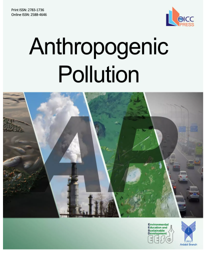

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Assessing the spatio-temporal variation of water quality over time at Malelane Area in the lower catchment of the Crocodile River, Mpumalanga, South Africa

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Abstract:

Freshwater is a limited resource experiencing accelerated contamination in several nations due to various reasons, including both natural and human-induced influences such as climate, topography, mining, industry, and agriculture. South Africa is characterized by water scarcity, a condition exacerbated by its status as a developing nation. Consequently, the country has the dual task of safeguarding water quality while simultaneously striving to enhance water supply and sanitation infrastructure. This study aims to assess the impact of agricultural activities on the water quality of the Crocodile River by using physiochemical tests and a water quality index tool. The grab sampling methodology was utilized on-site to collect water quality parameters which were analysed at a SANAS (South African National Accreditation System) laboratory. Statistical analysis was performed using the Seaborn software due to the extensive dataset contained in the present study. Highest concentrations of NO_2+NO_3 were recorded in the Autumn season between 2020 and 2022 with levels ranging between 1,2 to 0.7 mg/l. While spring and summer of 2018 and 2019 recorded the lowest concentration of NO_2+NO_3 at <0.4 mg/L, the low concentrations could be due to the dilution of the summer rainfalls as compared to the high concentrations that were recorded in the drier season of the year leading into winter. This could also explain significant concentration of PO_4 (0.35 mg/L) that were recorded during the winter of 2016. The findings indicate that throughout the autumn of 2017 and spring of 2019, the reported ammonia nitrate concentration exceeded 0.225mg/L. The WQI results revealed that the water quality at Malelane is regular at a value of 62.18, which suggests that the quality of the water is average to below standard.

Keywords: Agricultural; Spatio-temporal variation; Water quality index; Runoff, Pollution

1. Introduction

Freshwater is one of the most crucial but limited resources in the world. Ninety-seven percent of the earth's water is salt water, only the remaining 3% is fresh water and it is not evenly distributed (Kale, 2016). Out of the 3%, only about 1% is available and accessible for use to the world's population in the form of rivers, lakes, and ponds (Davies and Day, 1998; Kale, 2016). Freshwater resources are globally threatened by land-use activities and lack of environmental management practices (Addo-Bediako and Malakane, 2020). To this effect, Che et al. (2021) corroborate that the contamination of freshwater resources is exacerbated by inadequate environmental management practices that prioritise sustaining the economy at the expense of the environment. As such the inadequate environmental management practices have resulted in a rapid decline and degradation of this scarce resource. Though freshwater is a scarce resource, it is being contaminated at a faster rate in many countries due to both natural and anthropogenic factors such as climatic, topographical, mining, industrial, and agricultural activities just to name a few (Munyika et al., 2014; Uddin et al., 2021).

South Africa is a water-scarce country and on top of that, it is a developing country that is confronted by challenges in protecting water quality while on the other hand trying to improve water supply and sanitation (Carvalho et al., 2013). Most South African rivers are said to be stressed due to the increasing population and economic activities (Oberholster and Ashton, 2008; Soko and Gyedu-Ababio, 2015). These rivers have the burden of providing both water supply and transporting waste material in a country where a large proportion of the sewage is discharged into the rivers without being properly treated (Oberholster and Ashton, 2008). Industrial, domestic effluents and agricultural runoff are one of the most common sources of microbiological and chemical pollution of South African water resources (Phungela et al., 2022). Agriculture is the main cause of water pollution, as it releases agrochemicals and organic materials into water resources (Mohammadi et al., 2023). This problem is significant in Africa because of the enormous reliance of African countries on agriculture for both output and jobs in their economies. Che et al. (2021) raise worry about the harmful consequences of the misuse of river water supplies, mostly due to the need to maintain our economy. The mishandling has led to a fast deterioration and depletion of water resources in our environment. As an example, the agricultural industry in Africa makes up around 20 percent of the Gross Domestic Product, which is considerably larger than the worldwide average of roughly 5 percent (Uri and Sudry, 2022). According to Shi et al. (2019), the economic development of African countries relies largely on the availability of easily accessible freshwater resources, despite the fact that the continent's economy is mostly focused on agriculture. This is especially important since river water is the main source of freshwater, meeting the many needs of civilization (Fataei and Shiralipoor, 2011). Access to clean water sources is crucial for the survival of all living organisms (Jafarzadeh et al., 2015). In South Africa, the agricultural situation is complex due to the country's possession of the largest agricultural land area in Africa, while also facing the challenge of limited freshwater resources classified as semi-arid.

