How to cite: Bayne R., Pyle D., Maguire K., Oosthuizen R., Tandlich R. (2024) Examining water quality and transport implications of alternative supply during a drought in a South African municipality. *2024 "Air and Water – Components of the Environment" Conference Proceedings*, Cluj-Napoca, Romania, p. 221-241, DOI: 10.24193/AWC2024_20.

EXAMINING WATER QUALITY AND TRANSPORT IMPLICATIONS OF ALTERNATIVE SUPPLY DURING A DROUGHT IN A SOUTH AFRICAN MUNICIPALITY.

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DOI: 10.24193/AWC2024_20

ABSTRACT. Examining water quality and transport implications of alternative supply during a drought in a South African municipality. The Eastern Cape Province is a drought-prone area and it had been impacted by water service delivery problems for several decades. At the same time, there have been widespread instances of the need to supply water from alternative potable sources as to meet the drinking water demand of the population. Further to this point, there is an ongoing need to collect and evaluate water quality data from drought-affected areas in the Eastern Cape. In the current study, the authors seek to achieve two aims. Firstly, there is a need to conduct an investigation of the potable water quality from the local municipalities in the Eastern Cape where such investigations have not been common recently. Secondly, the authors seek to conduct an investigation into the carbon footprint of provision of alternative bottled water into a local municipality in the Eastern Cape Province of South Africa. Turbidity, pH and presence/levels of faecal contamination of drinking water were measured. In addition, the carbon footprint of the supply of bottled water was estimated for road transport of 5 litre bottles. Results indicate that microbial water quality is a problem and there is finite, but significant carbon dioxide emissions due to supply of alternative water sources. There is significant carbon footprint of the shipping of bottled water into the Eastern Cape Province, should the municipal water supply break down completely. The study results point to the need to monitor and treat the alternative sources of potable water in the study area. This is necessary protect human health and environment.

Keywords: water quality, South Africa, bottled water

Introduction

South Africa is a water scarce country receiving an average of around 464 mm of annual rainfall, which is less than the global annual average of 860 mm (as reported for the period of 1921-2015, EDC Tanks, 2019; Roffe et al., 2019). Many areas/provinces across the country have been declared drought disaster regions since

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2019. This is an extension of knowledge, which had been acquired from many studies of the recent decades, all indicating an increase in the occurrence and impacts of multi-year droughts across South Africa (Mahlalela et al., 2020). The most impacted provinces/the drought-disaster areas include the Eastern Cape, Western Cape and KwaZulu-Natal (Mahlalela et al., 2020). Erratic rainfall patterns, increasing water demand due to a growing population and poor infrastructure management and maintenance of water supplies make the Eastern Cape prone to not just drought but also water scarcity. Insufficient water supply has resulted in the disruption and breakdown of water services across certain areas in the province, including the Makana Municipality and Ndlambe Local Municipalities (study areas in the current article). Under these conditions, the socioeconomic drought has become entrenched in the study area and the Eastern Cape Province more widely (Botai et al., 2020).

Since 2015, South Africa has experienced drought impacts due the prolonged period of reduced rainfall caused by the El Niño conditions (Archer et al., 2022). Climate change is a main driver of this type of drought, as it increases the severity and duration of this slow-onset disaster. The impact of the anthropogenic carbon emissions on the atmosphere storage and distribution of heat and water vapour has exacerbated the existing drought susceptibility of South Africa (Dube et al., 2020). Local impacts of the drought vary in parts of the South African territory, e.g. in the province of the Eastern Cape. Situated between the summer and winter rainfall regions, the position of the Eastern Cape results in a climate which is an overlap between subtropical conditions associated with the KwaZulu-Natal Province and the Mediterranean climate conditions of the Western Cape Province. The average rainfall for this province varies between 100 and 520 mm per annum (Orimoloye et al., 2022). The large range is caused by a complex weather system in the province, the province's proximity to the Agulhas current, and the strong topographic gradients in the Eastern Cape's territory (Botai et al., 2020). Influences of both midlatitude and tropical systems creates a complex meteorology for the region and is linked to the continuation and accentuation of drought conditions.

The Eastern Cape drought has had severe social, economic and environmental impacts due to the prolonged shortage of water resources and supply to the Eastern Cape population and the main economic activities in the province. Rural and urban areas have experienced pressure on water supply services due to widespread breakdown of infrastructure and common instances of intermittent/non-existent service delivery (Orimoloye et al., 2022). Duration and intensity of the water supply shortages has culminated in loss of livestock and agricultural productivity, environmental degradation, reduced human and animal health, food insecurity and poverty (Ruwanza et al., 2022). Shortages of water supply in towns and cities result in water restrictions and supply disruptions. Water is a life-sustaining resource that is threatened both in availability and accessibility by prolonged drought conditions (Ruwanza et al., 2022). Mitigation measures are required to ensure the provision of a sustainable potable water supply to affected communities.

Water is a priority for the preservation of social, environmental, and economic conditions of human existence and the optimum status of the human wellbeing in the Eastern Cape and South Africa at large. For humans, water is necessary for three main activities: drinking water supply, sanitation provision and hygiene assurance (three aspects of human existence are lumped together under the term WASH). According to the World Health Organization, each person requires a minimum of 15 L of water per day, to ensure optimum WASH status (World Health Organization, 2022…these figures are one of the estimates in the literature). In South Africa, the Department of Water and Sanitation defines the governmental water supply responsibilities in the Government Gazette. The minimum water supply requirement is outlined as being 1500 L of potable water per household per week. In accordance with the Strategic Framework for Water Services, the water supply should be available 52 weeks per year, comply with the SANS 241 quality standard and be no further than 200 m from the household (Department of Water and Sanitation, 2017). The maintenance of the infrastructure, including point-of-use water treatment systems, falls under the responsibility of the Water Service Authority (Department of Water and Sanitation, 2017, pp. 22). According to the Department of Cooperative Governance and Traditional Affairs (2020), in 2018, 75.1% of households in the Eastern Cape have access to piped or tap water in their dwellings, off-site or on-site. Access to improved sanitation has increased from 33.4 % in 2002 to 88.0 % in 2018, showing an increase of 54.6 percentage points. Despite the improvement, this percentage is still 13.9 % lower than the national 2018 average of 89 %, placing the province second last in water service delivery across South Africa (Department of Cooperative Governance and Traditional Affairs, 2020, pp. 52.).

