Water quality assessment and evaluation of human health risk of drinking water from source to point of use at Thulamela municipality, Limpopo Province

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Water quality has been linked to health outcomes across the world. This study evaluated the physico-chemical and bacteriological quality of drinking water supplied by the municipality from source to the point of use at Thulamela municipality, Limpopo Province, South Africa; assessed the community practices regarding collection and storage of water and determined the human health risks associated with consumption of the water. Assessment of water quality was carried out on 114 samples. Questionnaires were used to determine the community’s practices of water transportation from source to the point-of-use and storage activities. Many of the households reported constant water supply interruptions and the majority (92.2%) do not treat their water before use. While *E. coli* and total coliform were not detected in the water samples at source (dam), most of the samples from the street taps and at the point of use (household storage containers) were found to be contaminated with high levels of *E. coli* and total coliform. The levels of *E. coli* and total coliform detected during the wet season were higher than the levels detected during the dry season. Trace metals’ levels in the drinking water samples were within permissible range of both the South African National Standards and World Health Organisation. The calculated non-carcinogenic effects using hazard quotient toxicity potential and cumulative hazard index of drinking water through ingestion and dermal pathways were less than unity, implying that consumption of the water could pose no significant non-carcinogenic health risk. Intermittent interruption in municipal water supply and certain water transportation and storage practices by community members increase the risk of water contamination. We recommend a more consistent supply of treated municipal water in Limpopo province and training of residents on hygienic practices of transportation and storage of drinking water from the source to the point of use.

**Abbreviations**

| Abbreviation | Description |
|--------------|-------------|
| APHA | American Public Health Association |
| CDC | Centres for Disease Control and Prevention |
| D | Dam |
| DWAF | Department of Water Affairs and Forestry |
| EC | Electrical conductivity |
| HI | Health risk index |
| HQ | Hazard quotient |
| HSC | Household storage containers |
| HT | Household taps |
| ICP-MS | Inductively coupled plasma mass spectrophotometer |
| ICP-OES | Inductively coupled plasma optical emission spectrophotometer |
| MPN | Most probable number |
| SANS | South African National Standards |

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tries, it has been observed that drinking-water frequently becomes re-contaminated following its collection and storage, inadequate knowledge and a lack of personal and domestic hygiene have all been linked with levels of contamination in households. Efforts by governmental and non-governmental organizations to ensure water security and safety in recent years have failed in many areas due to a lack of sustainability of water supply infrastructures. Water quality, especially regarding the microbiological content, can be compromised during collection, transport, and home storage. Possible sources of drinking water contamination are open field defecation, animal wastes, economic activities (agricultural, industrial and businesses), wastes from residential areas as well as flooding. Any water source, especially is vulnerable to such contamination. Thus, access to a safe source alone does not ensure the quality of water that is consumed, and a good water source alone does not automatically translate to full health benefits in the absence of improved water storage and sanitation. In developing countries, it has been observed that drinking-water frequently becomes re-contaminated following its collection and during storage in homes.

Previous studies in developing countries have identified a progressive contamination of drinking water samples with E. coli and total coliforms from source to the point of use in the households, especially as a result of using dirty containers for collection and storage processes. The type of water treatment method employed at household levels, the type of container used to store drinking water, the number of days of water storage, inadequate knowledge and a lack of personal and domestic hygiene have all been linked with levels of water contamination in households.

In South Africa, many communities have access to treated water supplied by the government. However, the water is more likely to be piped into individual households in the urban than rural areas. In many rural communities, the water is provided through the street taps and residents have to collect from those taps and transport the water to their households. Also, water supply interruptions are frequently experienced in rural communities, hence, the need for long-term water storage. A previous study of water quality in South Africa reported better quality of water at source than the water samples obtained from the household storage containers, showing that water could be contaminated in the process of transporting it from source to the point of use.

This study was conducted in a rural community at Thulamela Municipality, Limpopo province, South Africa, to describe the community’s drinking water handling practices from source to the point of use in the households and evaluate the quality of the water from source (the reservoir), main distribution systems (street taps), yard connections (household taps) and at the point of use (household storage containers). Water quality assessment

| ST            | Street taps                  |
|---------------|------------------------------|
| TDS           | Total Dissolved Solids       |
| UNGA          | United Nations General Assembly |
| UNICEF        | United Nations International Children Emergency Fund |
| USEPA         | United States Environmental Protection Agency |
| WHO           | World Health Organization   |

Water is among the major essential resources for the sustenance of humans, agriculture and industry. Social and economic progress are based and sustained upon this pre-eminent resource. Availability and easy access to safe and quality water is a fundamental human right and availability of clean water and sanitation for all has been listed as one of the goals to be achieved by the year 2030 for sustainable development by the United Nations General Assembly (UNGA). The physical, chemical, biological and aesthetic properties of water are the parameters used to describe its quality and determine its capability for a variety of uses including the protection of human health and the aquatic ecosystem. Most of these properties are influenced by constituents that are either dissolved or suspended in water and water quality can be influenced by both natural processes and human activities. The capacity of a population to safeguard sustainable access to adequate quantities and acceptable quality of water for sustaining livelihoods of human well-being and socioeconomic growth; as well as ensuring protection against pollution and water related disasters; and for conserving ecosystems in a climate of peace and political balance is regarded to as water security.

