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MINI REVIEW

Current Status and Key Challenges of Water Quality in the Olifants and Orange-Vaal River Systems, South Africa

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This comprehensive review assesses the water quality in South Africa, with a specific focus on the Olifants and Orange-Vaal River systems. Both rivers serve as vital water sources for domestic, agricultural and industrial purposes but face significant pollution challenges. This review integrates findings from recent peer-reviewed studies to characterize the dominant sources of contamination, evaluate their impacts on aquatic ecosystem integrity and assess associated risks to human health. It further outlines a suite of targeted, evidence-based recommendations to enhance water quality management within the Olifants and Orange-Vaal River catchments. These recommendations include implementing integrated and adaptive water resources management frameworks, expanding advanced monitoring, modelling and early-warning systems, strengthening regulatory enforcement, enhancing public environmental literacy, and improving coordination among government, industry and civil society. Collectively, the findings highlight the pressing need for coordinated, long-term interventions to protect South Africa's freshwater systems under intensifying anthropogenic pressures and projected climate-change impacts.

Keywords: Surface water quality, Pollution sources, Ecological impact, Health impact, Orange-Vaal river, Olifants river.

INTRODUCTION

Water quality assessment is a critical component of sustainable water resource management (WRM), especially in countries like South Africa where water scarcity, climate variability and escalating pollution pose serious challenges to socio-economic development and environmental health [1,2]. In this regard, the Olifants and Orange-Vaal Rivers are two of the nation's most significant river systems [3-5]. They support a variety of activities, such as industrial manufacturing, commercial agriculture, mining and have water consumption and they are vital to millions of people [3,4]. Despite their significance, these rivers are increasingly threated by a combination of human activities that comprise both water quality and ecologic al integrity [3,4].

Pollution in the Olifants and Orange-Vaal Rivers emanates from diverse sources such as industrial discharge, acid mine drainage, nutrient loading from fertilizers, pesticide runoff from agricultural lands and the inflow of untreated or inadequately treated municipal wastewater contribute to a complex and evolving contamination profile [6]. In addition to affecting aquatic life and ecosystem services, these pollutants also pose serious health concerns to people, especially in vulnerable rural and peri-urban communities who depend on these rivers for fishing, drinking water and sanitation [7]. This review seeks to provide a comprehensive and integrative analysis of the water quality challenges facing the Olifants and Orange-Vaal Rivers. It examines the variety of techniques used to evaluate the quality of water such as physico-chemical analysis, biological indicators and remote sensing technology. The review also attempts to find patterns, locate trouble spots of contamination and evaluate the efficacy of current management and policy measure by analysing both recent scientific research and long-term monitoring data.

METHODS

A systematic literature review was conducted to identify, synthesize, and critically evaluate existing knowledge on the current status of water quality in South African rivers, using the Olifants and Orange-Vaal Rivers as case studies, with emphasis on key challenges. This section outlines the procedures used to find and assess literature about the water quality in the Olifants and Orange-Vaal Rivers.

Data collection: The review adopted Nightingale's [8] methodology for data collection and analysis due to its systematic and robust framework for integrating research findings, reducing potential bias and delivering a thorough examination of the subject matter. Given its esteemed reputation and interdisciplinary scope, this approach is recognized within the Web of Science (WoS) scientific database [9]. The literature search in WoS was conducted using the following keywords: "surface water quality", "pollution sources", "ecological and health impacts", "Olifants River", "Orange-Vaal River" and "South Africa Rivers".

Data extraction: Following the application of the inclusion criteria, a total of 40 articles were selected. Key details from these sources, such as titles, authors, publication years and central themes, were compiled into a master document. After thoroughly reviewing the selected literature, comprehensive notes were taken and systematically organized within this study. These notes were categorized by relevant topics, including surface water quality in South Africa, the current state of water in the Orange-Vaal and Olifants Rivers, impacts of mining, agricultural activities and urbanization on water quality in the Orange-Vaal and Olifants Rivers and broader challenges related to water quality management across South African river systems. Studies were selected based on predefined inclusion criteria, whereby (i) only peer-reviewed publications written in English were considered, (ii) with relevance limited to the Olifants and Orange-Vaal River systems in South Africa, and (iii) with a specific focus on investigations addressing surface water quality and related environmental parameters within these catchments.