The Eastern Cape experiences challenges regarding water availability and accessibility due to the exacerbation of drought conditions by climate change. In recent years, the Eastern Cape has faced social, environmental, and economic impacts of water scarcity with towns across the province experiencing severe water shortages (Botai et al., 2020). According to documents from the Ndlambe Local Municipality, the area has experienced water shortages as the town's main water supply is affected by the drought (Germishuizen, 2022). Port Alfred requires approximately 6.3 ML/day, which can increase up to 8.3 ML/day in peak seasons (Germishuizen, 2022). In recent times, Ndlambe Local Municipality has, however, only been able to produce and supply its population with 4 ML/day, which has resulted in non-availability of water to most areas of the town (Germishuizen, 2022).

To combat the water shortages and non-availability of water in the Ndlambe Municipality, the municipality announced existing and planned interventions. Municipal water tanks, filled daily by hired water trucks, were placed at strategic positions around the Port Alfred area of Ndlambe Local Municipality (Germishuizen, 2022). Boreholes have been connected to the main water supply to supplement the available water. A Reverse Osmosis (RO) Plant contributes an additional 1.8 to 2 ML/day of water to the supply. In addition to these interventions, residents and businesses are urged to invest in and install rainwater tanks to assist in lowering the demand (Germishuizen, 2022). In addition to making use of alternative water sources, alternative water supply can be sourced from surrounding areas. Residents in the Ndlambe Municipality make use of various alternative sources of water including boreholes, springs, rain water tanks, dams and pools, rivers, water vendors, water tankers and others (Ndlambe Municipality, 2022). In extreme drought situations, disaster relief may come in the form of water brought in from surrounding areas where water supplies are available. According to the Gift of the Givers, in response to drought in parts of South Africa in 2015 and 2018, bottled water was brought into areas facing a critical shortage as an immediate response (Gift of the Givers., n.d.). All of these interventions provide a mitigation set of tools to deal with drought and its impact on water scarcity in the Eastern Cape Province of South Africa. However, they need to be investigated for potential risk enhancement or disaster cascading effects on the population of Ndlambe Local Municipality. Some of the potential effects or implication of this nature will be investigated by the authors in this study.

The water disruptions and shortages reveal a demand for alternative water sources and supply is of critical importance. Investigating the quality of the water supplied to the Ndlambe population is necessary for several reasons. Firstly, the potential challenges in the stored or supplied water quality must be known, as to address any treatment challenges which might have occurred. Practically, this would mean that the water quality from the stored tanks and in the water due to the potable water supply interruptions and restarting. Secondly, the water quality data is necessary to protect the human health of the Ndlambe population. There is an ongoing need to understand and monitor the water quality to mitigate or prevent any potential increase in the risk of diarrhoeal disease outbreaks, due to the Ndlambe's population consumption of water which does not mean regulatory standards. This could, for example, trigger an outbreak of a waterborne disease. Thirdly, various alternative sources being connected to the water supply grid increase the potential for contamination, or for single points of failure in the potable water supply to the Ndlambe population. Implications of risk enhancement or cascading effects are similar here to the previous point. Finally, it is necessary to investigate scenarios of water supply from alternative sources of potable water to mitigate and plan for potential current and future impacts of drought on water supply and scarcity. Impacts of the water quality and the scenarios of alternative water supply will also have impacts on the greenhouse gas production in the Ndlambe Local Municipality. This might specifically be an important cascading effect in terms of the shipping in of bottled water to Ndlambe Local Municipality.

To ensure water availability and accessibility in drought conditions does not exacerbate the climate change impacts in Ndlambe Local Municipality, it is imperative the relief operations are sustainable from an environmental and humanitarian point of view. Therefore the carbon footprint of the provision of water from alternative resources to the Ndlambe population must be known. Therefore it is the working hypothesis of this study that the microbial water quality in the various sources in Ndlambe Local Municipality is variable and could be compromised with time. In addition, the authors hypothesise that the provision of water from alternative sources will have a non-zero and finite carbon footprint. This will be investigated and its implications, in terms of climate change in the study area will be evaluated. Methods in this article will be those that focus on the microbiological and basic physico-chemical characterisation of the water samples from Ndlambe Local Municipality. The idea is to use tools that could be deployed under field conditions by disaster risk management practitioners or climate adaptation specialists. Access to limited laboratory facilities will be assumed in the current study.

Materials and Methods

Water Sampling and analysis in Ndlambe Local Municipality

The sampling occurred over seven sample sites, where a total of 32 samples were taken and analysed from July to September 2022. The sampling was limited to the Ndlambe Local Municipality in the Eastern Cape, specifically in Port Alfred area. The sampling in this area The sampling, preparation of the H_2S test kits and the consumables procurement was done as mentioned earlier by Malema et al. (2019). The pH, iron and nitrates test strips were purchased from Spellbound Labs (Gqeberha/Port Elizabeth, South Africa). After sampling, the water samples for laboratory analyses were refrigerated and stored and a temperature of 3 °C until analyses were performed at Rhodes University. All analyses were started and completed within 24 hours of sampling. Before analyses, all samples were brought to room temperature prior to the testing at a range of 21°C to 27°C (with a variance of ± 5 °C). For each sample, three pH, turbidity, iron, and nitrate tests were done to improve the accuracy and reliability of the results. Five separate H_2S kits were used for each sample. For each test, a control was tested concurrently using bottled water which was shown to contain faecal coliforms below 0 CFUs/100 mL, it had a turbidity value of 0 NTU and was free of detectable levels of nitrates and iron (below 0 mg/L). Finally, the control water sample/blanks had a pH of 7.0. Correspondence between the faecal/thermotolerant coliforms and the H_2S test kits was measured using the methodology of Malema et al. (2019).

