The Water Quality of the Lower Orange River and its Implications on Human and River Health

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Introduction

Human activities related to agriculture and settlements are increasing rapidly along the major river systems in southern Africa, but the effects of such developments on the water quality of the river systems is poorly documented. The Orange River drains an area in excess of 1,000,000 km and runs more than 2,200 km from its source in Lesotho to the mouth at Oranjemund.[2] The river supports millions of people within and outside of the basin in Botswana, Lesotho, Namibia, and South Africa.[3] Economic activities in the basin include those pertaining to agriculture, mining, power generation, tourism, and sewage treatment services. In addition, the river remains the main source of drinking water for humans and animals found in the area. Human activities such as agricultural practices, sewage discharges and residential development are known to deteriorate water quality in river systems when they are inappropriately managed,[4] and a link between reduced water quality and water-borne disease outbreaks is well documented.[5] The deterioration of water quality in river systems can also have a negative impact on the economic activities taking place along the river, such as fishing, swimming, and other tourist attractions. Public health is negatively affected by a lack of clean water and sanitation in the affected area.[6] Yet, many people in southern Africa withdraw and use untreated water from river systems for domestic consumption.

1 We thank the Carl Schlettwein Foundation and Space in Time project for their financial and logistical support. Namwater at Karasburg kindly provided the historical water quality data used in this study. We also thank the book editors and two anonymous reviewers for their insightful comments.

2 Troy et al. n.d: p. 3

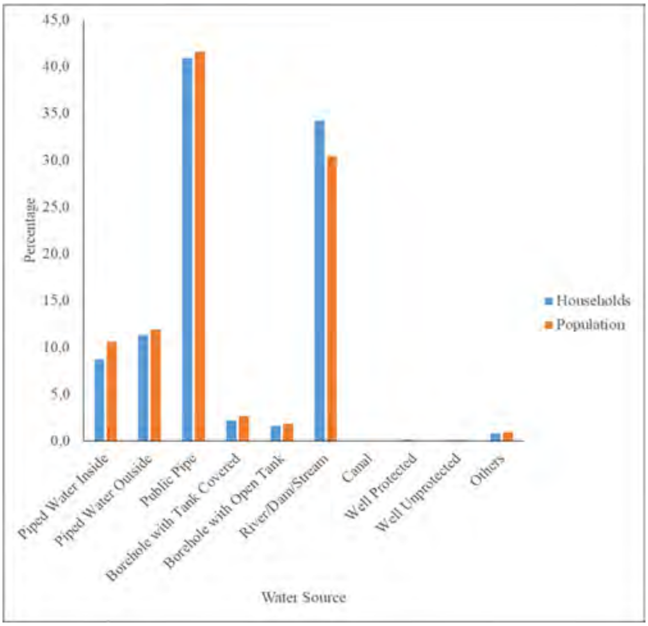
3 Mahlakeng 2020: p. 146

4 Minnesota Pollution Agency 2008: p. 2; Chislock et al. 2013: p 4; Munn 2018: p. 1.

5 Kulinkina et al. 2016: p. 26

6 Ustaoglu et al. 2021: p. 1; Hutton et al. 2016: p. 1; Tarrass et al. 2012: p. 1.

Fig. 1: Source of drinking water in Aussenkehr (Data acquired from: Namibia Statistics Agency).



The Orange River Basin is highly urbanised with densely populated areas mostly in its upper course, while the Lower Orange River is dominated by agricultural activities.[7] Population growth and agricultural expansion can strain water demands, therefore reducing water supply in the basin and affecting the quality of water in the river. The Orange Senqu River Commission (ORASECOM) revealed that declining water quality in the Orange River is due to acid mine drainage, inadequate sewage treatment and irrigation return flows.[8] These are also the major threats to the Orange River Basin's water resources. Additionally, they are the most known activities practised in the Lower Orange River. The Aussenkehr grape farm is the most prominent land use found on the northern bank of the Lower Orange River. Other types of land use found in Aussenkehr include animal grazing and recreational activities, such as swimming and car washing, which reportedly pose health issues to surrounding communities.[9] Some households in the Lower Orange River, including Aussenkehr (Figure 1), continue to use the water drawn directly from the stream for human consumption.[10] This is even though Aussenkehr has no proper sewage treatment plant, and the residents use the river for drinking water and as a toilet.[11] Against this background, this chapter aims to analyse and assess the water