This limited, valuable freshwater resource is at risk of contamination due to extensive agricultural productivity. This is a quagmire given that agriculture in the country is considered a strategic sector that plays an important role in job creation and poverty alleviation (Mathebula, 2015). However, while agriculture represents an important sector of the economy across the country, its activities impose a significant risk to the susceptible environment, especially the freshwater resource, which cannot be overlooked (Drizo et al., 2022). That is, agriculture disrupts all the freshwater resources from their pristine stage, as indicated by Moss (2008). Xiao et al. (2021) posits that the agricultural sector in developing countries is a significant contributor to water contamination. Nonetheless, developing nations often prioritize the focus on industrial water pollution over agricultural water pollution, because of the conflicting interests between economic development and food security. In essence, Xiao et al. (2021) premise that in developing nations such as South Africa, the level of environmental regulations imposed on the agriculture sector is rather low. Nevertheless, it is essential to emphasise that these nutrients can have a detrimental effect on the environment when they are removed from the ecosystem through stormwater runoff (Fataei et al., 2010). According to Wang et al. (2023) and Nasehi and Fataei (2012), the release of water from agricultural activities, referred to as runoff, is a significant kind of pollution that does not originate from a specific site. This runoff originates from agricultural fields and is a key contributor to the surplus water that leads to substantial environmental problems. The non-point source of pollution is intricately linked to nitrogen, ammonia, and phosphorus, which originate mostly from agricultural fertilisers and contribute to the degradation of river water quality. Insufficiently examined, the consequences of inadequate water quality can extend beyond the banks of rivers, impacting aquatic ecosystems, the quality of drinking water, and endangering the general welfare of populations who depend on this vital resource.

Therefore, given the extensive agricultural activities in South Africa and limited environmental regulation, agricultural runoff is considered one of the major contributors to the deterioration of water quality in the country (Parmar and Bhardwaj, 2015; Mbanga et al., 2020). The Crocodile River is not an exception; as it is situated in the north-eastern part of South Africa in Mpumalanga, it is a large basin covering a length of about 320 km and draining a catchment of 10,450km^2 (Soko and Gyedu-Ababio, 2015). Therefore, considering the above, the influence of these factors on water quality within the Eastern region of the Crocodile River is a complex and diverse phenomenon that necessitates meticulous investigation and understanding. This study aims to assess the impact of agricultural activities on the water quality of the Crocodile River by using physiochemical tests and a water quality index tool. Often water quality is determined using a large data of individual water parameters in a form that is hard to digest and comprehend. The water quality index (WQI) is one of the most effective and popular approaches to evaluating the water quality of a certain water resource (Fataei et al., 2013; Uddin et al., 2021). It has the capability to reduce the bulk of water quality parameters information into a single value to express the data in a simplified and logical form. It takes information from a number of sources and combines them to develop an overall status of a water system (Adelagun et al., 2021; Sadigh et al., 2015).

2. Material and methods

2.1 Study Description

The study was conducted in the Crocodile River catchment area, in a small farming town called Malelane located near the Kruger National Park in the Kruger Lowveld region of Mpumalanga in South Africa on the N4 national highway (Soko and Gyedu-Ababio, 2015; Phungela et al., 2022).

Table 1. Sampling location and description.

Sampling location	Coordinates	Rationale for Sampling location
Malelane	-25°24′08.9″S 31°35′53.7″E	The sites are most susceptible to substandard water quality; therefore, they will provide the most comprehensive data on the impact of agricultural activities on the river system

Over the years Malelane has developed rapidly and agricultural activities have greatly increased, as a result stormwater runoff from urban areas and agricultural runoff is the main cause of river pollution in the vicinity. Thus, the lowest reaches of the Crocodile River in Malelane are considered to be of poor water quality due to agricultural run-off, additional mining activities as well as the poorly treated effluent from the wastewater treatment plants (Soko and Gyedu-Ababio, 2015). The Crocodile River exhibits a sluggish flow rate, characterized by mostly rocky riverbeds and intermittent sandy pools and the average breadth of the river measures about 45 meters. Significant advancements have been made in the agricultural sector within the Lowveld region. These operations lead to the extraction of significant quantities of water from the river, leading to a decrease in its flow, especially in periods of low precipitation (Maphanga et al., 2022). The majority of the river's riparian zone is characterized by the presence of reeds (Figure 1, Table 1).