The pH tests were performed 3 times for each sample. Lovibond® pH test strips were dipped into the water to immerse all three pads. The excess water was shaken off and the colour change was observed and matched to the provided colour chart after 30 seconds. After repeating the process three times, an average was calculated to represent the pH of each sample. The average value was compared to the South African National Standard 241:2015 for domestic water. Turbidity was measured using a portable turbidity meter. Each sample was tested using three 10 ml vials of water. An average was calculated and compared to the South African National Standard 241:2015. Iron tests were performed for the samples collected during the second sampling occasion. MQuant™ Iron Tests using a colorimetric method with test strips was used to indicate iron levels between 0-500 mg/L Fe^{2+}. Once dipped in the water, the colour change of the pad was compared to the provided colour chart to determine the iron level. The test was repeated 3 times per sample and an average was calculated and compared to the South African National Standard 241:2015.

Similarly, samples collected during the second sampling occasion were tested for nitrate levels using a colorimetric method with test strips. MQuant™ Nitrate Tests were used to indicate nitrate levels of 10-500 mg/L NO_3^-. The test strips were dipped into the water and the colour changes of the pads were compared to provided colour chart. The test was repeated three times per sample and an average was determined and compared to the South African National Standard 241:2015. The test strips were calibrated against pH 4, 7 and 10 buffers, and accurately prepared solutions of $NaNO_3$ and $FeCl_3$. The accuracy of the test strips was equal to 90 % of the target across the kit working range and thus the semi-quantitative values were reported as measured without any correction.

Water sampling, analysis and transport implications Carbon emissions sampling

The next part of the study was focused on investigating the carbon emission and the water quality of bottled water which would be trucked or transported into the Ndlambe Local Municipality from outside if the internal municipal water supply stopped being feasible due to drought. Petrol stations in Cradock, Colesburg, Bloemfontein and Carletonville were visited and bottled water was purchased. It was transported to the laboratory at Rhodes University for analysis, as indicated in the previous section, at ambient temperature a range of 21°C to 27°C (with a variance of ± 5 °C). The sampled bottles ranged in volume from 1 litre to 5 litres. Next, the carbon emissions from the transport of the bottled water were calculated. This would indicate the climate change implications of the transport of bottled water to the Ndlambe Local Municipality. To calculate the carbon emissions for relief activities, common transport vehicles were selected. A sedan, pick-up truck (bakkie), van, small truck and a truck were selected. The water bottle dimensions used in the calculations were based off an average 5 L water bottle. This would maximise the supply of water to the Ndlambe population from commercial sources in major urban centres outside Ndlambe Local Municipality. Carbon emissions were calculated for varying distances heading inland at Cradock, Colesburg, Bloemfontein and Carletonville. The distance was calculated as a return trip from Port Alfred to the destination and back. The driving distance for the destinations was calculated and represented in Table 1.

Table 1. The driving distance from Port Alfred to Cradock, Colesburg, Bloemfontein and Carletonville.

Location	Distance One Way (km)	Distance Round-trip (km)
Cradock	230.9	461.8
Colesburg	431.3	862.6
Bloemfontein	640.4	1280.8
Carletonville	1009.1	2018.2

Carbon emissions are calculated to determine the amount of carbon dioxide (CO_2) produced per kilometre (km) of distance covered at a particular load. This can be calculated using a fuel consumption-based CO_2 emissions calculation. Such a fuel consumption-based equation determines the total carbon emissions (*TCE*) based off the distance travelled (*D*), the average fuel consumption per kilometre ($C_{average}$) and the total CO_2 produced per litre of fuel, which is also known as the conversion factor (Yaacob et al., 2020, pp. 7).

$$TCE = D \times C_{average} \times Y \tag{1}$$

The *TCE* (kg) is calculated by recording the total amount of fuel used (L), the distance travelled (km), the average petrol used per kilometre (L/km) and the conversion factor calculated as grams of CO_2 per litre of fuel (gCO_2/L). To calculate the average fuel used per kilometre, the cost of fuel (*TC*) for the travel is recorded and divided by the price of fuel per litre (*PPL*) and distance (*D*).

$$C_{\text{average}} = \frac{TC}{PPL}/D \tag{2}$$

The average fuel used per kilometre is calculated by determining the total fuel consumption in relation to the distance travelled. The fuel consumption is determined by dividing the total cost of the fuel (ZAR) by the price of fuel per liter at the time of the travel. This fuel consumption (L) is then divided by the distance travelled to determine the average fuel per kilometre (L/km). To calculate the conversion factor (*Y*), or the amount of CO_2 produced per litre of fuel consumed, a calculation of the fuel weight (*fW*), composition and percentage carbon (C_{carbon}), and amount of oxygen required for combustion (*O*; Ecoscore., 2022).

$$Y = (fW \times C_{\text{carbon}}) + O \tag{3}$$

The conversion factor is calculated for one liter of fuel, specifically petrol and diesel. For petrol, the weight of 1 L is 750 g and it consists of 87 % carbon which equates to 625 g of carbon per L. At the same time, 1740 g of oxygen is required for the combustion of 1 L of carbon into CO_2. Therefore, the total CO_2 produced per 1 L of petrol is 2392 gCO_2/L. Diesel weighs 835 g per L and consists of 86.2 % carbon which is 720 g per liter. It requires 1920 g of oxygen for the combustion of the carbon which results in an conversion factor of 2640 gCO_2/L of diesel.

Another method to calculate carbon emissions is making use of an activity based approach. This was the method selected for the research paper. This calculation makes use of transport activities and is effective for determining the carbon footprint of specific parameters in relation to the overall total (Jofred and Öster, 2011., pp. 12). An activity based approach includes the weight of the load (*W*), the distance travelled and the distance emissions factor (*DEF*) per tonne kilometre which considers the vehicle type/ mode of transport. Weight and Distance are relativity measures used to adjust the formula.

$$TCE = W \times D \times DEF \tag{4}$$

Calculating the weight of the transported goods accounts for the increase in energy being used and therefore an increase in carbon emissions. Additional factors such as the weight of the vehicle, driver/s or passengers and transporting materials, such as pallets, can be considered. However, W refers to the weight of the load for this research. The combination of weight and distance is referred to as the tonne-kilometre. This is calculated in combination with the DEF which dictates the average carbon emissions produced for one tonne for one kilometre for each mode of transport. Calculations were based off a two-leg journey; one way with an empty truck and the return leg carrying the maximum load. The fuel consumption was differentiated into the empty load consumption (C_{empty}) and maximum load consumption (C_{load}), which was calculated using the weight (W), empty load consumption and load consumption factor (LCF).

$$C_{\text{Load}} = (W \times LCF) + C_{\text{empty}} \tag{5}$$

A load consumption factor (LCF) is used to indicate the impact of additional load on the fuel consumption of a vehicle. Fuel consumption increases by 0.65-0.95 L/100 km per additional tonne of weight. The variance is dependent on the gradient of the operating route. Steeper slopes will increase the impact of additional load weight (Lajunen, 2014). As Port Alfred lies in an area of mountainous topography, the maximum value of 0.95 L/100 km was adopted for the calculations (Dalu et al., 2018).