Given the critical and multifaceted nature of water scarcity in South Africa, it was therefore essential to focus on high-quality, relevant literature that directly informs water quality within this context. In this systematic review, studies were excluded based on the following criteria:

(i) **Geographical irrelevance:** Those researches not focused on Olifants and Orange-Vaal Rivers, South Africa or lacking significant relevance to the South African context was excluded to ensure the review remains regionally grounded.

(ii) **Non-significance:** Studies that did not address aspects of water quality analysis were omitted.

(iii) **Inadequate methodological rigor:** Published articles lacking a clear methodology, including anecdotal reports, editorials or opinion pieces, were excluded to maintain the scientific integrity of the review.

(iv) **Language:** Only studies published in English were included, due to limitations in translation capacity and to ensure accurate interpretation of findings.

(v) **Redundancy:** Duplicates or studies presenting identical data without additional insights were excluded to avoid redundancy.

Olifants River Basin: The Olifants River catchment falls within the Limpopo River Basin, which is part of an international drainage basin that stretches across South Africa, Botswana, Mozambique and Zimbabwe [10,11]. The Olifants River is significantly for the entire basin because it supplies around 40% of the water that flows in the Limpopo River. The Olifants River is currently the only tributary that keeps the Limpopo River flowing during the dry season [10,11]. Fig. 1 presents the map of the Olifants River Catchment showing the upper, middle and lower regions of the catchment and the lower Limpopo Basin [11].

Pollution sources: The Olifants River Basin is subjected to a range of human activities that have significantly altered its water quality over time. Mining, farming, urbanization and industrial activity are the most important of them [11,12]. Each of these industries produces unique contaminants that when combined, deteriorate the river systems, affecting both the availability of safe drinking water and the health of the ecosystem [11,12]. Addo-Bediako [11] evaluates the risk of chemical pollution in Olifants River Basin, South Africa. His study highlights the risk posed to humans by exposure to potentially toxic elements in the Olifants River Basin. This study also underscores the need for regular monitoring of chemical pollution and the implementation of effective mitigation strategies to safeguard the river ecosystems and human health, including proper treatment of water for domestic and agricultural purposes [11]. Similarly, Dabrowski *et al.* [12] conducted routine sampling of water quality at sites along longitudinal gradient from upstream to downstream in the Olifants River. Their results showed that nutrients concentrations were relatively high and a number of sites within the catchment had average nitrogen to phosphorus (N:P) ratios that were indicative of eutrophic to hypertrophic conditions [12]. Lukhele *et al.* [13] reviewed the state of Ireland waterbodies in South Africa, identifying the major drivers of eutrophication and found that up to 76% of major water impoundments and approximately 70% of major river systems are eutrophic to hypereutrophic and experience protracted periods of cyanobacterial blooms, particularly in the summer months.

Mining activities, especially coal mining are the main causes of pollution in the Olifants River catchment. Numerous mining companies are located within the basin, particularly in the upper catchment regions such as the Mpumalanga Highveld [12,13]. Acid mine drainage (AMD), which is characterized by low pH levels, high concentrations of sulphates and heavy metals (iron, manganese, arsenic and lead), is a result of these operations [14]. Acknowledging these threats, Jessica *et al.* [15] pointed out that the water that decants from mine woods is incredibly low quality. By raising the number of suspended solids, mobilizing iron, aluminium, cadmium, manganese, cobalt and zinc and raising the pH of water overall, mine water has a detrimental effect.

Another significant source of water contamination in the Olifants River Basin is agricultural runoff [16,17]. Surface runoff and leaching of nutrients, especially phosphates and nitrates, into nearby water bodies are caused by the extensive use of chemical pesticides and fertilizers in both commercial and subsistence farming. The process of eutrophication, which is especially noticeable in impoundments such as Loskop and Flag Boshielo Dams, is fuelled by this nutrient enrichment and results in the creation of algal blooms. When dissolved oxygen levels in the water are reduced due to eutrophication, fish are

