Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2019.24576

167 (2019) 145–155
November

Households water quality in O'Kiep-South Africa and community perception of related health risks

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Received 1 February 2019; Accepted 17 June 2019

ABSTRACT

South Africa faced challenges related to potable water quality that has periodically deteriorated, coupled with inconsistent supply of tap water (TW) to households. These challenges are a primary exasperation in the arid O'Kiep region, where the community has few alternatives regarding drinkable water sources. The aim of this study was to assess the quality of drinking TW supplied to the O'Kiep community, focusing on health risks associated with the ingestion of such water. The study included both the quantitative assessment of water quality parameters and a qualitative assessment of adverse human health outcomes experienced by the residents. Furthermore, disease patterns which were associated with ingestion of supplied water were also identified and subjected to appropriate statistical data analyses. Due to the inadequate drinking water supply and shortages in O'Kiep, households often are dependent on water tankers and commercially bottled water, amongst other potential sources of drinkable water. Water samples (n = 53) from O'Kiep' drinking water supply system (DWSS), that is, n = 3 were collected from source and (n = 50) point-of-use (TW) while the questionnaires were simultaneously administered in households. None of the statistical models suggested physicochemical properties as predictors of any of the health symptoms. Approximately, 88% of community members indicated that the water supplied is often turbid, while a high number of people with teeth discolouration (72%) are living in the area and experience diarrhoea-like symptoms, which are likely to be associated with the ingestion of toxin-contaminated water. This was confirmed by some physiochemical parameters quantified, that is, low dissolved oxygen of 2.0 mg/L, a high electrical conductivity of 595 mg/L, and SO_4^{2-} and chlorine concentrations of 557 and 47.1 mg/L, respectively, which were not within the range prescribed for drinking water guidelines. Furthermore, a positive confirmatory test indicated the presence of toxins in the water. Therefore, regular monitoring and evaluation of DWSS is essential for this vulnerable community.

Keywords: Drinking water supply systems (DWSS); Drinking water quality; O'Kiep; Toxins; Health risk indicators

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1. Introduction

Drinking water supply and use in some areas of South Africa (SA) is generally unsustainable, with a multitude of communities without access to consistent water supply for drinking purposes [1]. Access to adequate water is a human basic right [2]. The National Water Act 36 of 1998 identifies drinking water as a scarce and an unequally supplied resource nationally that must be made available to all communities of the republic [3]. Currently, there is a multitude of communities in the country without access to consistent water supply for drinking purposes [1], including O'Kiep.

Generally in SA, drinking water from surface water is collected and distributed through a public drinking water supply system (DWSS) that may be supplemented by commercial bottled water and/or water tankers in the event of worsening water quality and/or water shortages for communities with poor infrastructure [4,5]. However, water supply through the DWSS remains problematic in some areas [6]. The maintenance of the DWSS varies from urban systems where maintenance is of good quality, but services a minor portion of the population. In O'Kiep, infrastructure is inadequate, with people having to rely on other sources such as bottled/purchased and water from tankers of drinking water. There are many problems associated with such DWSS, which are often related to microbial and inadequate treatment methods [7]. Biofilm growth [8] and microbially mediated corrosion [9] and proliferation of cyanobacteria in reservoirs are identified as contributing to contamination and disease outbreaks [10]. Therefore, adequate control measures for contaminants within the local DWSS are often achieved through disinfectants to limit waterborne diseases [11].

The production of drinkable water, which meets defined quality guidelines [12,13], does not guarantee suitable drinking water quality for the end-user due to maintanance problems and interruptions in the DWSS [14]. Overall, the majority of water health related problems are associated with microbial contamination [15], with bacterial and algal contamination contributing largely to the degradation of drinking water quality even in the presence of a disinfectant [16]. According to the World Health Organization (WHO) [13], some of the important parameters to be monitored within the DWSS are pH, turbidity and toxins. It is essential for water utilities to provide aesthetically satisfactory drinking water as end-users always initially judge the quality of the water by its odour, colour and taste. The confidence in the quality of a community's drinking water supply has in fact dropped by 8% since 2012 in SA [17], an indication of numerous problems associated with the supply of drinking water to households [18].

