EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2023, 24(8), 9–21
https://doi.org/10.12912/27197050/170168
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Received: 2023.07.12
Accepted: 2023.09.25
Published: 2023.10.13

Water Quality of Traditional Rainwater Storage Tanks in Southern Morocco – Risk for Consumer Health

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ABSTRACT

Around the world, the problems of water quality remain a major environmental concern. This study aimed to determine the health risk related to water consumption collected and stored in traditional tanks. In total, 26 water samples from Traditional Rainwater Storage Tanks (TRST) and 11 sediment samples were collected from 13 sites belonging to four different provinces in the Souss Massa region, Morocco. The water samples were subjected to bacteriological and physicochemical analysis. X-ray diffraction and scanning electron microscope analyses were performed to describe the different mineralogical and chemical properties of sediments. The results show that the bacteriological quality is not satisfactory to the required standards in 92% of the samples analyzed. This non-conformity is justified by the presence of microorganism's indicators of fecal contamination: Total Coliforms (54%), Intestinal Enterococci (62%), Escherichia coli (31%), and Spores of anaerobic sulfite-reducing microorganisms (46%). The physicochemical analyses carried out on the water sampled show that concentrations below the standards recommended by the World Health Organization (WHO) and the Moroccan standard of the different parameters studied. The Water Quality Index (WQI) calculated for all TRST ranges from 10 to 15, indicating excellent water quality. The analysis of the distribution of minerals in the various sediment samples taken shows the presence of several minerals in varying quantities without risk to human health. Clay minerals with tectosilicate are the most detected in the reservoirs. This study showed that the consumption of water stored in the TRST would be without risk to the health of the rural population if preventive maintenance and control measures were taken to improve their bacteriological quality.

Keywords: Traditional rainwater storage tanks; water quality; sanitary risk; bacteriology; physico-chemistry.

INTRODUCTION

Worldwide, the concern for the environment, and more specifically the issue of the potability of drinking water, is growing because of the health and economic consequences related to it [Gougueni et al., 2023]. According to WHO, about 30% of the world's population lacks the access to safe drinking water mainly in rural areas. Additionally, the satisfaction of water needs in semi-arid areas has steadily declined in recent years [Ait Haddou et al., 2023].

In rural areas, rural populations face several challenges including scarcity of water resources, population growth, and degradation of existing water structures [Adamou et al., 2020; Panagopoulos, 2021]. The use of water storage in tanks near or inside homes can have a significant impact on drinking water quality [Slavik et al., 2020].

The physico-chemical and bacteriological quality of the drinking water supplied to the population has been the subject of numerous studies, highlighting the health risks and impact on human health of poor-quality drinking water [Edberg et al., 1997; Chippaux et al., 2002; Wolf et al., 2018; Wright et al., 2018]. The drinking water that does not meet the required quality standard leads to the persistence and recurrence of waterborne diseases [Kapembo et al., 2022].

Rainwater cannot be used directly for drinking purposes [Tran et al., 2021]. The major problem with using untreated rainwater for drinking is the potential public health risk associated with microbial pathogens [Warish et al., 2011; Bain et al., 2014]. The presence of indicator germs of fecal contamination, as well as the presence of other germs responsible for waterborne infections, poses a threat to the health of the population [Odiyo et al., 2018].

Indeed, 58% of deaths from diarrhea are due to unsafe water and poor sanitation [Soboksa et al., 2020]. In contrast, improving water quality at source through chlorine treatment results in a 25–58% reduction in diarrhoeal risk for households in intervention areas [Kapembo et al., 2022; Soboksa et al., 2020]. Attention to the maintenance and disinfection of drinking water sources and regular biological assessment of these sources is imperative [Hassan et al., 2016].

Natural water resources in Morocco are among the lowest in the world; their potential has reached a critical threshold indicating the occurrence of shortages and latent water crises [Kostyuchenk et al., 2022]. Rainwater is receiving considerable attention to ensure a supply of drinking water [Kaushik et al., 2012; Gado & El-Agha, 2020]. In rural areas of the Souss-Massa region in southwestern Morocco, the local population, to meet their daily water needs during periods of drought, often resorts to collecting and storing rainwater as well as runoff in specially designed basins or cisterns called "Matfia".

