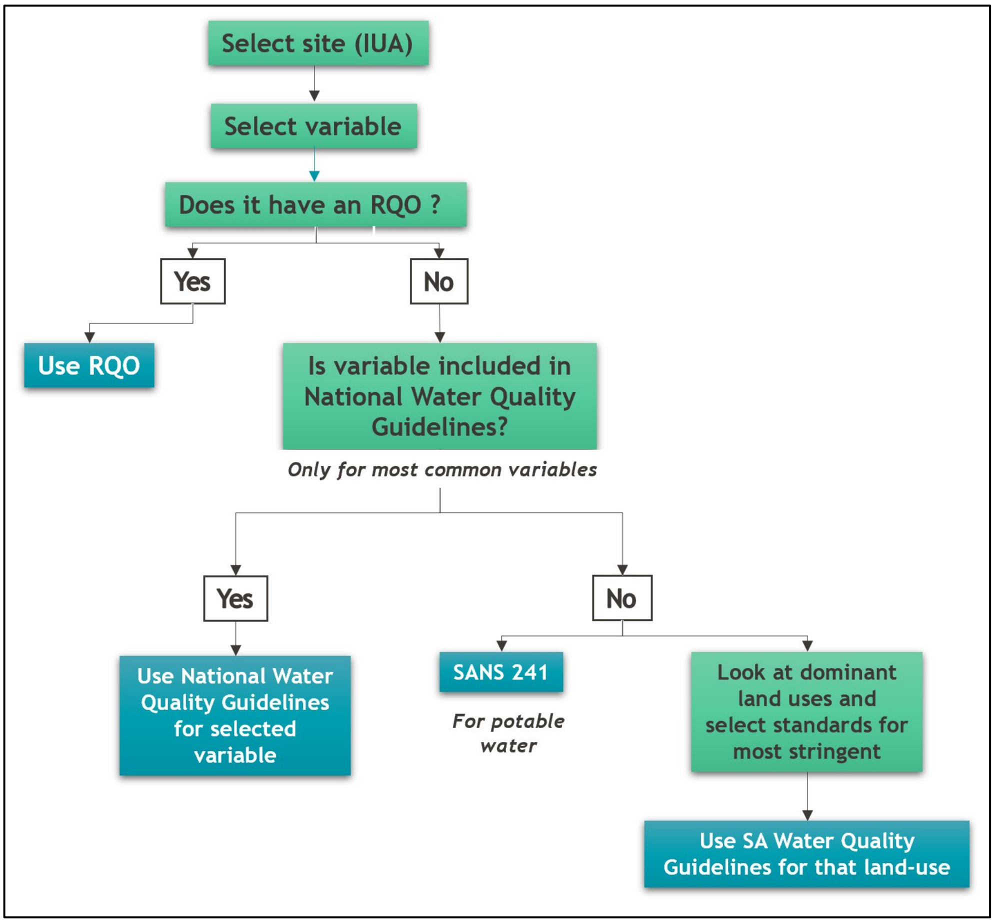


Figure 23 Overview of general protocol used by the IUCMA in selection of appropriate benchmarks/ limits for a variable at a site

6.2.3.2 Resource Quality Objectives

In the case of biological health, there are predefined parameters that have been set and that vary spatially and that are captured as the Resource Quality Objectives (RQOs) (see Table 10). These form part of Resource Directed Measures. The National Water Act states that the purpose of RQOs is to establish clear goals relating to the quality of the relevant water resources and stipulates that in determining RQOs a balance must be sought between the need to protect and sustain water resources and the need to use them. In line with the above, RQOs comprise both a descriptive which is useful for stakeholders and a Numerical Limit which can be used for monitoring and management (e.g. concentration of dissolved solids at x mgl-1). The RQOs are also key in terms of setting the conditions of a Water Use Licence (WUL) including discharge quality specifications. These form part of the Source Directed Controls within Integrated Water Resources Management in South Africa. It is recognised that site-specific conditions (such as geology) mean that the RQOs need to be context specific. In the absence of these, the IUCMA uses other guidelines as shown in Figure 23.

Table 10 Resource Quality Objectives used to report against by the IUCMA for the Crocodile River Catchment

Site	*E. coli*	*pH*	*PO4*	*EC*	*Cn*	*As*	*TIN*	*Turbidity*	*Temp*
C-1	120	6.5-8.0	0.015	30					
C-3	130	6.5-8.0	0.025	30					
C-17	130	6.5-8.0	0.015	30					
C-12	130	6.5-8.0	0.025	30					
C-14	130	6.5-8.0	0.015	55					
C-42	130	5.9-8.8	0.125	70					
C-63	130	5.9-8.8	0.125	70				Acceptable	
C-54	130	6.5-8.8	0.125	200	0.004	0.02	1		
C-72	130	5.9-8.8	0.125	70				Acceptable	**Not more than 2°C from baseline (Aquatic Ecosystem driver)**

6.2.3.3 National Resource Water Quality Guidelines

A generic set of Resource Water Quality Objectives (RWQOs) was developed for the country's surface water resources is also used to assess compliance. While it is recognised that water resources vary considerably and different management RWQOs are in place in many catchment areas, these provide a generic set of assessment RWQOs used to provide a consistent indication of fitness-for-use of water resources anywhere in the country. They were derived using the Resource Water Quality Objectives (RWQOs) Model based on the South African Water Quality Guidelines. These guidelines are used by the IUCMA.

Table 11 Generic Resource Water Quality Objectives at a National Level (DWA 2011)

Variable	Units	Bound	Ideal	Sensitive user	Acceptable	Sensitive user	Tolerable	Sensitive user
Alkalinity ($CaCO_3$)	mg/l	Upper	20	AAq	97.5	AAq	175	AAq
*Ammonia (NH_3-N)	mg/l	Upper	0.015	Ecological	0.044	Ecological	0.073	Ecological
Calcium (Ca)	mg/l	Upper	10	Dom	80	BHN	80	BHN
*Chloride (Cl)	mg/l	Upper	40	In2	120	In2	175	In2
*EC	mS/m	Upper	30	In2	50	In2	85	Ecological
Fluoride (F)	mg/l	Upper	0.7	Dom	1	Dom	1.5	Dom
Magnesium (Mg)	mg/l	Upper	70	Dom	100	Dom	100	Dom
NO_3 (NO_3-N)	mg/l	Upper	6	Alr	10	Alr	20	Alr
*pH	units	Upper	≤ 8	In2	<8.4	In2		
		Lower	≥6.5	Alr AAq In2	>8.0	Alr AAq In2		
Potassium (K)	mg/l	Upper	25	Dom	50	Dom	100	Dom
*PO_4-P	mg/l	Upper	0.005	Ecological	0.015	Ecological	0.025	Ecological
SAR	mmol/l	Upper	2	Alr	8	Alr	15	Alr
Sodium (Na)	mg/l	Upper	70	Alr	92.5	Alr	115	Alr
*SO_4	mg/l	Upper	80	In2	165	In2	250	In2
TDS	mg/l	Upper	200	In2	350	In2	800	In2
Si	mg/l	Upper	10	In2	25	In2	40	In2

Basic Human Needs BHN; Domestic use Dom; Agriculture - Irrigation Alr; Agriculture - Aquaculture AAq; Industrial - Category 2 In2

*Selected water quality variables used for the water quality status planning review

6.2.3.4 South African Water Quality Guidelines

The South African Water Quality Guidelines serve as the primary source of information for determining the water quality requirements of different water uses and for the protection and maintenance of the health of aquatic ecosystems (DWAF 1996). There are eight volumes addressing domestic, recreational, industrial, agricultural (irrigation, livestock, aquaculture) and aquatic ecosystems.

6.2.3.5 SANS 241

The SANS 241 Drinking Water Specification states the minimum requirements for potable water to be considered safe for human consumption. These requirements include microbiological, chemical and physical properties of the water. The current draft has been revised in-line with the latest World Health Organisation (WHO) guidelines for developing drinking water quality regulations and standards, international and national best practices in drinking water quality risk management, as well as using WRC research on water quality and emerging contaminants of concern. Other important considerations include the WHO guidelines and limits set in the Water Safety Plan of municipalities.

6.2.4 Literature review

Once the variables were selected, a review of global and local literature (state-of-knowledge) was undertaken[9]. The output was a *Literature review of the potential impacts and risks of water quality pollution for human health with a focus on risks and recommendations for the Crocodile River Catchment.* A summary: of potential health impacts of selected water quality variables is given below (Section 6.2.5). This focuses on the constituents of concern which were identified based on the water quality and health risk assessment.

6.2.4.1 Summary: Review of endocrine-disrupting chemicals (EDCs) in the Crocodile River (East), Mpumalanga, South Africa (BMZ-funded)

Additional funding from BMZ-SA facilitated the inclusion of some initial research and analysis on endocrine disruptors (EDCs). This is because EDCs have been linked to adverse health outcomes (including cancer, reproductive impairment, cognitive deficits and obesity) by interfering with hormone action (LaMerrill et al., 2019). The work was designed to complement this WRC project and hence is summarised here. Further details are available on request and project completion. This work, being undertaken by a team from the University of Pretoria, University of Stellenbosch and iThemba labs, aims to explore the following questions:

- What EDCs can be expected in the CRC (steroidal, non-steroidal, pesticides, herbicides) based on a review of the literature, land-use and what risks do they pose? (Pesticide and Herbicidal component?).
- Where are the endocrine disrupters entering the system and what they are?
- Are they being removed/treated by the WWTW
- Where do they end up? In fish, impact on human health based on the levels we observe?
- How far do they travel?

This included a literature review on EDCs as summarised below (Trutter et al., 2022). The endocrine system plays a key role in organismal chemical communication being involved in physiological processes such as metabolism, growth and development, reproduction, osmoregulation, behaviour, cardiovascular regulation, and immune function among others (Molina, 2010). The presence of EDCs has been shown in virtually every type of aquatic system including rivers, dams, marine environments, and ground- and tap water (Kassotis et al., 2015; Kloas et al., 2009; Krimsky, 2000; Metcalfe et al., 2022a; Shi et al., 2012). The identification of potential EDCs and sources of contamination in the environment is therefore of importance as part of water quality evaluations and from a human and biotic health and wildlife conservation perspective.

[9] largely by the research assistants with guidance as part of capacity development

Natural and man-made chemicals and elements have the potential to disrupt the endocrine systems of humans and wildlife. These endocrine-disrupting chemicals (EDCs) are **diverse in source and structure** and include: certain pharmaceuticals, personal care products, pesticides, surfactants, hydrocarbons originating from fossil fuels or the combustion thereof, metals, flame retardants, plasticisers and various other chemicals used in the manufacturing industry, and natural hormones excreted by humans (Casals-Casas and Desvergne, 2011; Jasrotia et al., 2021; Metcalfe et al., 2022a).

The major targets of EDCs described to date are

- The reproductive system (hypothalamus-pituitary-gonadal [HPG] axis),
- The thyroid system (hypothalamus-pituitary-thyroid [HPT] axis) and
- Adrenal system (or interrenal system in fish) (hypothalamus-pituitary-adrenal [HPA]; hypothalamus-pituitary-interrenal [HPI]) (Diamanti-Kandarakis et al., 2009).
- Metabolism is a further important target of EDCs which has received increased attention in the past decade due to the global rise in human metabolic disorders such as obesity and type 2 diabetes (Casals-Casas and Desvergne, 2011). A number of chemicals are now classified as obesogens, driving a positive energy balance (e.g. tributyltin, bisphenol-A and certain phthalates) (Egusquiza and Blumberg, 2020).
- EDCs can also modify the epigenome and influence endocrine physiology and behaviour across multiple generations (Alavian-Ghavanini and Rüegg, 2018; Major et al., 2020; Skinner et al., 2011).

Some of the earliest reported cases of EDC effects were in fish populations occurring in rivers downstream of wastewater treatment plants (WWTPs) (Jobling et al., 1998). Various further reports of adverse effects associated with fish reproductive systems due to EDC exposure have since been reported (Matthiessen et al., 2018). A further well-known case of endocrine disruption in a wild population is the American alligators, *Alligator mississippiensis*, inhabiting the polluted Lake Apopka, Florida, United States, where both males and female alligators were shown to exhibit developmental abnormalities in their reproductive systems (Guillette et al., 1994; Guillette et al., 1996). Moreover, the thyroid systems of juvenile Lake Apopka alligators were also significantly impacted with abnormal thyroid anatomy and thyroid hormone levels being observed in hatchlings (Boggs et al., 2013; Crain et al., 1998)

The potential sources of EDCs in the CRC include WWTW, agriculture (crops, livestock, aquaculture), forestry, landfills, paper and pulp effluent, trace metals and mining and metallurgy.

<u>Wastewater Treatment Works (WWTW; </u>see Table 3): None of the 20 WWTW was awarded Green Drop accreditation in 2021 (i.e. scores above 90%) although in several cases the effluent quality meets the regulatory standards with 94% compliance with physical – and 97% with chemical – limits. However problems are noted with only 50% compliance against the mandatory microbiological standards. *E. coli* sampling of 28 sites bi-annually since 2017 indicates a gradual deterioration of water quality.

<u>Agriculture:</u> The identities and concentrations of pesticides in the CRC water, sediment and biota are expected to be considerably different three decades after earlier studies (Van Dyk, 1978; Heath, 1999; Heath and Claasen, 1999; Roux et al., 1994) due to the banning of organochlorine pesticides, changes farming practices, and the growth of the agriculture industry in the region. Future investigations describing pesticide burdens in water, sediment and biota are needed to assess the risks agrochemicals pose to humans and wildlife in the CRC. The extent of macadamia orchards in Mpumalanga has increased from 3064 to 24052 hectares between 1999 and 2021 (SAMAC, 2021). Insecticides and fungicides are applied for stink bugs, nut borers and thrips as well as fungi, and the contamination of water courses by these chemicals is inevitable. No research to date has however been performed to assess the impact of the macadamia industry on waterbodies and such data will be of value considering the rapid expansion of the industry in Mpumalanga and other provinces.

Crops: Data on pesticide levels in the CRC is limited and mostly describes legacy chemicals that have been banned for decades (Van Dyk, 1978; Heath, 1999; Heath and Claasen, 1999; Roux et al., 1994). Land-use data suggest increased risk of pesticide pollution in the mid- and lower regions of the Crocodile River as well as in the Queens, Noord-Kaap and Kaap Rivers in the Barberton area.

Aquaculture: There are several aquaculture facilities in the Elands River Catchment. However, the quality of aquaculture wastewater in the CRC in terms of EDC burdens is yet to be determined.

Forestry: Forestry is extensive amounting to 26.88% of the total surface. Pesticides are used as part of forestry practices, but at considerably lower quantities and frequency of application than other forms of agriculture such as fruit and vegetable production (Palma et al., 2004). Nonetheless, they are a potential source of EDCs.

Landfills: There are four solid waste landfills in the CRC including the Baberton, Tekwane (Mbombela), Machadodorp and Ngodawana fills. Pappa's Quarry is a further landfill located in Mbombela and has been used as a disposal site for metallurgical waste by the Manganese Metal Company for decades (Heath, 1999). Runoff from the site is known to contaminate the Gladdespruit Stream and the Crocodile River with manganese and other trace metals (Heath, 1999). The screening of streams and rivers potentially receiving landfill effluents in the CRC for legacy chemicals and other CECs including EDCs (e.g. flame retardants, fluorinated compounds and hazardous metals) is needed.

Paper and pulp effluent: The Sappi Ngodwana paper mill is situated on the banks of the Elands River – a major tributary of the Crocodile River. Previous studies have reported increased Cl concentrations downstream of the paper and pulp mill (Roux et al., 2018; Soko and Gyedu-Ababio, 2015). The endocrine disruptive potential of wastewater or surface water downstream of the plant is yet to be tested.

Trace metals: Reports of potentially hazardous metals and other elements in water, sediment and fauna in the CRC are limited.

Mining and metallurgy: There are two manganese smelters in the CRC: The African Rainbow Minerals Machadodorp near the Leeuspruit Stream (upper Elands River), Manganese Metal Company, located in Mbombela approximately 300 m from the Crocodile River. The open-cast Strathmore magnesite mine is situated near Malelane.

Gold: The Kaap River Catchment has been a gold mining region since the late 19th C due to gold deposits of Barberton Greenstone Belt. A total of 154 mine and mineral workings were registered in the Barberton region of which 109 had closed by the late 1990s (Heath, 1999). These closures include the Bonanza mine in 1989 which represented a relatively large operational unit (Sibiya, 2019). Further closures have occurred including Lilly mine in 2016 due to the crown pillar collapse. Mines currently operational include Sheba, New Consort, Fairview and Agnes.

Acid Mine Drainage (AMD): Limited research has been published describing AMD prevalence and risks in the Barberton Greenstone Belt. However, Trutter et al. (this project) caution that this is a likely concern.

The IUCMA data indicates increased levels of metals in the Kaap River Catchment are likely associated with water seeping from active or inactive mining operations which may include AMD. Further research is needed to better understand the impact of mining operations on the water quality of the CRC and the potential adverse health effects (including endocrine disruption) of such water on wildlife and other water users.

The Inkomati-Usuthu Catchment Management Agency (IUCMA) reported on **As, Mn and Cr** in the CRC including the Kaap River Catchment for 2019-2021 (IUCMA, 2020; IUCMA, 2021).

- As: 20 µg/l

2019 & 2020: Arsenic exceedance of 20 µg/l in the Louws Creek and its tributaries and the Kaap River downstream of the Louws Creek confluence in both 2019 and 2020 (IUCMA 2020; IUCMA, 2021).

- Cr: 14 µg/l
  2019: Chromium exceedance of 14 µg/l in the Leeuspruit Stream in the Elands River Catchment, in the proximity of the Manganese/Chromium smelter (IUCMA 2020).
- Mn: 180 µg/l
  2019 Mn exceedance of 180 µg/l guidelines in the Gladdespruit and Besterspruit (Kaap River Catchment) and White River (IUCMA 2020).
  2020, Mn exceedance in the Gladdespruit and Besterspruit rivers (IUCMA 2021).

6.2.5 Development of draft narratives for risk mitigation

From the above data, two forms of narratives were developed: a longer version for this report and a summarised version for inclusion in the dashboard. Particular attention was given to avoid inferences of direct causality if data were not available. Because environmental exposures are complex and can be confounded by other socio-economic and environmental factors (including other water quality variables), making conclusive statements on causality can be challenging. Moreover, causal inference is indeed difficult because it is inherently focused on exposures which occur in dynamic and evolving environmental (climate change, hydrology and pollution), socio-economic and demographic contexts. Consequently many epidemiological studies often conclude that further studies are needed to address causality. The danger therefore is that no action is taken until such trials have been conducted. However, this is not a reason for inaction since problems are only likely to compound as demands on water (exacerbated by climate change) increase. Whilst the topic of inferences and causality is beyond the scope of this project, this topic is receiving increasing attention given the tension between the need to address deepening environmental public health challenges and the need for sound scientific approaches. However, there are epidemiological studies that are proposing more effective approaches to deal with this apparent dilemma, noting that 'Environmental epidemiologists have always attempted to make inferences about causality from imperfect data and have discovered many major environmental causes of disease" (Pearce et al., 2019). Our approach has been to invoke the precautionary principle, noting that there is sufficient global data on chronic and acute health risks for many variables to do so, and that 'fixing the problem' once it is being experienced is far costlier (socially and environmentally) than simply adopting a precautionary approach supported by robust management, monitoring and data where available. This is in accordance with Pearce et al. (2019) proposal for a more pluralistic approach to the triangulation of epidemiological evidence.

The database used for input into the water Quality Health Dashboard (see Chapter 9) followed a standard format as follows:

1. Introduction/ overview
2. Source: Many variables are found naturally in an environment due to geology which must be taken into account, together with potential anthropogenic sources.
   2.1. Natural
   2.2. Other
3. Health effects
   3.1. Acute toxic effects
   3.2. Acute chronic effects
   3.3. Carcinogenic effects
4. Limits
5. Treatment options which although not comprehensive offers some mitigation measures. In many communities this would require mediation and support

The following gives a high-level summary the potential health risks related to constituents of concern from the Human Health Risk Assessment.

Arsenic

Acute high-level exposure to arsenic can lead to symptoms such as vomiting, abdominal pain, diarrhoea, dehydration, and even death in severe cases. The dose that can cause extreme poisoning and potentially fatal outcomes can vary but in general, acute arsenic poisoning can occur at doses of approximately 70 mg or more of arsenic compounds, which can cause symptoms such as abdominal pain, vomiting, and diarrhoea, and may progress to seizures, shock, and death.

Chronic exposure to lower levels of arsenic can also cause health problems over time, including skin lesions, cardiovascular disease, diabetes, and neurological effects. Long-term exposure to low levels of arsenic through drinking water or food can also lead to chronic arsenic poisoning, which can cause a range of symptoms, such as skin pigmentation changes, peripheral neuropathy, and skin cancers. Arsenic can cause neurological effects, affecting memory, and intellectual function. Arsenic accumulates in the body during childhood and may induce neurobehavioral abnormalities during puberty, and neuro-behavioural changes as an adult. Foetal mortality and preterm birth increased as exposure to arsenic increased. It has also been associated with cardiovascular disease and diabetes.

The International Agency for Research on Cancer (IARC) of the World Health Organisation (WHO) has classified arsenic and arsenic compounds as carcinogenic to humans (Group 1). Arsenic can cause cancer of the skin, lungs, bladder, and kidneys.

Cadmium

Cadmium may cause serious toxic effects and numerous health problems, including acute and chronic toxic effects as well as carcinogenicity

- Kidney damage: Cadmium accumulates in the kidneys and can cause damage, leading to kidney disease and failure
- Lung damage: Inhalation of cadmium can cause lung damage, including emphysema and lung cancer
- Bone damage: Long-term exposure to low level cadmium can cause bone damage, including osteoporosis and fractures
- Cardiovascular disease: Cadmium exposure has been linked to an increased risk of cardiovascular disease, including hypertension and heart disease
- Reproductive and developmental problems: Cadmium exposure can also affect reproductive and developmental health, including reducing fertility and causing birth defects
- Gastrointestinal problems: Ingestion of cadmium can cause gastrointestinal problems such as nausea, vomiting, and diarrhoea

Acute toxic include abdominal pain, nausea, vomiting, diarrhoea, headaches, weakness and fatigue. In severe cases, cadmium poisoning can lead to coma and death.

Cadmium has been linked to several types of cancer, including lung cancer, prostate cancer, and kidney cancer. The IARC has classified cadmium and cadmium compounds in Group 2A (probably carcinogenic to humans). However, there is no evidence of carcinogenicity by the oral route.

Chromium

Numerous toxic effects are associated with excessive exposure to chromium. Renal, liver, gastrointestinal, cardiac, haematologic, and reproductive issues, growth difficulties, nasal perforation, and ocular damage are among the most serious symptoms of chromium exposure (Achmad, Budiawan and Auerkari, 2017).