Although the world’s multitudes have access to water, in numerous places, the available water is seldom safe for human drinking and not obtainable in sufficient quantities to meet basic health needs. The World Health Organization (WHO) estimated that about 1.1 billion people globally drink unsafe water and most diarrheal diseases in the world (88%) is attributed to unsafe water, poor sanitation and unhygienic practices. In addition, the water supply sector is facing enormous challenges due to climate change, global warming and urbanization. Insufficient quantity and poor quality of water have serious impact on sustainable development, especially in developing countries.

The quality of water supplied by the municipality is to be measured against the national standards for drinking water developed by the federal governments and other relevant bodies. These standards considered some attributes to be of primary importance to the quality of drinking water, while others are considered to be of secondary importance. Generally, the guidelines for drinking water quality recommend that faecal indicator bacteria (FIB), especially Escherichia coli (E. coli) or thermo tolerant coliform (TTC), should not be found in any 100 mL of drinking water sample.

Despite the availability of these standards and guidelines, numerous WHO and United Nations International Children Emergency Fund (UNICEF) reports have documented faecal contamination of drinking water sources, including enhanced sources of drinking water like the pipe water, especially in low-income countries. Water-related diseases remain the primary cause of a high mortality rate for children under the age of five years worldwide. These problems are specifically seen in rural areas of developing countries. In addition, emerging contaminants and disinfection by-products have been associated with chronic health problems for people in both developed and developing countries. Efforts by governmental and non-governmental organizations to ensure water security and safety in recent years have failed in many areas due to a lack of sustainability of water supply infrastructures.

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was done by assessing the microbial contamination and trace metal concentrations, and the possible health risks due to exposure of humans to the harmful pathogens and trace metals in the drinking water were determined.

**Methods**

**Study area.** The study was conducted at Lufule village in Thulamela municipality, Limpopo Province, South Africa. The municipality is situated in the eastern subtropical region of the province. The province is generally hot and humid and it receives much of its rainfall during summer (October–March)\(^2\). Lufule village is made up of 386 households and a total population of 1,617 residents\(^3\). The study area includes Nandoni Dam (main reservoir) which acquires its raw water from Luvuvhu river that flows through Mutoti and Ha-Budeli villages just a few kilometers away from Thohoyandou town. Nandoni dam is where purification process takes place to ensure that the water meets the standards set for drinking water. This dam is the main source of water around the municipality, and it is the one which supplies water to selected areas around the dam, including Lufule village.

Water samples for analysis were collected from the dam (D), street taps (ST), household taps (HT) and household storage containers (HSC) (Fig. 1).

**Research design.** This study adopted a quantitative design comprising of field survey and water analysis.

**Field survey.** The survey was done to identify the selected households and their shared source of drinking water (street taps). The village was divided into 10 quadrants for sampling purposes. From each quadrant, 6 households were randomly selected where questionnaires were distributed and household water samples were also collected for analysis.

**Quantitative data collection.** A structured interviewer-administered questionnaire was employed for data collection in the selected households. The population of Lufule village residents aged 15–69 years is 1,026 (Census, 2011). About 10% of the adult population (~103) was selected to complete the questionnaires to represent the entire population. However, a total of 120 questionnaires were distributed, to take care of those which might be lacking vital information and therefore would not qualify to be analysed. Adults between the ages of 18 and 69 years were randomly selected to complete the questionnaire which includes questions concerning demographic and socio-economic statuses of the respondents, water use practices, sanitation, hygiene practices as well as perception of water quality and health. The face validity of the instrument was ensured by experts in the Department of Public Health, University of Venda, who reviewed questionnaire and confirmed that the items measure the concepts of interest relevant to the study\(^3\). Respondents were given time to go through the questionnaire and the researcher was present to clear any misunderstanding that may arise.
Water sampling.  Permission to collect water samples from the reservoir tank at the Nandoni water treatment plant and households was obtained from the plant manager and the households’ heads respectively. Two sampling sites were identified at the dam, from where a water sample each was collected during the dry and the wet season. Similarly, 8 sampling sites were identified from the street and household taps, while 60 sampling sites were targeted for the household storage containers. However, only 39 household sites were accessible for sample collection, due to unavailability of the residents at the times of the researcher’s visit. Thus, water samples were collected from a total of 57 sites. Samples were collected from each of the sites during the dry (12th–20th April, 2019) and wet seasons (9th–12th December, 2019) between the hours of 08h00 and 14h30. A total of 114 samples were collected during the sampling period: 4 from the reservoir, 16 from street taps, 16 from household taps and 78 from households’ storage systems. Water samples were collected in 500 mL sterile polyethylene bottles. After collection, the containers were transported to the laboratory on ice in a cooler box. Each of the samples was tested for physico-chemical parameters, microbial parameters and trace metals’ concentration.

Physicochemical parameters’ analysis.  Onsite analysis of temperature, pH, Electrical conductivity (EC) and Total Dissolved Solids (TDS) were performed immediately after sampling using a multimeter (model HI “HANNA” instruments), following the standards protocols and methods of American Public Health Association (APHA)25. The instrument was calibrated in accordance with the manufacturer’s guideline before taking the measurements. The value of each sample was taken after submerging the probe in the water and held for a couple of minutes to achieve a reliable reading. After measurement of each sample, the probe was rinsed with de-ionized water to avoid cross contamination among different samples.

