Vol. 17(12), pp. 302-312, December 2023
DOI: 10.5897/AJEST2023.3237
Article Number: 95DCC4B71569
ISSN: 1996-0786
Copyright ©2023
Author(s) retain the copyright of this article
http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Groundwater quality assessment and human health risks in Ovitoto, Otjozondjupa Region, Namibia

Priskila Mwatukange[1], Erold Naomab[2] and Omotayo Rafiu Awofolu[1]*

[1]Department of Preventative Health Sciences, School of Health Sciences,
Namibia University of Science and Technology, Windhoek, Namibia.
[2]Office of the Vice-Chancellor, Namibia University of Science and Technology, Windhoek, Namibia.

Received 9 October, 2023; Accepted 23 November, 2023

Namibia, a dry country relies heavily on groundwater resources which is susceptible to anthropogenic contamination. The study assessed the quality and health risks of borehole water supplied to residents of the Ovitoto community in Otjozondjupa region of Namibia. Water samples were collected from nine boreholes across nine communities over a period of six months and subjected to physicochemical and microbial analyses. Heavy metals were extracted using mineral acid digestion and detected using Inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES). Microbial entities were analyzed using standard bacteriological method. Results revealed that the pH, temperature, and electrical conductivity (EC) of samples were within WHO permissible levels for human consumption while Turbidity and total dissolved solids (TDS) were above the limit. Overall mean concentrations of heavy metals were 0.83, 0.01, 0.02, 17.8, and 7.09 mg/L for Zn, Cd, Pb, Fe, and Mn respectively. WHO drinking water permissible levels were obtained for Cd, Pb, Fe and Mn and the water could also be regarded as unsuitable for irrigational use because it is above permissible levels of Cd, Fe, and Mn. Zn and Cd showed a strong correlation (r=0.99) with an average correlation (r=0.55) between Cd and Cu. The human health risk of the metals was assessed using the Target Hazard Quotient (THQ) and Carcinogenic Risk Index (CRI), where HQ >1 and CRI > 1.0×10-4 indicate non-carcinogenic and carcinogenic risks, respectively. THQ values < 1 was obtained for analyzed metals in both children and adults. However, CRI (Mn) values of 4.8 for adults and 18.1 for children indicate potential exposure to carcinogenic risk. Detection of HPC, Tc, and Fc in water samples above permissible levels also gives cause for concern. Pretreatment and monitoring of borehole water samples before distribution for consumption is highly recommended.

Key words: Water quality, human health, health risks, groundwater, Namibia.

INTRODUCTION

Clean and safe drinking water is regarded as an essential resource for human survival and has been recognized, globally as a fundamental human right (UNGA, 2015, 2016). Yet, about 1 in 3 people globally do not have access to safe drinking water (WHO, 2019). Given the diminishing availability of this critical resource due to compounding

---

*Corresponding author. E-mail: oawofolu@nust.na. Tel: +264612072500.

natural (geological, geomorphological formation, and bedrock-water-interaction) and anthropogenic (agricultural, industrial, and climatic) factors (Nagaraju et al., 2016), several countries have resorted to alternative processes such as groundwater abstraction (Foteinis and Masindi, 2021) and seawater desalination (Dhakal et al., 2022). In many rural communities of the developing countries, the main source of water for drinking and other domestic activities is the groundwater.

Due to a lack of access to modern machinery for the installation of boreholes with an average geological depth of between 100 and 150 m that can supply relatively cleaner and more potable water, rural community members usually use manual and less effective tools in creating and accessing groundwater commonly referred to as "wells" with depth varying between 6 and 9 m depending on groundwater level. Notwithstanding the depth of the groundwater source, the quality of water therefrom can become degraded as a result of pollution from point and non-point sources (UNEP, 2010; Daly et al., 2021; Ye et al., 2022).

Aquifers can become vulnerable to pollution due to disturbances and changes to the physical topography resulting from human activities such as road construction and mining which may further alter the hydrological dynamics of the groundwater (Mulyadi et al., 2020). Furthermore, the disposal of domestic and agricultural solid wastes containing contaminants such as detergents, heavy metals, and other organic pollutants on land can result in the leaching of these toxic chemicals into the soil with potential contamination of the groundwater. The deterioration of groundwater quality has been linked to landfill leachate with elevated Pollution Load Index (PLI = 29.14), which was above the permissible limits for the discharge of leachate (Fadili et al., 2022a). In a related study, the quality of groundwater was found to have been compromised by heavy metals-enriched soil in the vicinity of municipal solid waste dumpsites with moderate to high contamination levels (PLI = 1.84) (Fadili et al., 2022b). The application of the Water Quality Index (WQI) for assessing the quality of groundwater resources revealed that about 98.9% of analyzed water samples were contaminated (Khaneghah et al., 2020).

Due to cost, many subsistent farmers in the study area are known to use relatively cheap and toxic pesticides that are not environmentally friendly with serious long-term human health effects. Modern, biodegradable pesticides are usually more expensive and unaffordable for many of the rural farmers. The presence of toxic pesticides and other contaminants in groundwater sources has been reported (Bexfield et al., 2021). Generally, communal/ subsistence and commercial agricultural practices are common in many communities in the country as a source of livelihood.

The dry and arid climatic condition of Namibia makes it susceptible to water scarcity and drought across all regions of the country including the Otjozondjupa region in which the study area is located. Hence, many communities utilize groundwater from boreholes as a freshwater source to address the issue of water scarcity for agricultural and domestic use. However, there are growing concerns about groundwater quality in most municipal areas. This stemmed from the observation of incessant blockage of the water pipe network by particulate matter at residences in the community. Hence, the rationale for the borehole water quality assessment across the community. The governmental agency, Namibia Water Corporation was also interested in the assessment since the oversight of water quality management is within the mandate of the agency. Apart from the impact of anthropological factors on groundwater quality, the contribution from the prevailing geological formation of the area, the rate of recharge, and the reflux of water have been reported (Ahamad et al., 2018).

The presence of background level of some inorganic substances such as iron, manganese, calcium, and zinc in groundwater sources as may be influenced by the geological formation is not uncommon. However, this level may become enriched due to anthropogenic activities that occur as a result of the deposition of solid and liquid wastes on soil. These wastes may potentially contain toxic substances such as heavy metals (Cd, Pb, As, Hg, and Cr), pathogenic entities (*Escherichia coli*), and pesticides. Agricultural, construction, and local industrial activities are prevalent in the study area, hence potential contamination of the groundwater is highly probable. The presence of these toxic substances in groundwater sources that did not undergo a rigorous water treatment process before consumption gives serious cause for concern. These toxic substances may find their way into the aquifer through percolation and leaching processes (Li et al., 2021).