The IARC has classified chromium (VI) as a known human carcinogen (Group 1) and chromium (III) as not classified as to its carcinogenicity to humans (Group 3). In other words, it is known that

Chromium III does NOT cause cancer in humans. Chromium (VI) compounds are active in a wide range of in vitro and in vivo genotoxicity tests. There are no adequate toxicity studies available to provide a basis for a No Observed Adverse Effect Level, or NOAEL. The guideline value was first proposed in 1958 for hexavalent chromium, based on health concerns, but was later changed to a guideline for total chromium because of difficulties in analysing for the hexavalent form only.

Manganese

Although manganese is an essential element, it is neurotoxic in excessive levels. There is no evidence for manganese carcinogenicity in humans and it would be rated Group 3 (not classifiable) using the IARC Criteria.

At large doses, manganese toxicity represents a serious health hazard, resulting in severe pathologies of the central nervous system. In its most severe form, the toxicosis is manifested by a permanent crippling neurological disorder of the extrapyramidal system, which is similar to Parkinson's disease. In its milder form, the toxicity is expressed by hyperirritability, violent acts, hallucinations, disturbances of libido, and incoordination. The previous symptoms, once established, can persist even after the manganese body burden returns to normal.

Sulphates

The major health effect observed is a laxative action. Infants are most susceptible to excess sulphate levels, which is especially important if they are bottle fed.

Nitrates and nitrites

Upon absorption, nitrite combines with the oxygen-carrying red blood pigment, haemoglobin, to form methaemoglobin, which is incapable of carrying oxygen. This condition is termed methaemoglobinaemia. The reaction of nitrite with haemoglobin can be particularly hazardous in infants under three months of age and is compounded when the intake of Vitamin C is inadequate. Metabolically, nitrates may react with secondary and tertiary amines and amides, commonly derived from food, to form nitrosamines which are known carcinogens.

E. coli

The risk of being infected by microbial pathogens correlates with the level of contamination of the water and the amount of contaminated water consumed. Higher concentrations of faecal coliforms in water will indicate a higher risk of contracting waterborne disease, even if small amounts of water are consumed. Most water-borne pathogens can result in gastroenteritis which includes salmonellosis, dysentery, cholera and typhoid fever.

6.2.6 Review with partners/ IUCMA staff

Once draft narratives had been developed, these were reviewed with the IUCMA staff as key partners for the use of the system. Details were discussed around the HHRA method and results, the meanings behind various terms (see Chapter 8) and the management implications. In particular it was noted that such narratives would be very useful for reporting to multiple stakeholders on potential impacts; in other words, the “so what?” of non-compliance with a limit of a certain variable.

CHAPTER 7: WATER QUALITY RISK ASSESSMENT

7.1 INTRODUCTION

The most recent assessment of water quality at a catchment scale was that of Griffin et al. (2014) who noted that although the water quality in the catchment was previously considered good, there were indications of degradation in some areas, including the lower Crocodile, lower Kaap, and Elands Rivers (ICMA 2011, DWA 2011a, Griffin et al., 2014). The assessment undertaken for this project is less comprehensive than that of Griffin et al., (2014), where data was analysed across multiple sites in the context of the resource quality objectives (RQOs). This assessment used the same data extended to 2022 but is rather focussed on identifying the trend and source of key indicator water quality species (sulphates, orthophosphates and Total Inorganic Nitrogen) both in concentration and load in the different regions of the Crocodile River Catchment. For the purposes of the water quality risk assessment, the variables identified as important from the land use and as indicator variables or species (see Table 1) were used for this risk assessment. Furthermore, some of the available toxin (metals) and biological (e.g. *E. coli*) data that are analysed in Chapter 8 were also included in the context of their locality and potential risk to human health.

7.2 DATA SOURCES

The analyses were performed using two datasets, that provided by the Department of Water Affairs and Sanitation (DWS), Directorate of Resource Quality Information Services (RQIS) and the Inkomati Usuthu Catchment Management Agency which has been collected since 2016. These datasets contained all available physico-chemical and biological parameters for the Crocodile River Catchment. All verified data were extracted from INWARDS DSS (henceforth referred to as INWARDS) which sources all available verified data through an API provided by the DWS Hydrological Services Directorate.

7.3 DATA PROCESSING

The DWS water quality dataset was provided as a SQLite database (~3GB in size). The analyses only required data for the Crocodile River Catchment so an SQL query was used to extract these The data were further manipulated using Python scripts into the desired format required for the INWARDs database (performing unpivot and pivot functions at a scale that cannot be done in Excel). The data was then imported into various tables within the INWARDS database. Sites were linked to hydrological stations where possible, and the individual samples were then populated with a corresponding discharge value which represented discharge on the day that the sample was taken.

The IUCMA dataset was provided in the form of an excel spreadsheet, with each sheet within the spreadsheet containing a different water quality constituent. The sheets were combined manually to address some inconsistencies in data structure and format. These combined sheets were then imported into the INWARDS database. It is important to note that the IUCMA datasets were restructured to match that of DWS, which included relabelling to ensure consistency across the two datasets.

Finally it is important to note that a concerted effort was made to maintain the link of the detection limit[10] to each individual sample. This allows for the use of the measurement when using the accepted rule recommended by DWAF (2008a): if the sample value is below the detection limit, then the recommendation is

[10] The detection limit is the lowest concentration of a chemical that can be reliably measured depending on the lab equipment

to use half the detection limits value as the measurement in the analysis, e.g. if detection limit is 1 then the value would be 0.5.

7.4 SITE SELECTION

There are data available from many more sites across the catchment but these could not be used because a) many of these sites could not be linked to a hydrological site, b) insufficient data or c) locations were not applicable for an overview analyses. The issue of data variability is summarised in Figure 25. This time series analyses for sulphates, which is a commonly analysed variable, shows there are only a few sites which have consistent long-term data available.

The eight water quality monitoring sites (Table 12; Figure 24) were selected based on their location within the CRC, to give a spatially representative overview of the water quality status of the catchment. It is important to note that charts are labelled using the chart code as this provides the reader with a reference to the tertiary catchment within which the monitoring station is located. Specific sites were examined in detail (see below) if the initial analysis indicated concerns.

Table 12 Sites selected for analyses

DWS Station	*Chart Code*	*n*	*Site*	*Represents*	*Quat*	*Discharge Station*
102958	Montrose_102958	1660	Crocodile River at Montrose	Upper Crocodile	X21	X2H013
102961	Elands_102961	1413	Elandsrivier at Lindenau	Elands	X21	X2H015
102952	Nels_102952	801	Nels River at Boschrand	Nels	X22	X2H005
102967	Karino_102967	377	Crocodile River at Karino on	Middle Crocodile	X22	X2H023
102953	Wit_102953	708	Wit River at Goede Hoop	White River	X22	X2H006
102965	Kaap_102965	1078	Kaap River at Dolton	Kaap	X23	X2H022
102963	River_102963	2045	River Side at Kruger	Lower Crocodile	X24	X2H016
102987	TenBosch_102987	686	Crocodile River at Ten Bosch	Crocodile Outlet to Inkomati	X24	X2H048

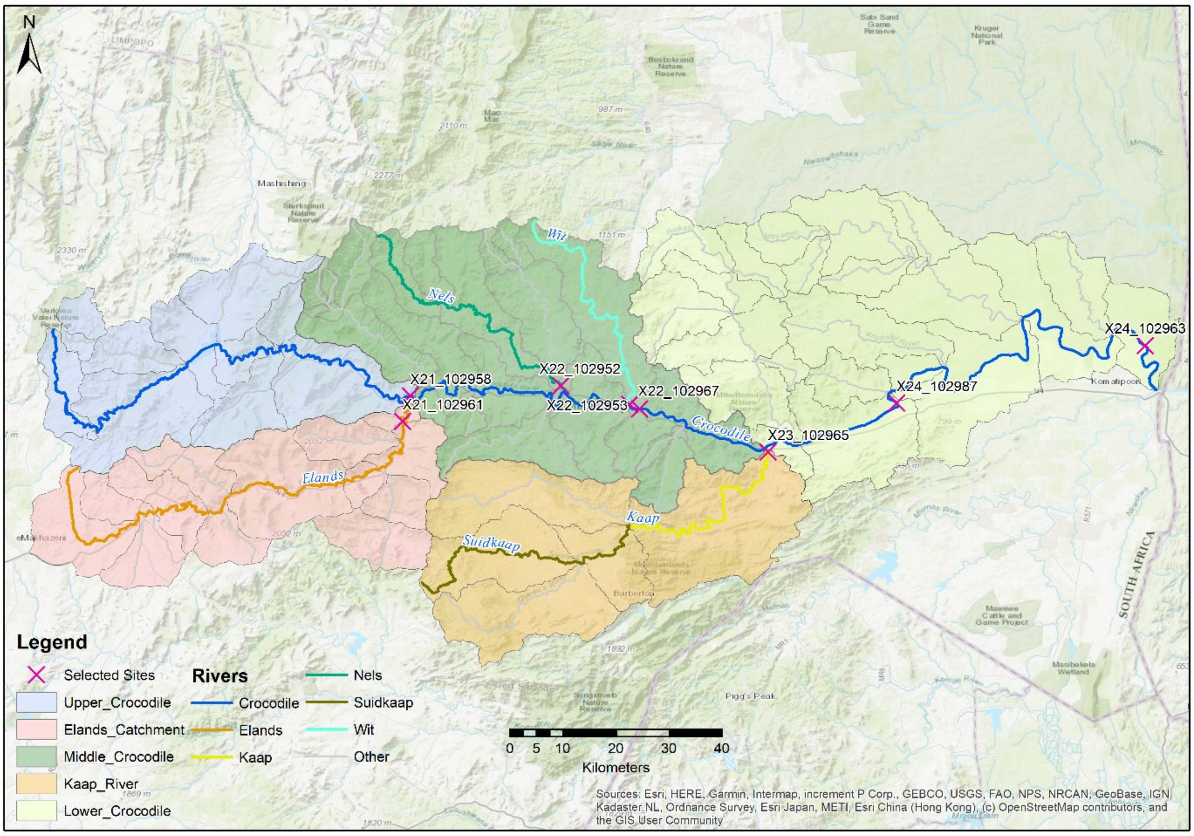


Figure 24 Map showing the distribution and locations of the eight water quality sites selected for the analyses

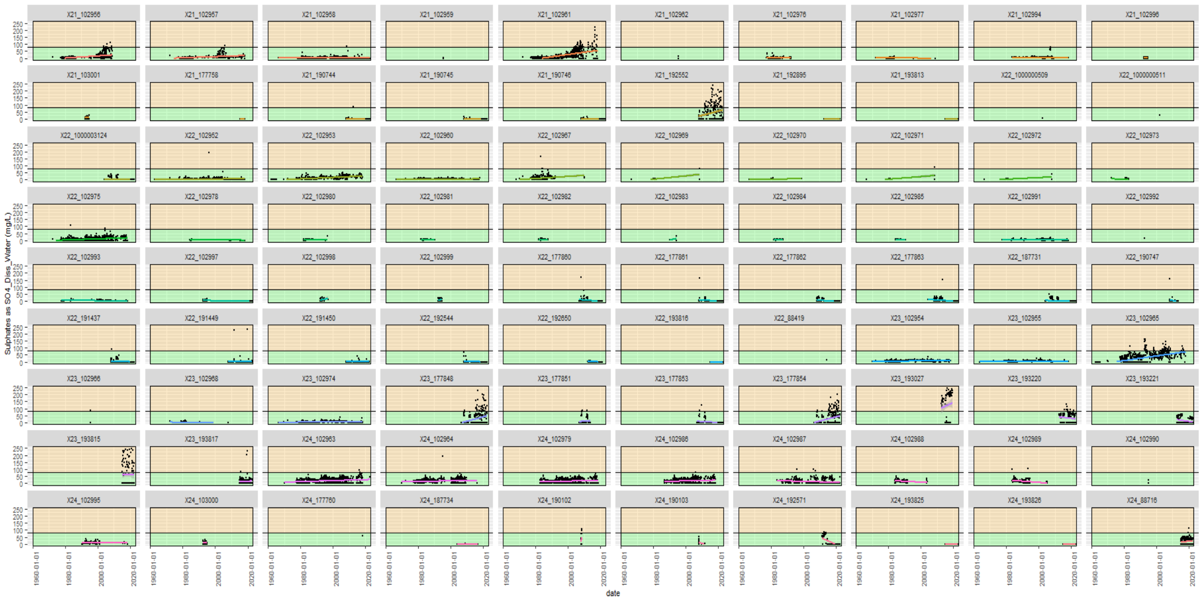


Figure 25 Time series plots for all available water quality sites indicating the significant variability in the availability of sulphate data in terms of location and length of datasets in the Crocodile River Catchment.

7.5 WATER QUALITY CONCENTRATION AND LOAD TREND ANALYSIS

Time series trend analysis is a statistical method used to analyse data over a period of time to identify trends and patterns. In the context of water quality analysis, time series trend analysis can be used to identify changes in water quality parameters such as orthophosphates, and sulphates over a given period. This analysis can help to identify the effects of human activities and natural processes on water quality.

One method used in time series trend analysis is loess regression, which is a non-parametric regression method that can be used to identify trends in noisy data. Loess regression uses a local weighted regression to fit a curve to the data and can be used to identify both linear and nonlinear trends. It is particularly useful when there is significant variability in the data, and can be used to identify trends even when the data is not normally distributed as is often the case of water quality data. For example Wang et al. (2019) used loess regression to analyse trends in nitrogen and phosphorus concentrations in a river over a 20-year period. Another study by Li et al. (2020) used loess regression to analyse trends in pH and dissolved oxygen in a lake over a 10-year period. Overall, time series trend analysis and loess regression can be powerful tools in water quality analysis, allowing researchers to identify long-term trends and patterns in water quality data.

INWARDs allows for the rapid and detailed assessment at the site level of trend, seasonal distribution, loads and compliance. However, there is no loess trend integration; thus, when dealing with multiple sites R scripts were used to produce the statistics and charts. Sites of concern were further interrogated using the more detailed analyses provided by INWARDS.

Water quality can be measured in two ways: by pollutant concentration or pollutant load. Each is useful but each has limitations. Concentration is the *mass of a pollutant in a defined volume of water* (for example, mg of sulphate per litre,). Concentration is a useful parameter to assess water quality because it has biological significance to organisms of concern where for example, a high concentration of nitrogen and phosphorus in surface water leads to the growth of phytoplankton (and hence lowers dissolved oxygen levels, with harm to fish and other aquatic organisms) or nitrate-nitrogen levels (concentrations as PPM) in drinking water can be harmful to infants.

Load is the *amount (mass) of a pollutant that is discharged into a water body during a period of time* (i.e. tons of sulphate per year). Pollutant loading is also a useful measure of water quality; when evaluating an entire catchment to calculate the load of a given pollutant that can be accommodated from various sources (agriculture, industry, WWWT) without the catchment exceeding a water quality standard. In the U.S. this is referred to as the Total Maximum Daily Load (TMDL).

The load duration curve analysis is an approach to estimate existing loads and assimilative capacity. They can be useful for can be useful in differentiating between possible loading from point and nonpoint sources. By estimating source loads, you can evaluate and compare the relative magnitude of major sources, and the timing and frequency of those loads.[11]

Some practitioners.[12] have suggested that assessing pollutant load is a more accurate approach to evaluating the contribution of individual agricultural concerns to regional water quality impairments, but they also note limitations including the fact that the actual measurement of loading can be complicated and expensive

7.5.1 Load Duration Curve Analysis

Water quality load analysis involves the quantification of the *mass of a pollutant transported by a river in a given time period*. Load duration curves (LDCs) are a commonly used tool in water quality load analysis that relate the frequency and magnitude of pollutant loads to time. LDCs are constructed by ranking the discharge

[11] https://www.pca.state.mn.us/sites/default/files/wq-iw3-50-11.pdf

[12] E.g. https://cemonterey.ucanr.edu/files/171000.pdf

and the associated pollutant loads from highest to lowest and plotting them against the percentage of time that the corresponding load was exceeded.

LDCs are useful for understanding the temporal variability of pollutant loads in a river and can help identify periods of high pollutant loading and the associated flow at the time. One challenge of using LDCs is that they require long-term water quality monitoring data to be effective.

7.5.2 Spatial and temporal overview of water quality

It is crucial to account for water quality loads when assessing spatial trends throughout a catchment While this section examines significant spatial patterns, it does not explicitly consider temporal changes which is dealt with below. It is essential account for temporal trends as the water quality status may change significantly in a short period of time, an aspect which is not captured in a broad spatial assessment. Ignoring water quality loads could lead to misinterpretation of the presented data, hindering effective decision-making for the management of water resources as interventions are most effective when the quantity of pollutant is controlled as the concentrations observed are a result thereof. Acknowledging this, loads are incorporated in the analyses for both spatial and temporal analyses. Many studies have been conducted in the Crocodile River Catchment, therefore this analysis excludes many of the more common variables by only focusing on three? major indicator species, i.e. sulphates, orthophosphates and total organic nitrogen which are accepted indicators for activities relating to mining and industry (sulphates) and wastewater treatment works (orthophosphates), as was described in the previous section. These sectors have been identified as key concerns and the following analyses will help provide an indication of the extent, trajectory and severity of their influence on water quality in the Crocodile River Catchment. In addition, to the spatial and temporal analysis of these water quality constituents, the toxins which may be present were also examined in the context of the indicator species.

7.5.2.1 Sulphates

The concentrations observed for the time period are predominantly within the ideal range for sulphates with some samples nearing the tolerable thresholds at the Elands and Kaap sites (see Figure 26). The largest loads are observed at Karino and at TenBosch (middle and lower Crocodile River). This is expected as the tributaries will load into the Crocodile River, and since sulphates are conservative, variable loads are not easily sequestrated. The two major tributaries influencing the sulphate loads in the Crocodile River are again the Elands and Kaap River reaches (see Figure 26). There is a small decrease in concentration (Figure 26) between RiverSide and TenBosch (the two lowest sites), suggesting that there is some kind of dilution occurring. However the data indicates that the loads (Figure 27) are reducing indicating that there is a removal of sulphates from the river between the two sites. This may be due to the sugar cane plantations with irrigation return flows being filtered. While this is an added benefit to the system, the potential sequestration of **sulphates means that there is the potential for significant toxin retention as well**. The most notable trends are the increasing trends for the Elands and the Middle to Lower Crocodile River catchment monitoring points (Figure 28). The loading into the system would suggest that the Elands is the primary driver of this trend. The load trends (Figure 29) show a clearer trajectory as the concentration trends are often masked by the dilution capacity of the system. Most notable are the trends seen at the Elands where the loads are again expressed in the trend downstream at Karino. The Kaap River while being a major contributor seems to have no trend but rather a consistent loading into the Crocodile over a very long period, which would be expected from the legacy mining impacts and potential ground water contamination.

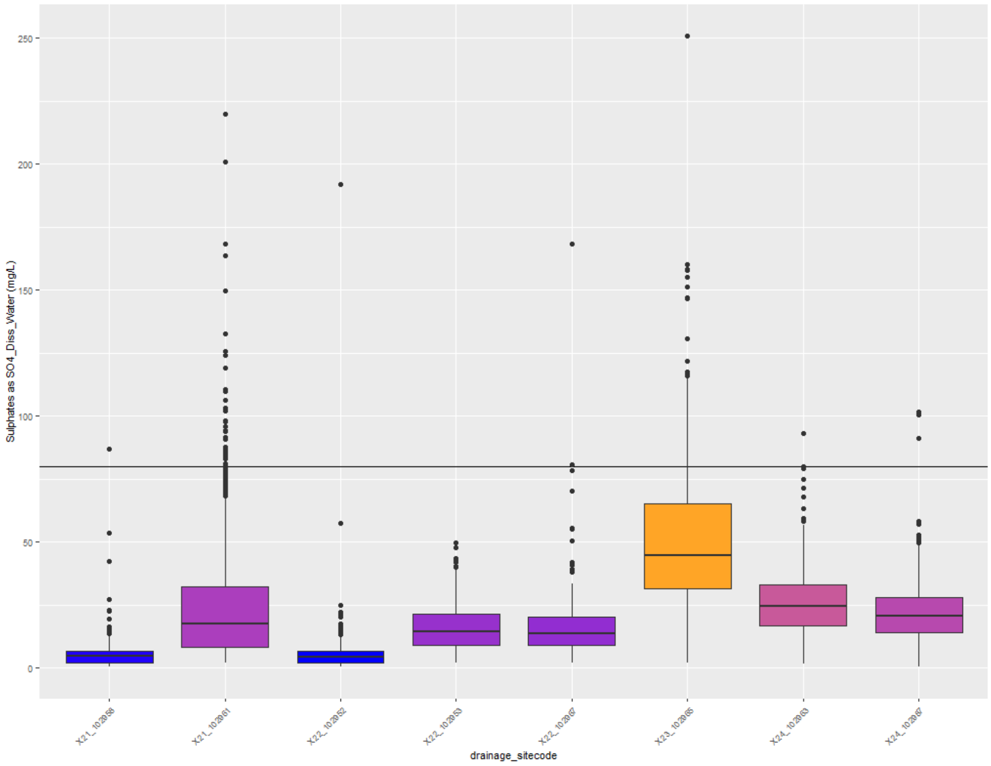


Figure 26 Boxplots of sulphate (mg/L) concentration for the selected sites (upper to lower catchment) from left to right this is Crocodile River at Montrose, Lindenau (Elandsrivier), Boschrand (Nels River), Karino (Crocodile River), Goede Hoop (Wit River), Dolon (Kaap River), Kruger (River Side), Ten Bosch (Crocodile River)

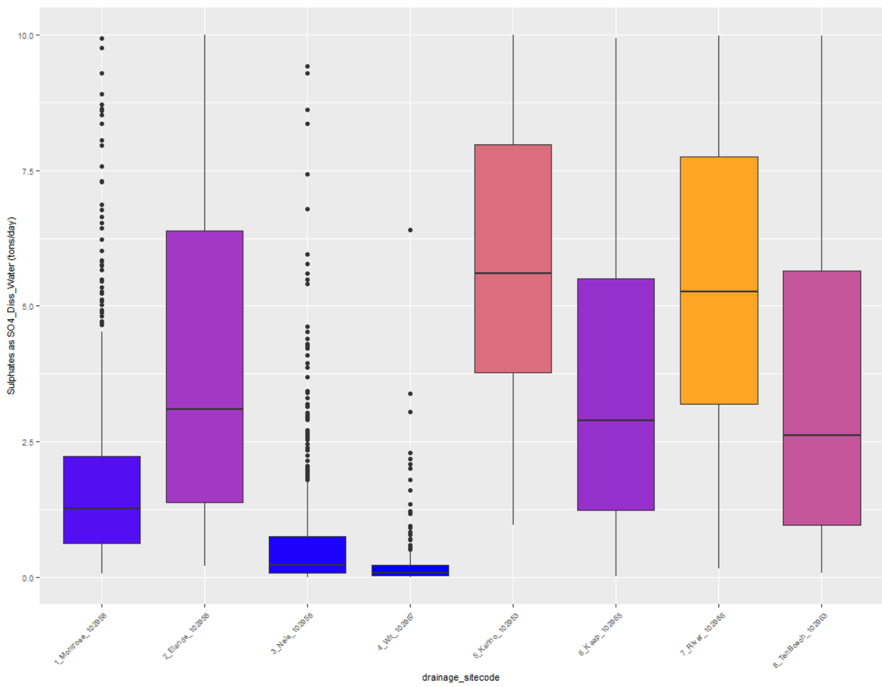


Figure 27 Boxplots of sulphate loads (Tons/ day) or the selected sites (upper to lower catchment)