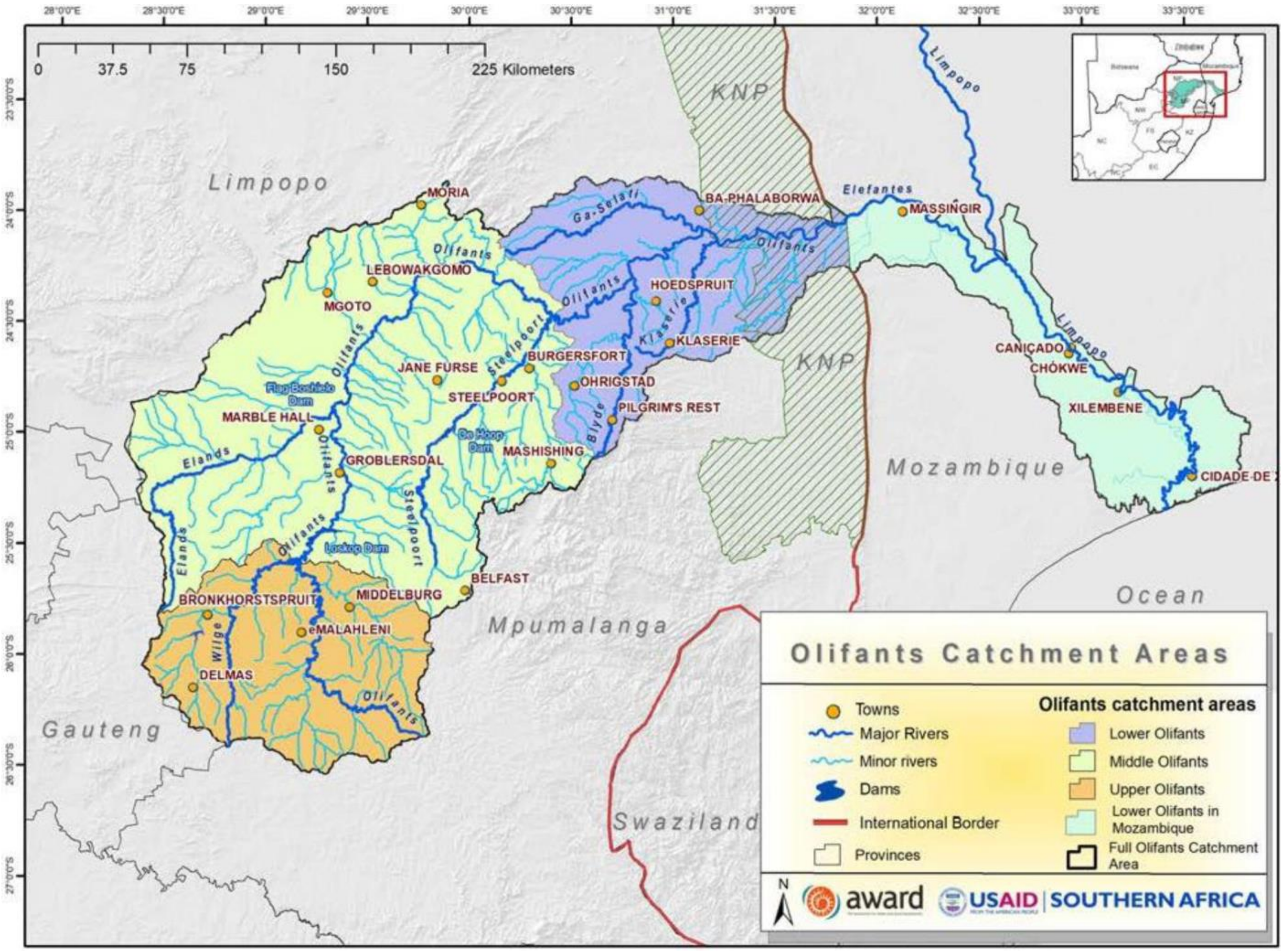

Fig. 1. Map of the Olifants River catchment showing the upper, middle and lower regions of the catchment and the lower Limpopo Basin (Reproduced from Addo-Bediako [11])

killed, habitat is lost and the water quality deteriorates, rendering it unfit for drinking or recreational use. For instance, a study on agricultural runoff on river water quality by Gomes *et al.* [17] found that the water's oxygen content may decrease if there are more suspended solids present from agricultural activities. Whereas, a study on the effects of irrigation return flows on the receiving waters' quality were investigated by Mhlanga *et al.* [18] reported that the drainage streams had high concentrations of sodium, magnesium and total dissolved solids (TDS), exceeding the South African standard for irrigation water.