7 Orange Senqu River Commission (ORASECOM) 2011: pp. 4–6
8 ORASECOM 2011: p. 10
9 Traore et al. 2016: pp. 9–12
10 Namibia Statistic Agency (NSA) 2011
11 Cloete 2011

quality in the Lower Orange River, using data from Noordoewer and Rosh Pinah, and to discuss the implications thereof on human and river health.

Water quality parameters

Time series data of 17 physicochemical properties, namely: pH, turbidity (Tur), electrical conductivity (EC), total dissolved solids (TDS), sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), sulphate (SO_4), nitrate (NO_3), silica (SiO_2), fluoride (F), chloride (Cl), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn), were analysed to assess the long-term temporal change in the water quality. These are the important parameters used to determine the suitability of water based on its intended use – such as irrigation and human consumption.[12]

Water quality is determined by a number of water's physicochemical properties because there is no single parameter that can adequately measure it.[13] In reality, water suitable for some uses might not be suitable for others. Therefore, water quality is evaluated against a set of standards put down by governmental or water regulation bodies to test suitability.

The pH measures the acidity or basic of water. Different aquatic organisms function well under a certain pH level and any slight change to that pH may cause disturbances in aquatic life.[14] A neutral pH is best for aquatic plants and animals.[15] Meanwhile, low pH might corrode metals and other substances dissolved in the water. Turbidity measures the ability of light to pass through water, determined by its cloudiness from clay, silt or other organic particles dissolved in the water. Measuring turbidity in water bodies can determine if the water is safe for various uses. Thus, measuring water turbidity is imperative for monitoring water quality.

Electrical Conductivity measures the ability of water to pass or conduct electric current.[16] It depends on the number of ions dissolved in the water. Water with high conductivity consists of many dissolved ions. Total dissolved solids refers to the amount of negative and positive ions in the water.

Chloride and sulphate in water varies depending on the area and can occur naturally in water sources.[17] However, they can also come from contamination from agricultural runoff and wastewater. When in higher concentration they might cause a noticeably unpleasant salty taste and have unwanted laxative effects.[18] Studies report that human consumption of chloride-contaminated water can cause cardiovascular diseases as well as kidney failure in humans.[19] Sulphate on the other hand poses no significant health is-

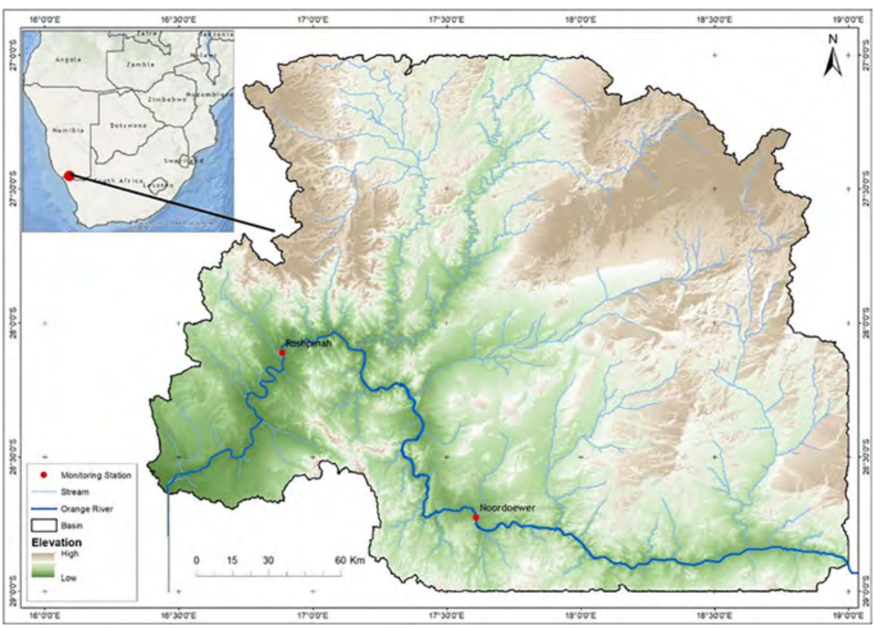
12 Omer 2019: pp. 3–6
13 Leščešen et al. 2017: p. 2
14 Patil et al. 2020: p. 31
15 Omer 2019: p. 7
16 Duraisamy et al. 2019: p. 859
17 Rai 2021: p. 106
18 Auwal 2021: pp. 15–16
19 Chen et al. 2021: pp. 783–785