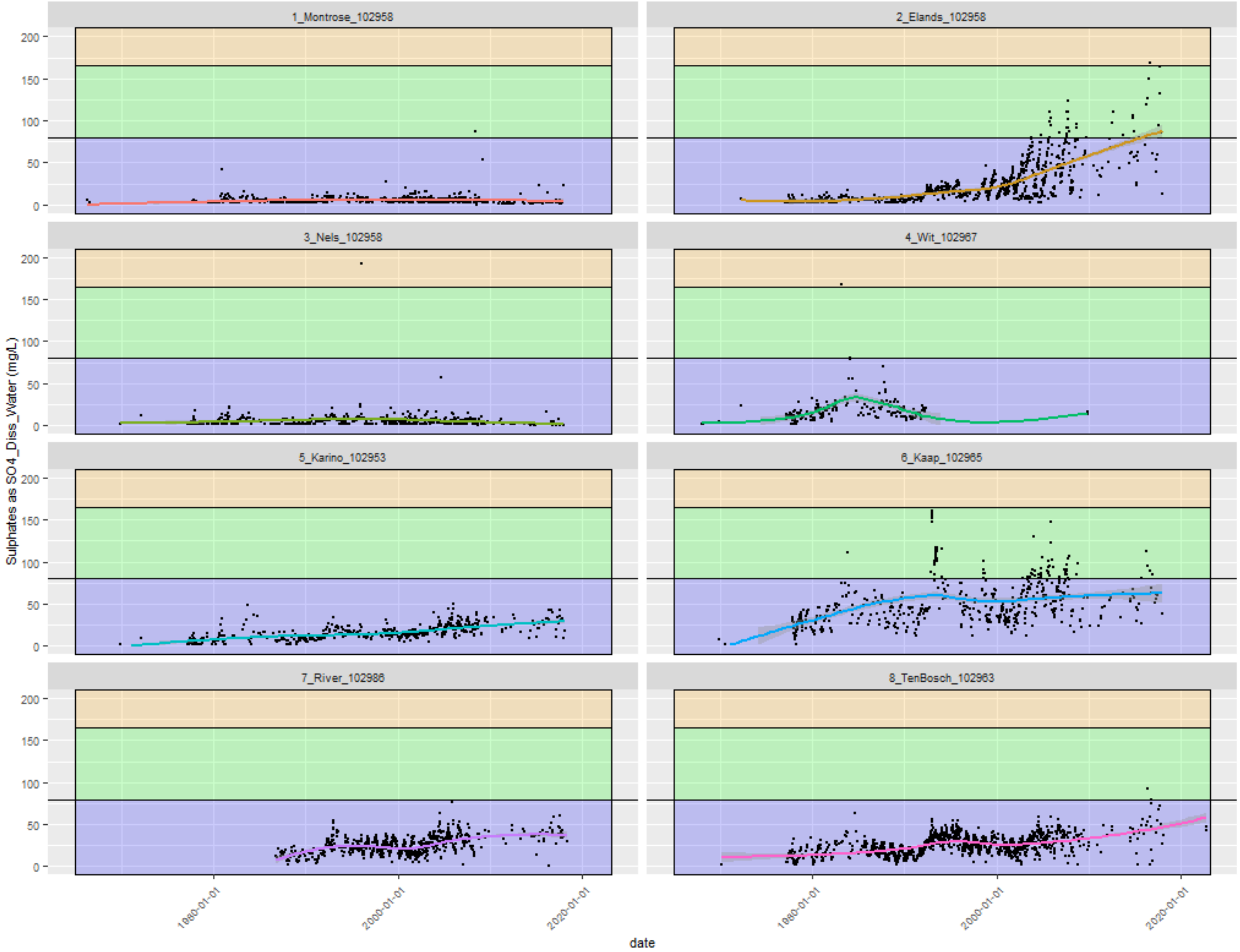


Figure 28 Trend analysis for sulphates (mg/L) for the eight selected sites

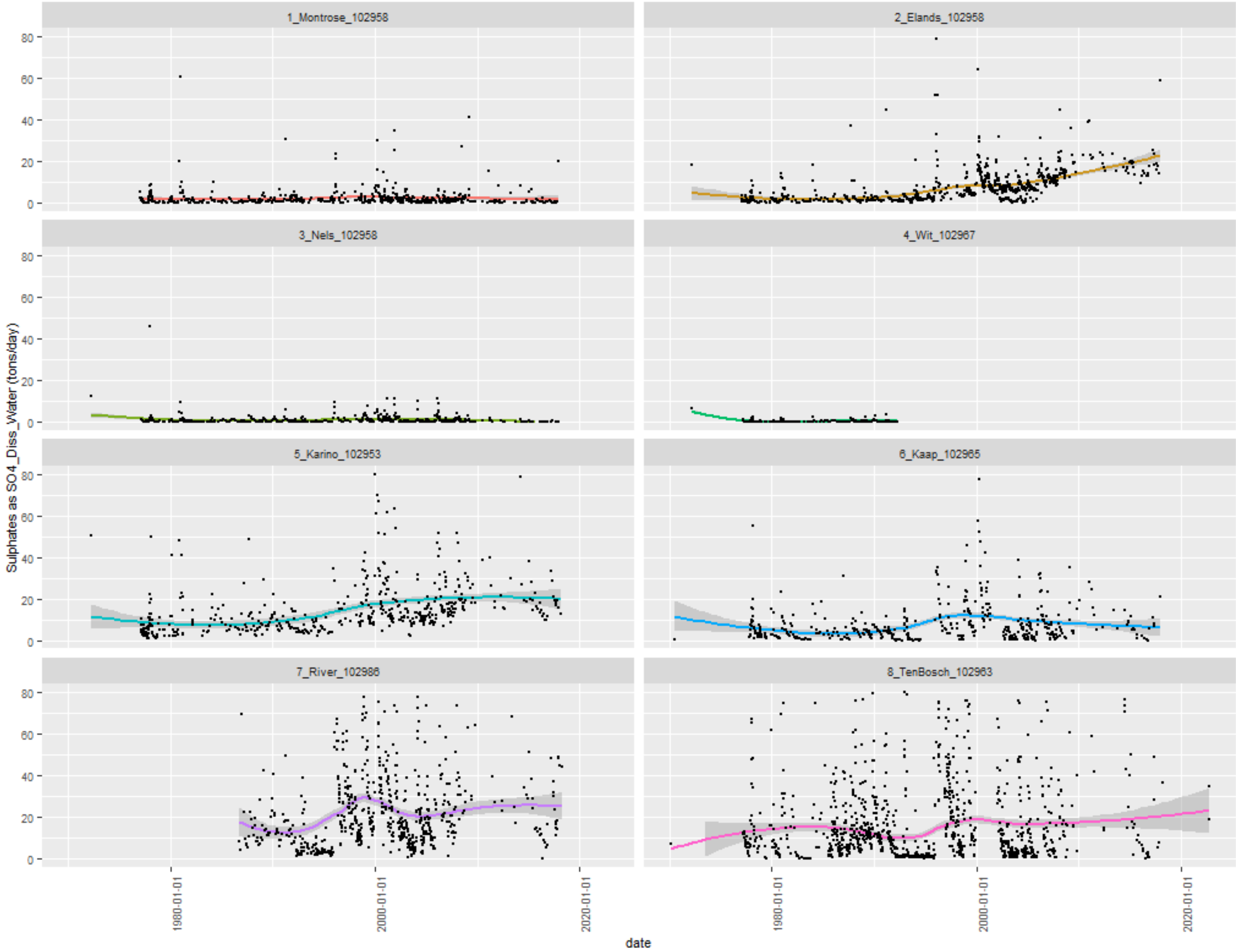


Figure 29 Load trend analysis for sulphates (Tons/ day) for the eight selected sites

7.5.2.2 Orthophosphate

The dominant water quality constituents analysed that are of concern are orthophosphates and ammonium, which appear to exceed the tolerable thresholds at all monitoring points (see Figure 30). The highest concentrations observed are at Karino and River View, where the median concentrations have exceeded the upper limit. Both these sites are situated downstream of large urban and industrial areas and one of the major driver of point source water pollution in the CRC is industrial and domestic wastewater disposal (Deksissa et al. 2004), with many sewage treatment works discharging effluent directly into the middle reaches of the Crocodile River and its tributaries. This is true for both these sites having a number of settlements and WWTWs upstream. It is important to note as explained above, these orthophosphate levels are associated with high levels of *E. coli*. While orthophosphates are a problem across the catchment, all sites are showing a downward trend since 2010 (i.e. improvement). This is a trend which has been noticed country wide and it is suggested that it has to do with a large manufacturer removing all phosphates from their cleaning products.

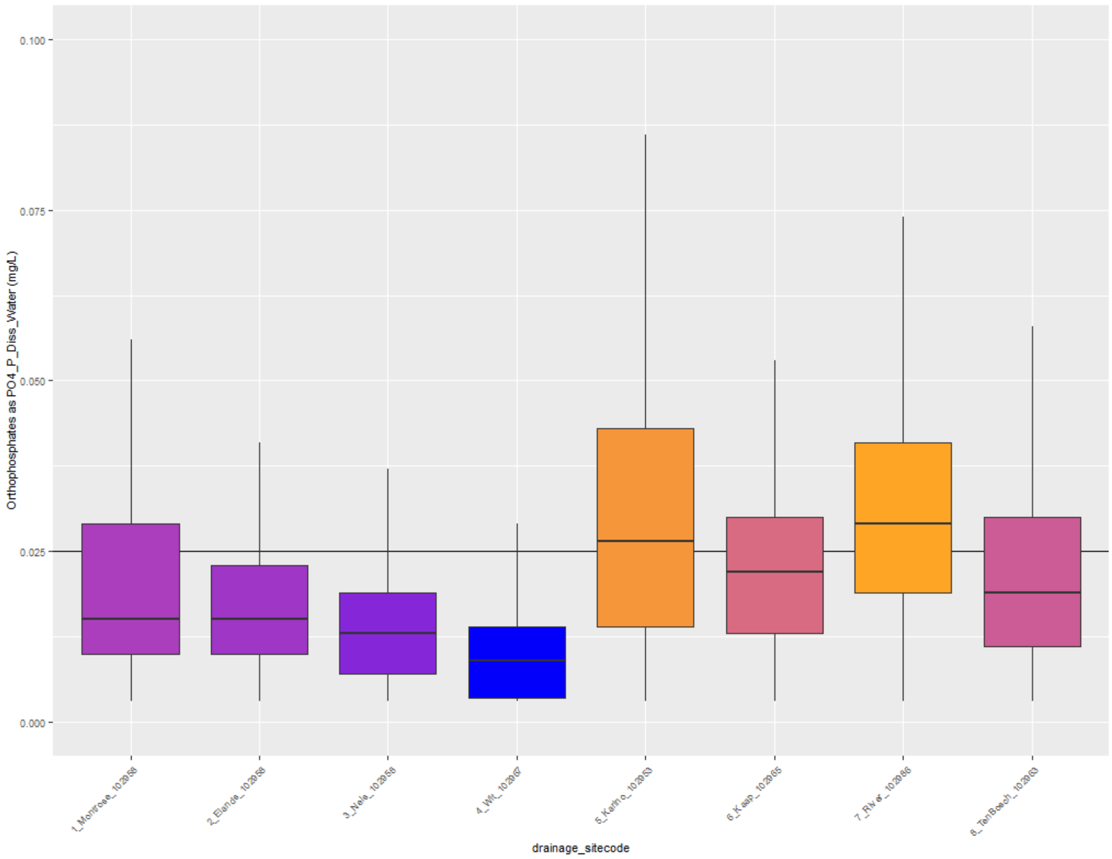


Figure 30 Orthophosphate (mg/L) concentration boxplots

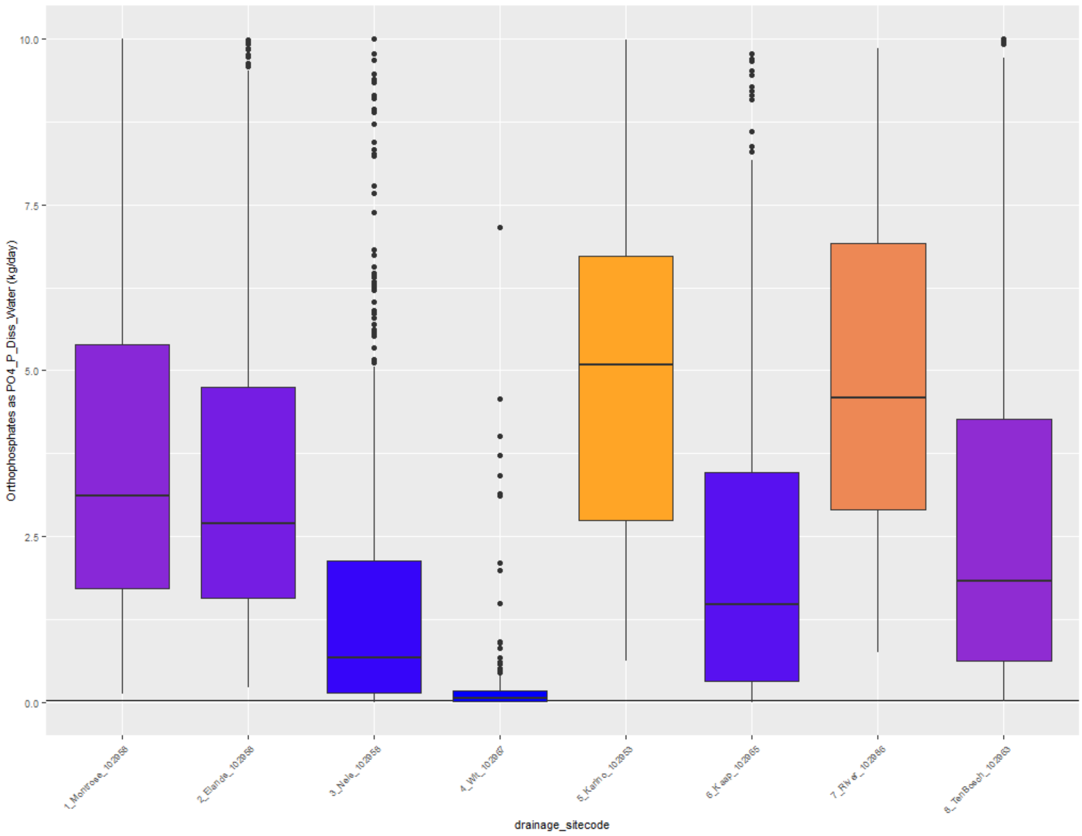


Figure 31 Orthophosphate loads per site represented as boxplots in kg per day

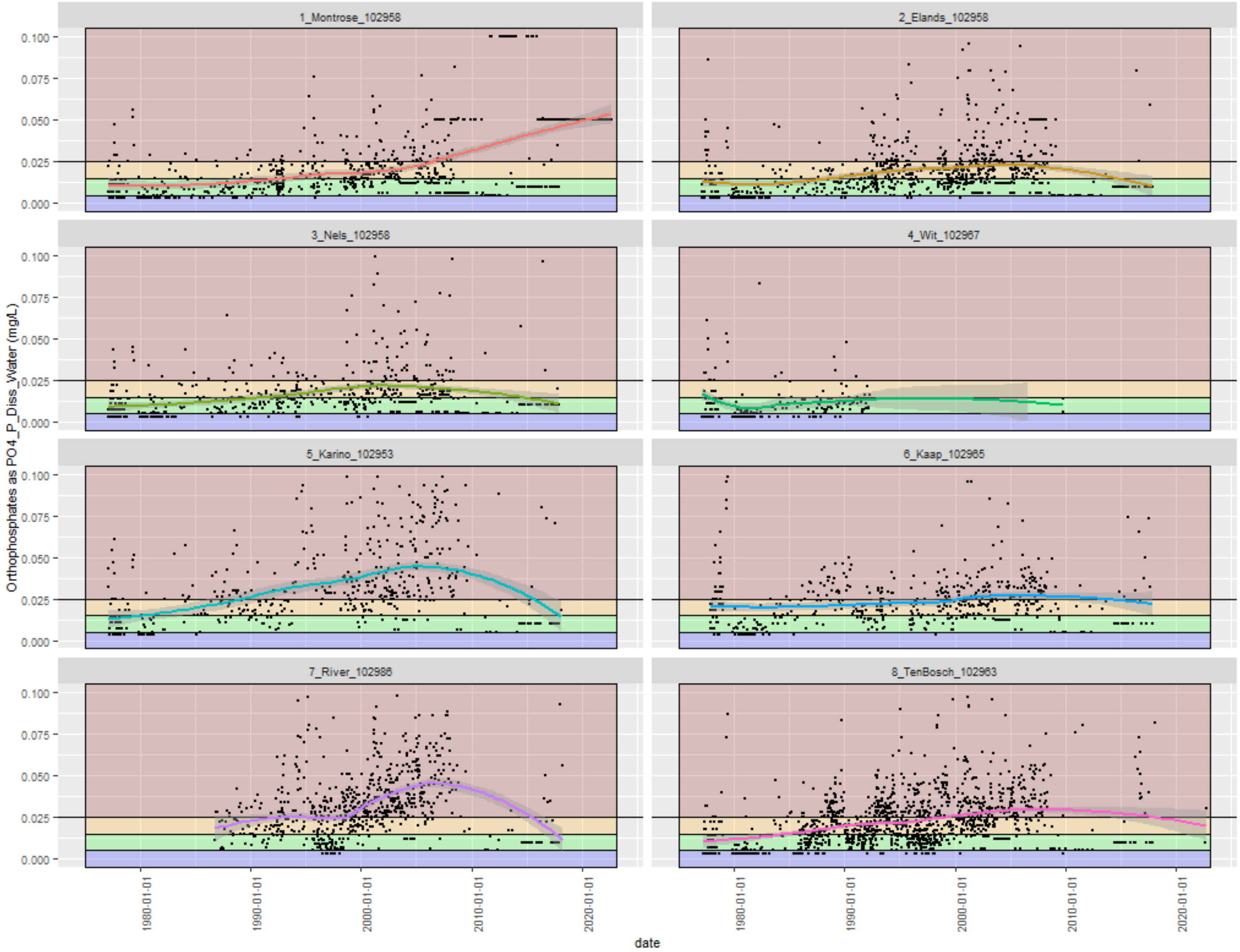


Figure 32 Orthophosphate (mg/L) trends

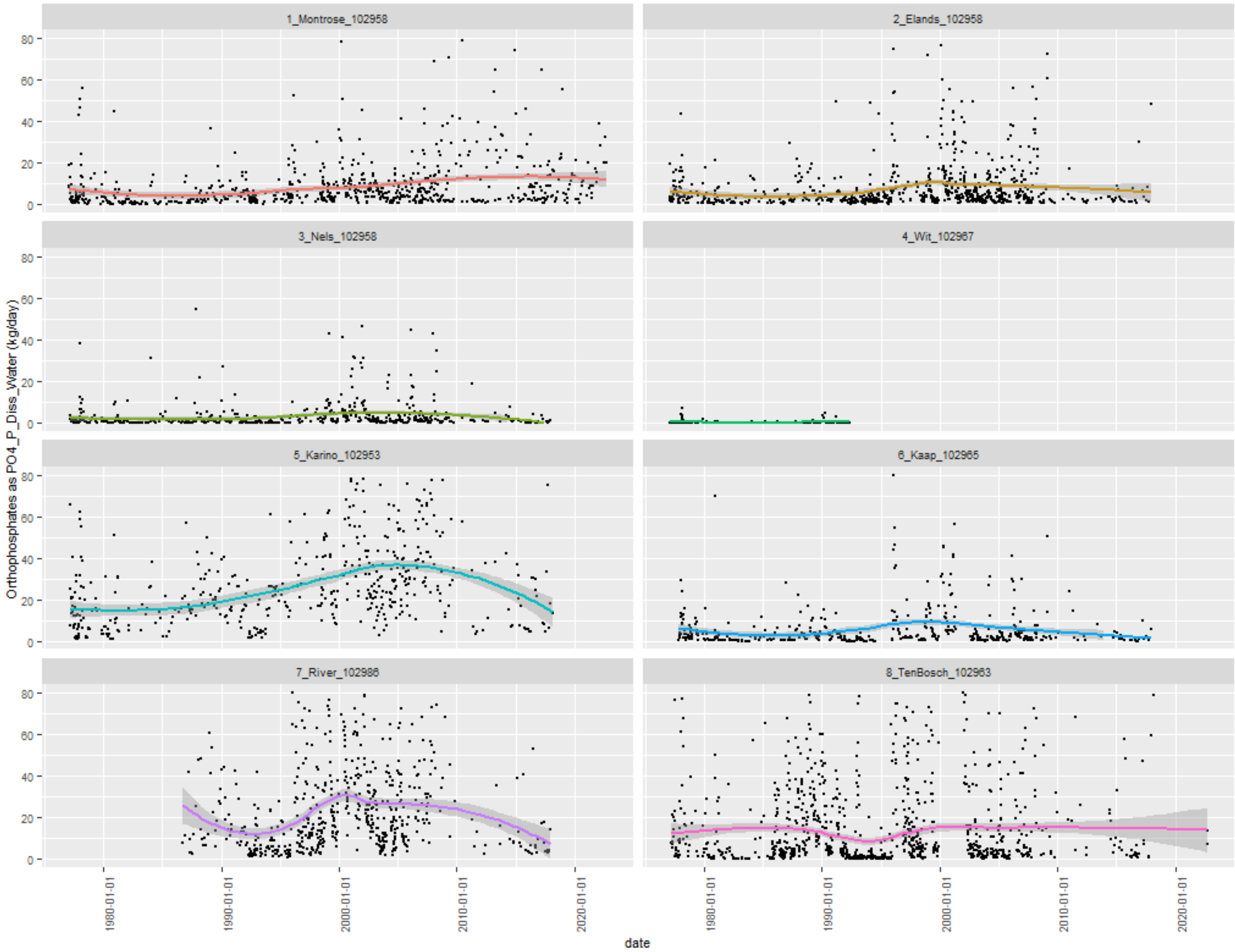


Figure 33 Orthophosphate (kg/day) load trends at eight sites

7.6 USING THE INWARDS DSS TO IDENTIFY POTENTIAL SOURCES OF WATER QUALITY VARIABLES

Using INWARDS DSS, the analysis focused on identifying the potential sources based on the seasonality of loading to the system. This is done by creating load duration curves and seasonal concentration box plots.