Urbanization and industrial development are major contributors to the pollution load in the Olifants River Basin, in addition to mining and agriculture [19]. Untreated or inadequately treated wastewater is frequently dumped straight into rivers and streams from urban settlements, particularly unofficial ones with inadequate sanitary facilities [19]. This increases the danger of water borne illness and makes downstream water treatment efforts more difficult by introducing microbes, organic materials and pharmaceutical residues into the water system. Along the river, industrial facilities discharge a variety of chemical pollutants, such as hydrocarbons, solvents and other dangerous materials, some of which are persistent in the environment and can build up in aquatic life [19]. For instance, a study by Jospeh [19] on the main issues causing deterioration of water quality and water scarcity showed that the water quality and services that rivers offer is seriously threatened by sewage wastewater discharges. While, a study by Mercy *et al.* [20] expressed that in urban areas, ineffective and collapse infrastructure can lead to a decline in river water quality.

Ecological and health impacts: The Olifants River's ongoing pollution has caused extensive ecological damage and pose major health hazards to aquatic life as well as the human communities that rely on the river for their livelihoods. The effects are complex, influencing ecological function, biodiversity and public health in interrelated ways.

The bioaccumulation of heavy metals in aquatic species is one of the most obvious indicators of ecological stress in the Olifants River. High concentrations of hazardous metals such as lead, chromium, cadmium and mercury have been detected in fish species like labeo rosae (*Rednose labeo*), a popular freshwater fish. Usually brought into the river by industrial discharges and mining runoff, these metals gradually build up in fish tissues. Fish growth, reproduction and immunological function can all be negatively impacted by prolonged exposure to these metals, which can eventually result in population decreases. A study by Jooste *et al.* [21] on the metal bioaccumulation in the fish of the Olifants River found that metals are accumulating in the muscle tissue of *L. rosae* and pose an unacceptable health risk to rural communities.

Consumption of contaminated fish by local communities poses significant health risks, including neurological disorders, developmental delays in children and an elevated risk of cancer and organ damage. Many of these people depend on subsistence fishing. In the middle and lower portions of the Olifants River, eutrophication and toxic algal blooms have become significant environmental hazards in addition to metal contamination. A study by Dupreez *et al.* [22] focuses on identifying the potential health hazards posed by chemical contaminations in fish and provides a framework for evaluating the risks to human consumers. Their study identified areas in the aquatic system where fish have unacceptably high chemical contaminant levels. Furthermore, the growth of cyanobacteria or blue-green algae, is encouraged by the over abundance of nutrients from wastewater effluent and agricultural runoff. These algae can create dense and hazardous algal blooms (HABs).

Orange-Vaal River Basin: The Orange-Vaal River Basin, recognized as one of South Africa's most significant and essential water systems, is crucial for sustaining the nation's economic and agricultural endeavours. Nevertheless, in recent decades, it has encountered rising pollution levels as a result of heightened human activities and insufficient regulation of waste disposal. Mnguni [23] reviewed the state of the Vaal River pollution, including the measures that have been designed to address the problem in short, medium and long term. The findings reported that the problem of water pollution in the Vaal River emanates from the lack of the application of basic principles of integrated asset management, which is defined as an integrated process of decision-making, planning and control over acquisition. Erasmus *et al.* [24] assessed the element contamination from six sites within the Orange-Vaal River Basin and found that the element concentrations accumulated correspond to the anthropogenic land-use activities associated with each site. Their results highlight the importance of monitoring toxic pollutants and their human health effects associated with the consumption of contaminated fish, while also linking the interaction between environmental animal and human health. Fig. 2 presents the map of the Orange-Vaal River Basin.

Pollution sources: The Orange-Vaal River system is confronted with considerable pollution issues arising from various human activities [23,24]. Overtime, these pollution sources have accumulated, severely impacting water quality, ecological integrity and sustainability of the river's water res-