In SA, the monitoring and management of drinking water quality is governed by legislation and by laws based on international standards and best practice. Municipalities or water service authorities and agencies are, therefore, required to periodically submit information concerning water quality status and to implement management strategies. Additionally, one of the critical aspects of water management is the monitoring of microbial prevalence in drinking water. Programmes such as the Green Drop Certification programme, which is a National Water Quality Monitoring system especially for the management of sewage water treatment plants, and the Blue Drop Certification programmes for drinking water quality monitoring were introduced by the Department of Water Affairs to encourage best practices [19,20]. Also, concerns grew about the quality of drinking water supplied to the residents of the Northern Cape Region [21]. According to the report [22], the Northern Cape provincial blue drop score (BDS) was 68.2%, as a result of inadequate measures for water safety planning. Furthermore, the Nama Khoi Municipality BDS was reported as 63.47% in 2012 [22]. The municipalities in the region were thus certified non-compliant, with a provincial average green drop score of 33%. As a result, these municipalities were placed under regulatory surveillance, in accordance to the Water Services Act (108 of 1997) Sections 62 and 63 [23].

O'Kiep is vulnerable due to its arid environmental conditions such as high temperatures in summer (37°C), and the population relying only groundwater as an alternative water source for future use [24]. Furthermore, a lack of adequate DWSS has either hindered or increased the burden on other basic services such as health services in O'Kiep, with water-related diseases being identified as possible human health threat due to an infrequent and possibly contaminated water supply. Other infrastructural irregularities include, but are not limited to burst pipes, an indication of poor maintenance of the drinking water supply in this community. The O'Kiep area was, therefore, selected for this study because of its arid environmental conditions, water scarcity, infrastructural inadequacies and population density. Accordingly, the aim of this research was to determine the quality of drinking water supplied to the community and to identify possible related human health risks.

2. Materials and methods

2.1. Study area and population

O'Kiep is located in the Northern Cape, South Africa [29°35′45″S 17°52′51″E], and has a geographical coverage of 38.63 km^2 (Fig. 1). Copper deposits were discovered in O'Kiep as early as 1862 and in the 1870s it was ranked the richest copper mining district in the world [25]. According to the Nama Khoi Local Municipality [26], the population size of O'Kiep was around 6,300 at the time of the 2011 Census and has remained stagnant or even decreased slightly since then. Applying the average South African household size of 3.3 persons [27], a sampled population size of roughly N = 1,900 households was established.

2.2. Background of DWSS

A Local Water Board Agent (LWBA) supplies O'Kiep with drinking water sourced from the lower orange river (LOR). Subsequent to its treatment and supply to various towns via a DWSS to households, and also to agricultural and industrial areas, the water is chlorinated, which is the preferred disinfection method prior to distribution [28]. In the unpublished report by LWBA, the 419 mm steel pipeline with coupon lining was replaced in sections in 2005. The mortar lining pipeline needs replacement as in many places the mortar has come loose and or water seeps between the