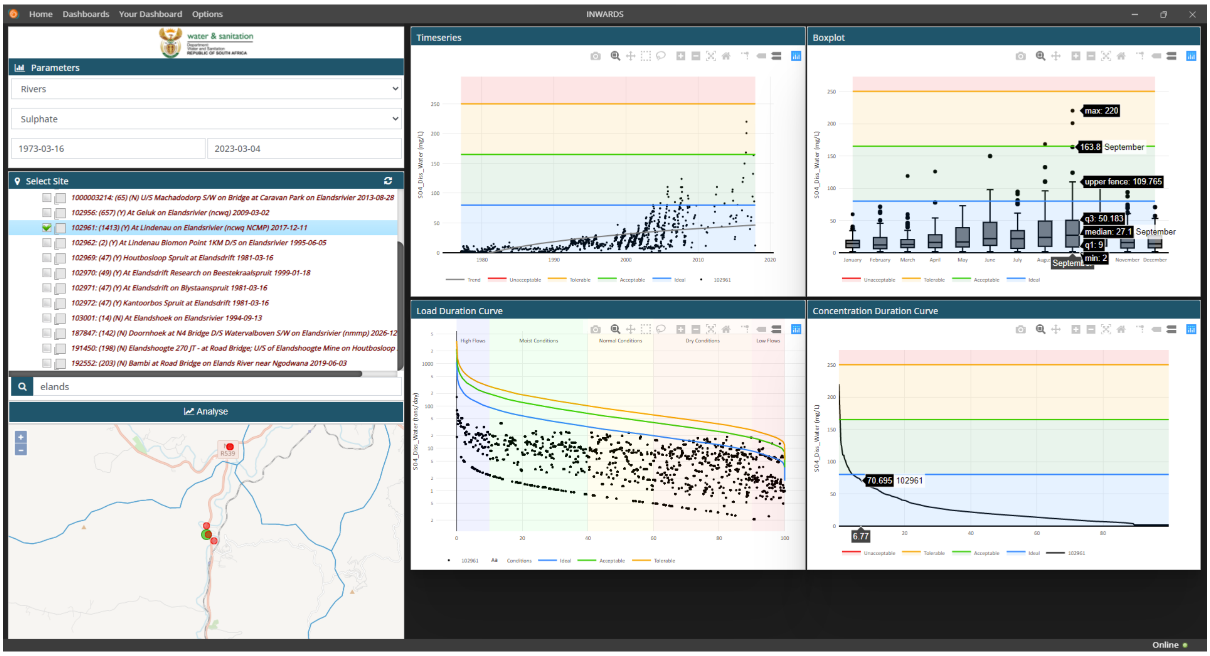


Figure 34 Screenshot of INWARDS highlighting the water quality analyses dashboard

7.6.1 Site specific analyses

7.6.1.1 Montrose (upper Crocodile River)

Based on the data and analysis, the water quality at Montrose on the Crocodile River is generally good, except for elevated levels of orthophosphate. Orthophosphate levels were acceptable until around 1990, but have since increased steeply to unacceptable levels. The orthophosphate levels exceed the tolerable threshold across all flow conditions (Figure 35) and therefore indicate both point and diffuse source pollution probably due to WWTWs and Settlements. The seasonal distribution as shown in Figure 36 indicate that diffuse sources are the biggest contributors as a result of surface mobilisation.

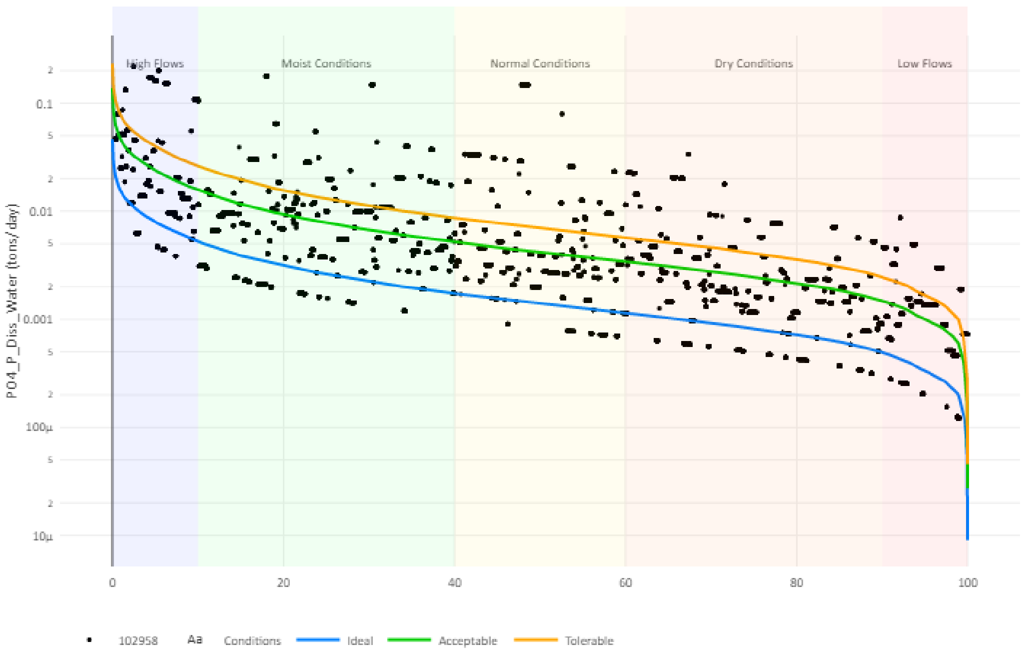


Figure 35 Orthophosphate load duration curve at Montrose

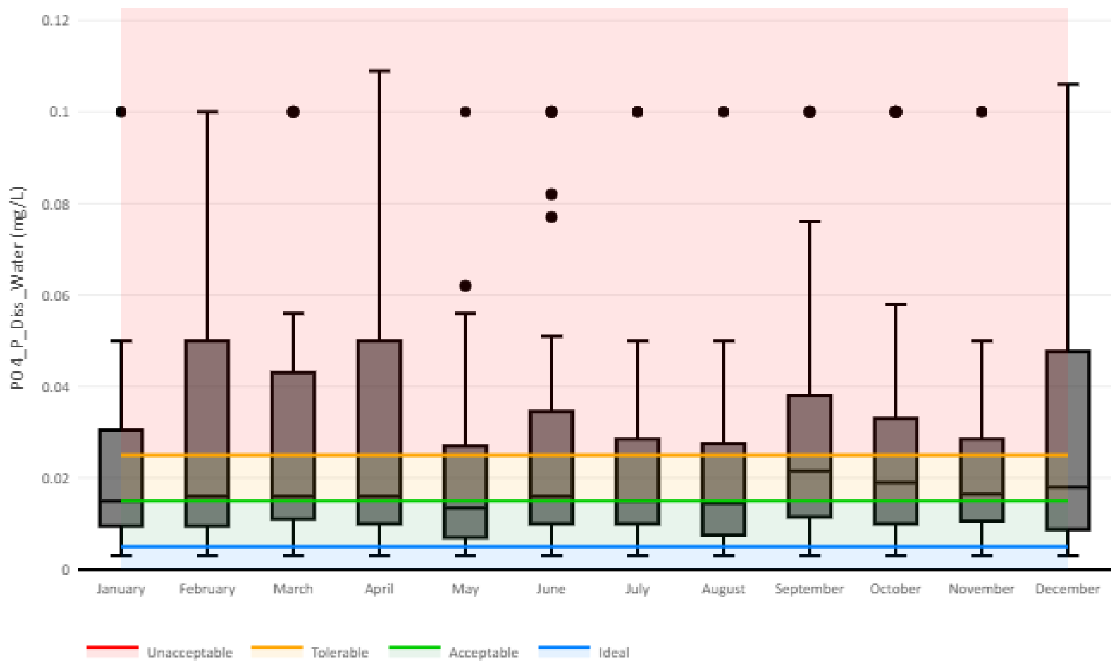


Figure 36 Seasonal concentration boxplots of orthophosphate concentrations (mg/L) at Montrose

7.6.1.2 Lindenau on the Elands River

Sulphate levels (concentrations and loads) remained ideal until the mid-1990s, when they increased to an acceptable level overall. The loads exceeding the thresholds are during the low and dry flow conditions (Figure 37) especially for the months of August-October. While the concentrations are currently in a relatively good state, the increasing trend as identified in the section above (Figure 28 and Figure 29) is of great concern with loads having almost doubled in the last decade. As stated before, the sulphate loads are clearly being transported through the system up to and beyond Karino. This means that other conservative variables which may be of a greater concern could be reaching as far as Mbombela.

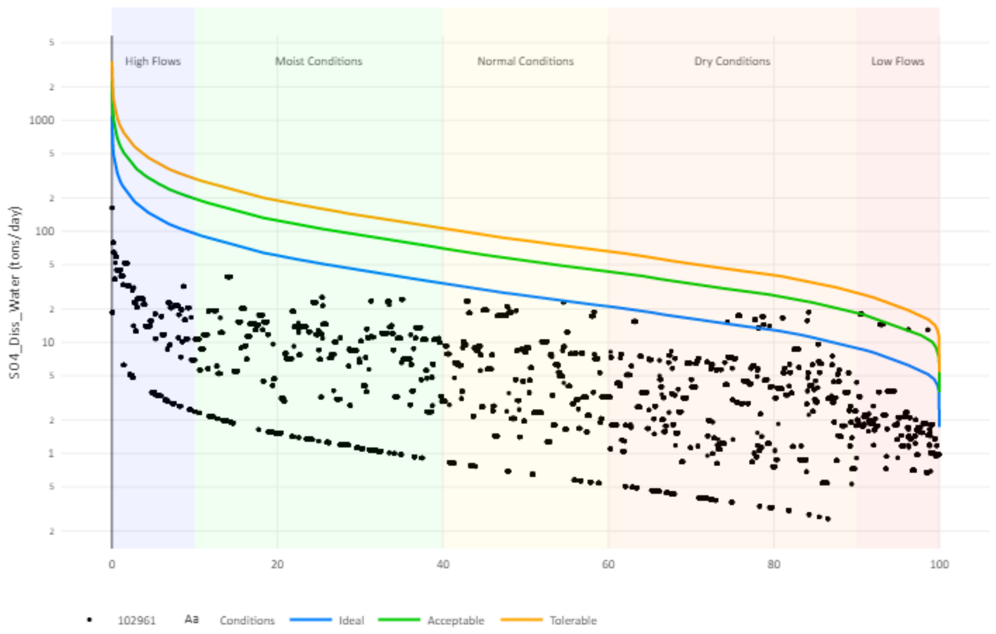


Figure 37 Sulphate load duration curve at Lindau on the Elands River

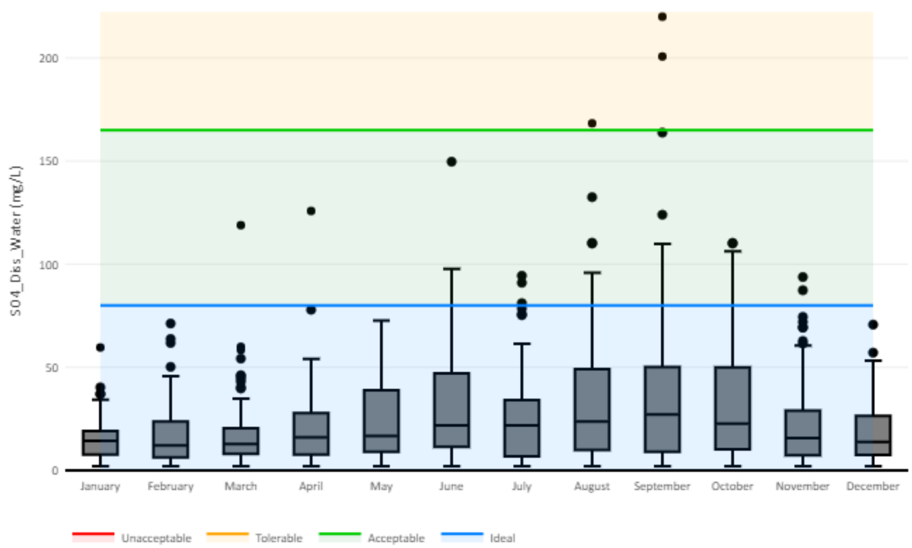


Figure 38 Seasonal concentration boxplots of sulphates (mg/L) observed at Lindau on the Elands River

7.6.1.3 Karino

The data record for orthophosphates at Karino on the Crocodile River shows several impacts on the river, which have been increasing over time although current levels are not yet serious in themselves. Orthophosphate levels have shown a steady, linear increase and unlike Montrose, loads are exceeding the thresholds mostly during dry and low-flow conditions (Figure 39 and Figure 40) indicative of point source pollution. This would likely indicate that the Wastewater Treatment Works upstream are contributing significantly to the overall observed load.

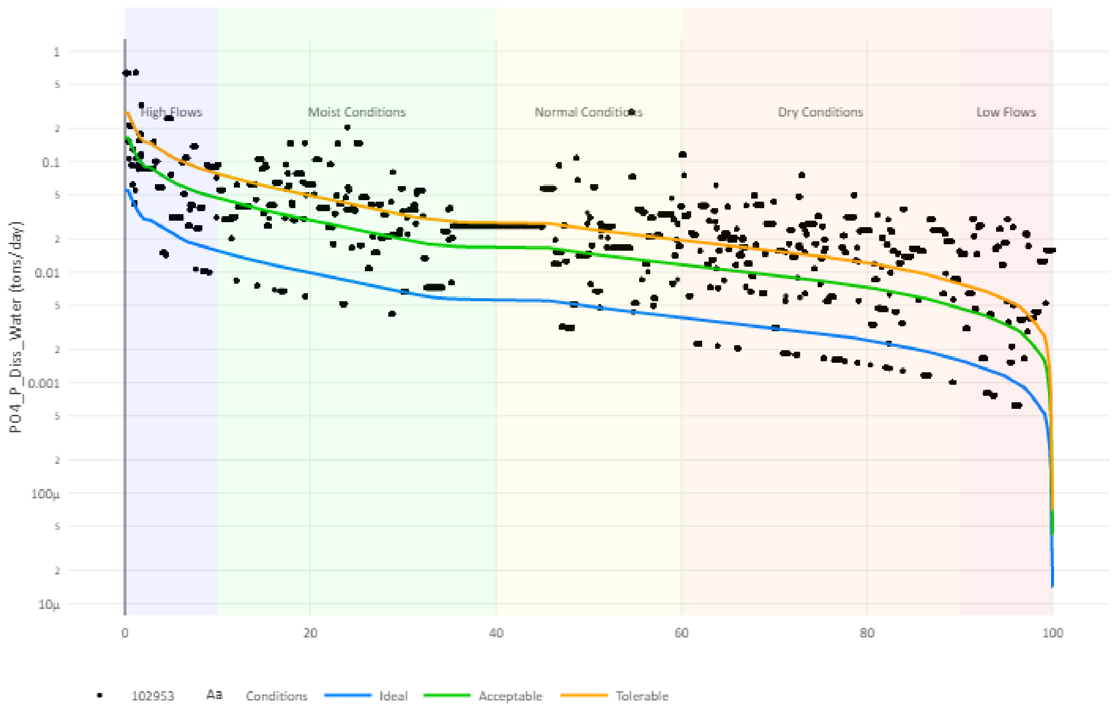


Figure 39 Orthophosphate load duration curve at Karino (tons/ day) on the Crocodile River

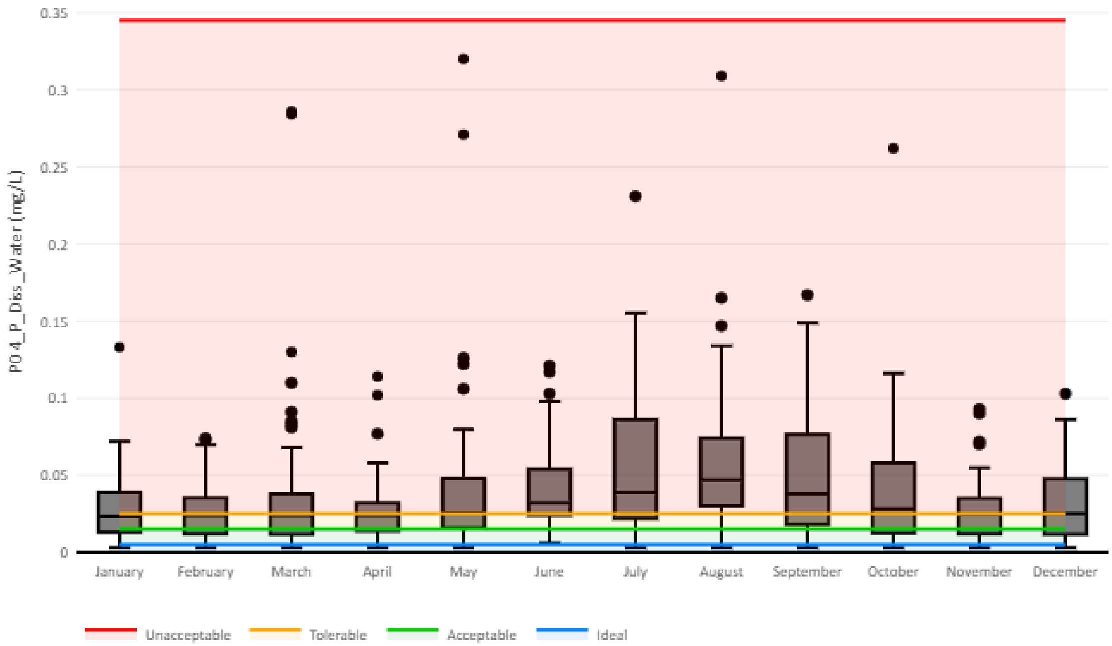


Figure 40 Seasonal concentration boxplots of orthophosphate (mg/L) at Karino on the Crocodile River

7.6.1.4 Dalton on the Kaap River

Sulphate concentrations and loads are relatively static with no major changes recently (Figure 41; Figure 42). However, the legacy of mining activities in the past is persistent, with the Kaap River continuously loading the Lower Crocodile River with significant levels of sulphates. Whilst sulphates may not be of concern in themselves there are other potential toxins which are making their way down the system with the loads from the Kaap being detected as far down as the outlet of the Crocodile River Catchment based on the increases in Sulphate loads observed at other sites. Unlike, non-conservative variables (e.g. orthophosphates that can potentially be sequestrated by the system (sand beds, reeds, etc.) conservative variables can travel large distances spreading the risk further downstream.

While the presence of sulphates does not necessarily indicate the presence of other toxins, it can be a useful indicator in certain situations. Elevated sulphates such as is observed in the Kaap River can indicate the potential presence of other contaminants, such as heavy metals or radionuclides (EPA, 1994), because these contaminants can be associated with the same geological formations that contain sulphate minerals. Given the history of gold mining in the Kaap River, sulphates could be indicating the presence of acid mine drainage (AMD) and groundwater contamination. Given that the highest concentrations are experienced during the low-flow periods, this would suggest that groundwater discharge is laden with sulphates. This would also explain the long period of high sulphate levels with very little variation, since groundwater – once contaminated – can take decades if not centuries to recover. This is further bolstered by the high levels of arsenic observed in the Kaap River Catchment rendering most of the sites as hazardous and also with a potential increase in the risk of cancer if the water is consumed (see Figure below).

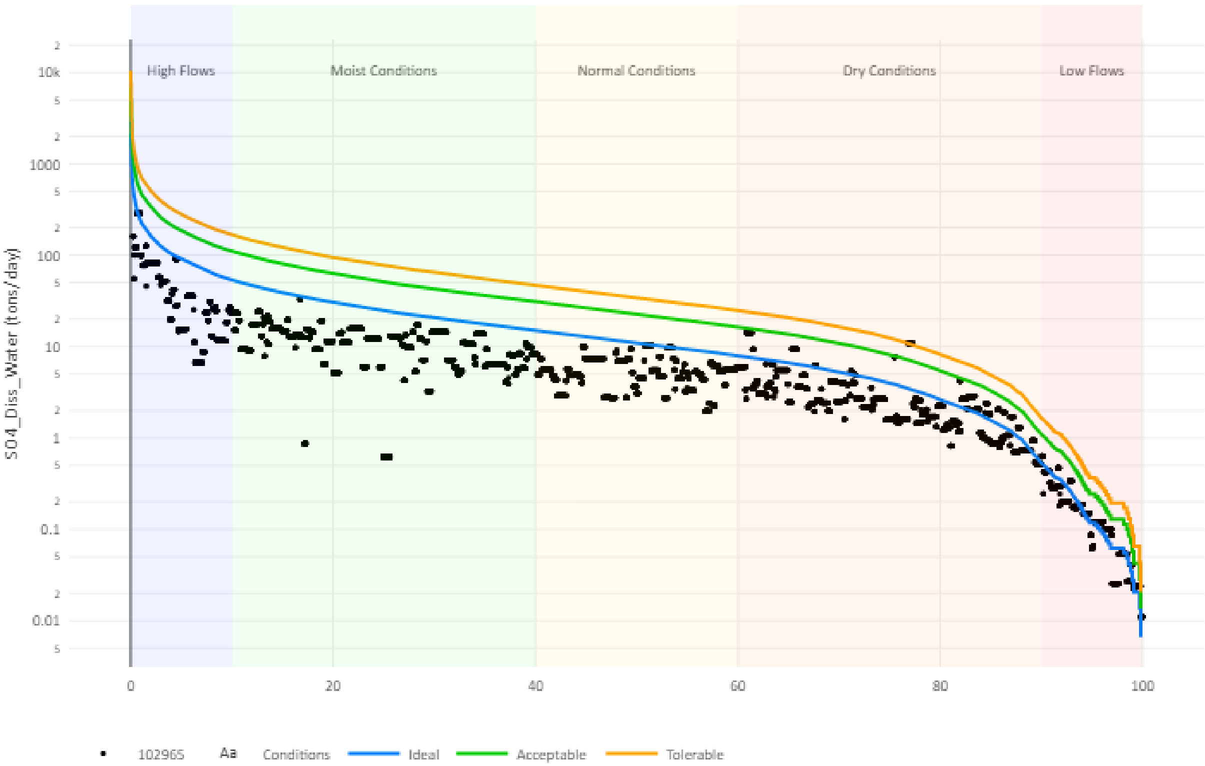


Figure 41 Sulphate load duration curve at Dalton on the Kaap River

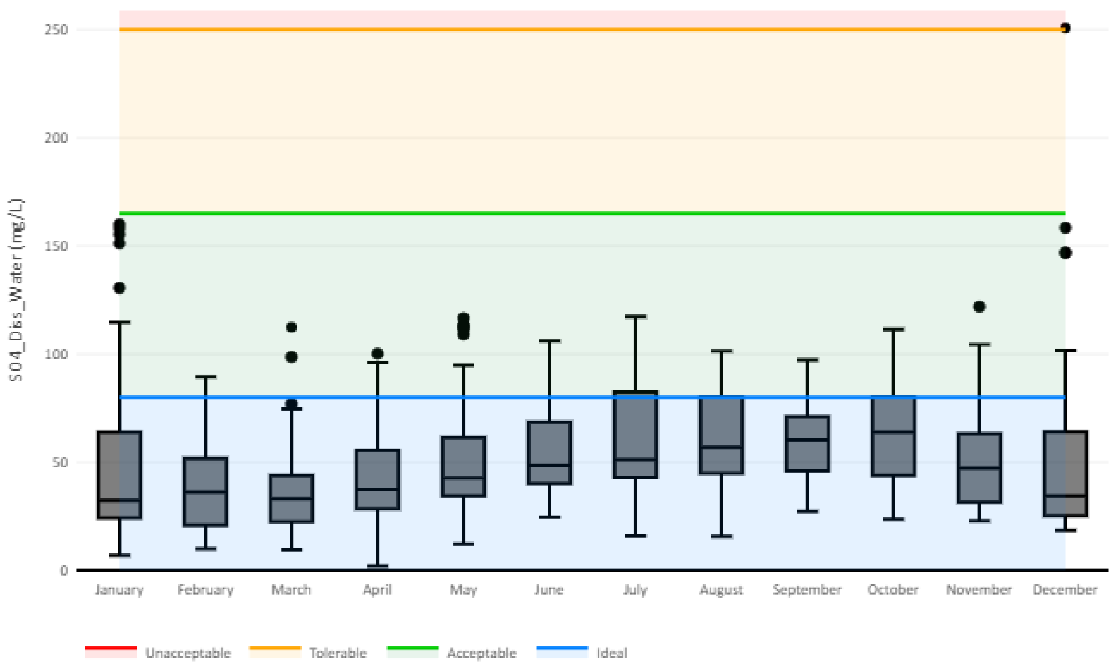


Figure 42 Seasonal concentration boxplots of sulphate concentrations at Dalton on the Kaap River