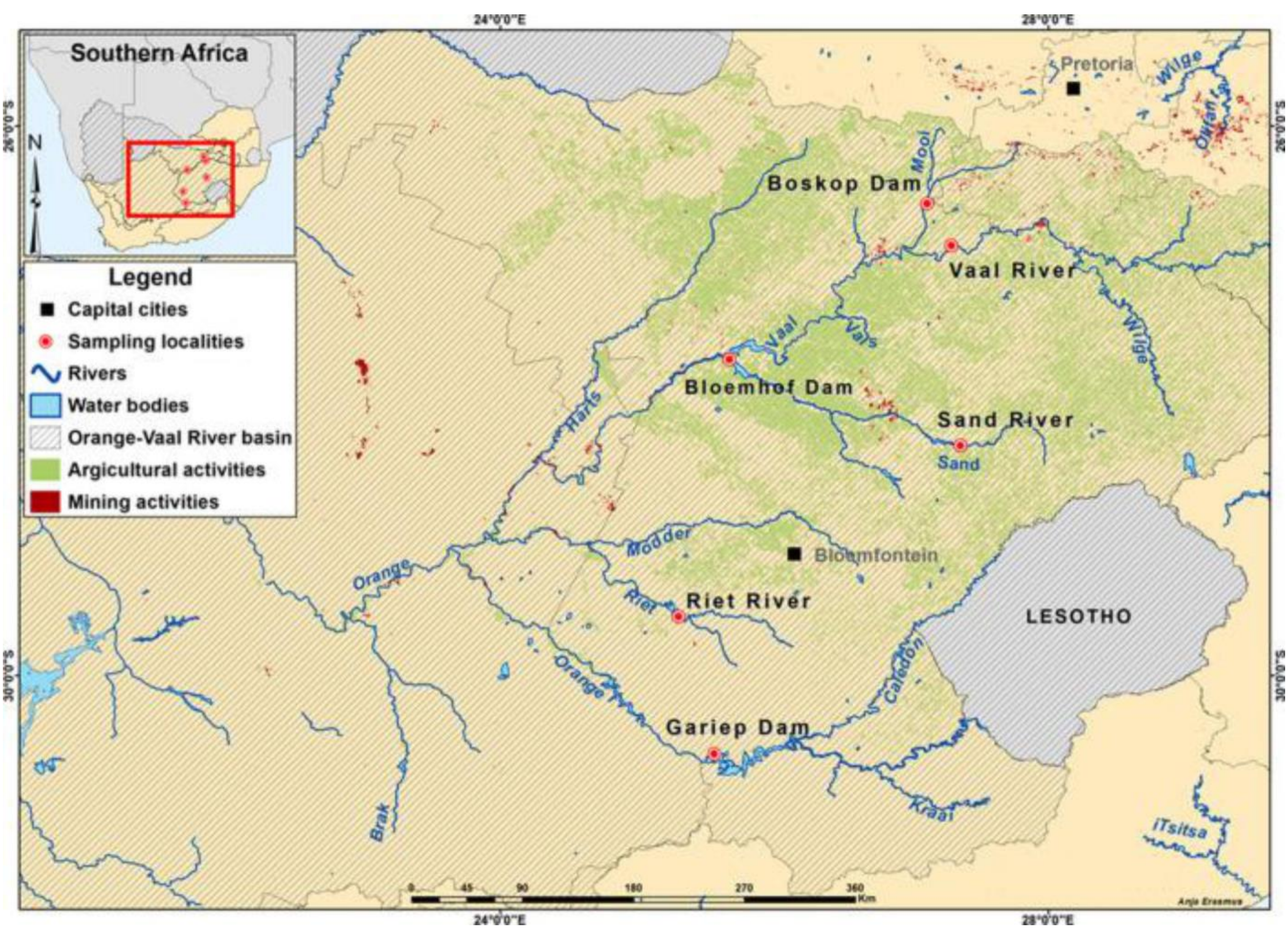

Fig. 2. Map of the study area, indicating the Orange-Vaal River Basin, Southern Africa (Reproduced from Erasmus *et al.* [24])

ources [23,24]. The main contributors to pollution in the Orange-Vaal River Basin consist of agricultural runoff, industrial effluents and untreated sewage, all of which lead to increased nutrient concentrations and a declining environmental condition [23,24]. A study by Odume *et al.* [25] on the perception and motivations underlying the stakeholder contestations of water quality use and management in the Vaal barrage catchment found the following:

(1) There is a need for a multi-pronged approach to increase water quality compliance;
(2) There is a need for trust within the regulatory system to increase confidence in the system;
(3) There is a need to strengthen institutional capacity both in terms of implementation and costs recovery for service delivered; and
(4) Transparent, open processes and methods are needed for deriving standards in water-use licence.

This study contributes to a better understanding of the intricacies of water quality management within a contested space.