In general, the capacity of Matfias or traditional rainwater storage tanks (TRST) varies from 1 m^3 to 20 m^3 for individual-use tanks to 20 or even 200 m^3 for collective-use tanks. Collective TRSTs are built outside the house, and individual TRSTs are usually built inside the house.

Rainwater is rarely subject to barriers that ensure its safety for human consumption [Plummer et al., 2010]. In a rainwater harvesting system, the factors influencing water quality occur during water collection, conveyance, and storage [Vialle, 2011]. Along the way, water becomes loaded with various residues and pollutants. Similarly, storage can impact the quality of rainwater. Some studies indicate a decrease in the bacteriological population through self-purification during storage [Evans et al., 2009; Martin et al., 2010].

Thousands of families in rural Morocco rely primarily on rainwater tanks for their consumption needs. To date, no studies have been conducted to assess the water quality of TRST in rural Morocco. Thus, the conducted study proposes to determine ultimately, whether the consumption of water stored in TRST (or "Matfia" in Arabic) could constitute a danger to human health.

MATERIALS AND METHODS

The study area is the Souss-Massa region, located in central Morocco, stretching from the Atlantic Ocean in the west to the border with Algeria in the east. Its administrative capital (chief town) is the city of Agadir [Bouchriti et al., 2022; 2023], (Figure 1). Located in the pre-Saharan zone in southern Morocco, the Souss Massa region is characterized by a diversified relief extending over several areas: The mountain ranges of the High and Anti-Atlas and fertile plains, the main ones being those of Souss and Chtouka. The region has several rivers, the most important of which are the Oued Souss which rises in the High Atlas, and the Oued Massa which arises in the Anti-Atlas. Several tributaries feed these wadis. The climate is semi-arid to arid, and aridity intensity increases as one moves from west to east. As far as rainfall is concerned, there is a wet period from October to April, which represents 90% of the annual rainfall, and a dry period from May to September. In the distribution of vegetation, the ocean front plays a very important role. The argan tree reserve is also the most important in this southern region in terms of plant diversity [Ait Haddou et al., 2022a & 2022b, Ezaidi et al., 2022].

The twenty-six TRST water samples were taken in 13 villages belonging to 4 different provinces: Taroudant, Chtouka Ait Baha, Tiznit, and Agadir Ida-Outanane (Figure 1). Taking into account the distance of the sampling sites from the laboratory, several trips (6 outings) on different dates were necessary to take the samples.

The water samples were collected and sent in an isothermal box with cold accumulators the same day to the laboratory for bacteriological and