ICP-OES and ICP-MS analyses of major and trace elements.  An inductively coupled plasma optical emission spectrometry (ICP-OES) was used to analyse the major metals (Calcium (Ca), Sodium (Na), Potassium (K) and Magnesium (Mg)) in the water samples while inductively coupled plasma mass spectrometer (ICP-MS) was used to analyze the trace metals. The instrument was standardized with a multi-element calibration standard IV for ICP for Copper (Cu), Manganese (Mn), Iron (Fe), Chromium (Cr), Cadmium (Cd), Arsenic (As), Nickel (Ni), Zinc (Zn), Lead (Pb) and Cobalt (Co) and analytical precision was checked by frequently analysing the standards as well as blanks. ICP multi Standard solution of 1000 ppm for K, Ca, Mg and Na was prepared with NH₄OAC for analysis to verify the accuracy of the calibration of the instrument and quantification of selected metals before sample analysis, as well as throughout the analysis to monitor drift.

Microbiological water quality analysis.  Analysis of microbial parameters was conducted within 6 h of collection as recommended by APHA25. Viable Total coliform and E. coli were quantified in each sample using the IDEXX technique approved by the United States Environmental Protection Agency (USEPA). Colilert media was added to 100 mL sample and mixed until dissolved completely. The solution was poured into an IDEXX Quanti-Tray/2000 and sealed using the Quanti-Tray sealer26. The samples were incubated at 35 °C for 24 h. Trays were scanned using a fluorescent UV lamp to count fluorescent wells positive for E. coli concentration and counted with the most probable number (MPN) table provided by the manufacturer27.

Health risk assessment.  Risk assessment have been estimated for ingestion and dermal pathways. Exposure pathway to water for ingestion and dermal routes are calculated using Eqs. (1) and (2) below:

\[
\text{Exp}_{\text{ing}} = \frac{IR \times C_{\text{water}} \times EF \times ED}{AT \times BW}
\]

\[
\text{Exp}_{\text{derm}} = \frac{C_{\text{water}} \times SA \times ET \times EF \times ED \times CF \times K_p}{AT \times BW}
\]

where \(\text{Exp}_{\text{ing}}\): exposure dose through ingestion of water (mg/kg/day); \(BW\): average body weight (70 kg for adults; 15 kg for children); \(\text{Exp}_{\text{derm}}\): exposure dose through dermal absorption (mg/kg/day); \(C_{\text{water}}\): average concentration of the estimated metals in water (µg/L); \(IR\): ingestion rate in this study (2.0 L/day for adults; 1.0 L/day for children); \(ED\): exposure duration (70 years for adults; and 6 years for children); \(AT\): averaging time (25,550 days for an adult; 2190 days for a child); \(EF\): exposure frequency (365 days/year); \(SA\): exposed skin area (18,000 cm² for adults; 6600 cm² for children); \(K_p\): dermal permeability coefficient in water, (cm/h), 0.001 for Cu, Mn, Fe and Cd, while 0.0006 for Zn; 0.002 for Cr and 0.004 for Pb; \(ET\): exposure time (0.58 h/ day for adults; 1 h/day for children) and \(CF\): unit conversion factor (0.001 L/cm³)28.

The hazard quotient (HQ) of non-carcinogenic risk by ingestion pathway can be determined by Eq. (3)

\[
\text{HQ}_{\text{ing}} = \frac{\text{Exp}_{\text{ing}}}{\text{RfD}_{\text{ing}}}
\]

where \(\text{RfD}_{\text{ing}}\) is ingestion toxicity reference dose (mg/kg/day). An HQ under 1 is assumed to be safe and taken as significant non-carcinogenic, but HQ value above 1 may indicate a major potential health concern associated with over-exposure of humans to the contaminants28.

The total non-carcinogenic risk is represented by hazard index (HI). HI < 1 means the non-carcinogenic risk is acceptable, while HI > 1 indicates the risk is beyond the acceptable level29. The HI of a given pollutant through multiple pathways can be calculated by summing the hazard quotients by Eq. (4) below.
Carcinogenic risks for ingestion pathway is calculated by Eq. (5). For the selected metals in the study, carcinogenic risk (CR<sub>ing</sub>) can be defined as the probability that an individual will develop cancer during his lifetime due to exposure under specific scenarios.<sup>30</sup>

\[
HI = \sum_{i=1}^{n} HQ_{ing/derm}
\]  

(4)

\[
CR_{ing} = \frac{EXP_{ing}}{SF_{ing}}
\]  

(5)

where CR<sub>ing</sub> is carcinogenic risk via ingestion route and SF<sub>ing</sub> is the carcinogenic slope factor.

**Data analysis.** Data obtained from the survey were analysed using Microsoft Excel and presented as descriptive statistics in the form of tables and graphs. The experimental data obtained was compared with the South African National Standards (SANS)<sup>31</sup> and Department of Water Affairs and Forestry (DWAF)<sup>32</sup> guidelines for domestic water use.

**Ethics approval and consent to participate.** The ethical clearance for this study was granted by the University of Venda Health, Safety and Research Ethics’ Committee (SHS/19/PH/14/1104). Permission to conduct the study was obtained from the Department of Water affairs, Limpopo province, Vhembe district Municipality and the selected households. Respondents were duly informed about the study and informed consent was obtained from all of them. The basic ethical principles of voluntary participation, informed consent, anonymity and confidentiality of respondents were duly complied with during data collection, analysis and reporting.