Table 2. The maximum number of water bottles that will fill the available space in each vehicle.

Vehicle Type	*Length (cm)*	*Number of bottles along (L/16.2 cm)*	*Width (cm)*	*Number of bottles across (W/16.2)*	*Number of Water Bottles per layer A/262.44cm²*	*Height (cm)*	*Number of layers (H/36cm)*	*Additional bottles*	*Total bottles*
Sedan	105	6	102.5	6	36	55	1	6+6+6+4 (back seats and passenger seat) 21	57
Bakkie	180.7	11	137.4	8	88	53.5 (open top)	2	6	182
Van	313	19	180	11	209	190	5	0	1045
Small Truck	473	29	177	10	290	216	6	0	1740
Truck	745	45	246	15	720	255	7	0	5040

The W was calculated using the maximum number of 5 L water bottles that could be transported by each mode of transport. This was determined using the available space in the vehicle and its maximum carrying capacity. All available space was considered, including boot or load box, open seats, and loading spaces. The water bottles assumed shipping dimensions of a 35 cm height, 16.2 cm width and length and a weight of 5.2 kg per 5 L bottle. The total weight calculations are depicted in Tables 2-4. These results were adjusted to observe the maximum carrying capacity of the vehicles and ensure the vehicles were not overloaded. The adjusted values are presented in Table 3. The maximum number of water bottles that could safely be transported by each mode of transport was used to determine the load weight (W) for each vehicle, as depicted in Table 4.

The fuel consumption and total carbon emissions per kilometre were identified for each mode of transport and used with the W and LCF to calculate the adjusted fuel consumption for the return trip (C_{load}). This is depicted in Table 5.

Table 3. The available space, maximum load capacity and maximum number of bottles that can be transported.

Vehicle Type	Available space	Maximum Load Carrying Capacity (kg)	Maximum bottles (weight based)
Sedan	592L (boot space) + 4 available seats	800	153
Bakkie	1240L/ 1.26m^3 (loadbox space) + 1 available seat	1000	192
Van	10.8 m^3 + 1 available seat	1520	292
Small truck	18 m^3	2260	434
Truck	46.73 m^3	9750	1875

Table 4. The total water (in L) and load weight (W) for each vehicle type.

Vehicle Type	Total number of bottles	Total L of water transported	Total weight of the load (bottles x 5.2 kg)
Sedan	57	285	296.4
Bakkie	182	910	946.4
Van	292	5225	5434
Small truck	434	8700	9048
Truck	1875	25200	26208

To calculate the total carbon emissions for the whole trip, the two legs of the journey were combined. The first trip contained no load and was calculated using the base weight of the truck. The second leg contained the maximum load and therefore the adjusted fuel consumption taking into account the additional weight. In the equation (6), the distance is calculated as the kilometres travelled for one way (or half of the total distance travelled). The average carbon emissions per kilometre (gCO_2/km) was calculated using the fuel consumption and fuel conversion factor. The conversion factors of 2392 gCO_2/L and 2640 gCO_2/L were adopted for petrol and diesel, respectively. Results will be analysed to determine the carbon efficiency of the modes on transport in relation to the amount of water resources carried.

$$TCE = \left(D \times C_{empty} \times Y\right) + \left(D \times C_{load} \times Y\right) \quad (6)$$

Table 5. The adjusted carbon emissions and fuel consumption for each vehicle.

Vehicle Type	*Fuel Type*	*CO_2/km*	*C_{empty} (L/100km)*	*W (kg)*	*LCF impact (L/100km)*	*C_{load} (L/100km)*	*Adjusted CO_2 (g/km)*
Sedan	Petrol	138	6.01	296.4	0.28158	6.29158	150.5
Bakkie	Petrol	192	9.7	946.4	0.89908	10.6	253.55
Van	Diesel	190	6.5	1518.4	1.44248	7.94248	209.68
Small truck	Diesel	308.7	12.4	2256.8	3.2068	15.6068	412.02
Truck	Diesel	642	24.3	9750	9.2625	33.5625	886.05

The *TCE* values where then used to calculate the carbon emissions per 5 L bottle and per one litre for each mode of transport for each distance. This was analysed to indicate the carbon emission impacts of the relief activities. Relief activities need to maintain a low carbon footprint and be sustainable to ensure they do not exacerbate the climate change conditions in the drought-prone province of the Eastern Cape.

Results

Water Quality results from Ndlambe Local Municipality

Results of the sampling are shown in Table 6 below. Designations of the sampling sites are as follows: K1 is the raw water from the Kowie river which flows through Ndlambe Local Municipality and the Port Alfred area. In addition, B1 and B2 stand for borehole water samples and the M1 is a sample from temporary municipal tank which is supplied by a municipal potable water. RT1 and RT2 are rainwater harvesting tank samples, while the RO1 is a sample from the reverse osmosis system where the municipal potable water was treated in a private dwelling. Throughout the data collection; the tests and procedures were consistent and sample plan was observed. Any disruptions or potential environmental influences were recorded. Over the three months, three events were recorded. On the 6 July 2022, the sampled tank at sample site B1, containing borehole water as an alternative water source, was removed from its location and was no longer available for sampling. An additional sample site was selected as a replacement. On the first sampling occasion on the 6 July 2022, disruptions to the local water supply was experienced. Sample M1 was taken when the water supply was made available again three days later on the 9 July 2022. It was also noted that scheduled cleaning and water treatment activities took place during the sampling period. Between the sampling on the 6 July 2022 and 24 July 2022, sample site B1 was treated using a ratio of 1 mL Miltons Sterilizing Fluid per 5l of water.