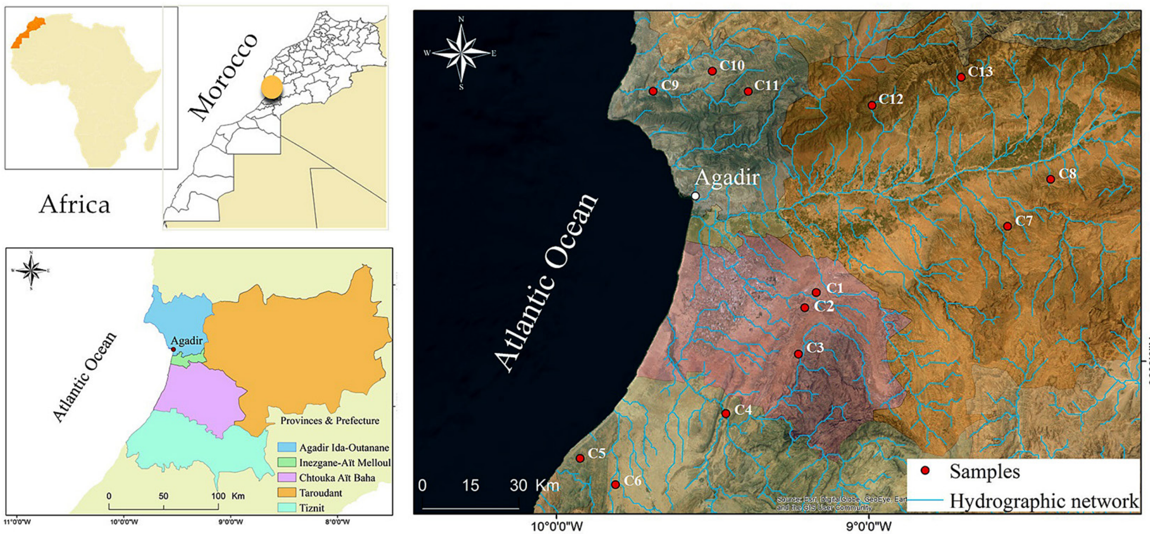


Figure 1. Study area and localization of sampling points

physicochemical analyses. The microbiological analysis included the search for total coliforms, intestinal enterococci, Escherichia coli, microorganisms revivable at 22°C and 36°C, and spores of sulfite-reducing anaerobic microorganisms at 37°C (clostridia). In turn, the physicochemical analysis was interested in the following parameters: pH, total phosphate; electrical conductivity, suspended solids, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total nitrogen, nitrates, nitrites, ammonium (NH_4), chlorides and sulfates.

The sediment samples were analysed at Ibn Zohr University using X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM). Determination of microbiological parameters as well as the measurement of physicochemical parameters was carried out using international standards that specify the method to be used for each parameter (Table 1).

The Water Quality Index (WQI) was used to analyze water quality. It is a simple mathematical method used as part of the overall water quality analysis using a group of parameters reducing large amounts of information to a single number [Talhaoui et al., 2020]. The index is calculated using the following equations:

The relative weight (*Wi*) of each physicochemical parameter and the proportionality constant k is calculated first using the maximum values of the Moroccan standard drinking water norm (Moroccan Water Quality Norm, 2002) of the physicochemical parameters studied according to the following equation 1:

$$Wi = \frac{Ki}{Si} \tag{1}$$

where: *Wi* – the weight of each parameter according to its relative importance in the quality of drinking water,
k – a constant of proportionality and can also be calculated according to the following Equation 2:

$$Ki = \frac{1}{\sum_{i=1}^{n}(1/Si)} \tag{2}$$

where: *n* – number of parameters,
Si – maximum value of the Moroccan standard for each parameter in mg/l except for pH, T°C and electrical conductivity.

Then, the authors proceeded to the calculation of a quality assessment scale (*Qi*) for each parameter by dividing the concentration by the standard of the said parameter and multiplying the whole by 100 as in the following equation 3:

$$Qi = \left(\frac{ci}{si}\right) \times 100 \tag{3}$$

where: *Qi* – a quality rating scale for each parameter,
Ci – the concentration of each parameter in mg/l.

Table 1. Methods and standards used for microbiological and physicochemical parameters

Parameters	Methods and standards used	Maximum allowable values
Microbiological parameters		
Total coliforms	Internal method-NF ISO 9308–1-September 2000	0 (CFU/100ml)
Intestinal Enterococci	NF ISO 7899–2	0 (CFU/100ml)
Escherichia coli β-glucuronidase positive at 44°C	Internal method-NF ISO 9308–1-September 2000	0 (CFU/100ml)
Micro-organisms revivable at 22°C	NF ISO 6222	100 (CFU/100ml)
Revivable microorganisms 36°C	NF ISO 6222	20 (CFU/100ml)
Spores of sulfite-reducing anaerobic microorganisms	NF ISO 26461–2	0 (CFU/100ml)
Physico-chemical parameters		
pH	NF ISO 10523–2012	6.5–8.5
Phosphate (PO_4)	NM ISO 11885–2014	-
Electrical conductivity EC	NM ISO 7888–2001	2.7 ms/cm
Suspended matter measures	NM EN 872:2013	50–100 mg/l
Biochemical oxygen demand (BOD_5)	NM ISO 5815–1 AND 2–2012	3–7 mg O_2/l
Chemical Oxygen Demand (COD)	MA.315-DCO 1.1–2016	-
Total nitrogen	Continuous flow	2 mg/l
Nitrates		50 mg/l
Nitrites		0.5 mg/l
Ammonium		0.5 mg/l
Chlorides		750 mg/l
Sulfates	NM ISO 11885–2014	200 mg/l

Finally, the overall water quality index is calculated by the following equation 4:

$$IQE = \frac{\sum_{i=1}^{n} Qi \times Wi}{\sum_{i=1}^{n} Wi} \quad (4)$$

RESULTS

The auscultation of the TRST has enabled to identify the physical characteristics that were indicated in Table 2.