**Consent for publication.** Not applicable.

**Results**

**Socio-demographic characteristics of respondents.** A total of 120 questionnaires were distributed but only 115 were completed, making a good response rate of 95%. The socio-demographic characteristics of the respondents are presented in Table 1.

| Socio-demographic characteristics | Frequency (n) | Percentage (%) |
|---------------------------------|--------------|----------------|
| Gender                          |              |                |
| Male                            | 78           | 67.8           |
| Female                          | 37           | 32.2           |
| Age (in years)                  |              |                |
| 18–24                           | 16           | 13.9           |
| 25–34                           | 40           | 34.8           |
| 35–44                           | 11           | 9.6            |
| 45–54                           | 19           | 16.5           |
| 55–64                           | 9            | 7.8            |
| >64                             | 20           | 17.4           |
| Level of education              |              |                |
| Primary school                  | 7            | 6.1            |
| Secondary school                | 34           | 29.6           |
| Matriculation                   | 53           | 46.0           |
| Undergraduate                   | 7            | 6.1            |
| Postgraduate                    | 14           | 12.2           |
| Employment status               |              |                |
| Permanent employment            | 25           | 21.7           |
| Temporary employment            | 4            | 3.5            |
| Self-employment                 | 49           | 42.6           |
| Grant holder                    | 29           | 25.2           |
| Others                          | 8            | 7.0            |

Table 1. Socio- demographic characteristics of the respondents.

Household water supply. Many households (68.7%) had their primary water source from the municipality piped into their yards, but only 5.2% have the water flowing within their houses. The others have to fetch water at their neighbours’ yards or use the public taps on the streets. When the primary water supply is interrupted (i.e. when there is no water flowing through the pipes within the houses, yards or the public taps due to water rationing activities by the municipality, leakage of water distribution pipes, vandalism of pipes during road maintenance, etc.), the interruption usually lasts between a week or two, during which the respondents resort to other alternative sources. A return trip to the secondary source of water usually takes between 10 and 30 min for more than half of the respondents (53.0%) (Table 2).
Water storage and treatment practices at the household. Household water was most frequently stored in plastic buckets (n = 78, 67.8%), but ceramic vessels, metal buckets and other containers are also used for water storage (Fig. 2). Most households reported that their drinking water containers were covered (n = 111, 96.5%). More than half (53.9%) of the respondents used cups with handles to collect water from the storage containers whereas 37.4% used cups with no handles. Only 7.8% households reported that they treat their water before use mainly by boiling. Approximately 82.6% of respondent are of the opinion that one cannot get sick from drinking water and only 17.4% knew the risks that come with untreated water, and cited diarrhoea, schistosomiasis, cholera, fever, vomiting, ear infections, malnutrition, rash, flu and malaria as specific illnesses associ-
ated with water. Despite these perceptions, the majority (76.5%) were satisfied with their current water source. The few (23.5%) who were not satisfied cited poor quality, uncleanness, cloudiness, bad odour and taste in the water as reasons for their dissatisfaction (Table 3).

Sanitation practices at the household level. More than half of the respondents (67%) use pit toilets, whereas only 26.1% use the flush to septic tank system, most of the toilets (93.9%) have a concrete floor. About 76.5% of households do not have designated place to wash their hands, however, all respondents indicated that they always wash their hands with soap or any of its other alternatives before preparing meals and after using the toilet (Table 4).

Water samples analysis. The water samples analyses comprise of microbial analysis, physico-chemical analysis and trace metals’ parameters.

Microbial analysis. The samples from the reservoir during dry and wet season had 0 MPN/100 mL of total coliform and *E. coli* and were within the recommended limits of WHO and SANS for drinking water. During the wet season, seven out of the eight water samples collected from the street taps were contaminated with total coliform, while four of the samples taken from the same source were contaminated with total coliform during the dry season. Water samples from street taps 3 and 7 (ST 3 and ST7) were contaminated with total coliform during the wet season. Water samples from household taps showed a similar trend with the street taps—with all samples being contaminated with total coliform during the wet season. Though 7 of the 8 samples taken from the household taps were contaminated with total coliform during the dry season, the samples from the same sources showed a higher level of total coliform in the wet season, with almost all the samples showing contamination at maximum detection levels of more than 2000 MPN/100 mL, except one sample (HT8) which showed a higher level of contamination with total coliform during the dry compared with the wet season. Only one sample (HT4) was found to be contaminated with *E. coli* during both dry and wet season. This shows that total coliform contamination levels are higher during the wet season than the dry season (Table 5).

Water samples from household storage containers (HSC) showed a higher level of total coliform during the wet season than the dry season and more samples were contaminated with *E. coli* during the wet season also (Table 6). A higher level of contamination was recorded for the street and household taps.