Agricultural runoff represents one of the most widespread factors contributing to the deterioration of water quality in the Orange-Vaal system. The extensive application of fertilizers, pesticides and herbicides in both commercial and subsistence farming practices leads to considerable nutrient loading, especially of nitrates and phosphates. These nutrients encourage algal growth, resulting in eutrophication, particularly in regions such as Vaal Dam and other reservoirs within the system. Eutrophication can lead to a series of environmental issues, including oxygen depletion, fish mortality and a decline in aquatic biodiversity. Wepener *et al.* [26] conducted a comprehensive review to critically examine the multifaceted impacts of chemical pesticides on environmental eco-systems and human health. The key findings advocate for a strategic shift toward practice that minimize environmental harm and safeguard human health. Moreover, the runoff frequently transports pesticides residues, which pose threats to aquatic organisms and may accumulate in the food chain, impacting both wildlife and human communities. Similarly, Omalanga & Shedrick-Ewens [27] assessed water quality issues in aquaculture areas to ensure optimal conditions for aquatic species: case of the Vaal River system in Gauteng, South Africa. Their results showed high TDS concentration (~177 mg/L) in the main stream of the Vaal River system, high concentration of metals leading to frequent first kills and high concentration in *E. coli* (240 counts/100 mL) and algal pigments constitute a high risk for the aquaculture production in the Vaal River system [27]. Another study by Ray *et al.* [28] investigated the bioaccumulation of pesticides in fish and their transfer through the food chain, demonstrating that these chemicals readily accumulate in fish tissues and pose significant health risks to humans upon consumption. Therefore, there is a need for research that would provide early warning signals for the contamination for certain pesticides in aquatic systems.

Industrial discharges are another major source of pollution in the Orange-Vaal River system, especially in urban and industrialized locales such as Vanderbijlpark, Sasolburg and various mining areas [29]. Industrial operations, particularly those associated with steel manufacturing, chemical production and mining emit a range of pollutants into the river system [30]. These pollutants include heavy metals (lead, cadmium and mercury), organic chemicals and suspended solids, all of which pose toxicity risks to aquatic life and disrupt the functioning of ecosystems. The industrial effluent frequently contains a combination of both dissolved and particulate contaminants, which can result in the bioaccumulation of toxins in fish and other aquatic organisms, consequently impacting biodiversity and public health. Furthermore, the pollution of water resources raises significant concerns for communities reliant on the river for drinking water, irrigation and recreational activities. A review on the impact of heavy metals from industrial wastewater effluent and removal technologies by Oladimeji *et al.* [30] reported that wastewater contamination causes significant environmental harm, including ecosystem degradation and dangers to human life, among other negative impacts.

Untreated sewage represents a significant source of pollution within the Orange-Vaal River system. A considerable portion of the pollution affecting the river originates from urban and transition zones where the infrastructure of wastewater treatment is either insufficient, outdated or entirely absent. In these areas, untreated or inadequately treated sewage is discharged directly into the river, resulting in the introduction of elevated levels of pathogens, organic matter and nutrients into the water [30,31]. This pollution not only diminishes water quality but also heightens the occurrence of water borne diseases, particularly among communities that depend on the river for drinking water or recreational purposes. The presence of human waste and pathogens in the river intensifier public health risks, leading to illness such as cholera, dysentery and typhoid fever, especially in underserved regions with limited access to safe drinking water and sanitation facilities. According to Marais de Vaal [31], AfriForum's advisor for environmental affairs, the sewage pollution crisis in the Vaal River's Catchment area can be attributed to municipalities' lack of the necessary capacity, expertise and ability to address the neglect of infrastructure.

Moreover, alongside these main sources, urban runoff from non-permeable surfaces like roads and parking lots, transports numerous pollutants, such as oils, heavy metals and plastic debris, into the river [32]. Sediment pollution is another issue in sections of the river experiencing considerable soil erosion, which may arise from deforestation, inadequate land management practices and construction activities [32]. The heightened sedimentation in the riverbed can suffocate aquatic species, interfere with the river's natural flow and diminish water clarity, consequently placing additional stress on aquatic life and water quality [32]. A review by Muller *et al.* [32] on the pollution conveyed by urban runoff reported that the atmospheric deposition, vehicular transportation-related activities and metallic building envelopes continue to be among the major pollution sources, which have been studied in a far greater detail than other sources.