2.2 Data collection

The grab sampling approach was employed to collect samples from the Crocodile River throughout the period spanning from 2016 to 2022. A total of 72 samples were collected. Polyethylene containers were employed for the purpose of collecting samples on a monthly basis, and a permanent marker was used to record the dates and times of sampling. The specimens were obtained from preset areas using hygienic containers and thereafter stored in a refrigerated environment at a temperature of 4 degrees Celsius. Subsequently, they were conveyed to the laboratory for the purpose of examination. The glassware and plastic components utilized in the experiment were submerged in a solution with a concentration of 2 M nitric acid and 2 M hydrochloric acid for a duration of 24 hours as stated by Phungela et al. (2022). Following the completion of the treatment, the goods underwent a comprehensive cleansing process with deionized water. A distinct identity was allocated to each container through the use of numbered labels. The readings of water pH, and electrical conductivity (EC, μs/cm), were conducted using a calibrated portable meter, namely the Hach multi-probe meter Model HQ40d in situ. The data collected during the onsite measurements were documented on prepared sheets.

2.3 Data Analysis

2.3.1 Laboratory analysis of parameters

The laboratory accredited by the South African National Accreditation System (SANAS) conducted an analysis of parameters including ammonia, nitrite-nitrate, and phosphate. The analysis was performed according to standard methods outlined by the American Public Health Associa-

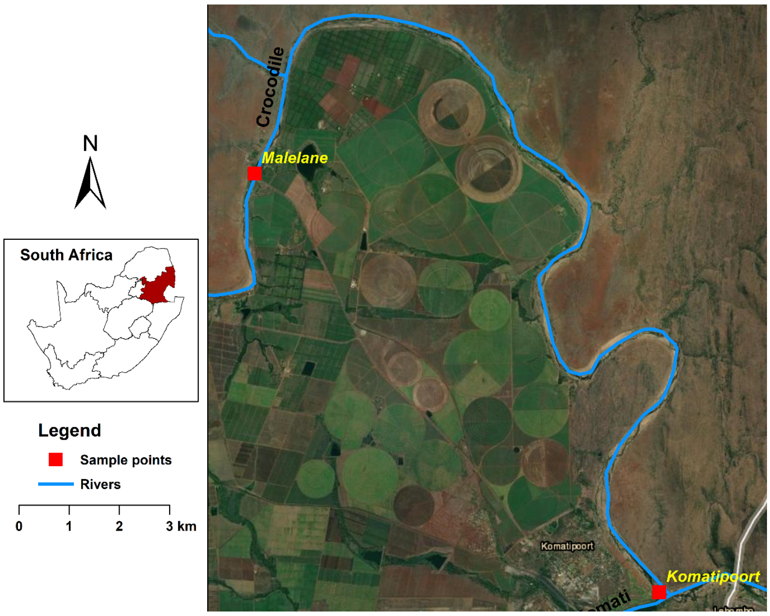

Figure 1. shows the study area as described above and the location of the sampled areas.

tion (APHA, 2012).

-Phosphate

The analysis of phosphate in the water samples was conducted using the Hach Ascorbic acid method 10209. During the process of phosphate determination, various reagents including sulphuric acid, ammonium molybdate solution, and ascorbic acid were employed. The quantification of phosphate was conducted using the ascorbic method, which is a colorimetric technique. To measure the absorbance, a spectrophotometer equipped with an infrared phototube set at a wavelength of 880 nm was employed.

-Ammonia

The concentration of ammonia was quantified utilizing the Hach Nessler method. The experimental procedure involved the utilization of various reagents, including methyl orange indicator, boric acid, Polyvinyl Alcohol Dispersing agent, and Nessler Reagent. Prior to analysis, an initial distillation of the sample was conducted. A spectrophotometer operating at a wavelength of 425 nm was utilized.

-Nitrate

The concentration of nitrate in the water samples was assessed utilizing the Cadmium Reduction method, as outlined in the Hach Water Analysis Handbook. In the determination of nitrate, various reagents including copper cadmium, ammonium chloride, EDTA, hydrochloric acid, and copper sulphate solution were employed. A spectrophotometer operating at a wavelength of 543 nm was employed due to its colorimetric nature.

2.3.2 Statistical analysis

Statistical analysis was performed using the Seaborn software due to the extensive dataset contained in the present study. Seaborn, a programming library utilized for data analysis and visualization, is programmed using Python, a widely adopted programming language known for its extensive collection of tools and modules in this domain. The Seaborn library in Python was employed for the purpose of evaluating data pertaining to water quality. This analysis encompassed tasks such as generating charts and examining the distribution and correlation of variables, utilizing the modules provided by matplotlib. The Python program Seaborn was utilized to build the necessary heat maps in order to enhance data visualization. In the context of correlation research, the statistical significance of the correlation and the estimation of confidence intervals were achieved.