Some studies have reported the contamination of groundwater as a result of the prevalence of pesticides (Herrero-Hernández et al., 2013), inorganic and organic substances (Singh et al., 2014), and microbial entities (Ifeanyi and Nwandkor, 2015). The preliminary physical observation of water samples from boreholes in conjunction with agricultural activities in the study area necessitates further examination of water from the boreholes in terms of their suitability for domestic use, in particular for drinking purposes. Hence, the aim of the study was an assessment of the quality and possible human health risks of borehole water at the Ovitoto community in the Otjozondjupa region, Namibia.

MATERIALS AND METHODS

Study area

Otjozondjupa region is located in the central part of Namibia. It has a total population of about 143,000 residents, with its capital at Otjiwarongo (NSA, 2013). The region is notable for cattle farming, livestock, and crop farming and is largely semi-arid with rainfall ranging from 300 to 600 mm, increasing from the southwest to the northeast. The climate condition of the area varies from arid to semi-

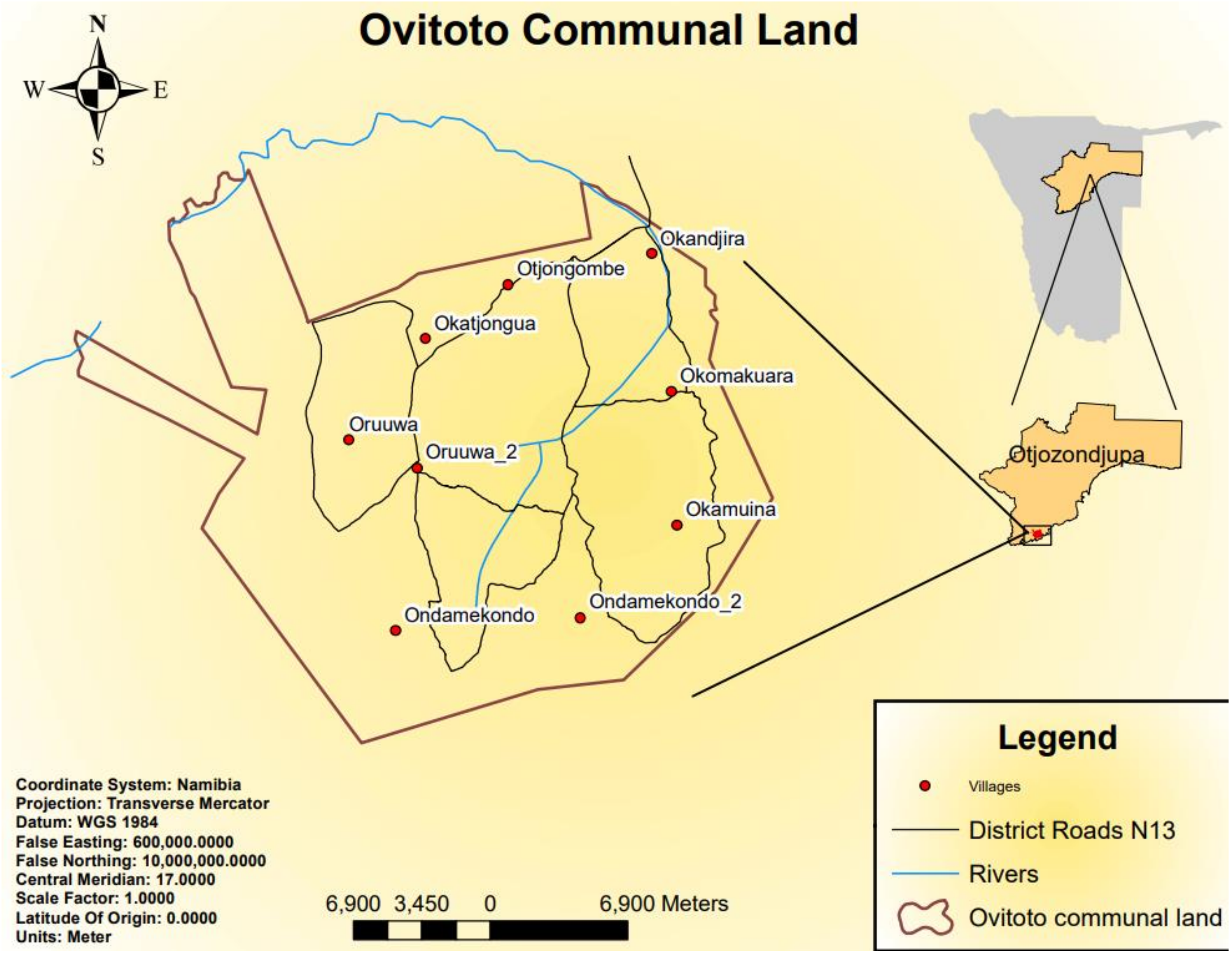

Figure 1. Map of Namibia and Otjozondjupa region (in set) and Ovitoto communal area showing sample collection points.

arid with an average day-day temperature of 33°C. Hence, the area is prone to annual droughts, making it peripheral for rain-fed crop production. The latitude and longitude of the area stand at -20.54869160, and the longitude is 17.66888700 (Latlong.Info, 2023).

Surface water resources are scarce and most of the communities depend on groundwater resources. Ovitoto municipal area within this region consists of nine communities namely Okasongua, Okomakuara, Okandjira, Ondamekondo, Okamuina, Ondamekondo 2, Oruuwa 01, Oruuwa 02, and Otjongombe. The average distance between each of the communities is about 6 km. The communities rely only on water supply from the boreholes which they use for all domestic activities including drinking. It is important to note that the water is utilized without any pretreatment. The map of the study area and sample collection points is presented in Figure 1.

Sample collection, preparation, and storage

Groundwater samples were collected from nine selected boreholes as outlined by Alley (2000). Briefly, 1-L Nalgene plastic bottles were washed and stored in 10% nitric acid for 2 days and rinsed with double distilled water before usage for water sampling. The purpose of this cleaning regime was to ensure that the sampling containers were free from extraneous contaminants that may compromise the outcome of the analysis. Water samples were collected from the boreholes by first allowing the water to run for about 30 s, rinsing the bottle twice with a small portion of the water, and then filled to nearly full to allow for space. Sampling was carried out at almost the same time intervals across the sampling sites between the months of March and August 2022. Two water samples were collected per site on a monthly basis for six periods. Hence, a total of 108 water samples were collected across the sampling stations (Figure 2). All samples were appropriately labeled, kept cool at 4°C in a cooler box, and transported to the laboratory for further analysis. Samples were stored in the refrigerator at 4°C and analyzed within a 6 h period. Sampling bottles were marked on-site, where point names, locations, dates, times, and types of analysis to be conducted were recorded.