sues to humans.[20] Low concentrations of fluoride in drinking water effectively reduces tooth decay, but it also causes dental fluorosis when in excess.[21] Similarly, copper and zinc are nontoxic when found in small amounts and beneficial to human health and the growth of plants. However, they can cause a disturbing taste and milky appearance in water.[22]

Iron and manganese are liable to a bitter taste in drinking water.[23] Although nitrate is a basic nutrient to the growth of aquatic plants, it can also cause the development of algae in water – which reduces oxygen and decreases water quality when in excess.[24]

Calcium, sodium, and magnesium are important ions for children's development; however, in higher quantities they may increase the likelihood of disease.[25] Silica, widely classified as salts, is found naturally in water – from the underlying rocks of the water body. It does not affect water quality for domestic purposes. Studies found that calcium, silica, potassium, magnesium, and sulphate are good indicators of drinking water quality status.[26] Calcium, silica, and potassium are associated with good taste meanwhile sulphate and magnesium might cause an unsavoury taste in drinking water.

Fig. 2: Stream networks found in the watershed and the sampling locations (Data acquired from Namibia Statistics Agency and United States Geological Survey).



20 Omer 2019: p. 9
21 Narsimha et al. 2017: pp. 2501–2512
22 Auwal 2021: p. 17
23 Rai 2021: p. 106
24 Chebet et al. 2020: pp. 4–8
25 Azoulay et al. 2001: pp. 168–175
26 Hashimoto et al. 1987: pp.185-195

Data for each water quality parameter, acquired from the Namibia Water Corporation (NamWater), was measured over a period of more than 20 years at two monitoring stations, located in Noordoewer (1997 – 2020) and Rosh Pinah (1998 – 2020) in the Lower Orange River (Figure 2). The two sites were selected due to their historical water quality information recorded over the years. The two monitoring stations are about 150 km apart. The main land use activity found between the two monitoring stations is Aussenkehr grape farm.

Physical and chemical indicators of water quality in the Lower Orange River

Table 1 presents the results of all water quality parameters averaged for different seasons and location of observations. The mean value of these parameters was compared with the water quality standards as set by the NamWater guidelines for drinking water.

The exploratory data analysis applied to the observed water quality parameters revealed that all parameters were within the highest recommended NamWater water quality guidelines, except for Tur and Mn. This means that they are all within Class A, with excellent water quality, except for Tur and Mn which both fall under Class D, which poses higher health risks, or is water unsuitable for human consumption. Similarly, turbidity concentration in this study area has previously been found to be above the recommended guidelines for drinking water.[27] This means that an increase in water quality values was recorded between Noordoewer and Rosh Pinah, although most of these values were within the recommended guidelines.

Based on seasonal analysis, F and NO_3 are the only parameters that increased during the wet season at Noordoewer. Meanwhile at Rosh Pinah EC, TDS, Na, K, Mg, SO_4, F, Fe, Cu and Zn all increased during the wet season. Spatial variation shows that EC, TDS, Na, K, Ca, Mg, SO_4, F, Cl, Fe, Mn, and turbidity increased at the downstream station, but still remained within the recommended guidelines (Class A).