| Variables | Frequency (n) | Percentage (%) |
|-----------|--------------|----------------|
| Do you usually treat your water before you drink? | Yes | 9 | 7.8 |
| | No | 106 | 92.2 |
| Which method of treatment do you usually use to make your water safe to drink? | Solar disinfection | 2 | 1.7 |
| | Water filter (ceramic/sand/etc.) | 3 | 2.6 |
| | Bleach/chlorine | 2 | 1.7 |
| | Boiling | 2 | 1.7 |
| Where do you store your drinking water? | Ceramic vessels | 24 | 20.9 |
| | Metal buckets | 5 | 4.3 |
| | Plastic buckets | 78 | 67.8 |
| | Jerry can | 3 | 2.6 |
| | Pans | 3 | 2.6 |
| | Water tank | 2 | 1.7 |
| How long does water stay in the storage container? | Less than a week | 101 | 87.8 |
| | 1–2 weeks | 8 | 7.0 |
| | Less than a month | 6 | 5.2 |
| Are your storage vessels covered? | No | 4 | 3.5 |
| | Yes | 111 | 96.5 |
| What do you use to get the water from the storage container? | Pour directly | 10 | 8.7 |
| | Use cup with handle | 62 | 53.9 |
| | Use cup with no handle | 43 | 37.4 |
| Do you think that you can get sick from the water you use? | No | 95 | 82.6 |
| | Yes | 20 | 17.4 |
| Are you satisfied with the quality of water you use? | No | 27 | 23.5 |
| | Yes | 88 | 76.5 |

Table 3. Water storage and treatment practices at the household.
### Table 4. Sanitation practices at the household level.

| Variables                                                                 | Frequency (n) | Percentage (%) |
|---------------------------------------------------------------------------|---------------|----------------|
| What kind of toilet facility do you and other members of your household usually use? |               |                |
| No facility/bush/fields                                                   | 3             | 2.6            |
| Pit latrine                                                              | 77            | 67.0           |
| Improved pit latrine without flush                                       | 3             | 2.6            |
| Flush to piped sewer system                                              | 2             | 1.7            |
| Flush to pit (septic) tank                                                | 30            | 26.1           |
| Does the toilet/latrine you use have a concrete floor?                   |               |                |
| No                                                                        | 7             | 6.1            |
| Yes                                                                       | 108           | 93.9           |
| How many households use this toilet facility?                            |               |                |
| 1–2                                                                      | 53            | 46.1           |
| 3–5                                                                      | 6             | 5.2            |
| 6–8                                                                      | 11            | 9.6            |
| 9–10                                                                     | 22            | 19.1           |
| 12–15                                                                    | 22            | 19.1           |
| 16–20                                                                    | 1             | 0.9            |
| Is there a designated place to wash hands by this toilet?                |               |                |
| No                                                                        | 88            | 76.5           |
| Yes                                                                       | 27            | 23.5           |
| How often do you wash your hands after using the toilet?                 |               |                |
| Always                                                                   | 115           | 100.0          |
| How often do you use toilet paper?                                       |               |                |
| Always                                                                   | 115           | 100.0          |
| How often do you wash your hands before preparing food?                  |               |                |
| Always                                                                   | 115           | 100.0          |
| How often do you use soap when you wash your hands? (soap can include ash, sand or the use of hand sanitizer gel/ cream) | Always 115 | 100.0 |

### Table 5. Total coliform and *E. coli* levels in water samples from the reservoir, street taps and household taps.

| Sample ID | Total coliform (MPN/100 mL) | E. coli (MPN/100 mL) |
|-----------|-----------------------------|----------------------|
|           | Dry season                  | Wet season           | Dry season | Wet season |
| Reservoir/ Dam (D) |                             |                      |            |            |
| D1        | 0                           | 0                     | 0          | 0          |
| D2        | 0                           | 0                     | 0          | 0          |
| Street taps (ST) |                             |                      |            |            |
| ST 1      | 0                           | > 2000                | 0          | 0          |
| ST 2      | 0                           | 144.8                 | 0          | 0          |
| ST 3      | 132.4                       | > 2000                | 0          | 1.0        |
| ST 4      | 0                           | 0                     | 0          | 0          |
| ST 5      | 123.9                       | 123.9                 | 0          | 0          |
| ST 6      | 770.1                       | 770.1                 | 0          | 1.0        |
| ST 7      | 221.3                       | > 2000                | 0          | 0          |
| ST 8      | 146.1                       | 62.9                  | 0          | 0          |
| Household taps (HT) |                             |                      |            |            |
| HT 1      | 1.0                         | > 2000                | 0          | 0          |
| HT 2      | 0                           | 410.6                 | 0          | 0          |
| HT 3      | 3.0                         | > 2000                | 0          | 0          |
| HT 4      | 78.7                        | 200.5                 | 1.0        | 1.0        |
| HT 5      | 157.5                       | > 2000                | 0          | 0          |
| HT 6      | 3.0                         | > 2000                | 0          | 0          |
| HT 7      | 15.8                        | > 2000                | 0          | 0          |
| HT 8      | > 2000                      | 307.6                 | 0          | 0          |
| Reference values |                             |                      |            |            |
| SANS51    | 10                          | 10                    | 0          | 0          |
| WHO8      | 0                           | 0                     | 0          | 0          |
Physico-chemical analysis. In the reservoir samples, the pH value ranged from 8.37 to 8.45, EC ranged between 183 and 259 µS/cm whereas TDS varied between 118 and 168 mg/L. Similarly, in the street tap samples, pH value ranged from 7.28 and 9.33, EC ranged between 26 and 867 µS/cm whereas TDS varied between 16 and 562 mg/L (Fig. 3).

In household taps, pH value ranged from 7.70–9.98, EC range between 28–895 µS/cm and TDS varied between 18 and 572 mg/L (Fig. 4).

In household storage container samples, the pH value ranges from 7.67–9.77, EC ranged between 19–903 µS/cm and TDS values ranged from 12–1148 mg/L (Fig. 5).