Collectively, these sources of pollution contribute to the environmental issues facing the Orange-Vaal River system [32]. They lead to increased levels of nutrients and chemicals, adversely affecting water quality, aquatic ecosystems and the communities dependent on the river for their livelihoods.

Tackling these pollution sources necessitates a unified strategy that includes more stringent regulations, enhanced waste management practices, improved industrial oversight and sustainable agricultural methods to protect and rehabilitate this essential water resource [32].

Ecological and health impacts: As already stated, the Orange-Vaal River system has experienced growing ecological and human health concerns due to widespread contamination by various pollutants, particularly heavy metals and nutrient-enriched runoff [33]. The One Health approach, an integrated paradigm that acknowledge the interdependence of environmental, animal and human health, has been used by researchers more frequently in recent years to evaluate these implications. The systematic effects of pollution in the basin and its extensive ramifications for ecosystem stability and community well-being have been made clear thanks in large part to this method. Pheiffer *et al.* [33] investigated the contamination of sediments and fish from the Vaal River, South Africa. Their results reported the contamination with fifteen metals of river sediments and organs of sharptooth catfish *Clarias gariepinus* from four widely separated sites along this important South African waterway. Similarly, a study by Gilbert *et al.* [34] on the evaluation of trace element and metal accumulation and edibility risk associated with consumption of *Labeo umbratus* from the Vaal Dam, South Africa. Their study revealed that trace element levels in *Labeo* umbratus are lower compared to other species inhabiting the Vaal Dam and further indicate that risks for consumers can be decreased if humans relying on fish from the Vaal Dam preferentially consume this species over others.

The bioaccumulation of harmful substances in aquatic creatures, particularly fish, is one of the main ecological issues in the Orange-Vaal system [35]. A global review of literature on Catfishes by Segaran *et al.* [36] has revealed that the African sharptooth catfish or *Clarias gariepinus*, is a commonly consumed fish species in the area. As a result, its tissue tends to collect high levels of heavy metals like arsenic, cadmium, lead, chromium and mercury. Usually mining runoff, municipal wastewater discharges and industrial effluents deposit these elements into the river. They accumulate over time in top predators like catfish after entering the aquatic environment and being absorbed by organisms either directly or through the food chain.

Serious public health consequences result from this accumulation, especially for the local communities whose primary source of protein comes from subsistence fishing. Consuming contaminated fish can put people at risk for both cancer and non-cancerous diseases. Long-term exposure to heavy metals like arsenic and cadmium is linked to neurological conditions, development problems in children, kidney and liver damage and an increased risk of cancer, including skin, lung and bladder cancers. Reproductive toxicity, compromised immunological responses and gastrointestinal distress are examples of non-carcinogenic consequences. Risk is increased for vulnerable populations such as children, pregnant women and individuals with compromised health. A study by Adedeji & Okerentugba [37] on the benefits, public health hazards and risk associated with fish consumption highlights the importance of fish as a source of protein and other essential nutrients, while also addressing concerns about contamination with substances like methylmercury, polychlorinated biphenyls (PCBs) and other toxins. The study also emphasizes the need for strategies to mitigate risks and promote safe fish consumption practices.

In addition to chemical pollutants, eutrophication and nutrient loading have caused the river system's ecological health to deteriorate, the natural equilibrium of aquatic ecosystems is upset by the overabundance of algae and aquatic weeds, which are driven by nitrogen and phosphorus from sewage and agricultural runoff [38,39]. These blooms have the ability to lower water oxygen levels, obstruct sunlight penetration and interfere with photosynthesis in submerged vegetation [39]. Fish kills and biodiversity loss result from hypotonic or anoxic conditions caused by the decomposition of dying algal blooms, which uses a lot of oxygen. A stressed and damaged aquatic environment is also indicated by the dominance of more tolerant, frequently invasive species and the decline of sensitive aquatic species [38]. A review on algal blooms in eutrophic marine environments by Land *et al.* [39] highlights the importance of combining monitoring and control strategies to mitigate the adverse effects of eutrophication on marine ecosystems. Their study also reports that there is a serious health risk from microbiological contamination of untreated or insufficiently treated sewage. Water samples have been shown to include pathogens like *E. coli*, *Salmonella* and other enteroviruses, particularly downstream from metropolitan areas. Increased rates of waterborne illness including cholera, typhoid, diarrhoea and hepatis A are associated with the prevalence of these pathogens, especially in rural and informal settlement, areas where access to clean drinking water and sanitary facilities is limited.