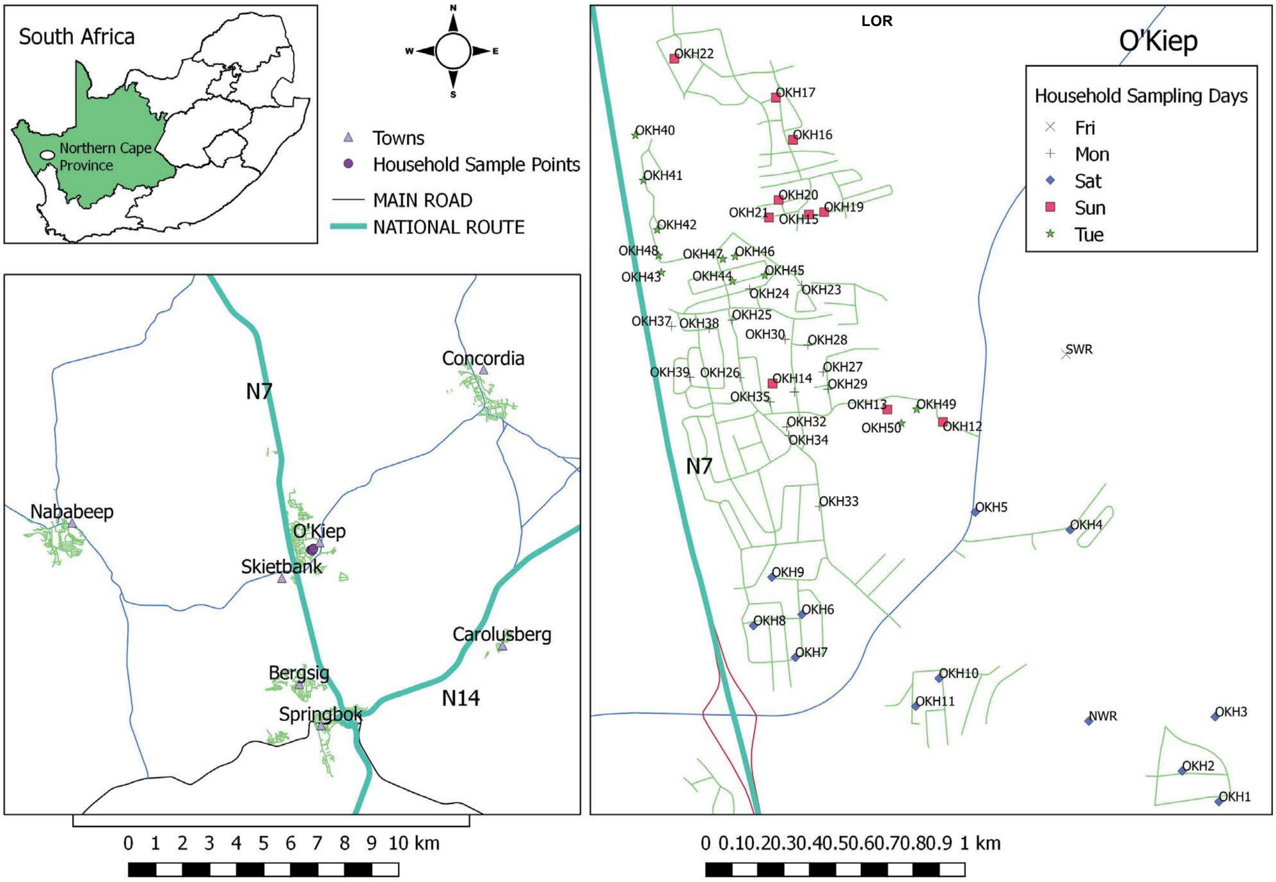

Fig. 1. Study are and sampling points: drawn using geological maps were generated using Quantum GIS software (v. 2.18.11) and data from National Geo-Spatial Information (NGI), a component of the Department of Rural Development and Land Reform, South Africa.

mortar and the pipe wall causing corrosion. The pipeline has deteriorated to such a state that frequent pipe burst occur and the supply to nearby towns is constantly interrupted, this includes O'Kiep.

2.3. Data collection methods

This research study was designed during April 2017 and samples collected from Tuesday to Friday as per the availability of the personnel. During this period, drinking water samples were collected from the source (n = 3), that is, LOR, a Local Water Supply Agency reservoir (LWSA) and a Municipal Reservoir (MR). For point-of-use (POU) (n = 50): households (questionnaires) and water samples were collected from household taps. A total of 53 (n = 53) water samples were collected from source to POU tap water (TW) in each household when identified as the primary source of drinking water by at least one individual. Fig. 1 shows the location of the study area and sampling points.

Prior to the administration of the questionnaire discussed below, and the collection of drinking water samples, permission was sought and granted by the Nama Khoi Municipality. Invasive human procedures such as medical examinations were not considered as part of the study. A structured questionnaire was used, consisting of both closed and open-ended questions. It had four sections: demographic information, drinking water, health-related questions, and water exposure history. The questionnaire was based on WHO and UNICEF [5] water hygiene guidelines. A skilled local interpreter, with considerable fluency in various languages (Afrikaans, Xhosa, and English) mainly used by the community, administered the questionnaires by means of face-to-face interviews. Individuals in each household were selected to respond to the questionnaire, with some households identifying a proxy to do so on their behalf. A sample size of n = 50 households was used. Purposive sampling was adopted from the study by Saladi and Salehe [29] used due to the low response rate: numerous people when approached at their household declined to participate in the study. The refusal by some households to participate in the study, made a pure probability sampling approach infeasible. The interviewees selected were >55 years, generally people responsible for the management of drinking water in each household. Participants (n = 50) agreed to undertake the survey with a household response rate of 100%. The majority of the respondents (66%) had lived in O'Kiep for a lifetime. The number of males (56%) was slightly higher than females (44%). The ethnicity distribution of the sample roughly fit the demographic profile of O'Kiep from the 2011 Census [26], although self-identifying Coloured persons were underrepresented in the sample (74% vs. 95% in the population).