Table 6. Results of the water sampling in chronological order.

SO	Date	Sample Site	pH Average	Turbidity Average (NTU)	Nitrates Average (mg/l)	Iron Average (mg/l)	H_2S test kit Score	m-FC (CFUs/100 mL)
1	2022-07-06	K1	6.2	16.32	0	0	2	ND[a]
		B2	7.3	0.00	0	0	2	ND
		B1	6.4	0.00	0	0	2	ND
	2022-07-09	M1	7.2	0.00	0	0	2	ND
2	2022-07-24	K1	6.4	10.38	0	0	2	ND
		M1	7.2	0.00	0	0	2	ND
		B1	7.9	0.00	0	0	Ø	ND
		RT1	6.4	0.00	0	0	2	ND
3	2022-08-11	K1	6.1	56.85	0	0	2	ND
		M1	7.0	0.00	0	0	2	ND
		RT1	7.4	0.00	0	0	2	ND
		RO1	5.8	0.00	0	0	Ø	ND
		B1	6.4	0.00	0	0	Ø	ND
		RT2	5.8	0.00	0	0	2	ND
4	2022-08-21	K1	6.2	8.85	0	0	2	ND
		M1	6.9	0.00	0	0	2	ND
		B1	7.8	0.00	0	0	Ø	ND
		RO1	7.1	0.00	0	0	Ø	ND
		RT2	7.2	0.00	0	0	2	ND
		RT1	7.6	0.00	0	0	2	ND
5	2022-09-10	B1	7.7	0.00	0	0	Ø	43
		K1	6.2	7.58	0	0	2	21
		M1	7.0	0.00	0	0	2	0
		RO1	6.3	0.00	0	0	Ø	0
		RT2	6.4	0.00	0	0	Ø	>300
		RT1	7.8	0.00	0	0	Ø	0
6	2022-09-20	RT1	7.0	0.00	0	0	2	>300
		M1	6.6	0.00	0	0	2	0
		RT2	6.2	16.01	0	10	2	>300
		RO1	7.0	0.01	0	0	Ø	5
		K1	6.2	19.87	0	0	2	>300
		B1	6.7	0.00	0	0	1	20

[a] Not determined.

This treatment was also recorded for sample sites B1 and RT1 between the sampling on the 11 August 2022 and 21 August 2022. In all cases, the testing was conducted a minimum of 48 hours after the treatments to ensure accuracy of the results.

As it can be seen from Table 6, the pH levels of the water samples on a scale from 0 to 14, with 0 being extremely acidic, 7 being neutral and 14 being extremely alkaline (Sajin et al., 2020, pp. 394). According to the South African National Standard (SANS) 241:2015, pH levels of water is an indicator of physical and aesthetic standards for domestic water. When at 25 °C, an acceptable pH should lie between ≥ 5 and ≤ 9.7. Values beyond this threshold are indicators of operational risk. The pH levels were recorded three times for every sample at each sampling occasion, the average of these scores were recorded and are presented in a line graph in Fig. 1.

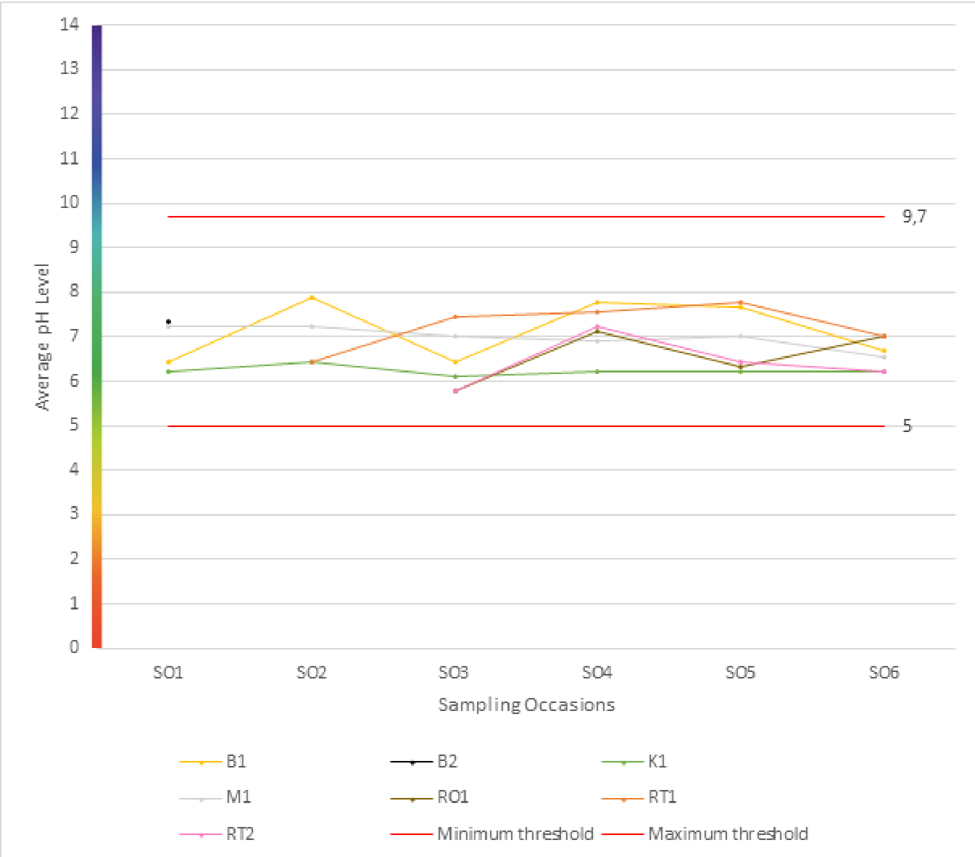

Fig. 1. Line graph showing the average pH results for each sampling site over the sampling period.

As evident in the graph, all the pH averages recorded during the sampling fell within the acceptable threshold outlined in the SANS 241:2015. The highest average pH (most basic) recorded was 7.9 at sample site B1 on the 24 July 2022. The lowest average pH (most acidic) was 5.8 for RT2 on the 11 August 2022. The pH range of all samples is 2.11. An overall average was calculated for each sample over the sampling period. In order from most acidic to most alkaline; K1 is the most acidic at 6.2, followed by RT2 at 6.4 and RO1 at 6.6. M1 has a neutral average of 7.0, followed by B1 at 7.2, RT1 at 7.2 and finally B2 as the most alkaline at 7.3.