2.4 Water Quality Index (WQI)

The Water Quality Index (WQI) was used to measure the water resource's quality and determine its ability to support aquatic life as well as social and economic growth. Water quality constituents analysed for the established sampling point were used for the computation of the water quality index, and these overall water quality constituents are transformed to a scale of 1-100 through mathematical equations and then weighed according to their apparent impact on the environment and health of the river. Five categories were assigned to water quality based on the water quality index: good quality water (1–25), acceptable quality (26–50), regular quality (51–75), bad quality (76–100), and very poor quality (>100) (Madalina and Gabriela, 2014; Tian et al., 2019). Below are the equations for the calculation of the water quality index.

1. Calculation of the unit weight (W_n) factors for each parameter by using the formula:

$$W_n = \frac{K}{S_n}$$

where

$$K = \frac{1}{1/S_1 + 1/S_2 + 1/S_3 + \ldots + 1/S_n} = \frac{1}{\sum \frac{1}{S_n}}$$

S_n = Standard desirable value of the n^{th} parameters

On summation of all selected parameters unit weight factors, W_n=1 (Unity)

2. Calculate the Sub-index $(Q_n = ([(V_n - V_0)])/[(S_n - V_0)]x100)$

where:

V_n = mean concentrations of the n^{th} parameters

S_n = Standard desirable value of the n^{th} parameters

V_0 = Actual values of the parameters in pure water (generally V_0=0, for most parameters except for pH

$$Q_{\text{pH}} = \frac{K(v_{\text{pH}} - 7)}{8.5 - 7} \times 100$$

3.Combining Step 1 & step 2, WQI is calculated as follows:

$$\text{Overall } W_{QI} = \frac{\sum W_n Q_n}{\sum W_n}$$

Classification of the water quality of the water resource concerning the weighted arithmetic W_{QI} is shown in Table 2 below and the computed W_{QI} for the study site. The present index is based on the desirable and permissible limits of pH, EC, phosphate, Nitrite- nitrate and ammonia defined by the resource quality objectives of Crocodile River.

Table 2. Resource Quality Objectives (RQO) set for the Crocodile River Water (DWS, 2016).

Constituents	Limits
Electrical conductivity (ms/m)	70
Nitrite and Nitrates (mg/l)	6
Phosphate (mg/l)	0.125
Ammonia-N (mg/l)	6
E-coli (count per ml)	130
pH	6.5-8.5

3. Results

3.1 Changes in physicochemical properties over a seven-year period, with a focus on seasonal variations

Figure 2 shows the temporal fluctuation of phosphate (PO_4) and Nitrate (NO_2+NO_3) in the form of heatmaps over a period of seven years with emphasis on seasonal variation. The results demonstrate that the highest levels of PO_4 (0.35 mg/L) were recorded in winter of 2016 and the second highest was recorded in summer 2019 at 0.20 mg/L which was above the set limits for the river as shown in Table 2. The lowest phosphate reading was recorded in winter 2020 and spring 2021 with both recording at 0.05 mg/L. On the other hand, the NO_2+NO_3 showed higher concentrations from 2020 to 2022 which clearly shows the spatio-temporal variation in seasonality; with the fluctuation ranging from 1.2 to 0.7 mg/L. According to Figure 2, the highest concentration of NO_2+NO_3 was 1.2 mg/L which was observed during the autumn season in 2021, surpassing the levels recorded in any other season among the sampled years. The lowest concentrations of NO_2+NO_3 were recorded in summer (0.8 mg/L) and autumn (0.7 mg/L) of 2020 and 2022 respectively. While spring and summer of 2018 and 2019 recorded the lowest concentration of NO_2+NO_3 at <0.4 mg/L. Furthermore, it is important to highlight that throughout the entirety of 2018, the combined concentrations of NO_2+NO_3 were less than 0.6 across all four seasons. This signifies that 2018 stands out as the only year with such low concentration levels. Therefore, looking at fluctuation NO_2+NO_3 throughout the 6-year period of sampling it can be said that it was always below the set limits of Resource Quality Objectives (RQO) set for the Crocodile River (Table 2).