Analysis of cations and trace metals in water. To detect the cations' and trace metals' concentrations in the water samples, representative samples from each of the sources were selected for analysis. The concentra-
tion of Calcium ranged between 2.14 and 31.65 mg/L, Potassium concentration ranged from 0.14 to 1.85 mg/L, Magnesium concentration varied from 1.32 to 16.59 mg/L, Sodium ranged from 0.18 to 12.96 mg/L (Table 7).

**Trace metals’ analysis.** The minimum and maximum concentrations of trace metals (Al, Mn, Fe, Co, Ni, Cu, Zn, As and Pb) present in water samples from selected street taps, household taps and household storage containers are presented in Table 8.
Hazard quotient (HQ) and carcinogenic risk assessment. Table 9 presents the exposure dosage and hazard quotient (HQ) for ingestion and dermal pathway for metals. The HQ_{ing} and HQ_{derm} for all analyzed trace metals in both children and adults were less than one unit, indicating that there are no potential non-carcinogenic health risks associated with consumption of the water. Table 10 presents the total Hazard Quotient and Health risk index (HI) for trace metals in the water samples, showing that residents of the study area are not susceptible to non-cancer risks due to exposure to trace metals in drinking water. Table 11 presents the cancer risk associated with the levels of Ni, As and Pb in the drinking water samples. The table shows that only the maximum levels of lead had the highest chance of cancer risks for both adults and children.
Discussion

This study provides information about the quality of drinking water in a selected rural community of Thulamela municipality of Limpopo province, South Africa, taking into consideration the physicochemical, microbiological and trace metals’ parameters of the treated water supplied to the village by the government, through the municipality. Many participants in the study have their primary source of water piped into their yards, while very few have water in their houses. This implies that getting water for household use would involve collecting the water from the yard and then into the storage containers. Those who do not have the taps in their yards have to collect water from the neighbours’ yards or the street taps. This observation is not restricted to the study area, as a similar situation has been observed in other rural communities of Limpopo Province. This need to pass water through multiple containers before the point of use increases the risk of contamination.

| Metals | Mean | Minimum | Maximum | Mean | Minimum | Maximum |
|--------|------|---------|---------|------|---------|---------|
| Al     | 2.07E-04 | 5.30E-05 | 5.73E-04 | 4.66E-04 | 1.20E-04 | 1.29E-03 |
| Mn     | 1.39E-03 | 1.48E-04 | 3.97E-03 | 1.87E-03 | 1.99E-04 | 5.34E-03 |
| Fe     | 7.88E-04 | 4.08E-05 | 5.13E-03 | 1.87E-03 | 9.20E-05 | 7.94E-03 |
| Co     | 3.60E-05 | 2.79E-05 | 5.60E-05 | 8.03E-05 | 6.23E-05 | 1.25E-04 |
| Ni     | 3.55E-04 | 5.30E-05 | 1.06E-03 | 7.91E-04 | 1.18E-04 | 2.36E-03 |
| Cu     | 4.95E-03 | 9.18E-04 | 3.41E-02 | 1.13E-02 | 2.09E-03 | 7.74E-02 |
| Zn     | 2.35E-03 | 2.49E-04 | 1.91E-02 | 5.36E-03 | 5.67E-04 | 4.36E-02 |
| As     | 6.18E-03 | 2.17E-03 | 1.69E-02 | 1.41E-02 | 4.95E-03 | 3.86E-02 |
| Pb     | 1.58E-03 | 2.15E-04 | 5.50E-03 | 3.14E-03 | 4.26E-04 | 1.09E-02 |
| HI     | 1.78E-02 | 3.87E-03 | 8.44E-02 | 3.88E-02 | 8.62E-03 | 1.87E-01 |

Table 10. Total Hazard Quotient and Health risk index (HI) for trace metals in the water samples.
 Residents of the study area, just like residents of other settlements in Thulamela Municipality, store their drinking water in plastic buckets, ceramic vessels, jerry cans and other containers. Almost all the respondents (96.5%) claim that their water storage vessels are covered and that their drinking water usually stays for less than a week in the storage containers (87.8%). Covering of water storage containers reduces the risk of water contamination from dust or other airborne particles. However, intermittent interruption of municipal water supply lasting for a week or more in the study area and the consequent use of alternative sources of water predispose the residents to various health risks as intermittent interruption in water supply has been linked to higher chances of contamination in the distribution systems, compared with continuous supply; in addition, the alternative sources of water may not be of a good quality as the treated municipal water, yet, more than half of the respondents in this study (53%) use water directly from source without any form of treatment. This is because many residents in rural communities of Limpopo province believe that the water they drink is of good quality and thus do not need any further treatment. The few who treat their water before drinking mostly use the boiling method. While boiling and other home-based interventions like solar disinfection of water have been reported to improve the quality of drinking water; drinking vessels, like cups, have also been implicated in water re-contamination of treated water at the point of use and most respondents (91.3%) in this study admittedly use cups to collect water from the storage containers. The risk of contamination is even increased when cups without handles are used, where there is a higher chance that the water collector would touch the water in the container with his/her fingers. The Centres for Disease Control and Prevention (CDC) recommends that containers for drinking water should be fitted with a small opening with a cover or a spigot, through which water can be collected while the container remains closed, without dipping any potentially contaminated object into the container. However, it is noteworthy that all the respondents claim to always wash their hands with soap (or its equivalents) and water after using the toilets, a constant practice of hand washing after using the toilet has been associated with it is noteworthy that all the respondents claim to always wash their hands with soap (or its equivalents) and water after using the toilets, a constant practice of hand washing after using the toilet has been associated with.