The cumulative effects on wildlife are becoming increasingly evident. In contaminated areas of the river, macroinvertebrates, amphibians and aquatic birds exhibit discomfort and population decreases [40]. Their decline indicates larger ecological dysfunction and these species are significant bioindicators of water quality. Pollution has serious long-term effects on ecosystem services like food production, recreation and water purification. If current patterns continue unchecked, they may have an impact on future generations. A study by Bernanke & Kohler [40] on the effects of pollutants on wildlife populations has established links between chemical exposure and individual organisms' effects (particularly in fish and amphibians). Their review emphasizes the need for long-term studies and integrated research to elucidate the complex interactions between chemicals and wildlife, thereby bridging the gap between laboratory investigations and real-world field observations [40].

Comparative analysis: The Olifants River and the Orange-Vaal River Basins represent two of the most significant yet severely affected areas due to pollution and ecological decline [38-40]. The Olifants River, located in the northeast, is primarily impacted by extensive mining and agricultural practices, which contribute to elevated levels of heavy metals, nutrient loading and sedimentation. These stressors have led to the degradation of aquatic habitats and a decline in biodiversity, threatening the ecological integrity of the basin. In contrast, the Orange-Vaal River, a crucial part of South Africa's largest river system, suffers from industrial effluents, urban wastewater and widespread irrigation methods [38-40]. These pressures have resulted in altered flow regimes, eutrophication and the proliferation of invasive species, further complicating water quality management and ecosystem resilience.

Given the socio-economic importance of these basins, supporting agriculture, industry and domestic water supply for millions, the urgency to address their environmental challenges cannot be overstated. This study aimed to offer insights that can guide the development of more effective and integrated Water Resource Management (IWRM) approaches throughout South Africa's varied catchments. By examining the drivers of degradation and evaluating current management frameworks, the research underscores the need for adaptive, cross-sectoral strategies that incorporate scientific data, stakeholder engagement and policy reform to ensure the long-term sustainability of the country's freshwater resources.

Conclusion and recommendations

The Olifants and Orange-Vaal River Basins rank among the most strategically significant and heavily utilized freshwater systems in South Africa, serving millions of individuals, vast agricultural areas, mining activities and essential ecosystems. However, both river systems are encountering escalating water quality issues, mainly caused by human activities including the discharge of industrial effluents, agricultural runoff, insufficient wastewater treatment and uncontrolled urban development. Scientific evaluations and case studies consistently highlight the existence of dangerous pollutants, such as heavy metals, excessive nutrients, microbial contamination and suspended solids, many of which surpass allowable limits and present significant ecological and public health threats. These circumstances lead to issues like eutrophication, fish deaths, loss of biodiversity and the proliferation of waterborne illnesses, especially in low-income and rural areas. Although various policy frameworks and management strategies have been established, including IWRM, Catchment Management Agencies (CMAs) and localized monitoring initiatives, their execution has frequently been disjointed and inconsistent. Deficiencies in institutional capacity, insufficient funding, inadequate maintenance of infrastructure and weak enforcement of regulations persistently obstruct advancement.

Moving forward, it is crucial to adopt a multidimensional and integrated strategy. Improved monitoring systems need to be implemented to deliver precise, real-time information and support evidence-based decision-making. More rigorous pollution control measures are required to address both point and non-point sources of contamination, especially in high-risk industrial and agricultural areas. Engaging the community and prioritizing public education should be emphasized to promote environmental stewardship and encourage behavioural change at the community level. Moreover, strong policy enforcement must guarantee that violations are identified, penalized and rectified promptly and transparently. Furthermore, collaboration among various sectors, including government, industry, academia, civil society and local communities, is essential for attaining common water governance objectives. Investment in infrastructure enhancements, capacity building initiatives and cross-border collaboration will additionally bolster sustainable management endeavours. In summary, the enduring health and productivity of the Olifants and Orange-Vaal River systems rely on a unified and ongoing dedication to the protection of water quality. Through innovation, accountability and inclusive participation, South Africa can preserve these essential water resources not only for present requirements but also for the welfare and prosperity of future generations.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

DECLARATION OF AI-ASSISTED TECHNOLOGIES

The authors declare that no AI tools were used in the preparation or writing of this research/review article.

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