Whilst on the other hand, Figure 3 heatmap shows the results of ammonia nitrate from 2016 to 2022 depicting the spatio-temporal seasonal variations. The results from this study show that there were high levels of ammonia nitrate between 2016 and 2019. It is during these periods that observed highest concentration while from 2020 to 2022 recorded relatively low levels with the highest concentration between that period is less than 0.175mg/L. Moreover, it is crucial to emphasize that over the course of the year 2020, the collective levels of ammonia nitrate remained below 0.050mg/L across all four seasons, representing the lowest recorded concentration within the tested timeframe. The results show that autumn of 2017 and spring of 2019 both recorded levels above >0.225mg/L of ammonia nitrate concentration. Between the years 2016 and 2019, an average concentration level of 0.2mg/L was observed. Notably, the lowest reported value during this period was in the summer of 2019, with 0.15mg/L. Moreover, the results for Table 3 indicate that a conclusion can be drawn that the mean is not statistically significant for at least one of the parameters groups ($P>0.5$). Considering that the F value for NO_2+NO_3 is 0.868, it is more probable that the variation linked to the independent variable is genuine rather than a result of random factors. It is important to note that ANOVA alone does not provide particular information about which means were different from each other.

Figure 4 displays the temporal variation in electrical conductivity (EC) and pH in the form of heatmaps over a span of seven years, with a particular focus on the patterns observed during different seasons. The physicochemical aspects of river water quality, such as pH and electrical conductivity, are influenced by variations in climate and seasonal patterns within the catchment area (Fataei, 2011). Figure 4 illustrates that during the winter season of 2020, there was a notable increase in electrical conductivity (EC) levels, reaching 42.35 s/cm. Conversely, the winter season of 2021 exhibited elevated pH levels, measuring 8.43 units. It is worth noting that these values represent the highest recorded levels within the duration of this study. The autumn season had the lowest values of electrical conductivity on average during the period under investigation. In contrast to other seasons, winter exhibited consistently greater levels of electrical conductiv-

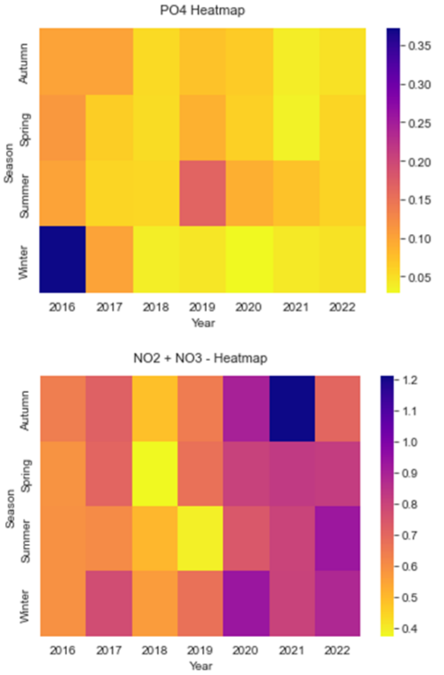

Figure 2. illustrate the temporal dynamics of phosphate (PO_4) and nitrate (NO_2+NO_3) concentrations over a span of seven years, with a particular focus on the patterns of variation observed throughout different seasons.

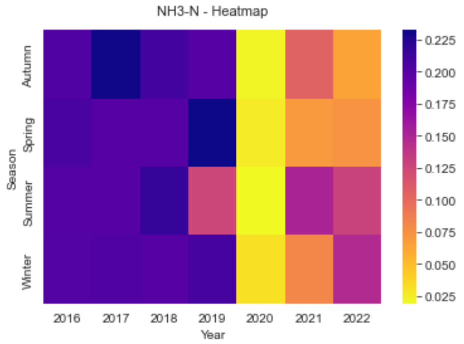

Figure 3. The results of ammonia nitrate from 2016 to 2022 depicting the spatio-temporal seasonal variations.

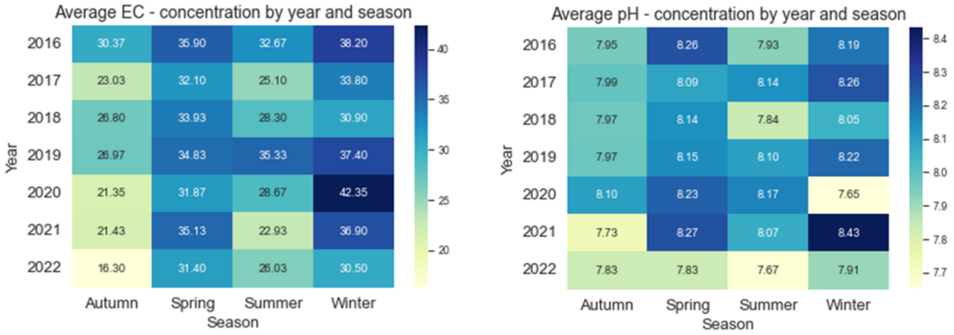

Figure 4. The temporal variation in electrical conductivity (EC) and pH as heatmaps over a seven-year period, with a particular emphasis on the seasonal patterns observed.