Station	Observed	Hazard Quotient	Cancer Risk	Half the Detection Limit
X2I047	0.005	0.2381	0.0003	TRUE
X2I050	0.06	2.8571	0.0035	
X2I054	0.02	0.9524	0.0012	
X2I058	0.04	1.9048	0.0023	
X2I059	0.02	0.9524	0.0012	
X2I060	0.005	0.2381	0.0003	TRUE

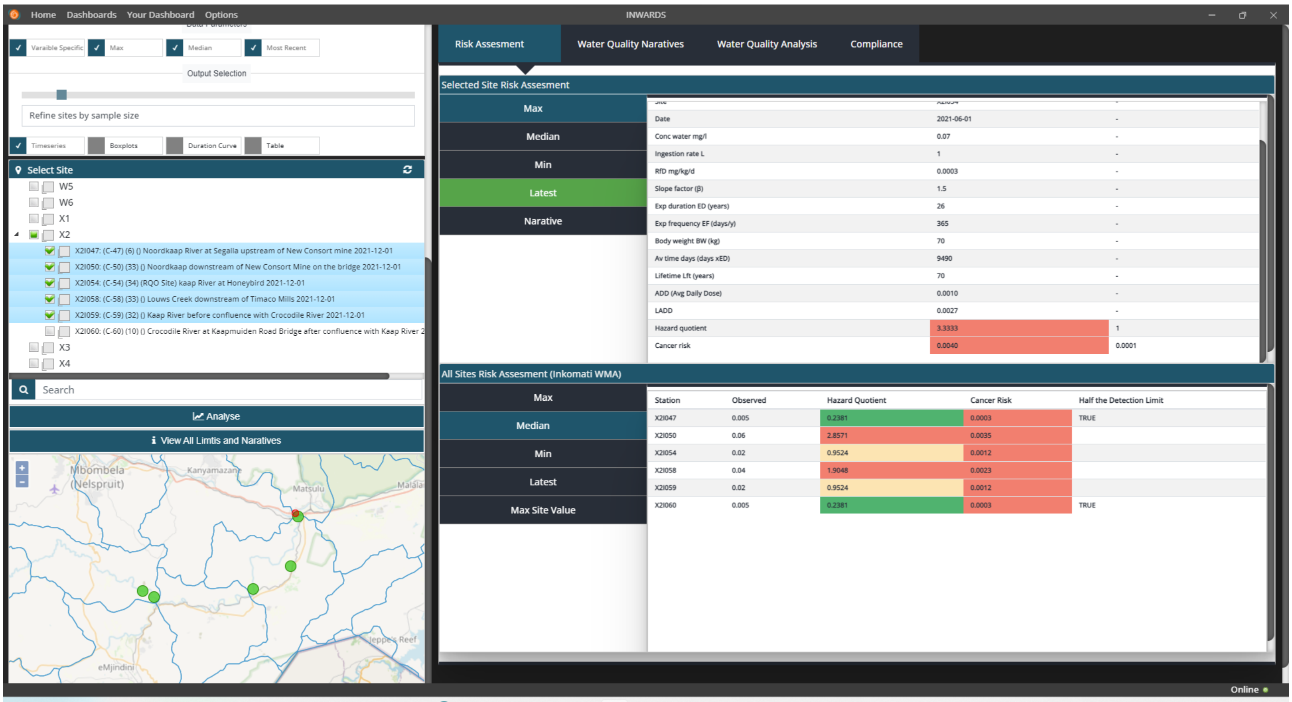


Figure 43 Example of the outputs of the Human Health Risk Dashboard showing potential health risks at a site and across the catchment for a variable of concern

7.7 CONCLUSIONS

- Trends in the Elands River indicate that sulphates are becoming more of a concern with a shift from Ideal to Acceptable. Historically, the Kaap River was long seen as the biggest contributor of sulphates to the system. However the most recent data suggests that the median loads contributed by the ElandsRiver have now surpassed that of the Kaap River.
- The data suggests that sulphate loads are being transported down the main stem of the Crocodile River as is evident by loads observed at Karino, Rivers View and Tenbosch in the lower reaches.
- Orthophosphates are elevated across the catchment. However, the highest levels are found downstream of major settlements and wastewater treatment works. These sites also have high levels of *E. Coli*. (Figure 44)
- The Crocodile River Catchment topography is steep with fast flowing rivers only leveling out near Mbombela and the Kruger National Park. This means that residence times are low as there is little to no attenuation. This is evident by the efficiency in load transfer, with median loads of sulphates balancing when lower sites are compared with source sites. While sulphates are not a constituent of concern they are a good indicator of the system's ability to transport other possible toxins, with the potential of transferring risks far downstream.
    - For example, arsenic, a toxin of concern particularly as a carcinogen has been detected at concerning levels in the Kaap River system. Upstream of a mine along the Suid Kaap River levels are below the detection limit. However below the mine and the confluence of the Kaap River all the way to the confluence with Crocodile River, levels are elevated and categorized as hazardous with an increased carcinogenic risk if untreated water is consumed.
- The lower Crocodile River is unique as a decrease in loads of both orthophosphates and sulphates being evident. This could be as a result sequestration by irrigated sugar-cane along the main stem of the Crocodile River. While reducing water quality loads is a benefit to the ecosystem, the concern is that if sulphate loads have made their way this far, this may also be the case for other toxins. Potentially crops being irrigated with such water could be accumulating the toxins transferred from the Kaap River. In addition, the same area is sequestrating orthophosphates which are primarily contributed by WWTWs. This would mean that *E. coli* levels or other pathogens which are also high, would transferred to the crops being irrigated. This requires further investigation.

Water quality data from both DWS and the IUCMA are integrated into the Human Health Dashboard and are used in the various risk assessments. There are some constraints that require consideration however. While the IUCMA data received by the team only spans from 2016 to 2023, hard copy records predating this exist as well and could be integrated. Currently the IUCMA has 83 active water quality monitoring points in the Crocodile River Catchment, and variables analysed vary according to site being monitored and the purpose of that site. Thus, some sites have toxin and/or biological data where as others only cover the basic physico-chemical parameters (e.g. sulphates). The DWS datasets obtained from RQIS show a consistent growth in active monitoring stations with a steep decline in data received from stations around 2015. Most of the long term monitoring sites are still active as they are part of the National Chemical Monitoring Programme. Although the physico-chemical parameters are well represented in the DWS data, toxin and biological data are sparse and outdated.

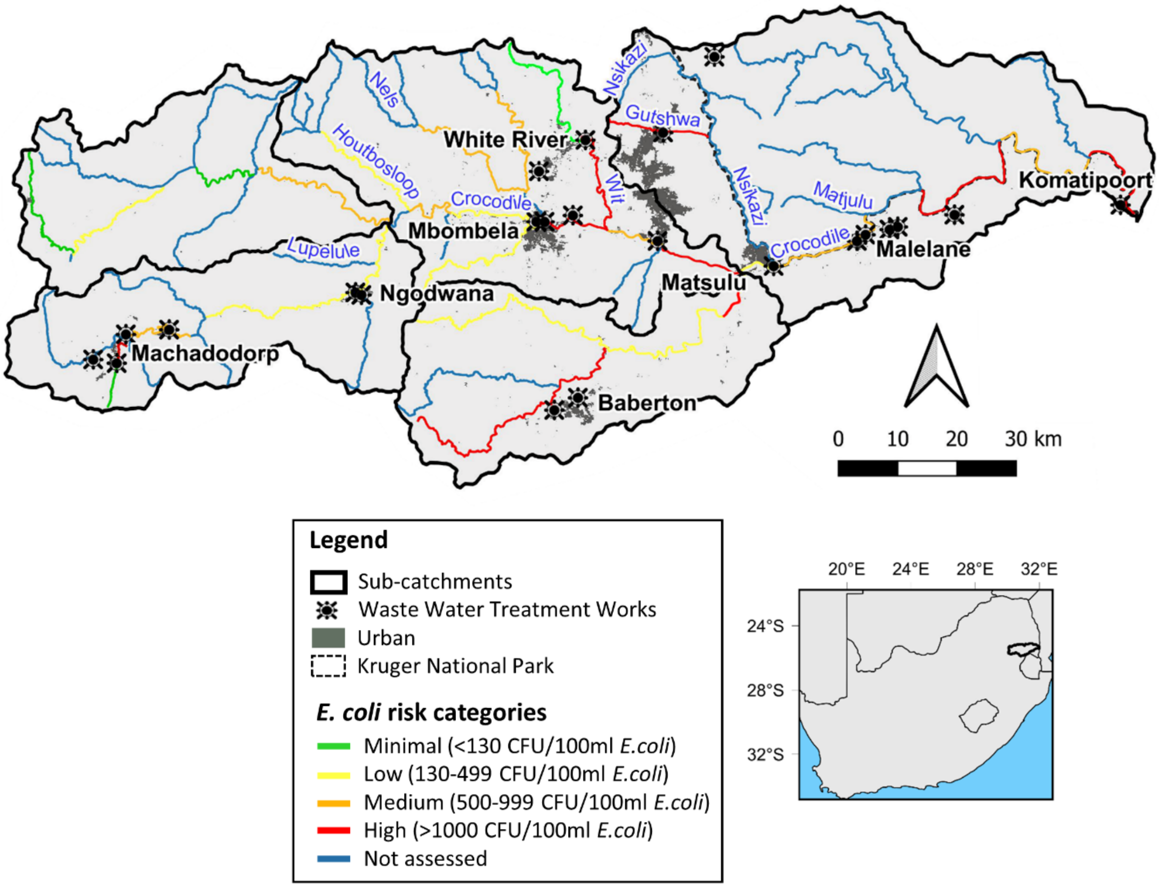


Figure 44 Map of the Crocodile River Catchment with colourized river reaches indicating four *E. coli* load classification groups (minimal, <130; low, 130-499; medium, 500-999; and high, >1000). The locations of urban areas and wastewater treatment plants (WWTPs) are also indicated. (from Trutter et al., 2022)

CHAPTER 8: COMMUNITY VULNERABILITY AND HUMAN HEALTH RISK ASSESSMENT

8.1 INTRODUCTION

This chapter outlines two important components of the overall risk assessment. The first details determining communities-at-risk which are those communities directly dependent on surface waters to meet some or all of their livelihood needs. The second involves a Human Health Risk Assessment which analyses water quality constituents of concern in terms of their potential risks to human health.

8.2 COMMUNITY VULNERABILITY ASSESSMENT

8.2.1 Overview

The simplest approach to providing an indication of community vulnerability to pollution risks is to analyse riparian communities that use water for some or all of their livelihood needs. However, it must be noted that vulnerability encompasses more factors than simply access alone (see below). Nonetheless for the purposes of this pilot study, locality and access were used as broad determinants of risk.

In terms of the Identification of vulnerable riparian communities, census data from StatsSA (2012) were the only data available for this purpose. In the census data access to water sources is captured in part under a sub-set of questions related to access to water and water uses. Included as direct dependency were

- Use of river water
- Water from vendors
- Water delivered via tankers

Data was drawn at a ward level and transposed to quinary catchments in order to integrate these demographic data and those on risks.

8.2.2 Results

The results indicate a higher level of the population with a direct dependency on run-of-river / untreated water (in 2011) than originally believed at the inception workshop with stakeholders. The communities with the highest direct dependency (where 40 to 50% of their water needs is from untreated water) are found in a band along the foothills of the escarpment region, including Hendriksdal, Brondal and areas west of Kaapsehoop (Figure 45). Concerningly given the risk assessment below, is also includes an area in the Kaap River Catchment. The urban centres of Mbombela, White River and Kanyamazane indicate a 7 to 30% dependency. A dependency of 20-28% is noted in the upper escarpment which requires attention given mining and potential impacts in that area.

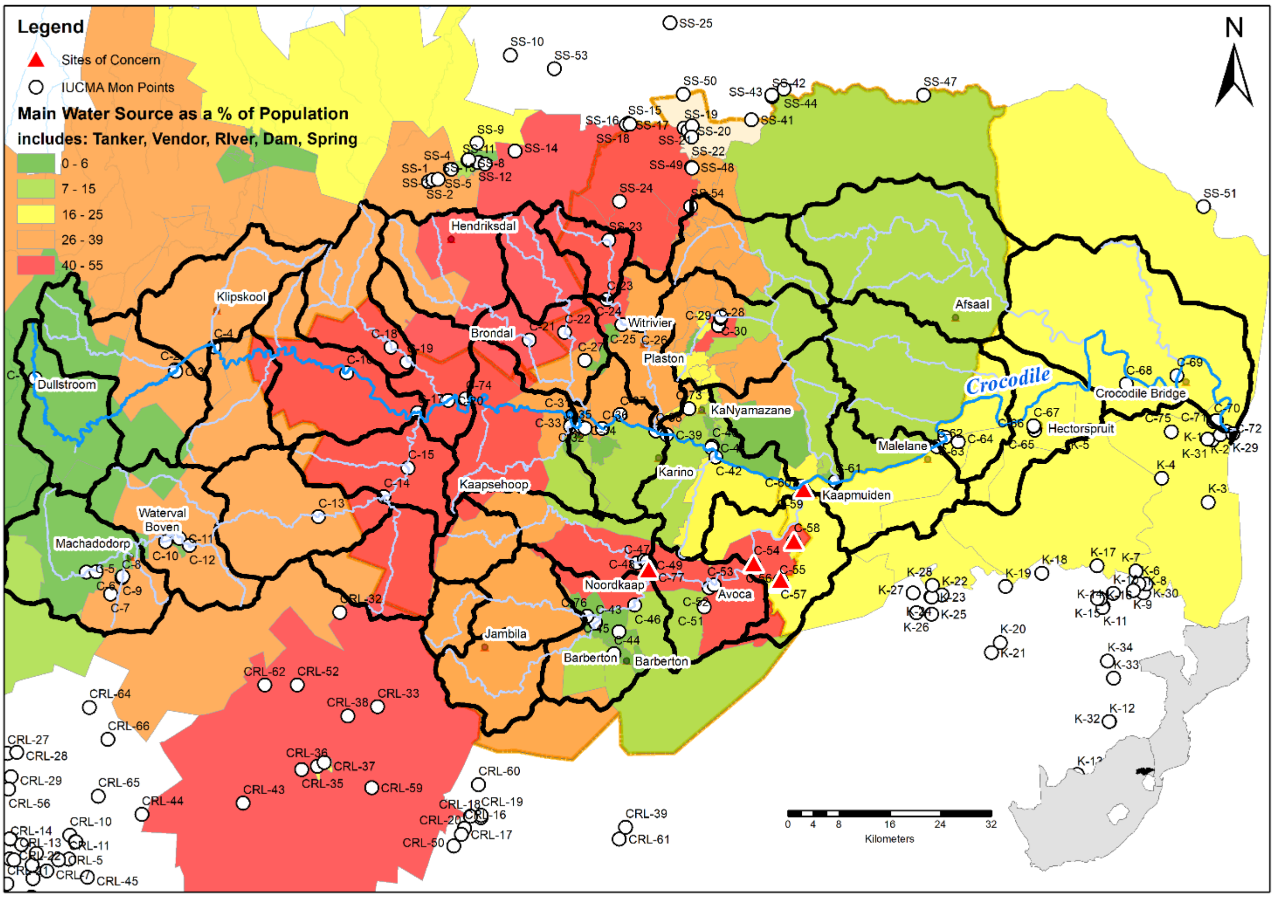


Figure 45 Map indicating location of people that are dependent on run-of-river to meet some or all of their water resource needs (based on Census 2011 data)

8.2.3 Limitations

There are a number of caveats and limitations to the above results. First is that the data is now a decade old. The team is awaiting data from the latest census to update the current data set when available.

Secondly, although the above approach provides a broad indication of vulnerable communities in general, vulnerability is a somewhat more complex issue than based simply on access alone and this needs to be considered in future work. Based on previous work in the lowveld on livelihood vulnerability and water, important aspects of determining vulnerability include understanding additional factors related to poverty since it is not only the dependency on untreated water or inadequately treated water and locality in relation to poorly functioning WWTWs and hazard sites (point or non-point) that would determine vulnerability. Other determinants of vulnerability related to poverty and social inequity are important. For example, if a household is poor or at risk of becoming poor, they are more likely to move to a greater direct dependency on natural resources with few other options, irrespective of the risks. In particular female-headed and child-headed households are of particular concern in a full assessment of vulnerability.

8.3 HUMAN HEALTH RISK ASSESSMENT

A Human Health Risk Assessment (HHRA) was undertaken to examine risks imposed by contaminants of concern. A summary of results is given below and further details are provided in Deliverable 3 of this project. The HHRA was undertaken based on data from the IUCMA collected between 2019 and 2021. The purpose of this was to a) highlight potential 'current' (recent) risks and b) input them into the Water Quality-Health Dashboard (see Chapter 3) which will then render potential risks based on incoming data. The latter is therefore part of a precautionary model, and an Early-Warning System when combined with an understanding of vulnerable communities (see above).

8.3.1 Data collection for the Human Health Risk Assessment

A number of steps were undertaken for this task. This included:

1. Final set of selected variables and proxies (Table 1);
2. Database of water quality, data sources (Chapter 3) and monitoring schedules (Table 8);
3. Examination of the database of waste-water treatment works (WWTW) (and their Green Drop status (Table 3); and
4. Two literature reviews. Two literature reviews are underway towards understanding the pollution-human health risks.
    a. The first is a general literature review with a particular focus on the selected variables for the CRC (see Chapter 6). The results been amalgamated into the dashboard
    b. The second is a review of endocrine-disrupting contaminants (EDCs) in relation to the CRC. (see Chapter 6).

8.4 METHODOLOGY

The HHRA was undertaken based on data from the IUCMA collected between 2019 and 2021. The purpose of this was to a) highlight potential 'current' (recent) risks and b) input them into the Water Quality-Health Dashboard (see Chapter 3) which will then render potential risks based on incoming data. The latter is therefore part of a precautionary model[13], and an Early-Warning System when combined with an understanding of vulnerable communities (see Section 8.2).

The methodology used for a Human Health Risk Assessment is described by the United States Environmental Protection Agency (US EPA, 1987; 1992) and the World Health Organization (WHO, 2010). The HHRA is primarily divided into four steps:

1) hazard identification,
2) dose response assessment,
3) exposure assessment and
4) risk characterisation.

The approach examines carcinogenic and non-carcinogenic, or toxic hazards.

At inception, the project identified a number of water quality variables linked to land-use in the CRC (see Table 1; those highlighted). A number of these were reviewed and some additional variables of concern were based on expert inputs added including Al, Bo, Cu and Zn.

8.5 SUMMARY OF RESULTS

The risk characterisation is summarised in Table 13.

[13] NB This can only indicate potential risks and cannot be used to infer causality. Therefore it adopts the precautionary principle which requires that, if there is a strong suspicion that a certain activity may have harmful environmental or human health consequences, advocating control of the activity now rather than waiting for incontrovertible scientific evidence is the recommended process

Table 13 Summary of results from the risk assessment

	Sample details	Hazard Quotient (HQ)-Non-carcinogenic risks	Cancer risk
Arsenic	Maximum health risk was based on a single occurrence of 1.37 mg/L As, found at **site C 50** (Noordkaap downstream of New Consort Mine on the bridge)	65.2 (65 times higher than the safe level)	0.011 (1.1 in 100)
Chromium VI	Only detected once over the 3-year period. However, only 3 sites were used for monitoring CrVI.	Below the safe level (0.57)	3,2 E^{-4} (3,2 in 10,000 risk).
Manganese	At site **C 33** on a single occasion. - 60,8 mg/l	6.2 times the recommended levels	
Nitrate	At site **C 6** Indicates a possible risk for bottle-fed infants in this area if the water is used for bottle feeding with formula milk.	HQ of 2.2. at C6 Maximum Nitrate level of 38 mg/L	

Arsenic, chromium VI and manganese were highlighted as compounds that present potential health risks to communities making use of river water if not treated to safe levels (Figure 46). Both cancer and toxic risks are anticipated, requiring action from water authorities to ensure that public health is protected. The analysis as summarised in Figure 46, suggests that arsenic is problematic in the Kaap River. Arsenic poses a risk in terms of cancer and is classified as a carcinogen by the International Agency for Research on Cancer (IARC). The cancer risk in the Kaap River is calculated as 0.011 (1.1 in 100). Cancer risks range from 1.27 in 1,000 to 2.39 in 10,000 based on a daily ingestion of 1 L untreated river water. Toxic impacts are expected from making use of this water for drinking purposes with hazard quotients ranging from greater than 7 to 1.4 times the safe concentration at the six sites in the Kaap River subsystem. This represents both an unacceptable cancer risk and a toxic risk and is a reason for concern. These results are summarised in Figure 47. An analysis of *E. coli* data (Figure 44; Figure 48) indicates additional concerns regarding *E. coli* both as being problematic in itself but also as an indicator of other pathogens and pointing to dysfunctional WWTWs.