2.4. Water sampling and quality parameter quantification

In the questionnaire, drinking water was defined as water obtained from the tap without additional treatment. All instruments were calibrated prior to sampling, as advocated by Gibs and Wilde [30]. Polypropylene sample bottles (500 mL) were thoroughly washed using soapy water and rinsed with dilute hydrochloric acid (0.5 M), followed by a final rinse with sterilised deionized water. The bottles were dried and stored with the caps on to prevent contamination prior to sample collection. The bottles were also rinsed with sample water before sampling and immediately after sampling, the following physical determinants were quantified in the morning between 7 am and 11 am: dissolved oxygen (DO), pH, temperature, electrical conductivity (EC), salinity, redox potential (Eh), and total dissolved solids (TDS). Most of these determinants were measured on-site using an EXSTIK II® EC500 probe, while the DO was measured using an EXSTIK II® CA895 probe, both instruments were supplied by Extech Instruments, USA. To ensure consistency, these probes were calibrated daily using appropriate standards while a 1,413 mS standard was used to verify the calibration for EC. The DO readings were taken first for every sampling point to avoid atmospheric influences [31,32]. All samples were handled according to the guidelines used for drinking water quality quantification [13]. Immediately after field analyses, samples were placed in an insulated box filled with ice and then transported to the laboratory where the samples were further analysed for turbidity, anions, cations, and dissolved organic carbon (DOC). Analyses were performed using an inductively coupled plasma instrument coupled either with an optical emission spectrometer (ICP-OES), or a mass spectrometer (ICP-MS), a high-performance liquid chromatography (HPLC), and a UV-Vis spectrophotometer, with confirmatory analyses being conducted at an external laboratory accredited by the South African National Accreditation System.

2.4.1. Cyanobacterial toxin analysis

Samples were further screened for algal toxins on-site using ABRA-520017 test strips which are used for finished drinking water, with a lower detection limit of 0.5 μg/L [33]. This method is used for monitoring and quantification of algal toxins in drinking water in South Africa [34], and is also used by the City of Cape Town as a primary screening test for finished drinking water.

3. Results

Table S1 presents the frequencies of the results obtained from the questionnaire. The identified primary sources of drinkable water were household taps (90%) while a minute proportion (10%) was attributed to purchased bottled water, which is indicative of the reliance on TW. Some respondents indicated that they were dependent on water tankers as a source of water during interruptions. All the participants reported water shortages at least once a week, with an average water shortage period between 1 and 2 d (20%). Furthermore, participants (86%) reported an unpleasant smell emanating from the TW, with a salty taste (100%) being identified as one of the predominant problems associated with the water. The majority of the participants (88%) stated that the perceived quality of the TW was indicative of its unsuitability for drinking and concerned that they might become ill from consuming water directly from the tap without additional treatment, a problem mitigated by either boiling (64%) or adding bleach (36%) prior to storage. Participants (81%) were convinced that the quality of the water could affect their health status. Furthermore, respondents reported diarrhoea-like effects subsequent to drinking the TW, attributing the effects directly to the quality of the water supplied, with 72% reporting periodic discolouration of their teeth over a lifetime and the POU TW measured *F*-concentration was up to 0.17 mg/L.

3.1. Statistical analyses

Basic statistical hypothesis tests such as *t*-tests and Wilcoxon signed-rank test, adopted from Luby et al. [35] and Lothrop et al. [36], were used to determine the relationship between the household questionnaires and drinking water physicochemical parameters. For each physicochemical determinant for which a SANS241-1 upper limit was available (F^-, Na^+, Mg, Cl^-, SO_4^{2-}, Zn, turbidity, EC), a one-sample *t*-test was used to test the null hypothesis that the mean household value is below the SANS241-1 upper limit (i.e., for the *j*th parameter, H_0: $\mu_j \leq s_j$) against the alternative that the mean household value is above the SANS241-1 upper limit (e.g., for the *j*th parameter, H_A: $\mu_j > s_j$). The *t*-test could not be used for two parameters (Al^{3+} and Cu) for which the data contained interval-censored values that were below the minimum detectable amount of the equipment (<0.05 for Al^{3+} and <0.01 for Cu). For these two elements, the Wilcoxon signed-rank test—a nonparametric method—was implemented with the interval-censored values considered to be tied at the lowest rank. Among all the parameters that were tested, there were two cases for which the null hypothesis was rejected at 5% significance level: SO_4^{2-} (p-value = 2.870×10^{-3}) and EC (p-value = 8.395×10^{-133}). This indicates that the average level of SO_4^{2-}, and average EC level in POU water in O'Kiep households is above the recommended upper limit of SANS241-1 [12].