Treated water from the dam tested negative for both total coliform and *E. coli* hence complied with regulatory standards of SANS and WHO. The results could probably be due to the use of chlorine as a disinfectant in the treatment plant. Using disinfectants, pathogenic bacteria from the water can be killed and water made safe for the user. Similar studies have also reported that treated water in urban water treatment plants contains no total coliforms and *E. coli*. In contrast, treated water sources in rural areas have been reported to have considerable levels of total coliform and *E. coli*.

From the water samples collected from the street taps, 62.5% were found to be contaminated with total coliform during the dry season, while the percentage rose to 87.5% during the wet season. The street tap which is about 13 km from the reservoir recorded high levels of total coliform ranging from 1.0 -2000 MPN/100 mL with most of the sites exceeding the WHO guidelines of 10 MPN/100 mL. In both seasons, all the samples tested negative for *E. coli*, this complies with the WHO guideline of 0 MPN/100 mL. While the water leaving the treatment plant met bacteriological standards, the detection of coliform bacteria in the distribution lines suggest that the water is contaminated in the distribution networks. This could be due to the adherence of bacteria onto biofilms or accidental point source contamination by broken pipes, installation and repair works. Furthermore, the water samples from households’ storage containers were contaminated by total coliform (73% and 85%) and *E. coli* (10.4% and 13.2%) during the dry and wet season, respectively. Microbiological contamination of household water stored in containers could be due to unhygienic practices occurring between the collection point and the point-of-use.

Generally, higher levels of contamination were recorded in the wet season than in the dry season. The wet season in Thulamela Municipality is often characterized with increased temperature which could lead to favourable condition for microbial growth. Also, the treatment plant usually makes use of the same amount of chlorine for water purification during both seasons, even though influent water would be of a higher turbidity during the wet season, hence reducing the levels of residual chlorine.

The pH of the analyzed samples from the study area ranged from 7.15 to 9.92. Most of the samples were within the values recommended by SANS (5 to 9.7) and comparable to results from previous similar studies. The electrical conductivity of all water samples from this study ranged from 28 µS/cm to 903 µS/cm which
complied with the recommended value of SANS: < 1700 µS/cm\(^3\)). The presence of dissolved solids such as calcium, chloride, and magnesium in water samples is responsible for its electrical conductivity\(^4\).

Total dissolved solids are the inorganic salts and small amounts of organic substance, which are present as solution in water\(^5\). Water has the ability to dissolve a wide range of inorganic and some organic minerals or salts such as potassium, calcium, sodium, bicarbonates, chlorides, magnesium, sulphates, etc. These minerals produced unwanted taste and colour in water\(^6\). A high TDS value indicates that water is highly mineralised. The recommended TDS value set for drinking water quality is ≤ 1200 mg/L\(^3\)). In this study, the TDS values ranged from 18 mg/L to 572 mg/L. Hence, the TDS of all the household’s storage samples complied with the guidelines and consistent with previous studies\(^47\).

The analysis of magnesium (1.32 to 16.59 mg/L) and calcium (2.14 to 31.65 mg/L) concentrations showed that they were within the permissible range recommended for drinking water by SANS\(^3\)) and WHO\(^8\). All living organisms depend on magnesium in all types of cells, body tissues and organs for variety of functions while calcium is very important for human cell physiology and bones. Similar studies in Ethiopia and Turkey also showed acceptable levels of these metals in drinking water\(^46,48\). Likewise, the levels of potassium (0.14 to 1.85 mg/L) and sodium (0.18 to 12.96 mg/L) were within the permissible limit of WHO and SANS and may not cause health related problems. Sodium is essential in humans for the regulation of body fluid and electrolytes, and for proper functioning of the nerves and muscles, however, excessive sodium in the body can increase the risk of developing a high blood pressure, cardiovascular diseases and kidney damage\(^35,50\). Potassium is very important for protein synthesis and carbohydrate metabolism, thus, it is very important for normal growth and body building in humans, but, excessive quantity of potassium in the body (hyperkalemia) is characterized with irritability, decreased urine production and cardiac arrest\(^51\).

Metals like copper (Cu), cobalt (Co) and zinc (Zn) are essential requirements for normal body growth and functions of living organisms, however, in high concentrations, they are considered highly toxic for human and aquatic life\(^45\). Elevated trace metal(loids) concentrations could deteriorate water quality and pose significant health risks to the public due to their toxicity, persistence, and bio accumulative nature\(^52\). In this study, the concentrations of Manganese, Cobalt, Nickel and Copper all complied with the recommended concentration by SANS for domestic water use.

Aluminum concentration in the drinking water samples ranged from 1.25—13.46 µg/L. All analysed samples complied with the recommended concentration of ≤ 300 µg/L for domestic water use\(^51\). The recorded levels of Al in water from this study should not pose any health risk. At a high concentration, aluminium affects the nervous system, and it is linked to several diseases, such as Parkinson’s and Alzheimer’s diseases\(^53\). Iron (Fe) is an essential element for human health, required for the production of protein haemoglobin, which carries oxygen from our lungs to the other parts of the body. Insufficient or excess levels of iron can have negative effect on body functions\(^44\). The recommended concentration of iron in drinking water is ≤ 2000 µg/L\(^3\)). In this study, the concentration of iron in the samples ranged from 0.96 to 73.53 µg/L. Similar results were reported by Jamshaid et al. in Khyber Pakhtunkhwa province\(^55\). A high concentration of Fe in water can give water a metallic taste, even though it is still safe to drink\(^56\).