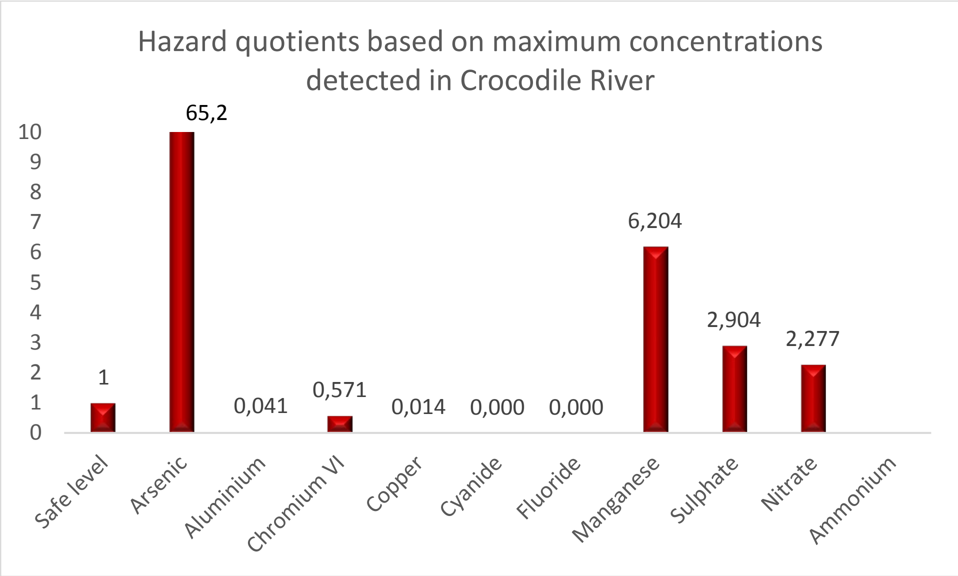


Figure 46 Hazard quotients based on maximum concentrations in Crocodile River

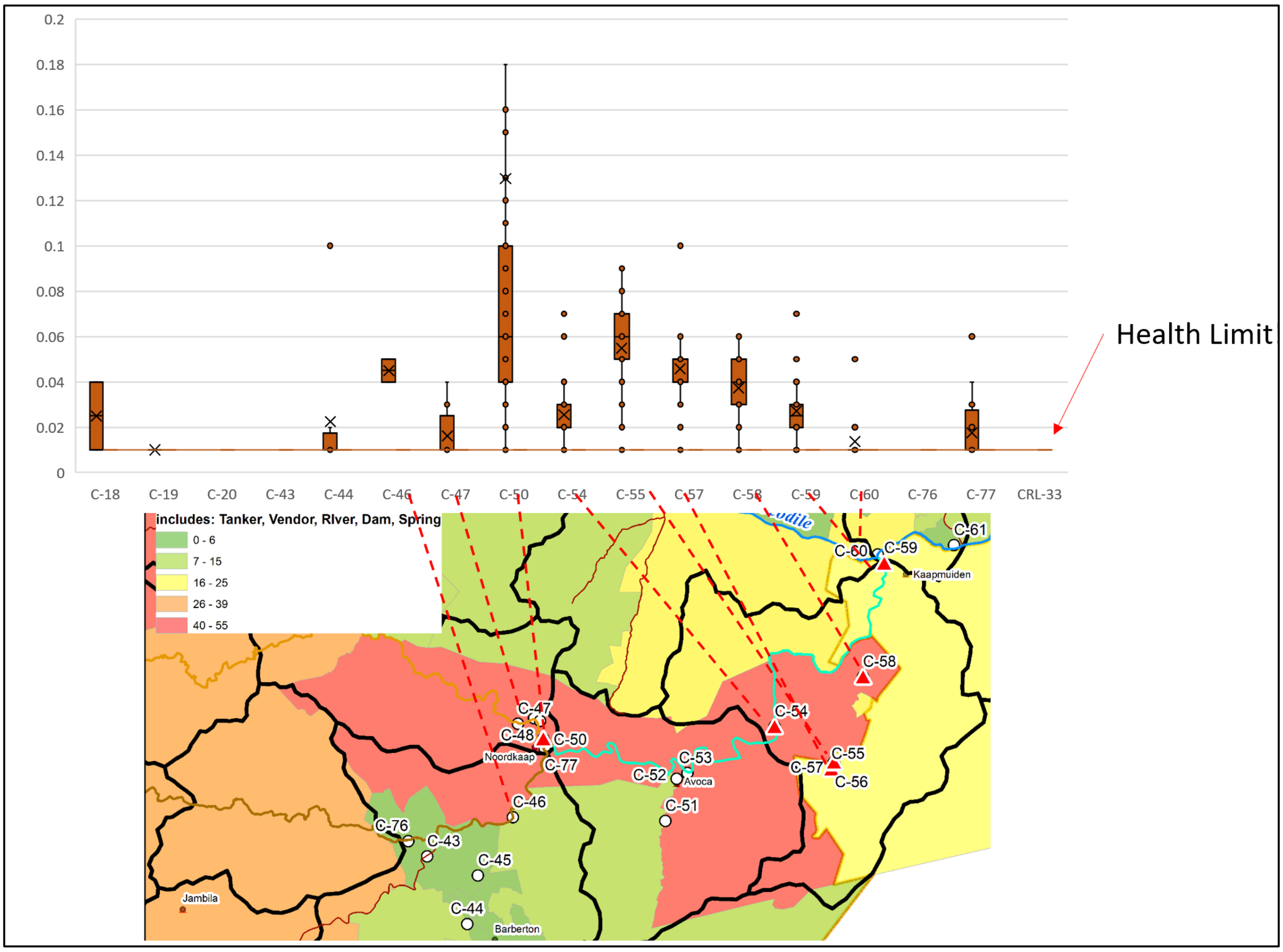


Figure 47 Figure summarising arsenic-related health risks along the length of the Kaap River

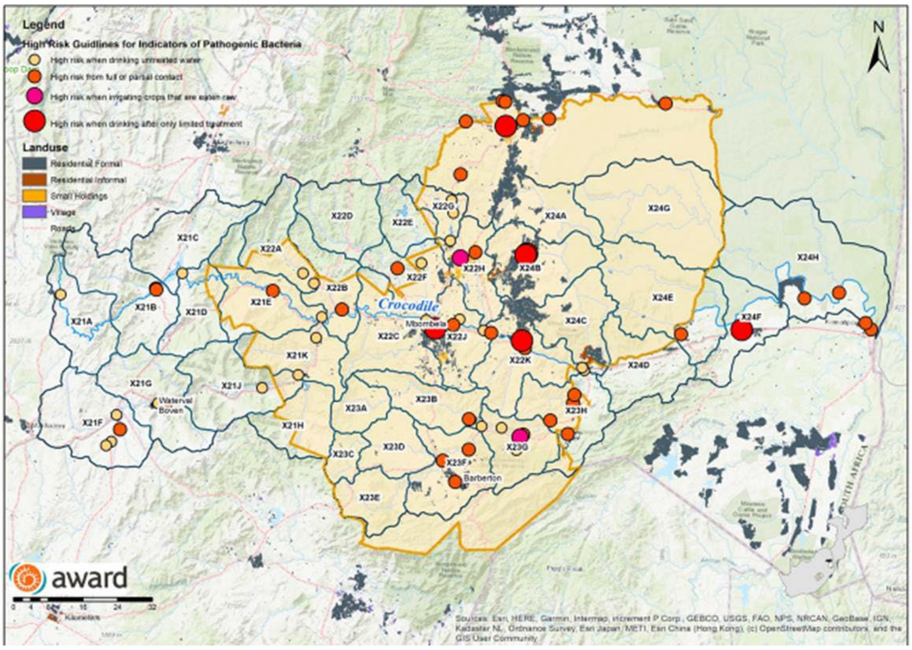


Figure 48 *E. coli* concentrations in the Crocodile River Catchment (see also Figure 44)

CHAPTER 9: DEVELOPMENT OF THE WATER QUALITY HEALTH DASHBOARD

9.1 INTRODUCTION

The following section describes in detail the Water Quality Health Dashboard development including server deployment, all backend datasets, models and front end functions and outputs. The dashboard consist of three sub-components namely human health, biotic health (referring to water biota, i.e. non-human) and finally drivers of change analysis. Each of these components depends on multiple underlying datasets and models which are elaborated below.

Figure 49 An overview of the Water Quality Health dashboard indicating dashboard panels

9.2 User Registration and Control

A component of INWARDS and consequently the Water Quality Health Dashboard which had to be considered, is the proper registration, tracking and reporting of users. This includes the ability to support users throughout their journey with the use of the dashboard. In addition, with collecting additional user information INWARDS needs to be Protection of Personal Information Act, or POPIA compliant, ensuring that their information is not available to all and that they can request a removal of their account. Thus, a number of server updates and modules were added to INWARDS to support user registration and management as explained below.

9.2.1 Server Security

9.2.1.1 Server Access Control

It is recommended that access control measures be deployed when hosting personal data and information on a server. Sections 19-22 of the POPI Act are particularly relevant in this regard. Access control measures include requiring a 4096-bit RSA key-pair for server access, with the private key encrypted by a passphrase. Additionally, root logins should be disallowed over SSH (Secure Shell), and SSH connections should be made using a non-root user with varying administrative privileges. It is recommended to listen on only one internet protocol, such as IPv4 or IPv6. Fail2Ban may be used to ban IP addresses with too many failed login attempts, while the UFW firewall may be used to manage firewall rules such as port access. Regular review and updates to security measures are necessary for maintaining the security and integrity of the server.

- *4096-bit RSA key-pair: This is a strong encryption method and is considered to be one of the most secure methods available. Requiring a passphrase to be used in conjunction with the private key adds an additional layer of security.*
- *Disallowing root logins over SSH: By disallowing root logins, you're limiting the access that potential attackers could have to your server. Allowing only non-root users with varying administrative privileges ensures that users can only perform actions for which they have permission.*
- *Listening on only one internet protocol: Limiting the protocols that your server listens on can help to reduce the attack surface and potential vulnerabilities that could be exploited.*
- *Fail2Ban: This is a useful tool that can help to protect against brute-force attacks by temporarily banning IP addresses that have too many failed login attempts.*
- *UFW firewall: This is a user-friendly tool for managing firewall rules, including port access. Using a firewall can help to prevent unauthorized access to your server.*

9.2.1.2 Server Backups

Back-ups are an essential component of any reliable system. They are critical in ensuring that information can be restored in the event of a system failure or data loss. In order to minimize the risk of data loss, the system currently has two backup features in place. The first backup feature is that daily server backup images are created. This means that a complete snapshot of the server, including all its data and configuration, is taken every day. This ensures that the latest version of the server can be restored in the event of a system failure or data loss. These backups are usually stored off-site (e.g. Linode) or in a secure location to ensure they are not lost if something happens to the server. The second backup feature is that images for one and two weeks prior are also accessible. This means that older versions of the server can be restored if necessary, depending on the time of the backup. This is particularly useful in situations where data loss or system failure is not immediately detected, allowing one to revert back to an earlier version of the system without losing all the data.

9.2.1.3 Domain security

In order to prevent security breaches and protect the privacy of users, an SSL (Secure Socket Layer) certificate has been implemented. This certificate establishes a secure, encrypted connection between the domain name and the intended IP destination. This is an important measure to prevent any reroute attacks that could potentially harvest sensitive information from users. The use of SSL certificates is an accepted standard in the industry and is an essential component of maintaining a secure and trustworthy website. By using SSL, users can be assured that their data is being transmitted securely and that their privacy is being protected. Implementing SSL certificates also helps to comply with POPIA, which aims to protect the privacy of personal information by establishing rules for the processing, storage, and use of personal information. By using SSL, websites can ensure that personal information is being transmitted securely and in accordance with POPIA regulations. Overall, implementing SSL certificates is an essential security measure for any website or online service that handles sensitive information. By ensuring secure, encrypted connections between domain names and IP destinations, websites can help to prevent security breaches and protect the privacy of their users.

9.2.1.4 Data Security

To ensure the security of sensitive data, encryption methods can be utilized during the storage and translation processes. This means that even if data is stolen during a breach, the data is not readable without the correct decryption process. In the current schema, two data encryption methods are used for accessing and processing data. Firstly, data that requires one-way data verification is MD5 (message-digest algorithm) hash-based encrypted. This means that the original data cannot be retrieved from the encrypted data, and the encrypted data can be used to verify the authenticity of the original data. Secondly, two-way encryption is performed using the Advanced Encryption Standard (AES). This encryption method uses a symmetric key algorithm that ensures that the data can only be decrypted by authorized parties with access to the encryption key. This method is used for data that requires two-way encryption such as passwords but could technically be applied to sensitive water quality data as well. These encryption methods ensure that sensitive data is protected from unauthorized access. However, it is important to note that encryption alone is not sufficient to ensure the security of sensitive data. Other measures such as access controls (see 1.2.2 and 1.2.3 below), regular security updates are also necessary to maintain the security and integrity of sensitive data.

9.2.1.5 Data access (POPIA compliance)

While the entire database can accessed through a terminal with SSH the following measure have been put in place:

- *Access restrictions based on user privileges: only allow specific users access to specific data tables and data from the database.*
- *Charting: involves writing scripts to provide data in chart format accessible through a panel in the current system*
- *Statistics: involves writing scripts to provide statistical data derived from the data stored in the database*
- *Advanced Querying: custom scripts providing API access with the specific data format outputs*

9.2.2 Registration Module

When a user first installs INWARDS, they will be presented with the option to either login or register (Figure 50). If they have previously registered, they can use the email address and unique code that was sent to them to login again. Once they have logged in, all of their user preferences such as sites selected, graphs added to the user dashboard, and other personalized settings will be synced from the cloud to the local instance. For new users, they will be required to fill in several fields to register, including general information such as the:

- sector they are from,
- designation they currently hold,
- reason for accessing information and using data

This information will be used to help administrators of INWARDS ensure that only authorized personnel have access to sensitive data. Upon requesting access, an email will be sent to the administrators of INWARDS, who can either accept the request directly from the email or through the Admin Dashboard. This allows administrators to review and approve user requests, ensuring that only authorized personnel have access to sensitive data. By implementing these registration and login measures, the security of INWARDS is enhanced, ensuring that only authorized personnel have access to sensitive data. It also provides a mechanism for administrators to control user access and ensure that only those with a valid reason for accessing the data are granted access.

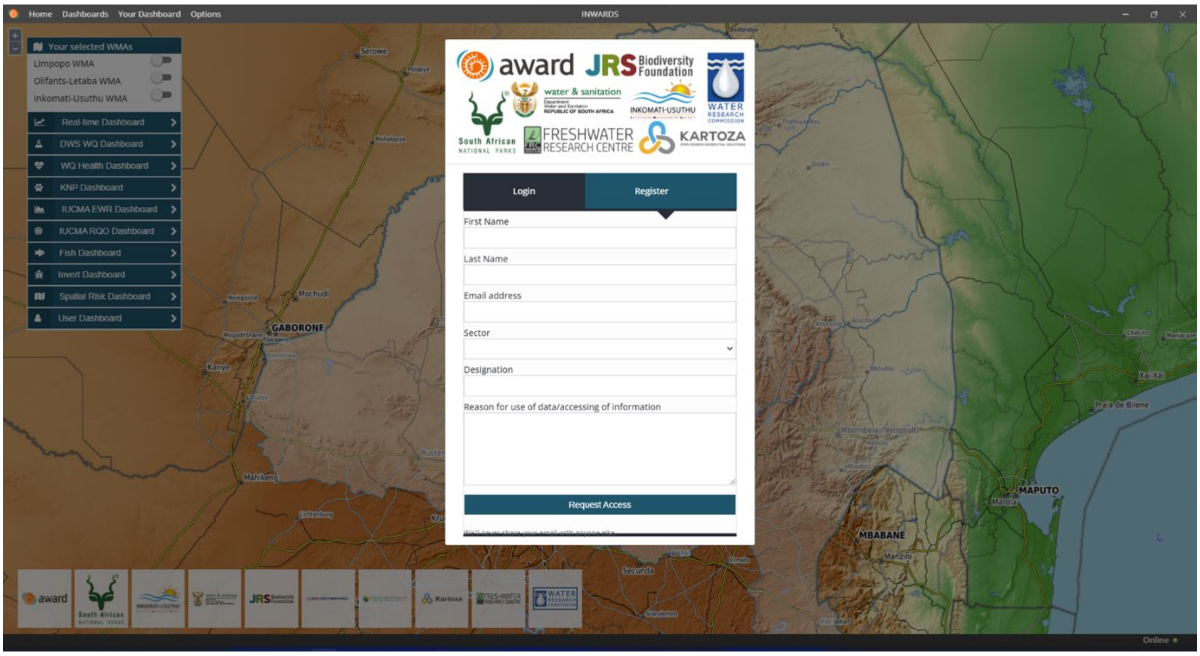


Figure 50 Screenshot of the registration module in INWARDS

9.2.3 Admin Module

The admin module in INWARDS (Figure 51) provides administrators with valuable information regarding the users and the platform. User and data metrics provide an overview of the number of users, sectors, requests made, and the amount of data available. This information allows administrators to monitor the usage of the platform and identify trends and patterns in user behaviour. The admin module also includes a ticket tracking system that allows users to log support tickets when they experience issues with the platform. The system tracks the status of the ticket and provides administrators with the ability to close out tickets once they have been resolved. This feature helps to ensure that issues are addressed in a timely manner and provides a way for administrators to track and monitor support requests.

Overall, the admin module is an essential component of INWARDS, providing administrators with valuable insights into user behaviour, user access control and allowing them to address issues and support requests quickly and efficiently. This helps to ensure the smooth operation of the platform and provides users with a reliable and secure system for accessing sensitive data.

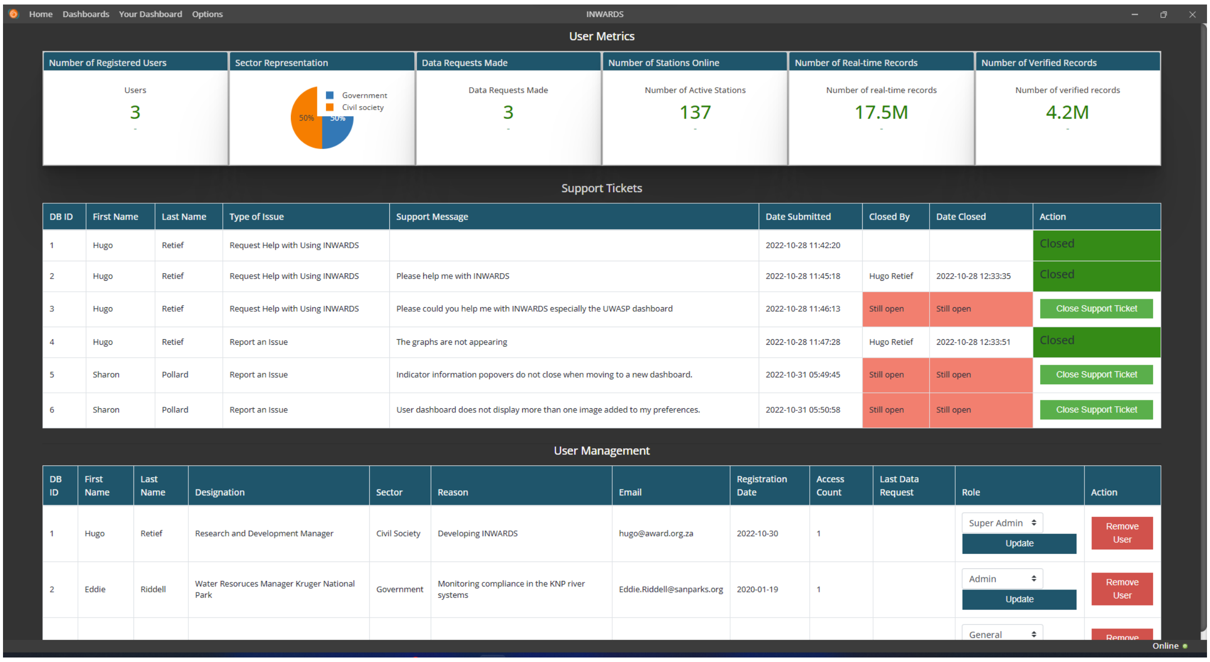


Figure 51 Screenshot of the Admin Dashboard in INWARDS

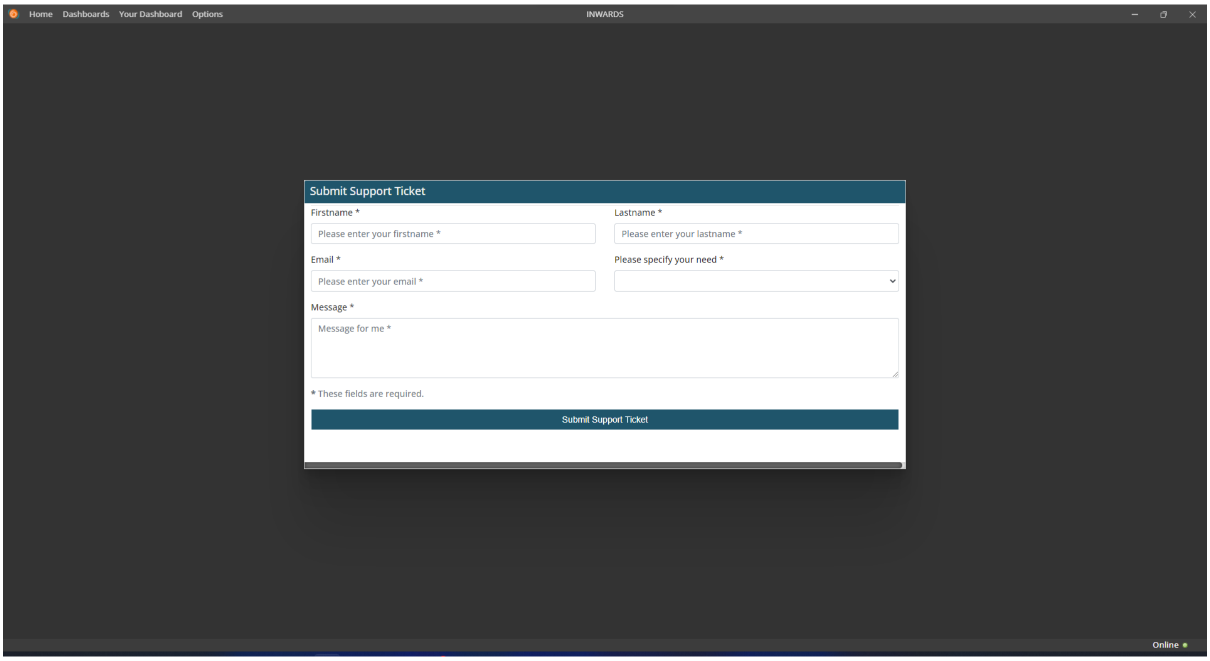


Figure 52 Screenshot of the support ticket form in INWARDS

9.3 Backend Datasets and Models

The front end of the INWARDS dashboard serves as a user interface that allows users to define their required outputs by selecting input options. However, the real work of the dashboard is performed by the backend, which is responsible for all data storage, retrieval, and analyses. Before users could test the water quality health dashboard, several datasets, modules, and outputs had to be developed. The datasets included water quality data, demographic data, and environmental data, which were collected and stored in the database. Several modules were also developed to enable data processing, analysis, and visualisation. These modules include data cleaning, data transformation, data analysis, and visualisation. The data cleaning module was used to remove missing or incorrect data, while the data transformation module was used to convert raw data into a more usable format. The data analysis module was used to perform statistical analyses and generate insights, and the visualisation module was used to create charts, graphs, and other visual representations of the data. The output of the dashboard includes various visualisations, such as maps, charts, and graphs, which display information on water quality, environmental factors, and demographic data (see Figure 49). These outputs enable users to explore and analyse the data in a variety of ways, and to generate insights that can inform decisions related to water quality and public health. Overall, the development of the datasets, modules, and outputs was a critical step in creating a robust and effective Water Quality Health Dashboard that can be used to monitor and manage public health concerns related to water quality.