3.2. Logistic regression models

Logistic regression model adopted from Cox [37] was used to assess possible relationships between health and other indicators from the household questionnaire, on the one hand, and chemical and physical properties of household water samples, on the other. The indicators fit to logistic regression models as the binary dependent variable were, respectively, "Does anyone in the family suffer from pain or tiredness?" (Yes/No), "Have you been sick from the water you drank?" (Yes/No), "How does the water smell?" (Unpleasant Smell/No Smell), "When you brush your teeth have you noticed bleeding gums?" (Yes/No), and "Have you noticed discolouration of your teeth in the past?" (Yes/No). The logistic regression model did suggest a statistically significant relationship between two physical parameters and the smell of the water. For every unit increase in DO, the odds of an unpleasant smell being reported by that household increased by a factor of 12.391 (significance *p*-value: 0.0186). For every unit increase in pH, the odds of an unpleasant smell being reported by that household increased by a factor of 260.083 (significance *p*-value: 0.0266). It is difficult to say whether this empirical relationship is spurious or real.

3.3. Questionnaire two-way frequency analysis

A few statistically significant relationships between categorical variables from the questionnaire were identified using the Pearson chi-squared test [38] of independence. (Tables 1, 2 and 3)

Interpretation: Those who do not use water from tankers during interruptions in water service are more likely to use bleaching to improve water quality than those who do use water from tankers during water service interruptions.

Interpretation: Those who do use water from storage tanks during interruptions in water service are more likely to use bleaching to improve water quality than those who do not use water from storage tanks during water service interruptions.

Interpretation: Those who do purchase water during interruptions in water service are more likely to use bleaching to improve water quality than those who do not purchase water during water service interruptions.

Table 4 provides detailed information on the physiochemical water quality parameters quantified for each of the sampling points used in this study from the source to the POU (i.e., TW), the results of the analysis were further compared with drinking water guidelines [12,13].

3.4. Cyanobacterial toxin analysis

The results of toxin screening test strips for microcystins indicated the presence of toxins from the water source to the POU as indicated in Fig. 2; WHO [13] guidelines restrict cyanobacteria toxin level in drinking water to 1 µg/L for microcystin-LR. Therefore, long-term toxin exposure of the community in O'Kiep needs to be considered with regard to implementing appropriate remedial action. Currently, cyanobacterial toxins, especially microcystins, are treated with the addition of free chlorine for toxin oxidation, thus deactivation. [34], while the O'Kiep community use bleach as a mitigation strategy for such toxins. The occurrence of microcystin in drinking water is generally unacceptable; most of the respondents criticized the quality and treatment processes used for processing the water sourced from the LOR, as reported in this study.

Table 1
Chi-squared test *p*-value: 8.389×10^{-3}

	Use of tankers for water during interruptions	
Bleaching	No	Yes
No	5	27
Yes	10	8

Table 2
Chi-squared test *p*-value: 2.885×10^{-4}

	Use of storage tanks for water during interruptions	
Bleaching	No	Yes
No	28	4
Yes	6	12

Table 3
Chi-squared test *p*-value: 8.389×10^{-3}

	Purchase of water during interruptions	
Bleaching	No	Yes
No	27	5
Yes	8	10

4. Discussion

The physicochemical properties of drinking water from the DWSS in O'Kiep were assessed using pH, oxidation–reduction potential, aqueous ions, toxin screening and turbidity as the primary water quality parameters quantified, because they directly affect water quality. The LOR samples quality was characterised by low Eh (–13.3 mV) and DO (2.3 mg/L) with a high average EC (574 mS/m) including SO_4^{2-} (528 mg/L), values deemed not within the drinking water guidelines set out in SANS241-1 and WHO [13]; while Na^+, Cl^-, and PO_4^{3-} were all within the drinking water guidelines set by the WHO [13] averaging 158, 43.6, and 1.7 mg/L respectively. The turbidity (18.1 NTU) of the TW was not within the SANS241-1 [12] drinking water guidelines, as expected. It was observed that both Na^+ and Cl^- increased when the water was stored in the MR, with concentrations of 191 and 48 mg/L being observed respectively, while the Eh decreased to –40,8 mV (Table 2). An increase in Cl^- was attributed to water chlorination prior to distribution to households. The source of Na^+ is presumably contributed to the salty taste of the TW. For observed increases in salinity, DWSS corrosion scales can be triggered by sudden water chemistry changes, resulting in a bad taste of water which is deemed drinkable and as such the water might become odorous, which often leads to non-compliant water quality [39]. All the other determinants for the source water were within the drinking water standards recommended by both WHO [13] and SANS241-1 [12]. The effect of source water quality on the deterioration of water quality parameters post treatment and within the DWSS is complex, with the mechanisms involved being especially unclear in O'Kiep.