Table 3. One-way Anova for (PO_4) and nitrate (NO_2+NO_3).

PO_4	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.074	3	.025	.522	.668
Within Groups	12.245	258	.047		
Total	12.319	261			
NO_2+NO_3	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.460	3	.153	.868	.458
Within Groups	45.595	258	.177		
Total	46.055	261			

ity (EC) from 2016 to 2022. The EC is subject to alterations caused by both natural phenomena and anthropogenic activities. Furthermore, the pH levels exhibited minimal temporal variability during the investigated timeframe (2016-2022), with the lowest recorded value being 7.67 and the highest reaching 8.43 throughout all seasons. Hence, the spatio-temporal seasonal fluctuation of pH was not perceptible in contrast to the electrical conductivity (EC). This observation is effectively illustrated through the utilization of heatmaps, as depicted in Figure 4. The biota is also influenced by the disparity in pH levels compared to rivers that have not been altered. The utilization of electrical conductivity as a salinity indicator becomes advantageous when employed in conjunction with other variables, particularly in cases where the origin of dissolved salts lacks a geological basis. The study found a statistically significant difference determined by the one-way Anova (Table 4) in average in the pH according to the required levels (F=3.221, P<0.023) and similar observation was made in the EC (F=19.833, P<0.001).

3.2 Water quality index for Malelane

Table 5 presents the categorization of water quality for the water resource based on the weighted arithmetic Water Quality Index (WQI) and the computed WQI for the study site. The current index is derived from the existing resource quality objectives of the Crocodile River, which define the acceptable and permissible ranges for pH, electrical conductivity (EC), phosphate, nitrite-nitrate, and ammonia levels. Table 6 below shows the calculation of the water quality index (WQI) of the Crocodile River in the sampled site and the standard value (Sn) of the selected water quality parameters, is according to the Resource Quality Objective of the catchment. According to the classification of water quality using the weighted arithmetic WQI method, as presented in Table 6, it was noted that the water quality index (WQI) value for the sampled site was measured as 62.18, indicating a level of water quality that is deemed acceptable. Although these indicators are valuable for assessing water quality, it is important to note that they are non-regulatory assessments.

Table 4. One-way Anova for pH and EC.

pH	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.947	3	.316	3.221	.023
Within Groups	25.275	258	.098		
Total	26.221	261			
EC	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	13492.077	3	4497.359	19.833	<.001
Within Groups	58503.596	258	226.758		
Total	71995.673	261			

Table 5. Classification of the water quality concerning the weighted arithmetic WQI (Banda and Kumarasamy, 2020).

Water Quality Index	Water Quality Status / Classification
0-25	Class 1 – Good water quality
26-50	Class 2 – Acceptable water quality
51-75	Class 3 – Regular water quality
76-100	Class 4 – poor water quality
>100	Class 5- Very poor water quality

Based on the findings presented in Table 6, (WQI), it can be concluded that the water quality in the sampled location can be classified as moderate, falling within class 3 as indicated in Table 5. These findings suggest that the water quality may be classified as ranging from Regular to Poor. The reason for this may be ascribed to the geographical location of the lower section of the river, situated at the confluence of the Komati and Crocodile rivers on the western inclines of the Lebombo Mountains. These mountains serve as a natural boundary between South Africa and Mozambique.

4. Discussion

The Classification of the water quality concerning the weighted arithmetic WQI is considered to be regular water quality as per Table 4. Moreover, the calculation of the water quality index of the sample site was 62,177 which support that indeed the classification of the river is consistent with the results of this study. When looking at the parameters that were analysed for this study in concurrent with the Resource Quality Objectives (RQO) set for the Crocodile River a conclusion can be made that the even though some parameters such as NO_2+NO_3 were found in some cases to be high, in general the water quality was not poor. In line with literature these indices exhibit ecosystem behaviour (Misaghi et al., 2017)and other studies have attributed the indices to reflecting the condition of the environment (Wato et al., 2020). Often, these indices are used to limit ecosystem dysfunction and provide information about pollution sources and how to control them. At the field level, indicators are rarely used for water quality management because they are mainly used for descriptive purposes. Due to increased demand for agricultural commodities, farmers are increasingly utilising non-conventional water sources of questionable quality, such as increased use of fertilizers (FAO, 2017). This is an attractive option since it contains a significant amount of nutrients, especially when there is a scarcity of organic fertilizer. The concentrations of NO_2+NO_3 exhibited an upward trend from 2020 to 2022, indicating the presence. Nitrates are essential nutrients for plants; yet elevated concentrations can lead to significant water quality concerns (Che et al., 2021). The combination of nitrates and phosphorus can accelerate the process of eutrophication by inducing substantial enhancements in the development of aquatic plants and alterations in the composition of plant and animal species inhabiting the river (Davis et al., 2016; Tan et al., 2022).