Analytical methods

Physico-chemical parameters of water samples were determined on-site using a calibrated portable multi-parameter water quality meter with a serial number (HACH HI9828). These parameters are important in the assessment of drinking water quality as they provide a vital indication of suitability concerning human health and acceptability in terms of aesthetics and palatability.

Standard microbiological analytical methods were applied in the determination of the bacterial load of the water samples. The bacteriological assay involves analysis of Total coliform (*Tc*),

Figure 2. Pictures of some borehole water sampling sites.

Heterotrophic plate (HTC), and *E. coli*. Coliform bacteria have generally been utilized as standard microbiological indicators of the quality of drinking water due to the simplicity of the determination process (Osmani et al., 2019). They are rod-like in shape, Gram-negative bacteria that ferment lactose, producing acid and gas at 35 to 37°C within 24 to 48 h. They have been recognized as appropriate organisms and have long been recognized as a suitable microbial indicator of drinking water quality, largely because they are easy to detect and enumerate in water (Halkman, 2014).

Since the coliform count is inadequate for differentiation between fecal and non-fecal contamination; hence, fecal coliform (*E. coli*) analysis was carried out. *E. coli* is a member of the family Enterobacteriaceae and is characterized by the possession of the enzymes β-galactosidase and β-glucuronidase and grows at 44 to 45°C. They ferment the lactose in appropriate media (using Tryptone Bile Agar (TBX) in this study) with the production of acid and gas (Shaikhan et al., 2019). The WHO regulation, however, specifies zero limits for these indicators.

The heavy metal content in water samples was extracted using mineral acid digestion. Briefly, 100 ml of filtered (Whatman 0.45 µm filter paper) water samples were digested slowly on a hotplate using a mixture of 5 ml of concentrated nitric acid (HNO_3) and 5 ml of concentrated sulphuric acid (H_2SO_4) until the volume was reduced to about 20 ml. This was allowed to cool to room temperature, transferred to a 100 ml standard flask, and made up to mark with double distilled water. The metallic content of the digested water sample was analyzed using Inductively Couple-Plasma Optical Emission Spectroscopy (PerkinElmer, Optima 3000 ICP-OES System) following a previously described method (Cobbina et al., 2015). Quality assurance of the extraction process was through blank digest using the standard metal addition technique.

Quantitative health risk assessment

Possible health risks that may be associated with the consumption of water samples were determined through the assessment of the following parameters.

Estimated daily intake (EDI)

EDI = Metal conc. in water (mg/L) × Average daily water intake (average per capita of water uptake in kg/person/daily in Namibia is 1-L) / Average body weight (av. Body weight of a Namibian is 59.58) (Walpole et al., 2012).

The health risk assessment was determined using the USEPA Risk Assessment Methodology (Iqbal and Shah, 2013). This was calculated with Equation 1:

$$\text{Exp} = C_{\text{water}} \times IR \times EF \times ED/BW \times AT \qquad (1)$$

Exp: Exposure dose via ingestion of water (mg/kg/day); average concentration of assessed metals in water (µg/L); IR = ingestion rate which is 2.2 L/day for adults and 1.8 L/day for children; Exposure Frequency (EF) = 365 days/year; Exposure Duration (ED) = 70 years for adults; and 6 years for children; Average body weight (BW) = 70 kg for adults; 15 kg for children; Averaging time (AT) = 365 days/year $\times$ 70 years for an adult; 365 days/year × 6 years for a child. For the characterization of risks, the Hazard Quotient (HQ) of the analyzed heavy metals must be determined with reference to non-carcinogenic exposure through ingestion in relation to the reference dose (R*f*D).

Non-carcinogenic health risks assessment

Human health risk assessment in relation to non-carcinogenic effect due to possible consumption of water that is contaminated by heavy metal was deduced as the quotient of daily intake (mg/kg/day) of the metal with reference to ingestion toxicity reference dose (R*f*D) for the development of hazard quotient (HQ) as specified (USEPA, 2004) (Equation 2):

$$\text{HQ} = Exp/RfD \qquad (2)$$

HQ is the hazard quotient through oral ingestion and R*f*D is the metallic reference dose (*µ*g/kg/day).

Total hazard quotient (HQ)

To measure the overall non-carcinogenic effects caused by more than one metal, the quantity of the calculated $\mathrm{HQ}s$ by all metals through oral ingestion was articulated as hazard index (HI) as computed in Equation 3 (Iqbal and Shah, 2013):

$$\text{Hazard index equation (HI)} = \sum \text{HQ} \qquad (3)$$

where HI is the hazard index through the ingestion pathway. Health Index, HI > 1 showed that exposure to the borehole water may pose possible impacts on human health (Igbal and Shah, 2013).

Chronic daily intake (CDI)

Chronic daily intake *(CDI)* of heavy metals via ingestion was deduced using Equation 4 (Shen et al., 2014):

$$CDI = C_{water} \times DI/BW \quad (4)$$

where DI = average daily intake of water (1.8 L/day for children; 2.2 L/day for adults); BW = body weight (15 kg for children and 70 kg for children), and Cwater = concentration of trace metal in water in (mg/kg).

Carcinogenic health risk index (CRI)

CRI assesses the probability of the development of carcinogenic effects, that is, the development of cancer as a result of ingestion of water samples. Equation 5 was used in expressing the carcinogenic risk (USEPA, 2004):

Carcinogenic Health Risk Index = Estimated Daily Intake/Carcinogenic Slope Factor (5)

For the carcinogenic slope factor of metals in mg/kg/day, R*f*D is the oral reference dose mg/L/day. A limit of 1.0×10^{-6} to 1.0×10^{-4} was anticipated as the permissible range (that is, 1 in 10,000) for carcinogenic harm over a 70-year generation (Igbal and Shah, 2013). The CRI was determined for possible indication of lifetime risk of exposure. A carcinogenicity risk value of 1.0×10^{-6} is the upper limit of acceptability with respect to the development of cancer. Values above this range indicate a higher propensity for developing cancer (USEPA, 2016).