Table 1: Overall water quality of the Lower Orange River based on the NamWater water quality guidelines for drinking water (Time series data acquired from NamWater).

Water quality Parameter	Noordoewer (upstream)								Rosh Pinah (downstream)							
	Wet season				*Dry season*				*Wet season*				*Dry season*			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
pH	8.2				8.3				8.3				8.3			
Turbidity (NTU)				34.6				26.9				114.5				38.2

27 Kimwaga et al. 2014: pp. 1–4

Water quality Parameter	Noordoewer (upstream)								Rosh Pinah (downstream)							
	Wet season				*Dry season*				*Wet season*				*Dry season*			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Conductivity (mS/m)	45.3				48.7				53.9				53.7			
TDS (calculated)	303.2				326.4				361.1				359.4			
Na (mg/l)	38.3				40.6				51.4				49.2			
K (mg/l)	3.1				2.8				3.7				2.9			
Ca ($CaCO_3$)	74.9				83.2				77.6				87.2			
Mg ($CaCO_3$)	67.4				73.8				77.				76.8			
SO_4 (mg/l)	44.1				53.7				66.3				64.8			
NO_3 (mg/l)	0.9				0.7				0.9				1.0			
SiO_2 (mg/l)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
F (mg/l)	0.4				0.3				0.4				0.3			
Cl (mg/l)	35.6				38.7				47.8				47.9			
Fe (mg/l)	0.02				0.02				0.06				0.04			
Mn (mg/l)				26.6				31.3				40.9				31.2
Cu (mg/l)	0.03				0.02				0.02				0.02			
Zn (mg/l)	0.02				0.02				0.02				0.02			

Note: NamWater guidelines for drinking water class **(**A= Water with an excellent quality, B= Water with good quality, C= Water with low health risk, D= Water with a higher health risk, or water unsuitable for human consumption**. * No guideline set)**

Trend Analysis of the Water quality parameters

Annual trend

Assessing changes in water quality over time is an important objective in water quality monitoring programmes. This is mostly done using trend analysis to track changes over time and identify and detect different drivers in water quality. To meet this important need, trend analysis has been widely applied in studies that have analysed the water quality of river systems over the years.[28] A trend test is carried out to determine if the measured water quality parameters have increased or decreased over a specific period at

28 See Antonopoulos et al. 2001: pp. 679–692; Hirsch et al. 1983: pp. 107–121; Yu et al. 1993: pp. 61–80; Baldy et al. 1995: pp. 93–102; Wan et al. 2018: pp. 2–6; and Mahmoodi et al. 2021: pp. 159–173.

a significance level of 0.05.[29] In this study, the non-parametric Mann-Kendall test was used to analyse and determine whether trends exist in the annual and seasonal water quality data. Seasonal analysis was divided into the wet (November to April) and dry season (May to October). Data analysis was performed using R software.

In general, water quality in the study area is better at Noordoewer compared to Rosh Pinah (figure 3), however they are both within the recommended guidelines. Conductivity, turbidity, TDS, Na, SO_4, NO_3, F, K, SiO_2, Zn, Fe, and Cl were higher at Rosh Pinah compared to Noordoewer (figure 3). This implies that there is an increase in pollutants entering the river between Noordoewer and Rosh Pinah; which was suggested to be due to the agricultural activities, sewage, or dolerite and shale rocks found at Aussenkehr.[30]

Although the overall water quality at both stations remains in the same Class A, the higher concentration of some water quality values recorded at Rosh Pinah is surprising considering that the upstream of the river is dominated by similar human activities – which include agricultural activities, practised at a larger scale than Aussenkehr; mining activities; and hydro-infrastructure construction, such as dams. It was therefore expected that the impact of the agricultural farm at Aussenkehr on the water quality should have been minor, compared to all combined upstream impacts, which was not the case in this study.