9.3.1 Database and datasets

9.3.1.1 Inkomati Usuthu Catchment Management Agency Water Quality Data

Through constant engagement with the Resource Quality Management senior scientist from the IUCMA we have acquired, restructured and populated a database table with all the IUCMA data for entire Inkomati water management area. This involved restructuring the datasets received to work in a format compatible with Structured Querying Language (SQL):

- Site codes were restructured to represent secondary catchment (e.g. X2 = Crocodile), data owner (I = IUCMA) and site number (001) represents the IUCMA site number so for example IUCMA site C-1 which represent crocodile site one is now X2I001 (see Table 14).
- Catchment attributes were added, e.g. WMA, Primary, Secondary, Tertiary and Quaternary
- Sample sizes determined representing the total number of samples, constituent sample sizes are captured in another data table (Table 15).
- Location attributes were transformed to work with WGS84 standard

Table 14 Screenshot of the IUCMA monitoring sites restructured for compatibility with the INWARDS database

id	wq_stat	old_id	desc	type	start_date	end_date	disch	verifiec	dws_wq_static	latitude	longitude	sample	wma	primary	secondary	tertiary	quaternary	ewr_site
1	X2I001	C-1	Crocodile River at Dullst...	Rivers	2016-01-01	2021-12-01	NULL	NULL	190744	-25.414175	30.111794	18	inkomati_usuthu	X	X2	X21	X21A	true
2	X2I010	C-10	Upstream of Waterval B...	Waste Water Trea...	2016-01-01	2021-12-01	NULL	NULL	1000003208	-25.641537	30.321469	19	inkomati_usuthu	X	X2	X21	X21G	FALSE
3	X2I011	C-11	Waterval Boven WWT...	Waste Water Trea...	2016-01-01	2021-12-01	NULL	NULL	1000009877	-25.636167	30.34295	18	inkomati_usuthu	X	X2	X21	X21G	FALSE
4	X2I012	C-12	Downstream of Waterv...	Waste Water Trea...	2016-01-01	2021-12-01	NULL	NULL	187847	-25.646237	30.359018	19	inkomati_usuthu	X	X2	X21	X21G	true
5	X2I013	C-13	Elands River at Hemlock	Rivers	2016-01-01	2021-12-01	NULL	NULL	NULL	-25.600398	30.55962	19	inkomati_usuthu	X	X2	X21	X21J	FALSE
6	X2I014	C-14	Elands River at Bambi	Rivers	2016-01-01	2021-12-01	NULL	NULL	192552	-25.569177	30.661401	19	inkomati_usuthu	X	X2	X21	X21K	true
7	X2I015	C-15	Elands River at Lindenau	Rivers	2016-01-01	2021-12-01	NULL	NULL	102962	-25.527963	30.697812	19	inkomati_usuthu	X	X2	X21	X21K	FALSE
8	X2I016	C-16	Upstream of Joubert an...	Rivers	2016-01-01	2021-12-01	NULL	NULL	193813	-25.395363	30.597854	19	inkomati_usuthu	X	X2	X21	X21E	FALSE
9	X2I017	C-17	Crocodile River at Mont...	Rivers	2016-01-01	2021-12-01	NULL	NULL	102959	-25.448528	30.710428	18	inkomati_usuthu	X	X2	X21	X21E	true
10	X2I018	C-18	Upstream of Elandshoo...	Mine Property	2016-01-01	2021-12-01	NULL	NULL	191450	-25.357013	30.66581	19	inkomati_usuthu	X	X2	X22	X22A	FALSE
11	X2I019	C-19	Downstream Elandshoo...	Mine Property	2016-01-01	2021-12-01	NULL	NULL	191449	-25.377317	30.691617	18	inkomati_usuthu	X	X2	X22	X22A	FALSE
12	X2I002	C-2	Lunsklip River Upstream...	Rivers	2016-01-01	2021-12-01	NULL	NULL	190746	-25.396769	30.329746	19	inkomati_usuthu	X	X2	X21	X21B	FALSE
13	X2I020	C-20	Crocodile River at Rivulets	Rivers	2016-01-01	2021-12-01	NULL	NULL	191437	-25.430151	30.757412	19	inkomati_usuthu	X	X2	X22	X22B	FALSE
14	X2I021	C-21	Nels River at Brodal Road	Rivers	2016-01-01	2021-12-01	NULL	NULL	1000009832	-25.341111	30.881667	19	inkomati_usuthu	X	X2	X22	X22F	FALSE
15	X2I022	C-22	Sand River at Brodal R...	Rivers	2016-01-01	2021-12-01	NULL	NULL	1000009833	-25.328889	30.936111	19	inkomati_usuthu	X	X2	X22	X22F	FALSE
16	X2I023	C-23	Downstream of Longme...	Rivers	2016-01-01	2021-12-01	NULL	NULL	192544	-25.280278	31.000556	19	inkomati_usuthu	X	X2	X22	X22H	FALSE
17	X2I024	C-24	Upstream of White Rive...	Waste Water Trea...	2016-01-01	2021-12-01	NULL	NULL	1000009835	-25.315556	31.025278	19	inkomati_usuthu	X	X2	X22	X22H	FALSE

Table 15 Screenshot of the sample size data table in INWARDS representing the number of valid samples at each site per water quality constituent

id	station	source	index	Al_Diss_Water	As_Diss_Water	BOD	Ca_Diss_Water	Cl_Diss_Water	COD	Cr_Diss_Water	Cu_Diss_Water	ECOLI_Susp_Water
1	X2I001	IUCMA	1	0	0	0	0	0	0	0	0	18
2	X2I002	IUCMA	2	0	0	0	0	0	0	0	0	19
3	X2I003	IUCMA	3	0	0	0	0	0	0	0	0	19
4	X2I004	IUCMA	4	0	0	0	0	0	0	0	0	19
5	X2I005	IUCMA	5	0	0	0	0	0	19	0	0	19
6	X2I006	IUCMA	6	0	0	0	0	23	14	0	0	9
7	X2I007	IUCMA	7	0	0	0	0	0	0	3	0	19
8	X2I008	IUCMA	8	0	0	0	0	0	13	0	0	15
9	X2I009	IUCMA	9	0	0	0	0	0	0	0	0	19
10	X2I010	IUCMA	10	0	0	0	0	0	0	0	0	19
11	X2I011	IUCMA	11	0	0	0	0	0	14	0	0	18
12	X2I012	IUCMA	12	0	0	0	0	0	0	0	0	19
13	X2I013	IUCMA	13	0	0	0	0	24	0	0	0	19
14	X2I014	IUCMA	14	0	0	0	0	23	0	0	0	19
15	X2I015	IUCMA	15	0	0	0	0	24	0	0	0	19
16	X2I016	IUCMA	16	0	0	0	0	0	0	0	0	19
17	X2I017	IUCMA	17	0	0	0	0	0	0	0	0	18
18	X2I018	IUCMA	18	24	0	0	0	0	0	0	0	19
19	X2I019	IUCMA	19	23	1	0	0	0	0	0	0	18
20	X2I020	IUCMA	20	0	0	0	0	23	0	0	0	19
21	X2I021	IUCMA	21	0	0	0	0	0	0	0	0	19
22	X2I022	IUCMA	22	0	0	0	0	0	0	0	0	19
23	X2I023	IUCMA	23	0	0	0	0	0	0	0	0	19
24	X2I024	IUCMA	24	0	0	0	0	0	0	0	0	19
25	X2I025	IUCMA	25	0	0	0	0	0	14	0	0	14
26	X2I026	IUCMA	26	0	0	0	0	0	0	0	0	19

9.4 Building the Analyses Through Input Selection

9.4.1 Step 1: Site/s Selection

The user can select a specific dataset (e.g. DWS which is still to be integrated and IUCMA) or a merged dataset (Figure 53). All sample sites within the dataset selected are classified according to the type of water body sampled (e.g. Rivers, Dams, WWTWs, etc.), the user is required to select a type of sample site. The user will then select the water quality constituent of interest to them (e.g. Arsenic), once selected a site tree and map will be populated with sites which have data for that specific variable. This removes the tedious task of manually removing sites that do not contain data for the selected water quality constituent. The user can select a site either from the site tree or the map (Figure 54). The user can then proceed to selecting the benchmark parameters described below in step 2.

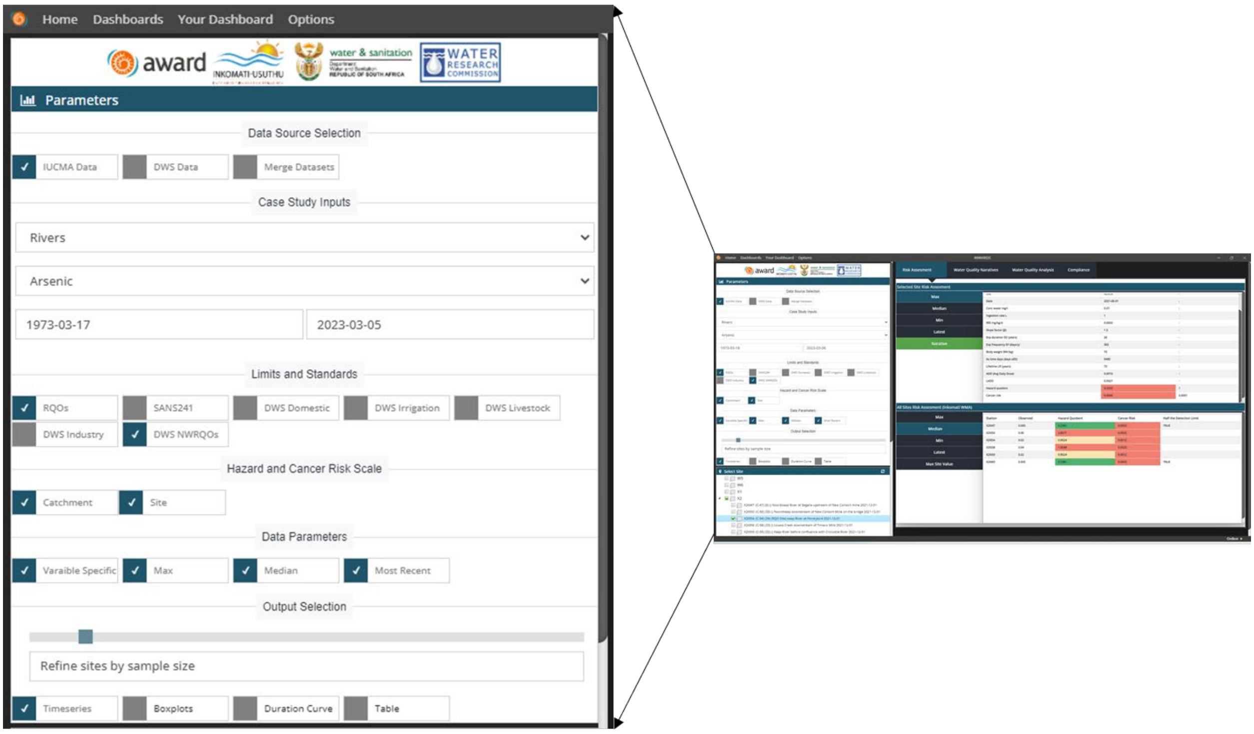


Figure 53 Screenshot of the dashboard highlighting the user controls for defining the analysis outputs

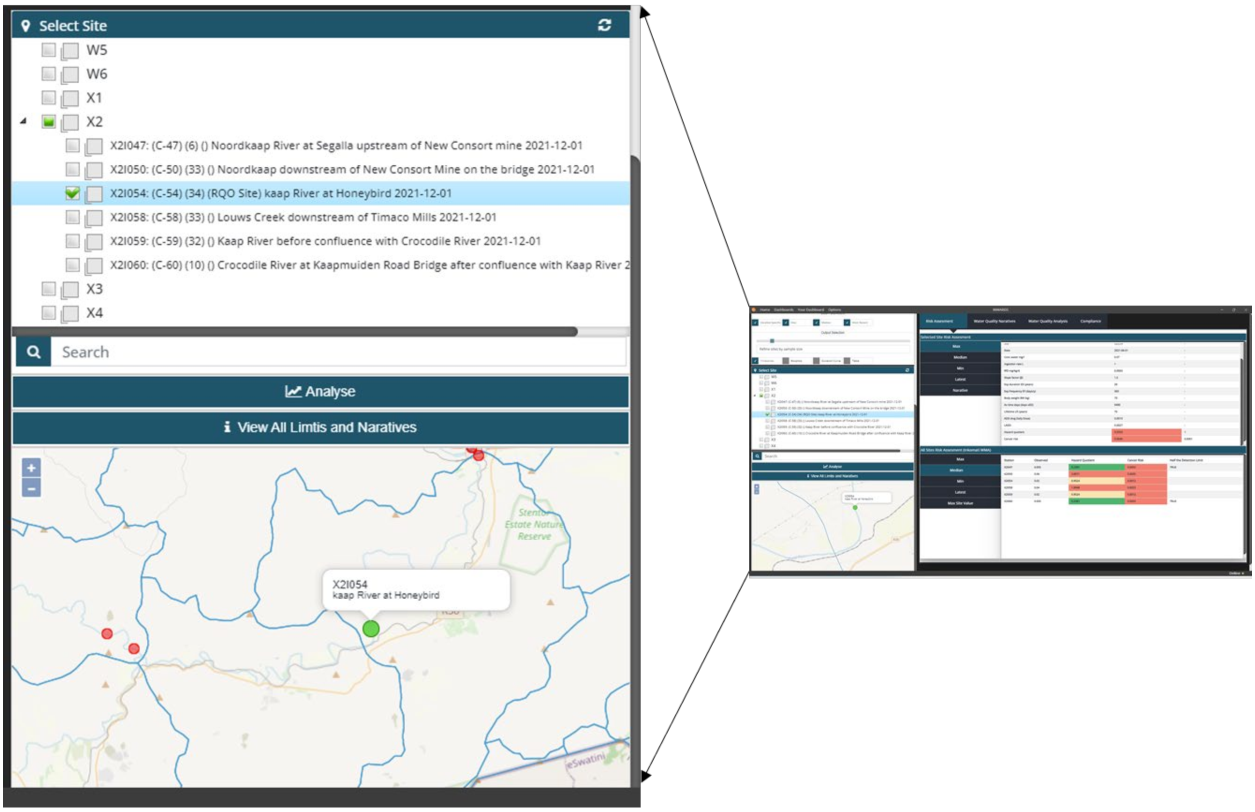


Figure 54 Screenshot of the health dashboard showing the site selection tree and site map in the left pane.

9.4.2 Step 2: Benchmark and limit selection

In order to identify a risk, some form of a benchmark or limit is required. If no benchmark is present very little can be said about the current state and the associated risks. In addition, without a benchmark a supporting narrative relating to the data being analysed cannot be provided. While both river biota and humans share similar risks associated with the same water quality constituents of concern, the degree to which each poses a risk is different. Moreover, different limits have been identified in relation to different uses (e.g. domestic versus agricultural use). Hence multiple benchmarks and limits have been derived for identifying concerns intended to guide the water resource management decision-making process.

i) The health of biota and humans are considered in such guidelines and benchmarks. In terms of riverine and biotic health, For example the water quality limits defined in the Resource Quality Objectives (RQOs), establishes concentrations as a standard for the healthy functioning of the river ecosystem.

ii) Human-related guidelines (e.g. WHO, SANS, etc.) are defined according to the water use such as consumption, recreation, irrigation, livestock or sanitation. While, environmental standards are generally single-limit based, human standards are more complex in nature requiring multiple parameters for calculating a value that can be translated into risk. For example, determining the risk of developing cancer from being exposed to water with arsenic in it, relies on a number of parameters such as the weight, volume consumed, duration of exposure. (see Table 16 and Report 3 for a detailed breakdown). The Water Quality-Health Dashboard is reliant on trigger values for displaying the severity of risk as well as for running the analyses against the observed data, which is determined by running the algorithms populated with the aforementioned parameters.

Benchmarks for determining potential risks to biotic and human health and well-being have been extracted and set for the Resource Quality Objectives (RQOs) and human risk related parameters (see Section 6.2). To this end, a range of benchmarks have been and can be utilised for determining the potential risks to biotic and human health including:

Human Health Indicators:

- Hazard quotients
- Cancer risk

Biotic Health Indicators:

- RQOs
- National RQOs

Potential Inclusions for the future as discussed during testing with partners and as part of a second phase (if funded):

- DWS Water Quality Standards
    - Irrigation Requirements
    - Livestock Watering Standards
    - Domestic
    - Industry
- SANS241 Drinking Water Standards

Table 16 Human risk algorithm parameter values for each water quality constituent of concern

	parameter	Al_Diss_Water	As_Diss_Water	Cd_Diss_Water	Cr_Diss_Water	Cr(VI)_Diss_Water
▶	Reference dose mg/kg/d	10000	0.0003	0.0001	0.005	0.003
	Cancer slope factor /mg/kg/d		1.5		0.5	0.5
	POD	1	0.0008	0.005	2.5	2.5
	Uncertainty factor	1	3	50	300	300
	Source/ reference	ATSDR 2022	ATSDR 2022	ATSDR 2022	ATSDR 2022	ATSDR 2022

9.4.3 Step 3: Defining calculation inputs

The dashboard also allows the user to structure the calculations performed based on the selection of a number of inputs. These include:

- the scale at which the analysis is performed
- data characteristics

9.4.3.1 Scale

One of the most powerful features of embedding research within a technological development such as a software-based decision-support dashboard is the ability to rapidly compute and replicate analyses. Therefore, users can choose to apply an analyses at the scale of a Water Management Area (WMA) or a single site (see Figure 55). The level of detail also differs between the single site and WMA wide assessment, with the single site showing the individual parameter values used in the risk algorithm in the backend.

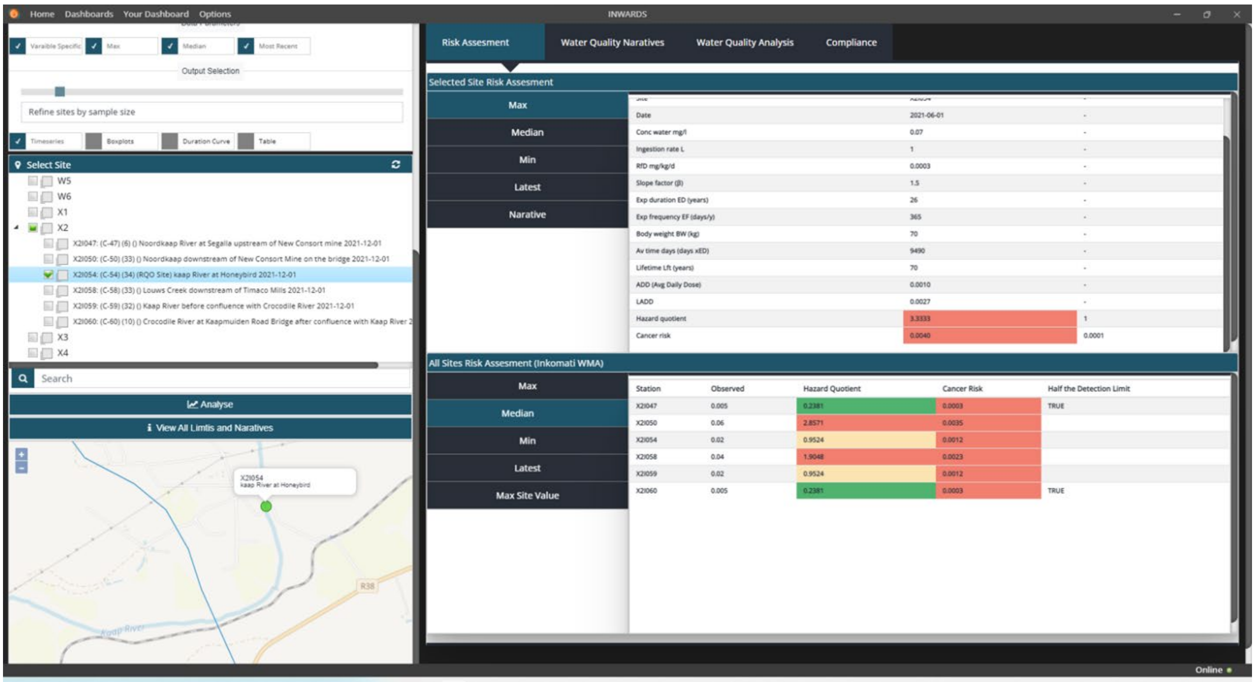
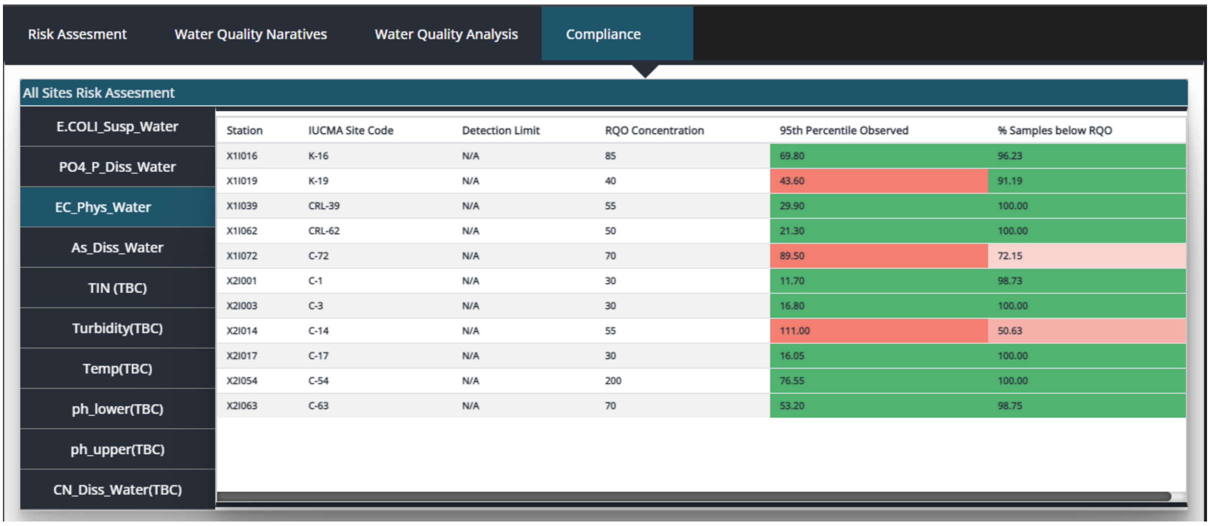


Figure 55 Screenshot of the dashboard showing the single site assessment on top and the catchment wide assessment at the bottom

9.4.3.2 Data Characteristics

A well-known attribute of water quality is the variability in concentrations observed which is influenced by drivers such as hydrology and point- and diffuse-source pollution. Thus, assessing risk or compliance against any one of the data characteristics alone for a site might be a misrepresentation of the true water quality profile. Thus, the dashboard allows for the selection of statistical and temporal-based values in the assessment. This includes determining the human health risk associated with the maximum, median, minimum and latest data points of a site’s observed data. In addition, the RQO compliance dashboard (see Figure 56) provides an assessment based on the data percentile point as defined and gazetted in the RQOs.