Microbial analysis

For the possible presence of microbial entities in water samples, the number of colonies in each plate was counted. Hence, the HTP, *Tc*, and *Fc* were determined. Hence, the Colony-Forming Units (cfu/ml) were deduced as:

Number of colonies × Dilution factor) / (Volume plated)

Statistical application

Data were subjected to descriptive and inferential statistics. The correlation coefficient was applied to establish a possible relationship or association between parameters. In addition, the Shapiro-Wilk test for normality was applied for the assessment of the normal distribution of data.

RESULTS AND DISCUSSION

Physico-chemical parameters

The physicochemical parameters that were assessed for the quality of water in sampled boreholes are presented in Table 1, while the results of the analysis of these parameters across the sampling periods (SP1-SP6) are shown in Table 2. The overall pH values of water samples ranged from 7.4 to 8.4 with an overall mean of 7.7±0.4. This range can be said to be within the acceptable recommended range of 6.5 to 8.5. A similar mean pH value of 7.22 and 7.21 during the dry and wet seasons, respectively was reported in a related study of groundwater quality (Fadili et al., 2022a). The pH of drinking water has been regarded as one of the most important water quality parameters given its role in water chemistry. Human health may not be compromised by elevated pH. However, the palatability of the water for drinking purposes may be affected (Muhammad et al., 2011). The measured temperature in °C of water samples also ranged between 19.0 and 24.0 with an overall mean of 21.5±2.0. This range is within the acceptable room temperature of 25°C depending on the preference of the consumer. A comparable mean temperature of 24.5°C has been reported in a related study (Gulilat et al., 2022).

Although cooler water is generally more acceptable and palatable than warmer ones, the borehole water across the communities can be deemed suitable for human consumption in this regard. However, high temperature is known to influence the rate of chemical and biological reactions since warmer temperatures promote microbial growth and may influence the taste, color, corrosion, and odor of water (Uribe-Lorío et al., 2019). Turbidity indicates the cloudiness of water due to suspended matter and precipitates. According to WHO, turbidity above 4 NTU reveals a whitish precipitate and reduces water acceptability for drinking purposes. Turbid water is of health concern due to the possible attachment of chemical and microbial contaminants. The turbidity level of analyzed water samples was in the range of 71.3 to 208.4 with an overall mean of 145.4±56.3. This range is well above the prescribed 4 NTU (WHO, 2022) and thus renders the water unsuitable for drinking purposes. This confirms the blockage of piped-water systems of the community by the powdery whitish substance. From this, the water from the boreholes undoubtedly is recommended for pretreatment before consumption. A higher groundwater turbidity range of 233.1 and 168.9 during dry and wet seasons was reported in a similar study (Gulilat et al., 2022).

The level of Electrical Conductivity (EC) obtained in the study varied from 122.1 to 137.2 µS/cm with an overall mean of 127.1±5.8 µS/cm. Electrical conductivity provides an indication of the degree of water conductivity and an indication of the concentration of inorganic components in the water. Although these values, including the overall mean, are within the permissible level of 300 µS/cm (WHO, 2022), the level of dissolved solids in water utilized for drinking purpose gives cause for concern. The range of EC obtained in this study was much lower than the range of 592 to 5032 µS/cm reported in a similar study (Fadili et al., 2022a). This high value might have been influenced by possible contribution from leachate from landfills within the study area. The level of TDS in the borehole water samples across the sampling periods ranged from 805.7 to 875.9 mg/L with an overall mean level of 832.8±24.4 mg/L. The range and overall mean concentration are higher than the prescribed level of 600 mg/L considered being ideal for drinking purposes. TDS above this level is

Table 1. Selected Physico-chemical parameters analyzed in the borehole water samples.

Parameter	Unit/Scale	Analytical technique
pH	0 - 14	Portable field meter
Temperature	°C	Portable field meter
Turbidity	NTU	Portable field meter
EC	µS/cm	Portable field meter
Total Dissolved Solids	mg/L	Portable field meter
Heavy Metals (Zn, Cd, Cu, Pb,Fe and Mn)	mg/L	ICP-OES
Microbial Analysis	cfu	PCR

PCR = Polymerase chain reaction; EC = electrical conductivity.

Table 2. Mean and overall mean levels of selected physicochemical parameters in borehole water samples.

SP	Parameters				TDS (mg/L)
	pH	Temp (°C)	Turbidity (NTU)	EC (µS/cm)	
SP1	7.5	20.3	175.0	130.7	875.9
SP2	7.4	20.0	208.4	122.7	821.9
SP3	7.6	19.0	174.0	124.5	834.6
SP4	7.8	23.1	164.0	125.3	840.1
SP5	8.4	24.0	79.4	137.2	805.7
SP6	7.5	22.7	71.3	122.1	818.7
X_0±SD	7.7±0.4	21.5±2.0	145.4±56.3	127.1±5.8	832.8±24.4
MAL	6.5-8.5	25°C	4.0	300	1000

SP = Sampling periods; X_0 = overall mean; MAL = maximum acceptable limit.

generally unpalatable with a salty taste (WHO, 2022). Although, this may not cause any adverse health effects in the short-term, however, the possibility of salt overload in sensitive individuals in the long term may occur (Hohls et al., 2002). Some elevated level 386 to 3.221 mg/L with a mean value of 1.185 mg/L during the wet season and 424 to 3.232 mg/L with a mean value of 1.199 during the dry season of TDS in drinking water has been reported (Fadili et al., 2022a).

Concentration of heavy metals in borehole water samples

The results of the analyzed heavy metals in water samples are presented in Table 3. The normality of data obtained in this study was evaluated through the application of the Shapiro–Wilk test. The obtained *P* value of 0.294 is > 0.05, indicating normally distributed data. The levels of Zn, Cd, Cu, Pb, Fe and Mn ranged from 0.1 to 1.8 (0.72±0.6 mg/L), 0.01, 0.01, 0.02, 0.02 to 9.2 mg/L (4.8±5.1 mg/L) and 0.1 to 19 mg/L (4.4±7.2 mg/L), respectively across the sampling periods (SP1-SP6). It is interesting to note that the level of analyzed metals, particularly Zn, Fe, and Mn were higher during SP1 and SP2 while the metallic concentrations across SP3-SP6 were fairly constant with marginal differences. This might be due to the mobilization of suspended or dissolved solids in the water aquifer as a result of higher water usage. Heavy metals have been reported to adhere to particulate matters which are later mobilized under favorable conditions of pH and other chemical factors (Han et al., 2020).