According to the results presented in Table 2, the water temperatures at the time of sampling in the different tanks ranged from 22°C to 34°C. The air temperatures are between 20°C as a minimum value and 41°C as a maximum value. The pH values of the water taken from the different tanks are between 7.4 as a minimum value and 7.8 as a maximum value translating their neutrality. The majority of the tanks surveyed are rectangular with fill rates that do not exceed 40%.

Bacteriological quality of water samples

The bacteriological analyses were carried out in an accredited laboratory of the international group VERITAS. The results obtained, indicated in Table 3, show that almost all the TRSTs have water of a microbiological quality that does not comply with the WHO guidelines and the Moroccan standard.

The distribution of microbes in the water of the surveyed tanks shows quantitative fluctuations independently of their geographical location and the use made of their water. Particularities can be observed, notably at site 3 where the microbiological quality is suitable for consumption, and at site 13 where the condition is a unique parameter.

Physicochemical quality of water samples

In addition, the characterization of water was also completed by a physicochemical analysis (Table 4).

The values of the physicochemical parameters of the water are within the limits described by the WHO and the Moroccan standard for the quality of drinking water. The pH varied from

Table 2. Geometric and shape characteristics of TRST and measurement of water and ambient temperature

Points	L[1] (m)	L[2] (m)	H[3] (m)	D[4] (m)	V[5] (m^3)	FR[6] (%)	Form	WT[7] (°C)	AT[8] (°C)	pH
C1	11.3	4.4	3.9	1.5	72	37	Rectangular	29	36	7.6
C2	14.2	7.3	3.8	1.2	124	29	Rectangular	30	38	7.4
C3	14.3	9.3	3.2	0.8	132	31	Rectangular	34	41	7.6
C4	4.2	3.2	3.6	0.8	8	21	Oval	28	24	7.8
C5	4.4	3.4	3.8	0.4	4	09	Oval	27	29	7.6
C6	7.2	3.2	2.6	0.5	11	19	Rectangular	28	37	7.6
C7	8.1	3.2	2.4	0.9	23	37	Rectangular	22	38	7.7
C8	6.3	2.4	2.0	0.6	9	29	Rectangular	24	40	7.4
C9	17.2	7.2	3.6	0.8	442	22	Rectangular	20	23	7.4
C10	15.0	10.0	3.8	2.2	330	58	Rectangular	26	26	7.4
C11	11.5	4.2	2.8	1.3	62	46	Rectangular	23	20	7.4
C12	10.5	2.9	2.8	0.5	15	18	Rectangular	18	24	7.6
C13	3.9	2.3	2.5	1.9	17	76	Rectangular	18	22	7.6

Note: 1 – length, 2 – width, 3 – height, 4 – depth, 5 – volume, 6 – fill rate, 7 – water temperature, 8 – ambient temperature.

Table 3. Results of microbiological analyses in colony forming units (CFU)/100 ml

Samples	TC[1]	IE[2]	EC[3]	MOR22[4]	MOR36[5]	SASR[6]	Compliance
C1	ND*	ND	ND	300	280	ND	No
C2	ND	ND	ND	160	120	ND	No
C3	ND	ND	ND	8	< 3	ND	Yes
C4	3500	210	ND	2100	2000	ND	No
C5	350	ND	ND	550	450	ND	No
C6	2100	140	3	190	1700	ND	No
C7	460	250	12	> 3000	> 3000	20	No
C8	310	120	120	3800	2600	16	No
C9	ND	400	ND	> 3000	> 3000	31	No
C10	ND	8	ND	110	78	7	No
C11	ND	20	ND	> 3000	1700	20	No
C12	750	90	200	> 3000	> 3000	20	No
C13	90	ND	ND	< 1	< 1	ND	No

Note: 1 – total coliforms, 2 – intestinal enterococci, 3 – Escherichia coli β-glucuronidase positive at 44°C, 4 – microorganisms revivable at 22°C, 5 – microorganisms revivable at 36°C, 6 – sulfite-reducing anaerobic microorganism’s spores, * – not detected.