Previous studies conducted elsewhere revealed that human activities, such as the construction of dams, have a positive impact on some water quality parameters downstream. This is attributed to the trapping and accumulation of sediments and nutrients more easily in reservoirs because of the long water residence.[31] This implies that good water quality recorded at Noordoewer could be attributed to the multiple dams located upstream of Noordoewer, as previously suggested in research conducted in the study area.[32] However, this was not further explored in the current study.

In this study, the time series water quality parameters were tested for trends using the non-parametric Mann-Kendall test. The significance of the trend was also carried out to determine if this change is statistically significant. Temporal trends for annual water quality show that all water quality parameters except pH, Na, Mg, NO_3, F, and Cl have no significant trends at both stations (table 2). Similar findings were found in the study area, whereby most parameters tend to increase as distance towards the river mouth increases.

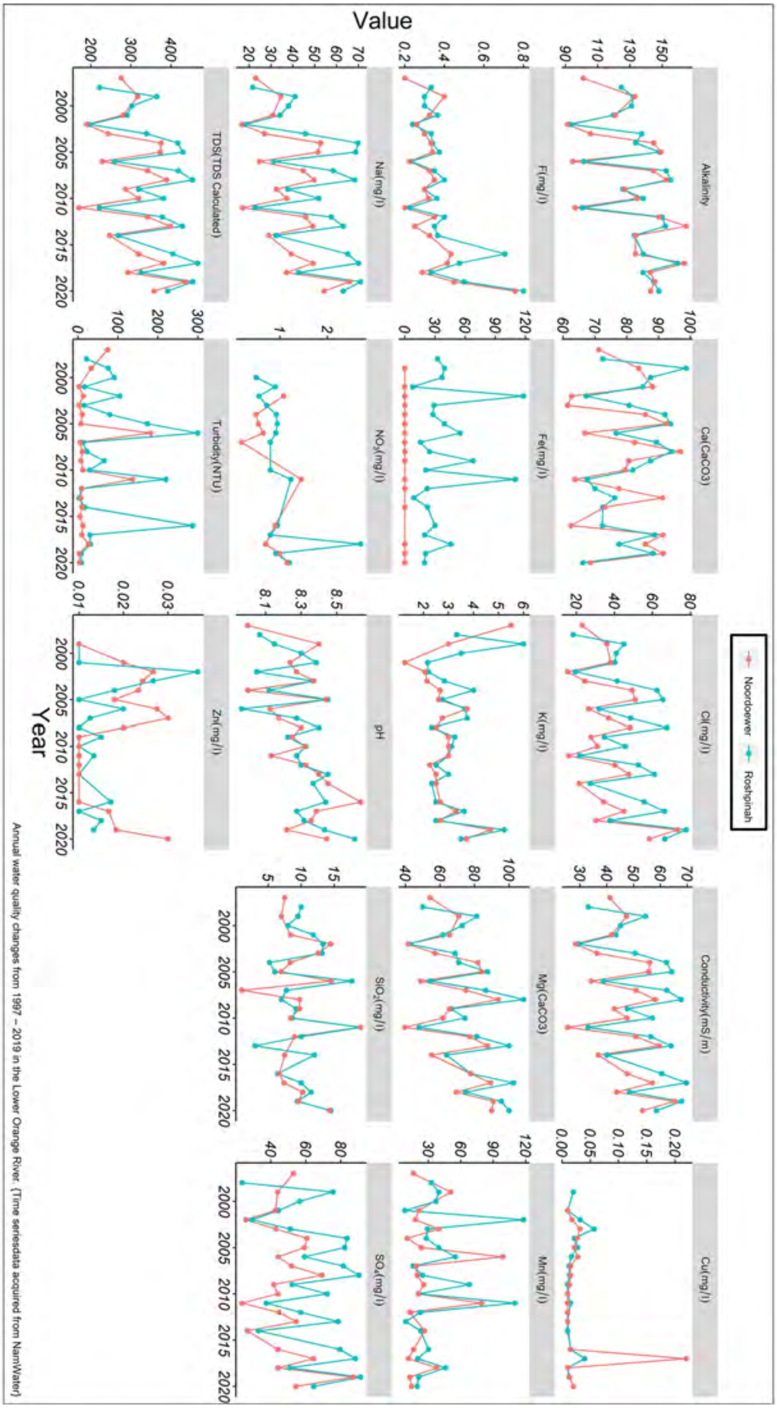
29 Antonopoulos et al. 2001: pp. 679–692