Zinc was detected in all analyzed water samples, however, the level obtained as well as the overall mean levels were lower than the permissible limit recommended for drinking (WHO, 2022) and irrigation purposes. The lower level of Zn was also obtained in a similar study (Fadili et al., 2022a). Zinc is among the metals that have been categorized as "essential" as a result of some roles played as a food supplement, particularly in sporting activities (Yang et al., 2003). However, elevated level of this metal has been reported to be toxic (Plum et al., 2010). The concentration of Cd obtained in water samples across the sampling periods was 0.01 mg/L. Cadmium is usually considered in many water contamination, toxicological, and public health studies given its toxicity and non-essentiality in human physiology even in small amounts. Cadmium has been associated with carcinogenic and endocrine-disrupting activities in humans (Pollack et al., 2011; Ali et al., 2012). The level of Cd obtained in this study was higher than the WHO drinking water permissible level and may also be unsuitable for irrigational use (Ayers and Westcot, 1985). Detection of Cd at this level gives cause for concern given its toxicity, potential for

Table 3. Mean and overall mean level of trace metals (mg/L) in water samples and EDI across sampling periods.

SP	Parameter				Fe	Mn
	Zn	Cd	Cu	Pb		
SP1	1.8	0.01	0.01	0.02	9.2	19.0
SP2	1.0	0.01	0.01	0.02	11.4	2.3
SP3	0.1	0.01	0.01	0.02	0.02	0.1
SP4	0.6	0.01	0.01	0.02	7.0	1.9
SP5	0.4	0.01	0.01	0.02	0.6	1.5
SP6	0.4	0.01	0.01	0.02	0.3	1.4
X_0±SD	0.72±0.6	0.01	0.01	0.02	4.8±5.1	4.4±7.2
EDI (adults)	2.6×10^{-2}	3.1×10^{-4}	3.1×10^{-4}	6.2×10^{-4}	5.6×10^{-1}	2.2×10^{-1}
EDI (children)	1.0×10^{-1}	1.2×10^{-3}	1.2×10^{-3}	2.4×10^{-3}	2.13×10^{0}	8.5×10^{-1}
WHO Limit(D)	5.0	0.003	2.0	0.01	0.3	0.08
FAO Limit(I)	2.0	0.01	0.2	5.0	5.0	0.2

SP = Sampling periods; X_0 = overall mean; EDI = estimated daily intake; SD= standard deviation; WHO_D = drinking water; FAO_I = Irrigation.
Source: Ayers and Westcot (1985).

bioaccumulation, and long-term health implications.

Concentrations of 0.01 and 0.02 mg/L were obtained respectively for Cu and Pb in analyzed water samples across the sampling periods. Copper (Cu) is among the metals that have been categorized as essential as a result of the role it plays in human physiology. However, toxicity at higher levels in humans has been reported (Osredkar and Sustar, 2011) including its implication in the genetic disorder of hepatic copper metabolism, also called the Wilson Disease (Aggarwal and Bhatt, 2018). The concentrations obtained in the study were generally lower than the WHO permissible limit of 2.0 mg/L in drinking water, however, long-term ingestion and bioaccumulation may result in health problems. The levels of Cu and Pb obtained in the study were also lower than the permissible limit of water used for irrigational purposes (Ayers and Westcot, 1985).

Lead (Pb) is a toxic, non-essential metal that has been implicated in several human health problems including disruption of cognitive capacity in children (Cruz et al., 2021). The level of Pb obtained in this study were higher than the permissible level for drinking purposes but generally lower for irrigation purpose. Detection of above permissible level of this metal in borehole water gives cause for concern given its noxious nature and health effects on humans. On the contrary, however, the concentration of Cu and Pb in groundwater reported in a related study was found to be higher than the permissible level (Dogra et al., 2023).

The level of iron (Fe) and manganese (Mn) in the analyzed samples varied from 0.02 to 11.4 mg/L (4.8±5.1 mg/L) and 0.1 to 19.0 mg/L (4.4±7.2 mg/L), respectively. The mean and overall mean levels of Fe obtained across the sampling periods, except for SP3 (0.02 mg/L) were generally higher than the permissible level for human consumption while some mean values recorded at SP1, SP2, and SP4 were found to be above the limit for irrigational purpose (Ayers and Westcot, 1985). The incidence of higher levels of Fe in drinking water has also been reported in a similar study (Gulilat et al., 2022; Dogra et al., 2023). High level of Fe in water is aesthetically undesirable and impacts the color and taste of the water. Possible sources could be a result of release from groundwater bedrock and suspension at the favorable condition of lower pH. It might also be due to possible leaching from waste disposed metals and storm runoff. It is not uncommon to find litters of metallic and other waste within the community. All the mean and overall mean levels of Mn obtained in analyzed water samples were found to be higher than the prescribed permissible level for drinking purposes and also higher for irrigational use except for the value recorded at SP3. Risk analysis of groundwater consumption reported elevated level of Mn in a similar study that was conducted in Pakistan (Shahzad et al., 2022). Consumption of water laden with high levels of Mn can lead to an increased risk of neurological disorders. Notwithstanding the essentiality classification of Mn in humans, excess amount has been linked to brain, liver, and kidney damage in developing fetuses (Markiv et al., 2023).

Microbial entities

The results of microbial entities in analyzed borehole water samples are presented in Table 4. Analysis of pathogenic organisms in drinking water is usually carried out due to the rapidity at which ill-health, aggravation therefrom and possible fatality may occur, hence, its public health importance. HPC and Tc were detected in water samples across the sampling periods except at SP6. Although HPC is not directly linked to human ill-health, high levels may

Table 4. Mean level of microbial entities analyzed in water samples across the sampling periods.

SP	Microbial entities		
	HPC	*Tc*	*Fc*
SP1	1083	3.8	ND
SP2	3	319	ND
SP3	652.4	14.4	0.7
SP4	1045	5	ND
SP5	986.8	75.5	5.6
SP6	ND	ND	ND
WHO limits	NG	0	0

NA = No guideline; ND= not detected.

however affect the aesthetic quality of water, an indication of the presence of nutrients and biofilms (Bartman et al., 2013). Detection of HPC values of 1083, 1045, and 986.8 at SP1, SP4, and SP5, respectively gives cause for concern. Other studies have reported high level (>500 cfu/ml) of HPC in desalinated household water (Yari et al., 2018) and groundwater (De Giglio et al., 2016).

Tc was detected at all sampling points with the exception of SP6. Although, detection does not necessarily indicate the onset of illness; however, it reveals the presence of harmful pathogens in the water system. Zero total coliform colonies/100 ml of water has been recommended.