The levels of Pb, As and Zn were in the range of 0.02—0.57 µg/L, 0.02—0.17 µg/L, and 2.54—194.96 µg/L, respectively whereas Cr was not detected in the samples collected. The levels recorded complied with the SANS\(^3\)) and WHO\(^8\) guidelines for drinking water. Similar results were reported by Mohod and Dhote\(^57\). Lead is not desirable in drinking water because it is carcinogenic and can cause growth impairment in children\(^51\). Inorganic arsenic is a confirmed carcinogen and is the most significant chemical contaminant in drinking water globally\(^45\). Zinc deficiency can cause loss of appetite, decreased sense of taste and smell, slow wound healing and skin sores\(^58\). Cr is desirable at low concentration but can be harmful if present in elevated levels.

The hazard quotient (HQ) takes into consideration the oral toxicity reference dose for a trace metal that humans can be exposed to\(^59\). Health related risk associated with the exposure through ingestion depends on the weight, age and volume of water consumed by an individual. HQ\(_{\text{ing}}\) and HQ\(_{\text{dom}}\) for all analyzed trace metals in both children and adults were less than one unit (Table 9), indicating that there are no potential non-carcinogenic health risks associated with the consumption of the water from the study area either by children or adults. The calculated average cumulative health risk index (HI) for children and adult was 3.88E-02 and 1.78E-02, respectively. HQ across metals serve as a conservative assessment tool to estimate high-end risk rather than low end-risk in order to protect the public. This served as a screen value to determine whether there is major significant health risk\(^60\). The results in this study signifies that the population of the investigated area are not susceptible to non-cancer risks due to exposure to trace metals in drinking water. Similar observation has been reported by Bamuwamye et al. after investigating human health risk assessment of trace metals in Kampala (Uganda) drinking water\(^4\). It should be noted that the hazard index values for children were higher than that of adult, suggesting that children were more susceptible to non-carcinogenic risk from the trace metals.

Drinking water with trace metals such as Pb, As, Cr and Cd could potentially enhance the risk of cancer in human beings\(^52,61\). Long term exposure to low amounts of toxic metals might, consequently, result in many types of cancers. Using As, Ni and Pb carcinogens, the total exposure risks of the residents in Table 11. For trace metals, an acceptable carcinogenic risk value of less than 1 × 10\(^{-6}\) is considered as insignificant and the cancer risk can be neglected; while an acceptable carcinogenic risk value of above 1 × 10\(^{-4}\) is considered as harmful and the cancer risk is worrisome. Amongst the studied trace metals, only the maximum levels of lead for both adults and children had the highest chance of cancer risks (1.93E−03 and 4.46E−03) while Arsenic and Nickel have no chance of cancer risk with values of 3.34E−06; 7.72E−06 and 2.24E−05; 5.18E−05, in both adults and children respectively. The only cancer risk to residents of the studied area could be from the cumulative ingestion of lead in their drinking water. The levels of Pb recorded in this study complied to the SANS guideline value for safe drinking water. While the levels of Pb from the dam and the street pipes were relatively low, higher levels where recorded at household taps and storage containers and this may be due to the kind of storage containers and pipes
used in those households. Generally, the water supply is of low Pb levels which should not pose any health risk to the consumers. However, the residents in rural areas should be properly educated on the kind of materials to be used for safe storage of water which should not pose an additional health burden. The likelihood of cancer risk was only associated with the consumption of the highest levels of Pb reported for a life time for adults (set at 70 years) and 6 years for children. Consistent consumption of water from the same source throughout an adult’s lifetime is unlikely as residents in those communities may change their locations at some points, hence reducing the possible risk associated with consistent exposure to the same levels of Pb.

Conclusions

The study shows that as distance increases from the treatment reservoir to distribution points, the cross-contamination rate also increases, therefore, good hygienic practices is required while transporting, storing and using water. Unhygienic practices at any point between collection and use contribute to the deterioration of drinking water quality.

The physicochemical, bacteriological quality and trace metals’ concentration of water samples from treated source, street taps and household storage containers were majorly within the permissible range of both WHO and SANS drinking water standards. HQ for both children and adults were less than unity, showing that the drinking water poses less significance health threat to both children and adults. Amongst the studied trace metals, only the maximum level of lead for both adults and children has the highest chance of cancer risks.

We recommend that appropriate measures should be taken to maintain residual free chlorine at the distribution points, supply of municipal treated water should be more consistent in all the rural communities of Thulamela municipality, Limpopo province and residents should be trained on hygienic practices of transportation and storage of drinking water from the source to the point of use.

Data availability

The datasets used and analysed during the current study are available from the first author on reasonable request.

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Author contributions
L.N. and J.N.E. conceptualized the study, L.N. collected and analysed the data, T.G.T., J.T. M., and J.N.E. supervised the data collection and analysis. F.C.O. drafted the original manuscript, J.N.E. reviewed and edited the original manuscript. All authors approved the final manuscript.

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Competing interests
The authors declare no competing interests.

Additional information
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