Station	IUCMA Site Code	Detection Limit	RQO Concentration	95th Percentile Observed	% Samples below RQO
X1I016	K-16	N/A	85	69.80	96.23
X1I019	K-19	N/A	40	43.60	91.19
X1I039	CRL-39	N/A	55	29.90	100.00
X1I062	CRL-62	N/A	50	21.30	100.00
X1I072	C-72	N/A	70	89.50	72.15
X2I001	C-1	N/A	30	11.70	98.73
X2I003	C-3	N/A	30	16.80	100.00
X2I014	C-14	N/A	55	111.00	50.63
X2I017	C-17	N/A	30	16.05	100.00
X2I054	C-54	N/A	200	76.55	100.00
X2I063	C-63	N/A	70	53.20	98.75

Figure 56 Screenshot of RQO compliance output tab in the dashboard

9.4.4 Step 4: Output selection

The dashboard has specific data representations that will automatically be rendered such as the many tables shown above. In addition to the automatically generated outputs, optional outputs can be selected such as the various graphs in the water quality analysis tab such as time series graphs, boxplots, duration curves and load duration curves if discharge data is available for the site (see Figure 57). The RQO concentration is plotted with the data on each of the graphs. Therefore, depending on the purpose of the analysis certain outputs can be switched on or off. This is intended to reduce the waiting time which is linked to outputting multiple renderings unnecessarily.

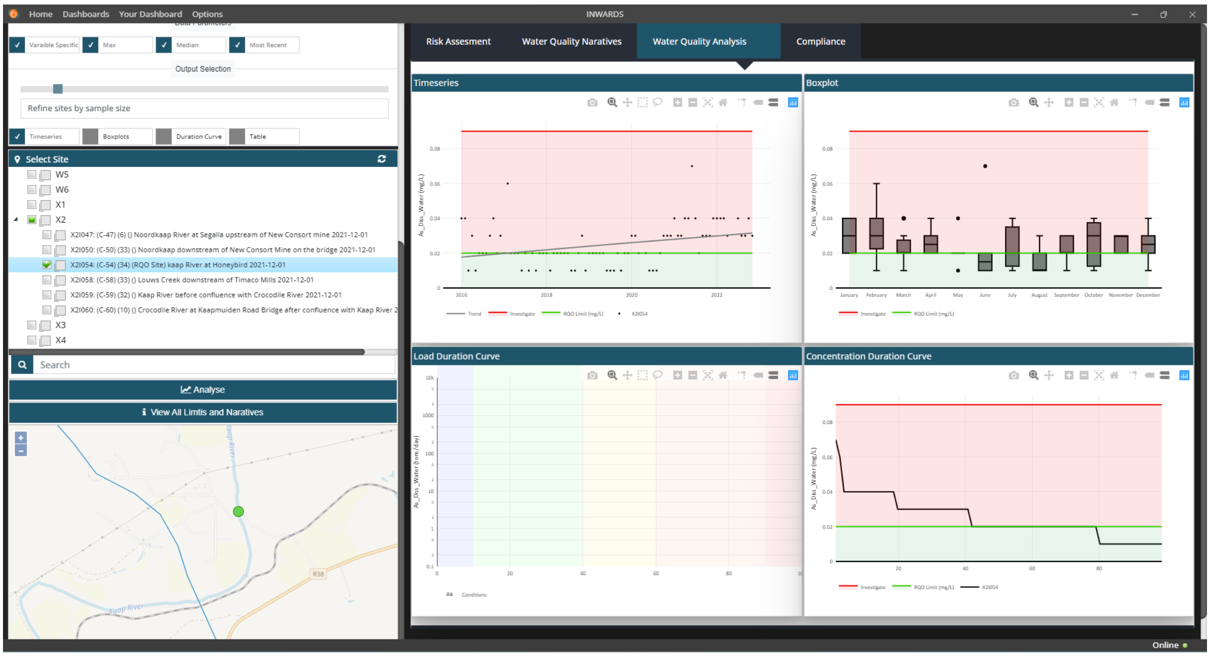


Figure 57 Screenshot of the dashboard showing the time series chart output as selected

9.4.5 Step 5: Submission and Interpretation

After completing steps 1 through 5, the user submits the inputs, Thereafter the server will then populate all equations with the parameters and run the analyses on the datasets associated with the site/s and water quality constituent selected. As shown earlier the four output tabs (Risk Assessment, Narratives, Water Quality Analyses and RQO Compliance) will be populated with the results of the analyses as various renderings including tables, charts and infographics. An important aspect to the analyses and what makes the Water Quality-Health Dashboard unique is the incorporation of narratives to support the user in making sense of the risk outputs (see Figure 58). These narratives are a combination of infographics and descriptions formulated to support the user in interpreting the results. In this way the dashboard helps with the structuring of an informed decision related to the risk or non-compliance output in the results. These narratives are being developed as part of a collaborative engagement. They are designed to fulfil a specific purpose, e.g. an RQO narrative may provide insight into the consequences for ecosystems[14] where as a health narrative may provide insight into the complexity of the risk as well as the key management actions required (e.g. contact municipalities). The latter component has to be co-developed with the IUCMA and partners. This co-development forms part of the testing process and has been discussed in previous chapters.

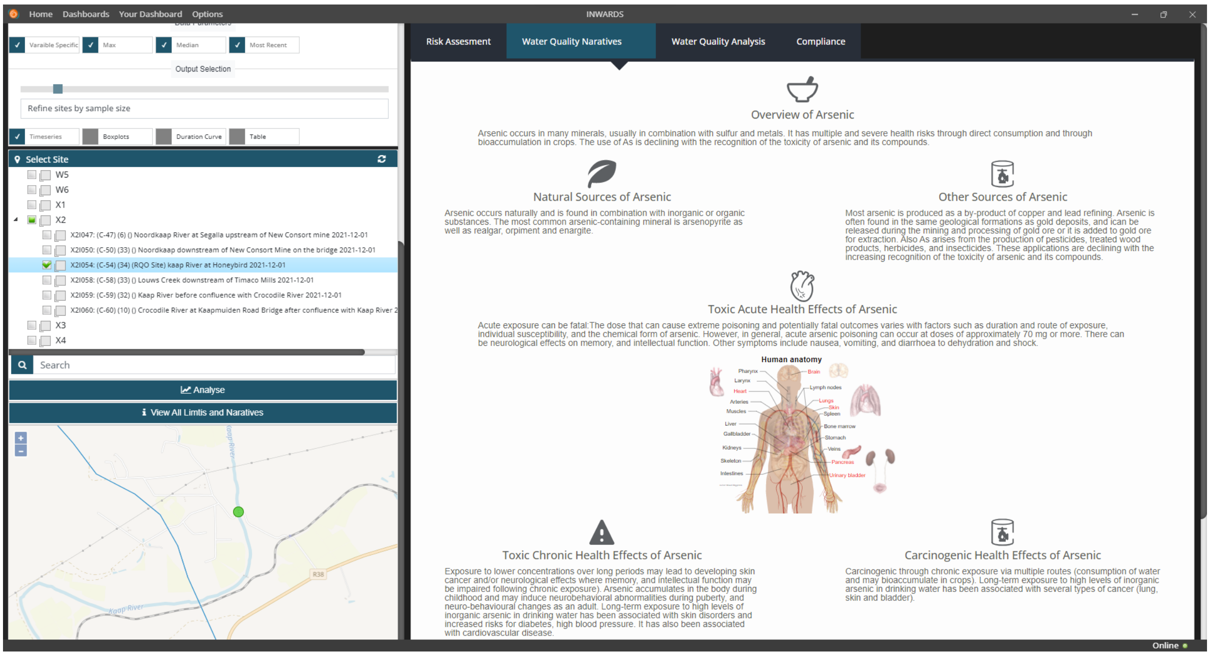


Figure 58 Screenshot of the dashboard showing the narrative associated with arsenic levels and human health

9.5 DISCUSSION

The WQHD has been developed in collaboration with users as detailed in Chapter 3 and has been discussed in detail over the course of the project. Currently a limited number of variables are included but these can be expanded should users require. A key recommendation is to update the data capture process for the IUCMA into a more structured procedure to limit the inclusion of erroneous comments or data.

[14] The narrative for ecosystem health is not part of this phase of the project but may be added if a second phase is funded

CHAPTER 10: CONCLUSIONS & RECOMMENDATIONS

10.1 OVERVIEW

Since the earlier assessment (Pollard et al., 2010), the past decade has seen a general improvement in river management and consequently in compliance with the various benchmarks (Tickner et al., 2020; Harwood et al., 2017; Pollard et al., 2023). Key to this has been improved institutional arrangements and collective action towards a common vision with established benchmarks (Pollard et al., 2023). Major progress was seen after 2010 with the progressive delegation of authority to the IUCMA to implement strategic functions including tracking compliance, the development of development of a Catchment Management Strategy, the establishment of a river system operations committee (Crocodile River Operations Committee), and the inclusion of the Reserve and RQOs as metrics for river operations and the development of a Rapid-Response-System for compliance management (McLoughlin et al., 2011). At the same time major challenges were evident with a revised hydrology suggesting increased deficits, increased demands for riparian land-reform from beneficiaries, domestic and agricultural needs as well as the need to plan for climate change impacts.

10.2 COMPLIANCE AGAINST TARGETS

A major purpose of the dashboard is to support the monitoring of compliance. However, it was noted that the issue of compliance needs further consideration as demonstrated for flow in the work done by Pollard and du Toit (2011) and Riddell, Pollard, Mallory and Sawunyama in 2013 as part of the Transboundary Rivers Project (also funded by the WRC). Water quality is more complicated than flow due to numerous variables and benchmarks. Some of the nuances relate to understanding compliance technically, legally and from a management perspective.

Discussions on compliance highlighted the need for further consideration and reference to earlier AWARD work on compliance is made, noting the following considerations. Technically if a benchmark is gazetted and is not met, this would constitute 'non-compliance'. However in South African law, there is a recognition of progressive realisation. Thus from a monitoring perspective a site may be non-compliant but in legal terms one would examine if the situation is getting progressively worse or better. From a management perspective there will be different responses depending on the severity of non-compliance and the trend. For example, non-compliance on a few occasions in the wet season may not require the same level of response as consistent non-compliance throughout the dry season.

Importantly, the IUCMA needs to be able to report on this to their board and in their engagements with stakeholders such as at the CMF and CROCOC meetings. This needs the following:

- A timeline of the trend. The dashboard offers this analysis.
- Direction of trend; whether a variable is improving or worsening over time. For example 10% of samples are non-compliant – this may be an improvement over 5 years or a worsening
- How often, how many and when sample(s) were non-compliant. For example if there is 'low-flow/ seasonal non-compliance". It was noted that the dashboard offers this through the B&W plots

AWARD has undertaken to examine and respond on potential additions to assist in such analytical and monitoring needs. The version of INWARDS at this point of the project has attempted to meet some of the reporting needs as described by the IUCMA. The integration of trends, seasonal boxplots, and duration curves and load duration curves. These perform the following:

- Timeseries charts with a best fit trend line plotted against the RQOs provide the IUCMA with the direction, distribution and performance over time
- Monthly Boxplots, allow the IUCMA to incorporate seasonality into their interpretation which provides a link to the hydrological conditions. Boxplots also provide the degree to which the samples for a specific month are exceeding the RQO
- Boxplots provide a more comprehensive link to hydrology as well as the quantity of the pollutant (see Chapter 8 for a more comprehensive example)
- Concentration duration curves provide the IUCMA with a quick assessment of the percentage of samples that are either exceeding the RQO and how many are below.

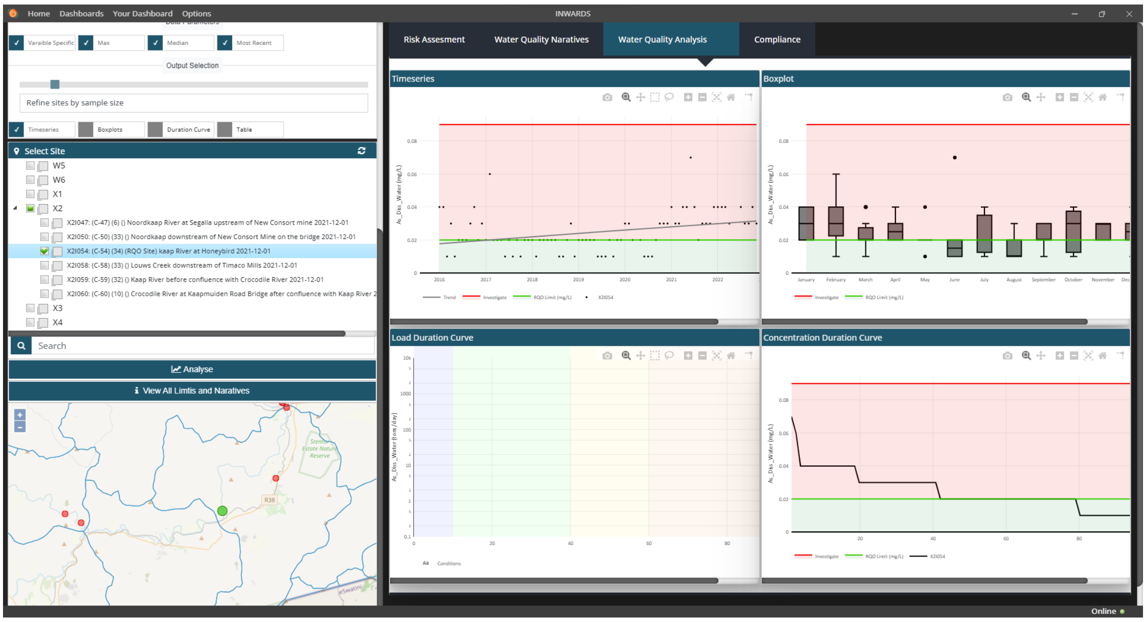


Figure 59 The demand driven dashboard as a key output

The IUCMA noted that they have a 5-year strategy with targets, e.g. a 5% improvement against which they need to report, especially to the Board. Within this there are intermediate targets. Again, AWARD noted that this will be developed as far as possible in this phase but that the development of a full *Progress against Targets* might need to be further developed under a second phase. This will greatly support communicating to staff less familiar with compliance and targets and to the Board.

10.3 OPPORTUNITIES FOR MAINSTREAMING

An important component of highlighting risks and ensuring that these are considered involves looking for opportunities to mainstream the discourse. Work was therefore undertaken on understanding what opportunities and pathways exist for mainstreaming issues related to health risks imposed by poor and deteriorating water quality (Table 17). These include the following:

Table 17 Potential opportunities for mainstreaming into policies and plans

Policy/ plan	Description/ rationale	Comment
Catchment Management Strategy	Facilitated by the IUCMA. Includes various strategies which relate to water quality, disaster management, information management and CME	Next round
IDP for the CoM	The Mbombela Integrated Development Plan (IDP) guides and informs all planning, development and budgeting decisions within the municipality. The current plan covers 2017-2022.	
IDP for the EDM	Priorities include: implementing and planning for water and sanitation projects, waste management especially aiming for the reduction of dumping sites, recycling and green economy, job creation, rural and local economic development, management and mitigation of disaster, municipal health and planning, rendering support to local municipalities, supporting the establishment of agri-hubs and integrating systems to the mainstream economy of scale	
Spatial Development Framework	This is produced by the City Planning & Development department. A biodiversity layer has been included in the current SDF.	A Water Quality-Health layer could also be included and " marketed" Due for review in 2023.
Land Use Management System (LUMS)and Land use Scheme; CBA	Refers to all the tools, systems and procedures a municipality requires in order to manage land and its use effectively. An SDF and a Land Use Scheme are some of the critical components of the LUMS. A Land Use Scheme is a planning tool that allows or restricts certain types of land uses to certain geographic areas. It sets out the various Use Zones Critical Biodiversity Areas (CBA) are terrestrial (land) and aquatic (water) areas that must be safeguarded in their natural or near-natural state because they are critical for conserving biodiversity and maintaining ecosystem functioning (water quality and integrity)	Due for review in 2023, and draft comments can be submitted now.
District Development Model (DDM)	The DDM, spearheaded by CoGTA and approved by Cabinet in 2019, is an integrated planning model for Cooperative Governance which seeks to be a new integrated, district-based, service delivery approach aimed at fast-tracking service delivery and ensures that municipalities are adequately supported and resourced to carry out their mandate	These meetings are ongoing
<u>Climate change</u>		
Just Transition: Strategies to decarbonize the economy	National and provincial efforts to move away from a coal-based economy by planning to lower the risks faced by the most affected and vulnerable stakeholders, such as working people, small businesses and low-income communities, while providing an opportunity to maximise the development of new opportunities and redress historical injustices.	

Policy/ plan	Description/ rationale	Comment
CoM Climate Change Strategy and Implementation Plan (2017)	Important to make the links between climate change and reduced water availability and security and water quality	Track if this is to be updated
Climate change compact of Mayors & stakeholders	Important to make the links between climate change and reduced water availability and security and water quality	Track
CoM Environmental Management Plan	Important plan to raise the risks of water quality deterioration and mitigation	Currently being gazetted
COM Spatial Planning	Update CoM spatial data on land use constraints to include - climate change-related vulnerabilities - risks and vulnerable areas in land use decision making Incorporate WQ-H risks & considerations into the development and update of various CoM land use and human settlement planning documents	
COM Disaster Management Plan	Update the CoM Disaster Management Plan to meet the requirements of the Disaster Management Amendment Act 2015	

10.3.1 Systems and processes for sharing information

A range of platforms and processes are being identified and discussed through which the profile of Water Quality-Health Risks can be raised. This work is ongoing. Some examples include

1. Inkomati-Usuthu WMA, various operations committees for the Crocodile River. Such as the CROCOC and the CMF
2. Climate change compact of Mayors & stakeholders
3. DDM: Forum meetings
4. Environmental Management Forum
5. Disaster Management Advisory Forum
6. Council meetings (CoM and EDM)

10.4 CONCLUSIONS

The Water Quality Human Health System was successfully developed together with key partners using data from both the DWS and the IUCMA. This has greatly strengthened water governance functions, as noted by the IUCMA and SANParks. Nonetheless some gaps and challenges are noted below under recommendations.

The Crocodile River Catchment was used as a pilot site to explore water quality health risks and their incorporation into both a decision support system for IWRM and as an approach to raise awareness and shared actions regarding pollution-related risks. From the project work undertaken through this project it is clear that, water quality poses potential health risks particularly in terms of arsenic, chromium, manganese and *E. coli*. Subplate and orthophosphate loads are also concerning indicators of other pollution sources. The collaborative approach has enabled key partners to co-design a system and dashboard that captures such risks and in ways that can respond to their various needs. This has greatly strengthened water governance functions, as noted by the IUCMA and SANParks. The project has also examined institutional arrangements and shared responsibilities as the basis for shared practices around monitoring, regulation, reporting.

Nonetheless a number of gaps and challenges are noted below as recommendations for future work.

10.5 RECOMMENDATIONS

The following recommendations emerge from the above conclusions and address some of the gaps and challenges

Expansion of the WQHS

- The WQHS needs to be expanded to the entire Inkomati-Usuthu WMA if their functions regarding compliance monitoring against the Reserve and RQOs is to be strengthened.

Monitoring: data and variables monitored

- Water quality data from both DWS and IUCMA are integrated into the human health dashboard and are used in the various risk assessments. While the IUCMA data received by the team only spans from 2016 to 2023, hard copy records predating this exists as well which should be included. Currently the IUCMA has 83 active water quality monitoring points in the Crocodile River Catchment, variables analysed for vary according to site being monitored and the purpose of that site. However, whilst the physico-chemical parameters are well represented in the DWS data, toxin and biological data are sparse and outdated. Given the potential increase in pressures on water resources and recent work on EDCs, these factors need to be considered. The lack of reference sites for long-term heavy metal data (toxins) is a major constraint in examining relationships between indicator species and contaminants of concern, e.g. sulphates and heavy metals. Full spectrum monitoring does need to happen at an identified long-term site(s) that is lightly impacted, e.g. Montrose and would include physico-chemical, biological and toxins.

Understanding water quality risks

- The Elands River has shown an increase in salinization which is likely to impact on irrigated agriculture and soil health and requires further examination
- At Montrose Falls: orthophosphates appear to be a problem during high flows; examine the source of this runoff. (for example through a feedlot) which could also signify other contaminants of concern
- Given the rapid transfer of water quality risks downstream and the changes in indicator water quality species before and after the sugar-cane agriculture, toxic screening for sugar cane may be an interesting research initiative given the accumulation that seems to be occurring at this point

Impact practices and pathways

- Whilst we were not therefore able to establish clear relationships due to a lack of reference sites, the use of indicator water quality species has indicated the high level of risk transfer due to the nature of river channel. This needs to be further explored
- It is recommended that changes in practices be explored in depth at a number of sites:
    - Ngodwana in order to understand the higher levels of sulphates that have been recorded. It was noted in a meeting that they were moving from gum to pine with implications for water use and for changes in processing for example)
    - The new Consort mine (gold) in the Kaap River (as part of the Barberton mines) to explore the increasing trends in arsenic from about 2017 as shown in the above analysis from IUCMA data and the potential to transfer risks downstream.

Communities at risk

- Updated census data from 2021 is needed to provide a more recent understanding of communities at risk since 2011. Furthermore, a more nuanced approach may be needed to look at vulnerability more holistically to include more determinants of vulnerability, including dimensions of poverty and inequality.

Dashboard development

- Currently a limited analysis of the array of variables has been included but these can be expanded should users require further inclusion of variables.
- In the future, additional datasets on water quality standards covering each user (domestic, industry, agriculture and so on) should be included
- A key recommendation is to update the data capture process for the IUCMA into a more structured procedure to limit the inclusion of erroneous comments or data and to support the submission process to RQIS, which has their own clear submission requirements.

Stakeholder engagement and capacity development of affected communities

- Resource constraints meant limited engagements with the local structures regarding community health and information sharing (clinic committees) and this remains an important area of work in taking forward outputs and community capacity development. This should be linked to building resilience for climate change
- In terms of stakeholder networks and community capacity development, further work is needed. The inclusion of the Provincial Department of Health as well as the clinic committees which would represent local-level concerns and information on water quality and health requires further work. Clinic committees are governance structures legislated by the National Health Act. They have an oversight function for quality of care at clinics. Each primary health care facility should have a committee comprised of community members and a facility manager and local government ward councillor. Health requires a broad purview including social determinants so early warning would be in their scope.
- Based on the inclusion of visuals and a narrative, further work is still required to communicate risks (for example, in order to explain the importance of loads versus concentrations). These concepts may not be easily understandable by many staff and would be important in the communication of results: to the IUCMA board and other stakeholders

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