Turbidity refers to the optical quality of suspended matter in water that affects the optical quality of water. At the same time, turbidity is also measured as it is an indicator of poor water quality (Stevenson et al., 2019., pp. 72). According to the parameters outlined in South African National Standard (SANS) 241:2015, the turbidity should be ≤ 1 Nephelometric Turbidity Units (NTU) to for it to be considered free of operational risks and ≤ 5 NTU for aesthetic risks. The averages of the turbidity tests done during the sampling are presented in the bar graph in Fig. 2. As evident in the graph, sample sites B1, B2, M1 and RT1 maintained a turbidity level of 0 NTU throughout the sampling period. They were therefore compliant with the SANS 241:2015 regulations for acceptable domestic water. RO1 showed an average of 0.01 NTU on the 20 September 2022. This was an outlier as all preceding tests indicated 0 NTU. The result was ≤ 1and ≤ 5 and therefore fell within the acceptable limits of both operational and aesthetic SANS 241:2015 thresholds respectively. Samples K2 and RT2 presented with recorded levels that exceeded both the operational and aesthetic SANS 241:2015 thresholds. Tests at sample site RT2 on the 20 September 2022 indicated an average of 16.01 NTU.

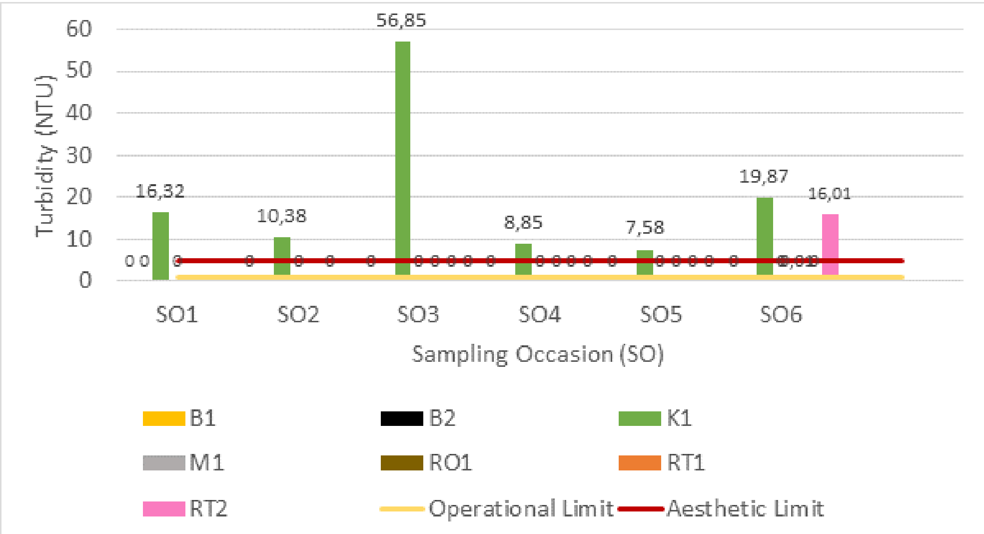

Fig. 2. Bar graph showing the average turbidity in NTU for each sampling site over the sampling period.

This is beyond the acceptable limits outlined in the SANS 241:2015. Prior to the unacceptable reading, RT2 had a consistent score of 0 NTU which was compliant with the respectable guidelines. Opposingly, sample site K1 consistently recorded turbidity above the acceptable threshold. The maximum average turbidity recorded at K1 was 56.85 NTU on 11th August 2022 and the minimum being 7.58 NTU on the 10 September 2022 and therefore had a range of 49.27 NTU. The overall average turbidity of all sampling occasions for K1 was 20 NTU.

Nitrates are indicators of water quality as excess nitrates can result in decreased levels of dissolved oxygen (hypoxia) and potentially they can impact the oxygen transfer in the human body at concentrations of 10 mg/L and above (United States Environmental Protection Agency, 2012). The SANS 241:2015 defines acceptable nitrate levels as being ≤ 11 mg/L. The SANS 241:2015 identify nitrate levels beyond this threshold as being an acute health risk. Nitrate levels are chemical and macro-determinants of water quality. The average nitrates recorded from the NO_3^- tests for all sample sites was 0 mg/L (as evident in Table 6). This is below the nitrate threshold of ≤ 11 mg/L defined in the SANS 241:2015 and is therefore conducive to acceptable water quality.

Iron (Fe) levels are a parameter of water quality as excess iron can result in a build-up of body iron stores, increasing the risk of adverse health effects, and increase the risk of certain bacteria (Ghosh et al., 2020., pp. 5206; Illinois Department of Public Health., 2010). Iron can also impact the taste of water, giving it a metallic taste (Illinois Department of Public Health, 2010). Iron levels outside the threshold outlined in the SANS 241:2015 pose chronic health and aesthetic risks. This chemical and micro- determinant is considered acceptable at a concentration of ≤ 2000 µg/L and ≤ 300 µg/L (or 2 mg/L and 0.3 mg/L) for chronic health and aesthetic purposes respectively. All samples throughout the sampling period, bar one, indicated an average of 0 mg/L of iron. B1, B2, K1, M1, RO1 and RT1 consistently maintained an average iron level < 0 mg/L, which is within the acceptable guidelines of the SANS 241:2015. Sample site RT2 maintained an iron level < 0 mg/L for three consecutive sampling occasions (SO). The sampling site tested as a 10 mg/L on the 20 September 2022 (as evident in Table 6). This level is above the 2 mg/L and 0.3 mg/L thresholds for acceptable thresholds regarding chronic health and aesthetic risks respectively.