30 Nangolo 2021; Kimwaga et al. 2014: pp. 1–4.

31 See Wei et al. 2008: pp. 1763–1780; Kamidis et al. 2021: pp. 1–16; and Kimwaga et al. 2014: pp. 1–4.

32 Kimwaga et al. 2014: pp. 1–4

Fig. 3: Annual water quality change from 1997 – 2019 in the Lower Orange River. (Time series data acquired from NamWater).



pH (slope = 0.01), Na (slope = 1.41) and Mg (slope =1.41) had a significant positive trend at Rosh Pinah. Similar results were found at Noordoewer for the same parameters (pH slope = 0.01), Na (slope = 0.03) and Mg (slope = 1.14). This implies that the water quality in terms of pH, Na and Mg decreased at both stations over the last 20 years. However, NO_3 (slope = 0.03), F (slope = 0.08), and Cl (slope = 1.18) had no significant trend at Noordoewer, but a positive significant trend was observed for all three variables at Rosh Pinah. This denotes that water quality in terms of the three variables decreased at Rosh Pinah compared to Noordoewer over the same period. As suggested earlier, these changes could be attributed to land use activities occurring along the river between Noordoewer and Rosh Pinah. Vineyard plantation at Aussenkehr is the most significant land use between the two towns. The application of fertilisers with other land use activities at Aussenkehr may thus be attributed to that NO_3 increase.[33] Other studies found similar results, noting that anthropogenic influences, such as wastewater discharge into the water body; runoff from industrial and agricultural areas; decomposition of organic matter; storm water and runoff from residential areas and infiltration from landfills were the reason for the increasing trend of nutrient-related parameters such as NO_3 and Cl.[34] Some studies found that high amounts of NO_3 can be poisonous to humans and fish.[35]

In this study, pH was found to be increasing over time at both monitoring stations. High pH is detrimental to aquatic life. pH, here, was at the upper end of water with excellent quality. In addition, alkaline water might cause eye irritation in humans.[36] Thus, the increase in pH and NO_3 needs to be closely examined.

Table 2: Annual trend analysis of the water quality parameters and river discharge at Noordoewer (1997 – 2019) and Rosh Pinah (1998 –– 2019).

Parameter	Noordoewer	Rosh Pinah
pH	↑	↑
Turbidity	-	-
Conductivity	-	-
TDS	-	-
Na	↑	↑
K	-	-
Ca	-	-
Mg	↑	↑

33 Nangolo 2021; Kimwaga et al. 2014: pp. 1–4.

34 See Singh et al. 2012: pp. 4473–4488; Mustapha 2013: pp. 5630–5644; Gonzales-Inca et al. 2016: pp. 166–180; Purnaini et al. 2018: pp.1-5; Antonopoulos et al. 2001: pp. 679–692; Bucas 2006 and Rahman et al. 2021: pp. 1–13.