Fc however, was detected during SP3 and SP5. According to WHO, no water intended or designated for human consumption should contain no pathogenic entity per 100 ml. However, it is important to note that *Fc* was detected only at a single sampling site. Notwithstanding, the presence of *Fc* in the borehole water sample is quite worrisome given its effects on human health, particularly in children. A similar study of the microbiological investigation of groundwater quality in Spain reported 18.12% fecal contamination out of 154 sampled wells (Suárez-Varela et al., 2014).

Consumption of drinking water that is contaminated with *Fc* may lead to incidences of diarrhea, nausea, vomiting, cramps, and other gastrointestinal distress which could be fatal in severe cases (Wang et al., 2022). A possible source of *Fc* in the water could be from animal fecal matter since large cattle farming is a traditional and one of the major agricultural activities among community members. Generally, the detection of coliform bacteria indicated contamination by fecal matter of human or animal origin (Haramoto et al., 2018).

Health risks of consumption of water from the boreholes

Results of potential health risks from the consumption of analyzed water samples are presented in Table 6. Zinc occurs naturally in the earth's crust; however, its background level has been tremendously increased due to anthropogenic activities. The level of metals in groundwater could generally be exacerbated by the geological formation of the prevailing area. Metallic association in water samples revealed a strong association between Zn and Cd (*r* = 0.99). The THQ and CRI of Zn for adults are 8.6× 10^{-4} and 0.3; while THQ and CRI of Zn for children are 3.3× 10^{-3} and 0.49, respectively; hence, there is no harm of carcinogenic and non-carcinogenic effect on human health from drinking water from Ovitoto boreholes as these values are < 1 (Table 5).

Cadmium (Cd) is a poisonous metal with no beneficial physiological properties and has been designated as a possible carcinogen. A possible source of Cd in water samples may be associated with the use of fertilizer and improper use of wastes in the community. There was no correlation between Cd and Mn (*r*= -0.83) while there was a weak correlation between Cd and Cu (r= 0.55). The THQ and CRI of Cd obtained for adults were 6.3× 10^{-4} and 6.3× 10^{-3}, while THQ and CRI of Cd obtained for children were 2.4× 10^{-3} and 0.24, respectively. From this, there is no danger of carcinogenic and non-carcinogenic effects on human health from drinking borehole water, as these values were < 1.

Copper is one of the metals classified as an essential element, however, at high levels, it has been linked to the genomic syndrome known as Wilson disease at high concentration. The association between the metals in water samples showed no association between copper and other metals. The THQ and CRI of Cu for adults are 7.4×10^{-6} and (Nil; Not Available), while THQ and CRI for children were 3.0× 10^{-5} and (Nil); therefore, there is no non-carcinogenic harm, since these values < 1.

Pb is viewed as non-essential, contaminated metals with harmful health concerns in humans. Lead has been associated with undesirable impacts on the cardiovascular system, the Central Nervous System (CNS), as well as on the immune system. The level of Lead (Pb) was above the WHO-recommended limit at all the sampling points across the sampling periods. The level of lead might be caused by aged pipes, faucets, and plumbing. Pb quantities in

Table 5. Health risk assessment of analyzed heavy metals in water samples.

SP	Parameter				Fe	Mn
	Zn	Cd	Cu	Pb		
THQ (adults)	8.6×10^{-4}	6.3×10^{-4}	7.9×10^{-6}	4.5×10^{-4}	8.0×10^{-4}	9.3×10^{-3}
THQ (Children)	3.3×10^{-3}	2.4×10^{-3}	3.0×10^{-5}	1.7×10^{-3}	5.0×10^{-3}	3.5×10^{-2}
CRI (Adults)	0.13	6.3×10^{-2}	-	7.3×10^{-5}	-	4.74
CRI (Children)	0.49	0.24	-	2.8×10^{-4}	-	18.10

THQ = Targeted hazard quotient; CRI = carcinogenic risk index.

Table 6. Results of the correlation co-efficient of heavy metals in the water samples.

Metal	Zn	Cd	Cu	Pb	Fe	Mn
Zn	1					
Cd	0.9998	1				
Cu	0.5077	0.5580	1			
Pb	0.5279	-0.4713	-0.4351	1		
Fe	0.9999	-0.4763	0.5417	-0.4532	1	
Mn	0.9920	-0.8350	-0.5432	0.5642	-0.4325	1

borehole water are similar to quantities observed for Cu whilst there was no association with other analyzed heavy metals. The THQ and CRI of Pb for adults were 4.5×10^{-4} and 7.3×10^{-5}, while THQ and CRI of Pb for children were 1.7×10^{-3} and 2.8×10^{-4}; hence, there is no risk of carcinogenic and non-carcinogenic effect on human health from the drinking of Ovitoto borehole water, as these values are < 1.

A high concentration of Fe in water could make the water aesthetically undesirable due to coloration impact on the medium. There was no correlation between Fe and other analyzed metals in water samples. The THQ and CRI of Fe for adults are 8.0×10^{-4} and (Nil); while THQ and CRI for Cd for children is 5.0×10^{-3} and (Nil); therefore, there is no risk of non-carcinogenic, as this value < 1. Excess Mn in water can lead to an increased risk of susceptibility to neurological disorders. Consuming excess manganese over prolonged exposure has also been associated with Parkinson-like syndrome referred to as manganism. There was no correlation of Mn with other analyzed metals. The THQ and CRI of Mn for adults were 9.3×10^{-3} and 4.7, while THQ and CRI of Mn for children were 3.5×10^{-2} and 18.1; hence, there is no harm of non-carcinogenic effect on human health from drinking Ovitoto borehole water in both adults and children. A similar study of groundwater quality investigation in Ethiopia revealed higher HQ values of 1.1108 and 1.5537 for adults and children, respectively, hence unacceptable non-carcinogenic risk (Gulilat et al., 2022).

However, there is a risk of a carcinogenic effect on human health from the consumption of borehole water in both adults and children, since these values are > 1. A similar cause for concern was expressed by Gyimah et al. (2023) where Cd (CRI: 6.1×10^{-4}) contributed most to the total carcinogenic risk with adults being more vulnerable to the cancer risk than children.