The presence of faecal coliforms in a sample is an indicator of compromised microbial water quality and acute health risks (Malema et al., 2019). Presence and number of faecal colonies in a water sample is a microbiological determinant of domestic water quality that is linked to acute health risks. According to the SANS 241:2015, in a 100 mL sample, *E.coli* or faecal coliforms count should be undetected. H_2S tests were used to determine the presence of faecal coliforms at the alternative water source sample sites. There was a 58 % correspondence between the results of the faecal coliform concentration and the H_2S test kit (see Table 6). The H_2S test kit results represent an overview of each sampling occasion, with Ø representing the sampling occasions where none of the five samples indicated the presence of faecal coliforms. If 1-4 of the samples tested positive, a score of 1 was awarded, and if all

5 samples tested positive for faecal coliforms a score of 2 was awarded (all scores are the same defined in Malema et al., 2019; Tandlich, 2020). Sample site RO1 received a consistent score of 0, indication a negative result for faecal coliforms over all sampling occasions. This met the stipulations in the SANS 241:2015 and indicated an acceptable microbial water quality for domestic use. Sample sites B2, K1 and M1 received scores of 2 for each sampling occasion. The presence of faecal coliforms in the water sources does not meet the SANS 241:2015 criteria for acceptable domestic water quality. Sites B1, RT1 and RT2 tested differently at different sample occasions.

Samples from sample sites B1, RT1 and RT2 exhibited irregular results for the H_2S tests. Site B1 tested positively for the presence of faecal bacteria on the 6 July 2022 with a score of 2, classifying the site as an unacceptable domestic water source. On the 24 July, 11 August, 21 August and 10 September 2022, the site received a score of 0, indicating a negative result for faecal bacteria and meeting the requirements of an acceptable source of domestic water for the SANS 241:2015. On the 20 September 2022, a score of 1 was recorded, indicating the presence of faecal coliforms and therefore an unacceptable source of domestic water. Sample sites RT1 and RT2 tested positively for faecal coliforms with a score of 2 for all sampling occasions bar sampling occasion (SO) 5 on the 10 September 2022. This indicates that the samples do not constitute acceptable domestic water sources according to the SANS 241:2015 for all occasions excluding SO5. The samples on the 10 September received a score of 0 and indicates a negative test for faecal bacteria which meets the standards outlined in the SANS 241:2015. Results from this study are comparable to the water quality data from Malema et al. (2019) and Tandlich (2020), i.e. other studies on water quality from the Eastern Cape Province of South Africa. The correspondence and potential reliability of the

Table 7. showing the total carbon emission cost (gCO_2) for each relief vehicle per trip, 5 L bottle (unit) and individual litre.

Location	Cradock			Colesburg			Bloemfontein			Carletonville		
Vehicle Type	TCE/ Load (g)	TCE/ 5 L (g)	TCE/ L (g)	TCE/ Load (g)	TCE/ 5 L (g)	TCE/ L (g)	TCE/Loa d (g)	TCE/ 5 L (g)	TCE/ L (g)	TCE/ Load (g)	TCE/ 5 L (g)	TCE /L (g)
Sedan	66384	1165	233	124430	2183	437	184755	3241	648	291125	5107	1021
Bakkie	102521	563	113	192166	1056	211	285330	1568	314	449605	2470	494
Van	91966	315	63	172382	590	118	285330	877	175	403317	1381	276
Small truck	165838	382	76	310847	716	143	461549	1063	213	727279	1676	335
Truck	351604	188	38	659048	351	70	978563	522	104	1541955	822	164

Water quality results and carbon emissions

The results of the carbon emissions calculations for various relief vehicles at distances between Port Alfred and Cradock, Colesburg, Bloemfontein and Carletonville for a return trip are presented in Table 7. The calculation of Total Carbon Emissions (TCE) for the transport of water for relief activities was calculated using standard relief vehicles and their associated carbon parameters. The most carbon efficient form of transporting bottled water was in large quantities using a truck. As anticipated, increased distance resulted in a corresponding increase in TCE. The second most efficient form of transport is a van, followed by a small truck, a bakkie and finally a sedan. Impact of the weight of the load on the carbon emissions is minor in comparison to the benefit of maximising the available loading space in a vehicle. The carbon efficiency per unit of water of the different vehicles increased as a greater quantity was transported in a trip. This is true for all vehicle types except for the van, which proved to be more efficient than a small truck. All H_2S test kit results had a score of 0, pH was always < 0 NTU, nitrate and iron concentrations were below < 0 mg/L in all samples and the bottled water was always free of faecal coliform (concentration was equal to < 0 CFUs/100 mL). Therefore the importing of the bottled water can provide an alternative supply of water which is physico-chemically and microbiologically safe for human potable uses. However, the calculated carbon production from the transporting in of such water must be carefully considered in terms of long-term implications and local climate change.

Discussion

The information gathered throughout the research culminated into results that are able to guide future actions and research relating to drought and the viability and sustainability of water resources. A greater understanding of the current conditions in the Eastern Cape of South Africa was established in addition to greater insight into the extent and limitations of available knowledge in these areas. Results of the water quality sampling provide a comprehensive representation of Port Alfred’s experience of water supply from alternative resources. At the same time, these results indicate that holistic approach to drought management is not only preferred, but essential in ensuring the sustainability of disaster response activities. Addition of bleach and other on-site treatment will be required for some raintanks in Port Alfred. Calculations for carbon emissions of disaster response expand the parameters upon which drought response is proposed. The results of the research proved useful in securing data upon which future decisions and research can be based.

Drought is a complex and critical stressor of water supply in the Ndlambe Local Municipality area. These findings are consistent with those of Mahlalela et al. (2020), Orimoloye et al. (2022) and Botai et al. (2020). Location of the Eastern Cape between the warm and cold ocean currents and the topography of the area result in it being naturally water deficient. Germishuizen, G., reported on the maximum deficit of 4.3 ML/D of water supply and the resultant disruptions and shortages of available water resources. In the 2022-2027 Ndlambe Municipality IDP (Ndlambe Local Municipality, 2022-2027), the necessity of decentralizing water resources through the use of alternative supply sources is emphasized. In the sampling period, the water supply disruptions were spotlighted as the sampling was delayed due to the lack of municipal water supply. The continued water scarcity after the implementation of planned government drought response activity, such as the RO plant, further emphasizes a deficiency in the drought management measures.