35 Dey et al. 2021

36 Khatoon et al. 2013: pp. 80–90

SO_4	-	-
NO_3	-	↑
SiO_2	-	-
F	-	↑
Cl	-	↑
Fe	-	-
Mn	-	-
Cu	-	-
Zn	-	-
Note: — = No significant trend, ↑= significant positive trend, ↓ = negative significant trend		

Seasonal trend

Seasonal analysis of the studied variables revealed that the water quality of the Orange River at Noordoewer during the dry season remained the same over time (table 3). However, it deteriorated for Mg (slope = 1.504), and Na (slope = 1.208) during the wet season; all implying that there has been a significant decrease. This means that Mg and Na are influenced by the rainfall, thus resulting in an increase in the trend during the wet season. Similarly, this increase could be due to surface runoff of the materials, wastes or sewage effluents – as documented in Finland.[37]

At Rosh Pinah, pH (slope = 0.025), Na (slope = 1.672), Mg (slope = 2.11), F (slope = 0.001), and Cl (slope = 1.91) had a positive trend during the wet season. However, no trend was found for these variables during the dry season. This is similar to the findings at Noordoewer, and it is likely due to surface runoff.

No significant change was recorded for Fe and Cu during the wet season, but a negative trend was found during the dry season at the same station (Cu slope = -0.001 and Fe slope = -0.002). The detection of negative trends in these two variables during the dry season suggests that there is an improvement in the water quality during the dry season, which could be due to changes in the contaminant sources around the river. Similar results were found in a study done in Kansas rivers.[38] Meanwhile, NO_3 concentrations had no trend during the wet season but had a positive trend during the dry season. This implies that during the dry season some water got lost through evaporation, leaving the concentrated water solution in the river and thus increasing the content of the NO_3. Trends in Mg, NO_3, SO_4, Cl, and pH found in this study are inconsistent with trends found in the Nisava River, Serbia.[39]

Chloride, F and pH had no significant trends during the dry and wet season at Noordoewer; however, they decreased at Rosh Pinah during the wet season. This implies that

37 Pereira et al. 2018 : pp. 2701–2710

38 Yu et al. 1993 : pp. 61–80

39 Gocic et al. 2013: pp. 199–210

the water quality declined between Noordoewer and Rosh Pinah, which could be due to surface runoff from farms in the sub-catchment.

Despite the statistically significant increase in some parameters – as explained above – the water quality remained within the recommended guidelines of Class A, with excellent water quality at both stations. This is despite new and increased anthropogenic activities in the study area over the years.

Table 3: Annual trend analysis of the water quality parameters and river discharge at Noordoewer (1997 – 2019) and Rosh Pinah (1998 – 2019).

Water quality Parameter	Noordoewer		Rosh Pinah	
	Wet Season	**Dry Season**	**Wet Season**	**Dry Season**
pH	-	-	↑	-
Turbidity	-	-	-	-
EC	-	-	-	-
TDS	-	-	-	-
Na	↑	-	↑	-
K	-	-	-	-
Ca	-	-	-	-
Mg	↑	-	↑	-
SO_4	-	-	-	-
NO_3	-	-	-	↑
SiO_2	-	-	-	-
F	-	-	↑	-
Cl	-	-	↑	-
Fe	↓	-	-	↓
Mn	-	-	-	-
Cu	-	-	-	↓
Zn	-	-	-	-

Note: – = No significant trend, ↑ = significant positive trend, ↓ = negative significant trend

Implications on human and river health

Nutrients are essential for plant growth, however when in excess they can pose harmful health and environmental effects.[40] The ongoing nutrient-loading – such as nitrate and chloride – into the Orange River system as shown in this study, could lead to a series of adverse effects known as eutrophication. Excessive amounts of nutrients in water bodies can cause water pollution from algae which can reduce dissolved oxygen in the wa-

40 United States Geological Survey (USGS) n.d.

ter. Algae production in water bodies can die and decompose and this process consumes too much oxygen and therefore causes insufficient oxygen for both aquatic plants and animals. Dissolved oxygen in water bodies gives an indication of the aquatic vegetation growth and potential stress to aquatic life.

High amounts of nitrate in water can have harmful effects on humans and animals and can cause severe illness in infants and domestic animals.[41] Additionally, some forms of algae can produce toxins that can be harmful if ingested by humans and animals.[42] Some of the significant risks associated with drinking water with a high content of nitrate from applications of inorganic fertilisers and animal manure in agricultural areas includes cancer, methemoglobinemia, an enlargement of the thyroid gland, and diabetes mellitus.[43] Although the nitrate found in the water in this study is within the class with excellent quality, if it continues increasing it might pose a similar health issue and therefore should be tackled to avoid the continuous consumption of nitrate-contaminated water.