Conclusion

Results of the quality and health risk assessment of borehole water samples from the Ovitoto municipal community revealed what can be regarded as an isolated yet significant cause of concern regarding the contamination of water samples. Most of the analyzed physical parameters were within the permissible level except for TDS which could have been influenced by the geological characteristics of the area. However, a significant human health threat from TDS is not expected. The detection of some metals (Cd, Pb, Fe, and Mn) above the WHO permissible limits for drinking and irrigational purposes is quite worrisome given possible bioaccumulation and long-term health implications. The detection of coliform bacteria in some of the water samples gives cause for concern since drinking water is expected to be of zero count. Of further concern are the carcinogenic health risks index (CRI) outlook for Mn in both adults and children. Summarily, pretreatment of water from susceptible boreholes before utilization for drinking purposes is highly recommended.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors are grateful for the assistance provided by the Namibia Water Corporation towards the analysis of water samples.

REFERENCES

Ahamad A, Kumar A, Kushawaha J, Singh P, Mishra PK (2018). Geochemical assessment of groundwater quality for its suitability for drinking and irrigation purpose in rural areas of Sant Ravidas Nagar (Bhadohi), Uttar Pradesh. Geology, Ecology and Landscape 2(2):127-136.

Ali I, Damdimopoulou P, Stenius U, Adamsson A, Akesson A, Berglund M, Håkansson H, Halldin K (2012). Cadmium-Induced Effects on Cellular Signaling Pathways in the Liver of Transgenic Estrogen Reporter Mice. Toxicological Sciences 127(1):66-75.

Alley ER (2000). Water Quality Control Handbook, 2nd Edition. The McGraw-Hill Companies, Incorporated, New York.

Aggarwal A, Bhatt M (2018). Advances in Treatment of Wilson Disease. Tremor and Other Hyperkinetic Movements 8:252.

Ayers RS, Westcot DW (1985). Water quality for agriculture. Rome, Italy: Food and Agriculture Organization (FAO) of the United Nations.

Bartman J, Cotruvo J, Exner M, Fricker C, Glasmacher A (2013). Heterotrophic Plate Counts and Drinking-water Safety: The Significance of HPCs for Water Quality and Human Health. IWA Publishing, London 12:1.

Bexfield LM, Belitz K, Lindsey BD, Toccalino PL, Nowell LH (2021). Pesticides and Pesticide Degradates in Groundwater Used for Public Supply across the United States: Occurrence and Human-Health Context. Environmental Science and Technology 55(1):362-372.

Cobbina SJ, Duwiejuah AB, Quansah R, Obiri S, Bakobie N (2015). Comparative Assessment of Heavy Metals in Drinking Water Sources in Two Small-Scale Mining Communities in Northern Ghana. International Journal of Environmental Research and Public Health 12(9):10620-10634.

Cruz VP, Ortega RD, Esquivel DFG, Ayala TB, Pineda B, Manzo SG, Quino JM, Mora PC (2021). Cognitive Impairment Induced by Lead Exposure during Lifespan: Mechanisms of Lead Neurotoxicity. Toxics 9(23):1-30.

Daly S, Lowe J, Hornsby G, Harris A (2021). Multiple water source use in low- and middle-income countries: a systematic review. Journal of Water and Health 19(3):370-392.

De Giglio O, Barbuti G, Trerotoli P, Brigida S, Calabrese A, Di Vittorio G, Lovero G, Caggiano G, Uricchio VF, Montagna MT (2016). Microbiological and hydrogeological assessment of groundwater in southern Italy. Environ Monit Assess 188(11):638.

Dhakal N, Salinas-Rodriguez SG, Hamdani J, Abushaban A, Sawalha H, Schippers JC, Kennedy MD (2022). Is Desalination a Solution to Freshwater Scarcity in Developing Countries? Membranes 12:381.

Dogra S, Sharma K, Singh N (2023). Water quality and health risk assessment of heavy metals in groundwater of Ranbir Singh Pura tehsil of Jammu and Kashmir, India. Environmental Monitoring and Assessment 195(9):1026.

Fadili HE, Ali MB, Mahi ME, Cooray AT, Lotfi EM (2022a). A comprehensive health risk assessment and groundwater quality for irrigation and drinking purposes around municipal solid waste sanitary landfill: A case study in Morocco. Environmental Nanotechnology, Monitoring and Management 18:100698.

Fadili HE, Ali MB, Touach N, Mahi ME, Lotfi EM (2022b). Ecotoxicological and pre-remedial risk assessment of heavy metals in municipal solid wastes dumpsite impacted soil in Morocco. Environmental Nanotechnology, Monitoring and Management P 17.

Foteinis S, Masindi V (2021). Groundwater contamination in sub-Saharan Africa: Implications for groundwater protection in developing countries. Cleaner Engineering and Technology 2:100038.

Gulilat H, Gintamo B, Khan MA, Shukla RK, Mekonnen Z (2022). Determination of the Physicochemical Quality of Groundwater and its Potential Health Risk for Drinking in Oromia, Ethiopia. Environmental Health Insights P 16.

Gyimah E, Myers RA, Gbemadu, K, Osei B, Akoto O (2023). Appraising groundwater quality and the associated health risks of heavy metal contamination at Suame magazine. Scientific African, p. 21.

Halkman HBD (2014). Indicator Organisms, In: Encyclopaedia of Food Microbiology, 2nd edition (Eds: Batt CA, Tortorello ML, Academic Press, New York, USA pp.358-363.

Han G, Yang K, Zeng J (2020). Assessment and sources of heavy metals in suspended particulate matter in a tropical catchment, northeast Thailand. Journal of Cleaner Production 265:121898.

Haramoto E, Malla B, Shrestha RG, Tandukar S, Bhandari D, Inoue D, Sei K, Tanaka Y, Sherchand JB (2018). Identification of Human and Animal Faecal Contamination in Drinking Water Sources in the Kathmandu Valley, Nepal, Using Host Associated *Bacteroidales* Quantitative PCR Assays. Water 10(12):1796.

Herrero-Hernández E, Andrades MS, Álvarez-Martín A, Pose-Juan E, Rodríguez-Cruz MS, Sánchez-Martín MJ (2013). Occurrence of pesticides and some of their degradation products in waters in a Spanish wine region. Journal of Hydrology 486:234-245.

Hohls BC (2002). National Water Resource Quality Status Report: Inorganic Chemical Water Quality of Surface Water Resources in SA. The Big Picture. Report No. N/0000/REQ0801. ISBN No. 0-621-32935-5. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa. At http://www.iamb.it/incosusw/Leone.pdf

Ifeanyi OE, Nwandkor UU (2015). Bacteriological Assessment of Different Borehole Drinking Water Sources in Umuahia Metropolis. International Journal of Current Microbiology and Applied Sciences 4(5):1139-1150.

Iqbal J, Shah MH (2013) Health risk assessment of metals in surface water from freshwater source lakes Pakistan. Human and Ecological Risk Assessment: An International Journal 19(6):1530-1543.