The temperature of the TW samples ranged from 21.2°C to 35.4°C with the water temperature within the DWSS being affected by environmental temperature changes throughout the day. Thus, the DWSS might exhibit different corrosion behaviour in the morning when compared with the afternoon [40]. The DOC quantified as 3.7 mg/L in this study and a reduced Eh (–11.4 to –69.5 mV) are related to the quantity of oxidisable constituents or trace elements in the water [41]. The pH values (7.6 to 8.9) were not within the permissible limit set by SANS241-1 [12] and WHO [13], with the EC and salinity being in the range between 570 and 660 mS/m, and 277 and 326 mg/L, respectively, as EC is largely influenced

Table 4
Physicochemical determinants compared with drinking water quality guidelines

	Source			Point-of-use (POU): tap water					
Determinants	LOR	LWSA	MWR	Minimum	Maximum	Average	POU (Tap Water): % of Households Above SANS241-1 [12] limit	SANS241-1 [12]	WHO [13]
Colour, Pt-Co-true	<10	<10	<10	<10	<10	<10	–	<15	–
Dissolved oxygen (DO), mg/L	2.3	3.4	2.9	0.5	2.9	2.0	–	–	5
Electrical conductivity (EC), mS/m	574	578	581	570	660	595	100%	≤170	100
pH at 25°C	8.3	8.0	8.0	7.6	8.9	8.3	0%	5–9,7	6,5–9,5
Redox, mV	–13,3	–26,8	–40,8	–69.5	–11.4	–45.5	–	–	–
Salinity, mg/L	284	288	288	277	326	293	–	–	–
Temperature, °C	28	29.3	25.0	21	35	28	–	–	–
Total dissolved solids (TDS), mg/L	401	407	405	396	459	414	0%	≤1,200	500
Turbidity, NTU	18.1	0.4	0.3	0.15	7.8	0.45	2%	≤5	–
Fluoride (F^-), mg/L	0.16	0.15	0.15	0.12	0.17	0.15	0%	≤1,5	1.5
Calcium (Ca), mg/L	38.3	38.5	38	36.9	40.9	38.2	–	–	–
Sodium (Na), mg/L	158	136	191	99.5	228	159	14%	≤200	100
Magnesium [38], mg/L	18.9	19.1	18.5	18.0	19.6	18.7	0%	400	–
Potassium (K), mg/L	10.4	8.91	11.4	8.3	11.0	9.1	–	–	–
Chloride (Cl^-), mg/L	43.6	49.4	48	42.4	51.4	47.1	0%	≤300	5
Sulphate (SO_4^{2-}), mg/L	528	449	679	314	867	557	64%	≤500	200
Ammonia (NH_3), mg/L	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	0%	≤1,5	–
Nitrate (N), mg/L	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	–	–	–
Ortho-phosphate (P), mg/L	<1.7	<1.7	<1.7	<1.7	<1.7	<1.7	–	–	0.4
Zinc [39], mg/L	0.05	0.15	0.17	0.06	0.97	0.16	0%	≤5	2
Aluminium (Al^{3+}), mg/L	0.06	0.06	0.07	0.05	0.12	0.06	0%	≤0,3	–
Arsenic (As), mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%	≤0,01	0.01
Copper (Cu), mg/L	<0.01	<0.01	<0.01	0.01	0.21	0.02	0%	≤2	1
Iron (Fe), mg/L, mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0%	≤2	0.3
Manganese (Mn)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%	≤0,4	0.05
Dissolved organic carbon (DOC), mg/L	6.1	3.6	4.0	2.0	5.0	3.7	–	–	–