To determine the water quality and potability of the alternative water sources, the pH, turbidity, iron, nitrate and faecal coliform levels were tested for various sources over a period of 3 months, as depicted in the Results section. This testing provided useful information for decision making and reference for future research. Little literature, if any, was found in the way of water quality of the different alternative water supply sources in drought conditions in Port Alfred. The tests revealed acceptable levels of pH (Fig. 1) and nitrates (Table 6) across all sample sites. Iron levels were also consistently of acceptable limits in all water sources except one sample taken from a rainwater tank (Table 6). This outlier was determined to be due to the use of steel fittings for the tap connections rusting after a humid period. Turbidity was a constant indicator of poor water quality for the river source which indicated this was not an acceptable source of alternative water supply, as evident in Fig. 2.

Of all sampling sites, the reverse osmosis water was the only source to maintain a clean microbiological record of consistent compliance with SANS 241:2015 standards. Borehole water and rainwater received varying results, with the latter tending more towards a positive result for faecal coliforms, as evident in Table 6. The results indicate that both the river and tap water maintained unacceptable levels of *E.coli* bacteria. A need for active monitoring of alternative water sources was identified in the testing process to ensure the drought response strategies provide viable alternatives to satisfy the human need for safe, potable water for domestic use. This must be considered in terms of the swimming and water sports in the area of the Kowie river, which forms a major residential and recreational resource/income generation capacity in Ndlambe Local Municipality. It is clear that treatment and compliance/regular monitoring of water quality will be required in Port Alfred area to maintain and protect human health.

Results of the carbon emissions calculations, depicted in Table 7, were indicative of the importance of including sustainability as a parameter for drought response measures. Decisions as simple as selecting the type of vehicle to transport water resources can have a vastly different impact on the carbon footprint of the activity. To reduce the carbon cost of the relief activities, the water should be sourced locally, and the distance of the transport kept to a minimum as the carbon emissions increases with the distance travelled. Impact of the weight of the load on the carbon emissions is minor in comparison to the benefit of maximising the loading space to minimise the total number of supply runs/trips into the drought impacted area, or to reduce the total number of vehicles required for the supply runs/trips. It is more carbon effective to make one trip with a large load than many trips with smaller loads.

The current research indicated that, when choosing a vehicle, the maximum capacity required should be used to determine the corresponding mode of transportation. For larger quantities, the truck was the most efficient, followed by the van, small truck, bakkie and finally, sedan. Vehicles, such as the Sedan and small truck, should not be used in relief efforts as their carbon footprint exceeds that of other vehicles with the same or greater capacity. This research is beneficial as it provides a guide for recommendations that assumes a more holistic approach to drought management. Additional studies should be done to determine alternative sustainability indicators for disaster response. Climate change implications as potential disaster risk enhancers or sources of cascading effects of drought must be considered. Collecting activity information, such as the amount of fuel used per trip, will also enable the use of the fuel consumption based carbon footprint calculation. This calculation is more accurate than the activity based calculation as it makes use of actual records as opposed to theoretical studies. When combined with the results of the water quality testing, recommendations can extend beyond the generalized approaches of international agencies, such as the gift of the givers, by offering critical data required for the personalization of drought response strategies.

The existing disaster response to drought in the Ndlambe Municipality has a 'crisis management focus' and is therefore an incomplete strategy. As presented by Germishuizen (2022) in the '*Ndlambe Municipality: Water Status*' and the Ndlambe Municipality IDP, the municipal response to the drought resultant water shortages include water tanks with borehole water, a RO Plant and the decentralization of water supply by encouraging residents and businesses to install rainwater tanks. Theoretically, these plans should combat the water supply shortages, however, the results do not correspond with this assumption. In addition to the continuation of the water disruptions and shortages, the quality of the alternative sources doesn't meet the requirements outlined in the SANS 241:2015. The municipal strategies do not incorporate preventative and mitigative measures. Without considering the sustainability of the projects, the drought itself is not managed, only its consequences.

To improve Ndlambe Municipality's current drought management strategies, additional focus should be given to the implementation and planning of the response activities. Immediate action can include the standardization and reliability of existing strategies. By ensuring the municipal water tanks are effective, they should become a reliable source of safe, potable water for surrounding residents. Constant monitoring and sampling of water sources should be practiced to ensure the SANS 241:2015 requirements are maintained. Education should be disseminated informing rainwater tank owners of appropriate purification actions to ensure a potable water quality. The results gathered in this study, can be used as a comparison to determine the success of purification measures. In addition to the immediate changes, changes should be made to the decision-making process for drought response. By including sustainability as a factor in response planning, activities will be vetted to ensure their impact on the environment does not exceed their impact as a response. More sustainable practices, such as recycling of water resources, can be implemented as a long term project to increase the sustainability of the drought response.

Despite the limitations observed, the study results serve to corroborate existing information and link national parameters to a local scale, extend existing literature and assist in the definition of critical sustainability parameters to guide future decision making and research. The physico-chemicals and microbial tests performed produced useful results that corresponded with literature data on water quality in other parts of the Eastern Cape Province. Results and subsequent analysis will provide guidelines that will increase awareness on previously underestimated factors and literature deficits and serve as a basis and point of comparison for vital future monitoring and analysis. The research is effective in providing a framework to reduce and manage the impacts of drought on water quality and to quantify potential impacts of the water provision in terms of climate change in the study area.

Conclusion

Drought is a complex, slow-onset natural disaster especially when considered in the scope of the Eastern Cape Province and the in combination with water scarcity in the area (primary but also secondary water scarcity). Disaster risk management in such conditions requires a comprehensive and holistic response to ensure the viability and sustainability of the activities related to the economy of the area and the WASH situation of the population in areas such as Ndlambe Local Municipality. Drought propagates along temporal and spatial scales as it increases in severity, duration and frequency. Climate change emphasizes these affects and is therefore can be a driver of drought propagation, as a risk enhancer or a cascading effect. Drought manifests as water supply shortages and disruptions and requires drought management strategies which includes the use of alternative water sources. For this strategy to be a viable response, the water quality must meet the acceptable criteria to ensure its potability for domestic use. To ensure drought management strategies do not contribute to the advancement of the drought, the activity should be evaluated against sustainability measures. By managing the carbon footprint and preventing increased climate change affects, the propagation of the drought will be mitigated. The viability and sustainability of disaster response is imperative in managing and reducing the current and future impacts of drought.

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