Khaneghah AM, Saleh HN, Valipoor S, Zarei A, Yousefi M, Asghari FB, Mohammed AA, Amiri F (2020). Assessment of groundwater quality around municipal solid waste landfill by using Water Quality Index for groundwater resources and multivariate statistical technique: a case study of the landfill site, Qaem Shahr City, Iran. Environmental Geochemistry and Health 42:1305-1319.

Latlong.Info (2023). Latitude and longitude of Otjozondjupa Region of Namibia (NA). Available at: https://latlong.Info/namibia/otjozondjupa-region

Li P, Karunanidhi D, Subramani T, Srinivasamoorthy K (2021). Sources and Consequences of Groundwater Contamination. Archives of Environmental Contamination and Toxicology 80:1-10.

Markiv B, Expósito A, Ruiz-Azcona L, Santibáñez M, Fernández-Olmo I (2023). Environmental exposure to manganese and health risk assessment from personal sampling near an industrial source of airborne manganese. Environmental Research 224:115478.

Muhammad S, Shah MT, Khan S (2011). Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. Microchemical Journal 98(2):334-343.

Mulyadi A, Dede M, Widiawaty MA (2020). Spatial interaction of groundwater and surface topography using geographically weighted regression in built-up area. Earth and Environmental Science pp. 477.

Nagaraju A, Thejaswi A, Sreedhar Y (2016). Assessment of Groundwater Quality of Udayagiri area, Nellore District, Andhra Pradesh, South India Using Multivariate Statistical Techniques. Earth Sciences Research Journal 20(4):E1-E7.

NSA (2013). Namibia Statistics Agency. Namibia Labour Force Survey 2013 Report. Windhoek, Namibia.

Osmani M, Mali S, Hoxha B, Bekteshi L, Karamelo P, Gega N (2019). “Drinking water quality determination through the water pollution indicators, Elbasan district,” Thalassia Salentina 41:3-10.

Osredkar J, Sustar N (2011). Copper and Zinc, Biological Role and Significance of Copper/Zinc Imbalance. Journal of Clinical Toxicology S3:1-18.

Plum LM, Rink L, Haase H (2010). The Essential Toxin: Impact of Zinc on Human Health. International Journal of Environmental Research and Public Health 7(4):1342-1365.

Pollack AZ, Schisterman EF, Goldman LR, Mumford SL, Albert PS, Jones RL, Wactawski-Wende J (2011). Cadmium, Lead, and Mercury in

Relation to Reproductive Hormones and Anovulation in Premenopausal Women. Environmental Health Perspectives 119(8):1156-1161.

Shahzad B, Mughal A, Sultan K, Ashraf K, Hassan A, Qu Z, Haider FU (2022). Risk Analysis of Heavy Metals and Groundwater Quality Indices in Residential Areas: A Case Study in the Rajanpur District, Pakistan. Water 14(21):3551.

Shaikhan BA, Güven K, Bekler FM, Acer O, Güven RG, Güven K (2019). A highly inducible β-galactosidase from enterobacter sp. Journal of the Serbian Chemical Society 85(5):609-622.

Shen C, Naveedullah MZH, Yu C, Shen H, Duan D, Lou L, Chen Y (2014). Concentrations and Human Health Risk Assessment of Selected Heavy Metals in Surface Water of the Siling Reservoir Watershed in Zhejiang Province, China. Polish Journal of Environmental Studies 23(3).

Singh R (2014). Microorganism as a tool of bioremediation technology for cleaning environment: a review. Proceedings of the Int. Academy of Ecology and Environmental Science 4(1):1.

Suárez-Varela MM, Llopis-González A, Sánchez AL, Requena PM (2014). Assessment of the microbiological quality of groundwater in three regions of the Valencian Community (Spain). International Journal of Environmental Research and Public Health 11(5):5527-5540.

UNEP (2010). Water quality outlook. UNEP GEMS/Water Programme, Burlington, Ontario, L7R 4A6 Canada https://archive.worldwaterday.org/2010/downloads/water_quality_outlook.pdf

UNGA (2015-16). United Nations General Assembly. The human rights to safe drinking water and sanitation. Resolution adopted by the General Assembly 49:6. NY.

Uribe-Lorío L, Brenes-Guillén L, Hernández-Ascencio W, Mora-Amador R, González G, Ramírez-Umaña CJ, Díez B, Pedrós-Alió C (2019). The influence of temperature and pH on bacterial community composition of microbial mats in hot springs from Costa Rica. Microbiology Open 8(10):1-26.

USEPA (19892004). Risk Assessment Guidance for Superfund, Vol. 1, Human Health Evaluation Manual. Part E (supplemental guidance for dermal risk assessment), EPA/540/R/99/005. Office of Superfund Remediation and Technology Innovation, Washington, DC, USA. https://www.epa.gov/sites/default/files/2015-09/documents/part_e_final_revision_10-03-07.pdf

USEPA (2016). Risk-Based Concentration Table. United States Environmental Protection Agency. Available at: https://archive.epa.gov/region9/superfund/web/html/index-23.html

Walpole SC, Prieto-Merino D, Edwards P, Cleland J, Stevens G, Roberts I (2012). The weight of nations: an estimation of adult human biomass. BMC Public Health 12:439.

Wang T, Guangzhi X, Wei Y, Zhang Y, Chen J (2022). Fecal coliform distribution and health risk assessment in surface water in an urban-intensive catchment. Journal of Hydrology 604:127204.

World Health Organization (WHO) (2019). 1 in 3 people do not have access to safe drinking water- UNICEF, WHO, Geneva.

WHO (2022). Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda. Geneva: World Health Organization. License: CC BY-NC-SA 3.0 IGO.

Yang XE, Long XX, Ni WZ, Ye ZQ, He LZ, Calvert DV, Stoffella JP (2003). Assessing Zinc Thresholds for Phytotoxicity and Potential Dietary Toxicity in Selected Vegetable Crops. Communications in Soil Science and Plant Analysis 34(9-10):1421-1434.

Yari AR, Mohammadi MJ, Geravandi S, Doosti Z, Matboo SA, Jang SA, Nazari S (2018). Assessment of microbial quality of household water output from desalination systems by the heterotrophic plate count method. Journal of Water and Health 16(6):930-937.

Ye C, Xie ZJ, Li C, Shi X, Shao Y, Qi W (2022). The global progress on the non-point source pollution research from 2012 to 2021: a bibliometric analysis. Environmental Sciences Europe 34:121.