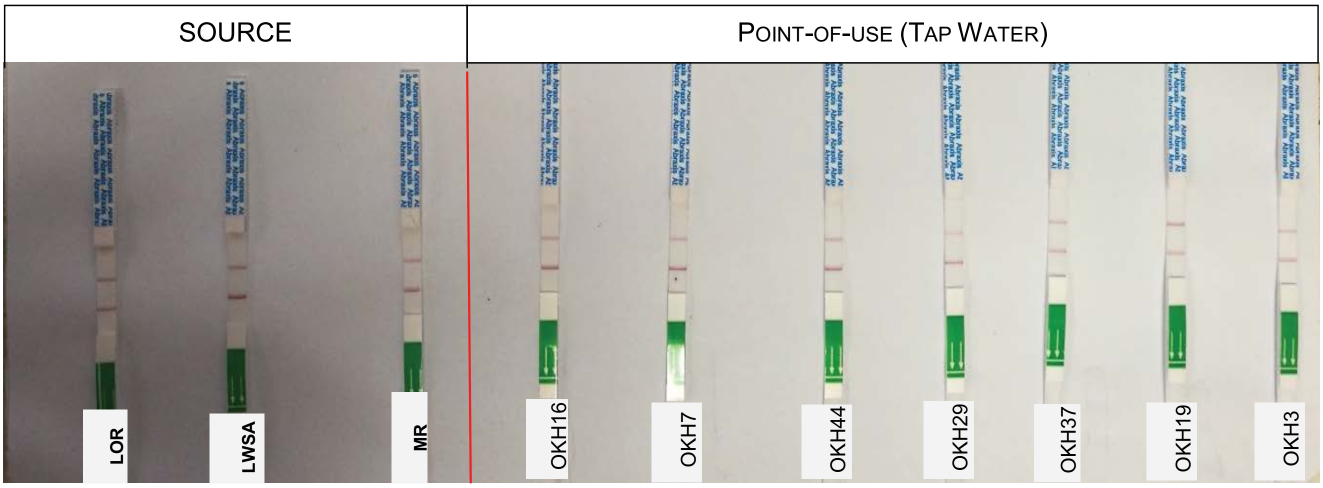

Fig. 2. Dipsticks for screening of microcystins.

by salinity [42] and TDS [43]. The maximum TDS observed within the DWSS reached a maximum of 459 mg/L, which is within the prescribed drinking water guidelines by SANS241-1 [12] and WHO [13]. However, the DO averaged 2.0 mg/L, which is lower than that required for drinking water [13]. At higher temperatures, reduced DO suggests that microbial proliferation within DWSS is prevalent [40]. Furthermore, the low DO could also be an indication of a high concentration of dissolved minerals in the water, as the salinity averaged 293 mg/L, conditions suitable for excessive algal growth in drinking water. Some researchers ascribe this to the chemical instability of Fe^{2+} released from corroded iron pipes [44]. However, quantified metals and their ions, that is, Al^{3+}, As, Cu, Fe, Mn, F^-, Mg, and Zn, were all determined to be within SANS241-1 [12] and WHO [13] drinking water guidelines.

Although F^- in the sampled drinking water was low, 72% of the respondents indicated discolouration of teeth. This was hypothesised to be due to a lifetime exposure to fluorine. According to WHO [13], the optimum fluoride levels in drinking water should not exceed 1.5 mg/L, with higher concentrations being associated with human health complications, including teeth discoloration, decay, and neurological problems in severe cases [45–47]. Additionally, treated TW should have a positive Eh (200–400 mV), depending on the locality of the source water and the treatment method being used [48]. Samples from this research showed Eh of –11.4 to –69.5 mV with an average of –45.4 mV. The redox conditions within DWSS can widely vary under anoxic conditions, particularly for disinfected drinking water, due to the existence of redox reactions; while TW is largely a weak pro-oxidant, particularly where Cl^- concentrations are below an average of 47.1 mg/L [49].

Characteristically, the anions also play an important role in the quality of drinking water, particularly when anions such as SO_4^{2-} are high (549–679 mg/L) at the POU. The intake of elevated concentrations of SO_4^{2-} through drinking contaminated water may cause health effects such as diarrhoea particularly to consumers not accustomed to drinking water with a high concentration of sulphates [50,51], with a large proportion of the respondents complaining about diarrhoea subsequent to ingestion of TW supplied, which might contain bacteria. Generally, elevated concentrations of SO_4^{2-} are common in water in mining areas [50], including when air-exposed reservoirs are utilized for treated water storage. For water quality assessments, numerous standards for drinking water can be used, and most are categorized into two classifications, that is, primary and secondary standards. Primary standards are based on health concerns and are intended to safeguard individuals from pathogens, radioactive elements and toxic pollutants including chemicals. Secondary standards are based on staining properties, taste, smell, colour, and corrosivity, of which sulphates must not exceed a maximum of 250 mg/L [52], with higher concentrations being associated with microbial growth [53] which further exacerbates water colour problems in a DWSS, such as the O'Kiep DWSS studied. Biofilms in the DWSS can also be influenced by water temperature, chlorine levels, organic compound concentrations and compositional characteristics of storage, and by DWSS pipe materials [14]. Thiobacteria and sulphate-reducing bacteria are also the main indicators of sulphurous compounds in DWSS with mycobacteria being associated with an earthy and musty odour [16,54]. Similarly, the DOC (3.7 mg/L) can have adverse aesthetic implications including water colour, odour and taste, although, concentrations up to 5 mg/L have minimal effects on human health in chlorinated water [12]. However, long-term high DOC exposure can have deleterious effects on human health; the supplied water in O'Kiep was reported in this study to have green (28%), brown (28%) and white (26%) tints.