Ammonia has the potential to be released into the atmosphere from water under specific conditions, namely when the pH level is elevated, and the solution mostly comprises gaseous ammonia. Under conditions of low or neutral pH, the predominant form of ammonia is the ammonium ion. A notable increase in electrical conductivity might indicate potential pollution of a river. According to Wang et al. (2023), the principal natural constraints on electrical conductivity in rivers are geology and soil type. During precipitation events, water infiltrates the soil and then flows through its surface, ultimately reaching our rivers (Laan et al., 2012). Throughout this process, the water undergoes dissolution and absorption of various contaminants. Nitrogen-containing chemicals, namely nitrate (NO3) and nitrite (NO2), are present in water and soil (Walsh and Wepener, 2009; Du Preez et al., 2018). The detection of nitrate and nitrite in water often signifies the potential presence of pollutants originating from sources such as pastures, manure piles, decaying plants, or agricultural fertilizers (Soko and Gyedu-Ababio, 2015)(Islam et al., 2017). However, it is important to note that these compounds can also be derived through the erosion of naturally occurring deposits. The town of Malelane has had significant growth and development throughout the years, accompanied by a notable increase in agricultural endeavours within its vicinity. Therefore, it may be inferred that the main contributors to river pollution in the area are city stormwater runoff and agricultural runoff. The Crocodile River at Malelane is characterized by suboptimal water quality at its lowest levels, mostly attributed to agricultural runoff, and intensified mining operations (Phungela et al., 2022; Molekoa et al., 2022). Schilling and Wolter (2001) argue that agricultural

Table 6. Calculation of the water quality index (WQI) of Malelane area, Crocodile River.

Parameters	Standard Value (S_n)	$\frac{1}{S_n}$	$\sum \frac{1}{S_n}$	$K = 1/\frac{1}{\Sigma(\frac{1}{S_n})}$	$W_i = \frac{K}{S_n}$	Ideal Value (V_0)	Mean Conc. Value (V_n)	$\frac{V_n}{S_n}$	$Q_n = \frac{V_n}{S_n} \times 100$	W_nQ_n
Electrical conductivity	70	0,014286	8,473	0,118021952	0,00168603	0	39,7	0,56714286	56,71428571	0,095621867
pH	8,5	0,117647	8,473	0,118021952	0,01388494	7	7,96	0,93647059	93,64705882	1,300283375
Phosphate	0,125	0,166667	8,473	0,118021952	0,94417562	0	0,08	0,64	64	60,42723947
Nitrate + Nitrite	6	0,166667	8,473	0,118021952	0,01967033	0	0,89	0,14833333	14,83333333	0,291776493
Ammonia	6	8,465266	8,473	0,118021952	0,01967033	0	0,19	0,03166667	3,166666667	0,062289364
									WQI = Sum of all W_nQ_n =	62,17721057

operations have the potential to negatively influence water bodies, leading to a gradual decline in water quality as a result of cumulative effects. In a study conducted by Laan et al. (2012), it was shown that agricultural activities in the area were responsible for the increased levels of phosphate concentrations in the water supply, much like the Crocodile River.

The assessment of water quality is a critical issue in the effective management of rivers, especially in densely populated regions (Liu et al., 2016). Due to the adverse impact of nitrate pollution on water resources, it is imperative to enhance our understanding of nitrate pollution in semi-arid areas, characterized by high water demands and ecosystem restoration costs (Beutel et al., 2016; Tan et al., 2022). The results of this current study indicated that there are fluctuations ranged between 1.2 and 0.7 mg/L of PO_4 and NO_2+NO_3. Based on the data provided, the present study has identified that the maximum concentration of PO_4 was recorded at 0.35 mg/L during the winter season of 2016, while the second highest concentration was seen as 0.20 mg/L during the summer of 2019. Given the set standard of the Crocodile River as per the resource quality objective as shown in Table 2 the levels of PO_4 were above the set limits; while NO_2+NO_3. was below the set limits.