Similarly, although notable changes were recorded in fluoride concentration in the water, the water quality has remained in Class A over the last two decades. Although a high amount of fluoride and nitrate in drinking water might cause dental and skeletal fluorosis, methemoglobinemia in infants, and stomach cancer in adults[44], the current status of the water quality in terms of the observed parameters is not of concern when it comes to human health.

Algae blooms can also yield an unpleasant odour and appearance that can reduce the aesthetic appeal of the environment and harm the water quality.[45] This can cause economic damages, including loss of recreational revenue through a reduction in fishing, swimming, and the tourism industry; decreased property values from a reduction in social activities occurring in the area; and increased drinking and agricultural water treatment costs.[46]

An increase in the concentration of turbidity in water quality, as seen in this study, can also increase the water treatment costs.[47] The high amount of Tur observed in this study is of concern because the materials suspended in the water can also cause other health issues in humans, such as headaches and nausea, when directly consumed. The observed increasing trend in Na in the study area is also of concern, given that high amounts of Na in water commonly limits the use of water for irrigation purposes[48] and the study area is mainly dominated by agricultural practices, with irrigation water sourced from the river in question. In addition, a study in Japan found that high Na was closely related to death rate due to epilepsy.[49] This means that we should continuously

41 Chitra et al. 2020
42 Chislock et al. 2013: p. 6
43 See World Health Organisation (WHO) 2011; Ward et al. 2018 and Parvizishad et al. 2017.
44 Sunitha et al. 2020: pp. 150–161
45 Chislock et al. 2013: p. 7
46 Parvizishad et al. 2017
47 Omer 2019: pp. 2–3
48 Brindha et al. 2017: pp. 89–104
49 Hashimoto et al. 1987: pp. 185–195

monitor the concentration of Na and other parameters in water to ensure that it does not reach the threshold and cause similar health issues in humans.

Conclusion

This study analysed the water quality of the Lower Orange River as well as the associated river and human health from two monitoring stations. The water quality of the Lower Orange River is declining, mainly at Rosh Pinah where the concentration of nutrient-related water quality parameters (Na, Cl, F, Mg, and NO_3) and pH is increasing, however they remained within the recommended guidelines of class A with excellent water quality. Similarly, at Noordoewer, an annual increase in Na and Mg was detected. When analysed based on seasons, Na, Cl, F, Mg, and pH have increased over time during the wet season at Rosh Pinah, whereas NO_3 increased during the dry season. At Noordoewer, Fe, Na and Mg increased over time during the wet season.

Despite an increase in some parameters, the overall water quality of the Lower Orange River remained in the category of excellent water quality (Class A) for human consumption when compared against the NamWater guidelines. Turbidity and Mg are the only parameters that are regarded as having a higher health risk (Class D), thus urgent and immediate attention should be given to this matter. However, the statistically significant increase in nutrient-related water quality parameters in the water of the Lower Orange River is a concern. It suggests that there is ongoing nutrient-loading into the river system originating from human activities, especially between Noordoewer and Rosh Pinah. Left unchecked, continued loading of such nutrients has a potential to compromise the health of the biologically diverse Lower Orange River system and that of many people residing along the Orange River between Noordoewer and Rosh Pinah, who use untreated water from the river for domestic consumption. Therefore, further field-based study is urgently needed to investigate the sources of nutrient-related parameters between Noordoewer and Rosh Pinah. In addition, the increase in most parameters was found to be statistically significant, but not significant enough in terms of water quality, and this is despite new and increased anthropogenic activities in the study area. Thus, there is a need for a large-scale study to be carried out on the whole Orange River, especially the upstream of the river, to fully investigate and compare the effects of different anthropogenic activities on its water quality.

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