5. Conclusion and recommendations

To address concerns such as diarrhoea-like symptoms and taste and colour associated to the drinking water supplied to O'Kiep by the local DWSS, it is paramount that effective treatment systems and distribution infrastructure are in place. Although, most of the drinking water quality indicators were deemed to be within the required quality guidelines as indicated by WHO [13] and SANS241-1 [12], some parameters were out of specification, in particular, DO, which was below the recommended levels in all samples analysed.

Temperature, DO, DOC, Eh, EC, TDS, Na, Cl^-, SO_4^{2-} were the parameters contributing to low water quality in the study area. These factors are responsible for aesthetic qualities of the drinking water when out of specification, due to a lack of appropriate treatment systems. Further, contaminant seepage into the DWSS and an irregular water supply can contribute to the negative perception of the water quality supplied. The drinking water of the study area should thus be boiled or disinfected using bleach prior to consumption, as is currently the norm. There is also a need to develop cost-effective water testing capabilities within the region for daily monitoring of water quality, focusing on Eh, which must be measured at regular intervals as an indication of the effectiveness of the dose of chlorine used within the O'Kiep DWSS. None of the statistical models suggested physicochemical properties as predictors of any of the health symptoms. However, it must be remembered that each water sample represents a single point in time; one would need to assess the long-term water quality at the respective households to be able to identify relationships with health indicators. It is reasonable to conclude that DWSS vulnerability plays some role on POU drinking water quality, and that methods for improvement should be studied. The study has further revealed high concentration of EC, salinity, TDS and SO_4^{2-} from source to POU. This means that it will be likely in future to better understand the sources of these elements in the DWSS for the betterment of drinking water quality. The long-term exposure of the community to microcystins must be considered with regard to implementing appropriate remedial action. Furthermore, biofilm growth and microbially mediated corrosion and the proliferation of cyanobacteria in the DWSS studied needs further investigation in O'Kiep.

Acknowledgments

The authors are appreciative to the financial support from the North-West University, from Cape Peninsula University of Technology (CPUT), University Research Fund (Grant no. URF RY12), and the National Research Foundation (NRF) in South Africa. Authors would also like to thank all our study participants for providing their valuable time to the study.

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Supplementary information

Table S1
Frequencies from questionnaires

Section A: Drinking water source and quality	
Variable	Frequency (%)
Where do you get your water?	
Water tap	90
Water tap + purchase	10
Where do you think water of the highest quality is found?	
Bottle purchased water	100
What are you doing to improve the water quality?	
Boil	64
Boil + bleach	36
Are you satisfied with the quality of drinking water?	
Could be better	12
No	88
What is the colour of the drinking water from your tap?	
Brownish	28
Greenish + brownish	14
Greenish	28
Whitish	26
Whitish + brownish	4
Section B: Possible health risks	
Variable	Frequency (%)
Does anyone in the family suffer from pain or tiredness?	
Yes	54
N/A	18
No	28
Have you been sick from the water you drank?	
Yes	88
No	12
If yes, you got sick from?	88
Diarrhoea	12
N/A	
How does the water smell?	
No smell	14
Unpleasant smell	86
Does the water have a taste?	
Salty taste	100
Have you noticed decolouration of your teeth?	
Yes	72
Dentures	8
No	20
Section C: Drinking water supply	
Variable	Frequency (%)
Who supply you with your drinking water?	
Municipality	90
Municipality + store	10
Does your household experience any interruptions of the drinking water supply?	
Yes	100

(*Continued*)

What is the frequency of interruptions of the drinking water supply?	
Once a week	42
1–2 d per week	20
3–4 d	38
If there are interruptions of drinking water supply, how do you access water?	
Tanker-truck	48
Tanker-truck + bottle purchased water	22
Bottle purchased water + stored water from containers	10
Stored water from containers	20
What type of storage container you use for your drinking water?	
Bucket	88
Jojo tank	12
Are you satisfied with your drinking water service?	
No	100
In your view, who should be accountable for the drinking water quality and supply?	
Government	12
Government + municipality	22
Municipality	66