Elevated pH levels within a river system might potentially exert an impact on the toxicity levels of certain contaminants. The observed phenomenon can be attributed to the climatic circumstances prevalent in the investigated area, characterized by the occurrence of midsummer precipitation that extends into the early fall period. A reduction in pH levels might potentially lead to a decline in the solubility of vital elements, including selenium. Although in general the pH levels were within the prescribed limits of the Crocodile River (Table 2) winter of 2021 recorded the highest level of pH. The results of the study show that the pH of the water at the sampled station was always acceptable throughout the sampling years and seasons. The study done by Mohamed et al. (2014) in the urban west region of Zanzibar revealed that during periods of limited rainfall, there is an increase in EC levels and a decrease in pH levels. Similarly, the study conducted by Mohamed et al. (2014) provided evidence that periods of rainfall were often accompanied by elevated pH levels compared to periods of lower precipitation. The study period revealed that autumn had the lowest average levels of electrical conductivity. Between the years 2016 and 2022, it has been observed that the winter season continuously exhibits elevated levels of electrical conductivity (EC) in comparison to the other seasons. The electrical conductivity (EC) is vulnerable to both natural and human-induced alterations. In addition, it is noteworthy that the pH levels exhibited little temporal fluctuations over the duration of the research, spanning from 2016 to 2022. The recorded pH values ranged from a minimum of 7.67 to a maximum of 8.43, including all seasons. In contrast to electrical conductivity (EC), the spatial-temporal seasonal change of pH was found to be negligible (Soko and Gyedu-Ababio, 2015; Gqomfa et al., 2023).

The Water Quality Index (WQI) was designed with the purpose of evaluating the quality of surface waters at a state-wide level, therefore serving a common goal. Although these indicators have considerable importance in assessing the quality of water, it is essential to recognize that they are non-regulatory assessments. The WQI results revealed that the water quality at Malelane is regular at a value of 62.18 (Table 6). The findings of this study suggest that the water quality may be classified as ranging from average to below standard. The results given in this study align with the research conducted by Ewaid and Abed (2017), whereby it was shown that the observed diminished water quality, as seen by the WQI values, might be attributed to both natural phenomena and human interventions occurring along the river. The results presented in this study are consistent with the findings reported by Şener et al. (2017), who employed a Water Quality Index (WQI) to assess the water quality of the Aksu River. Azevedo Lopes et al. (2016) posited that the primary objective of the WQI was to facilitate discourse pertaining to the extent of environmental quality between environmental managers and the broader public.

5. Conclusion

Ensuring the health of the environment and the well-being of the populations who depend on these resources is of utmost importance, therefore necessitating the monitoring of water quality in the Malelane region. By comprehending the spatial and temporal fluctuations of water quality indices, we may recognise possible risks and execute efficient tactics to safeguard this vital natural resource. The physicochemical characteristics of river water quality, such as pH and electrical conductivity, are affected by changes in climate and seasonal patterns in the catchment region. Conversely, the levels of NO_2+NO_3 exhibited an increase in concentration between 2020 and 2022, indicating significant spatio-temporal variation in seasonality and the fluctuation ranged from 1.2 to 0.7 mg/L. The biota is also impacted by the discrepancy in pH levels in comparison to unaltered rivers. The use of electrical conductivity as a means to measure salinity becomes beneficial when combined with other factors, especially in situations where the source of dissolved salts is not geologically determined. Both the Water Quality Index (WQI) and the Trophic State Index (TSI) serve a shared objective, since they were both specifically developed to assess surface waters on a statewide scale. In light of the detrimental effects of nitrate pollution on water shortage, it is crucial to augment our comprehension of nitrate pollution in semi-arid regions, which are distinguished by elevated water requirements and the expenses associated with ecosystem restoration. Under certain circumstances, like when the pH level is increased and the solution mostly consists of gaseous ammonia, it is possible for ammonia to be emitted into the atmosphere from water. In circumstances characterized by low or neutral pH levels, the ammonium ion is the prevailing species of ammonia. To safeguard water resources in the Malelane area, it is crucial to adopt a proactive strategy that involves monitoring water quality levels and implementing tight regulations on pollution discharge.

Limitations

Due to limited financial resources the study did not include temperature, Dissolved oxygen which are key for in water quality studies.

The study did not consider the gradient of the farms, moreover there was no estimation of the potential runoff rate from the farm into the water.

The study lacks the inclusion of microbial contamination into the analysis.

Recommendations

Enhancing monitoring strategies in the Malelane area: To stay on top of the water quality rollercoaster, we need to up our monitoring game. Investing in cutting-edge technology, expanding monitoring networks, and fostering collaboration between stakeholders are crucial steps in keeping tabs on water quality trends in the Malelane area.

Exploring the impacts of emerging contaminants, studying the effects of climate change on water quality, and investigating the effectiveness of water treatment methods are just a few avenues for future research in the Malelane area.

There is a need to mapping water quality parameters in the Malelane area, which will enable visualization the spatial distribution of key indicators and identify hotspots of potential contamination.

Authors Contributions

Authors have equal contribution role in preparing the paper.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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