7.33 to 8.26. No water sample showed a value outside the range [6.5; 8.5].

The conductivity allows determining in a non-specific way that the ionic strength of a solution varies between 0.17 ms/cm as a minimum value and 0.50 ms/cm as a maximum value.

For the parameters, PO_4, TSS, BOD_5, COD, NTK, NO_3, NO_2, NH_4, Cl, and SO_4, all the sampled waters conform to the standards. The concentrations of these parameters are lower than the maximum admissible values.

Water quality index

After calculating the global of WQI using the results of physico-chemical analysis and the standard values of the Moroccan standard of quality of water for human consumption, the quality class of water for the samples taken was determined (Table 5). The results show that the WQI for all the RTSEPs ranges from 10.97 to 15.48. These values indicate excellent water quality for all intra- and extra-domestic uses, with reference to the WQI classes defined by Brown et al. [1972].

Table 4. Results of the physicochemical analyses

Samples	pH	EC (ms/cm)	SM (mg/l)	BOD5 (mg O_2/l)	COD (mg O_2/l)	NTK (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	NH_4 (mg/l)	Cl (mg/l)	PO_4 (mg/l)	SO_4 (mg/l)
C1	7.33	0.30	<4	<5	<5	2.80	<1.5	<0.04	<0.02	11.71	<0.02	<10
C2	7.73	0.31	<4	<5	<5	4.20	<1.5	<0.04	<0.02	10.11	<0.02	<10
C3	7.96	0.20	<4	<5	<5	2.80	<1.5	<0.04	<0.02	11.27	<0.02	<10
C4	8.26	0.26	6	<5	<5	4.07	5.62	<0.04	<0.02	9.57	<0.02	<10
C5	8.19	0.35	<4	<5	<5	6.25	2.86	<0.04	<0.02	16.25	<0.02	11
C6	8.23	0.39	10	<5	<5	2.80	<1.5	<0.04	<0.02	14.62	<0.02	13
C7	7.87	0.34	<4	<5	<5	4.20	<1.5	<0.04	<0.02	<3.2	<0.02	23.2
C8	7.37	0.40	35	5	18.6	5.60	<1.5	<0.04	<0.02	<3.2	<0.02	23.1
C9	8.08	0.41	<4	<5	<5	7	<1.5	<0.04	<0.02	17.96	<0.02	97.8
C10	7.86	0.27	<4	<5	<5	5.6	<1.5	<0.04	<0.02	8.76	<0.02	<10
C11	7.78	0.50	<4	<5	<5	4.2	<1.5	<0.04	<0.02	10.56	<0.02	137
C12	7.86	0.19	41	10	14	8.84	8.17	<0.04	<0.02	6.76	<0.06	<10
C13	8.03	0.17	67	<5	<5	4.20	3.15	<0.04	<0.02	4.08	<0.06	-

Table 5. Weight of physico-chemical parameters according to the Moroccan standard of quality of water for human consumption

Parameters	Moroccan standards	Si (maximum standard value, Morocco)	1/*Si*	*Wi*
pH	6.5–8.5	8.5	0.118	0.0219
T (°C)	20–30	30	0.033	0.0062
Cond (µs/cm)	750–2700	2700	0	0.0000
NH4+ (mg/l)	0.1–0.5	0.5	2	0.3721
NO2 (mg/l)	0.5	0.5	2	0.3721
NO3- (mg/l)	50	50	0.02	0.0037
SO_4^{2-} (mg/l)	100–250	250	0.004	0.0007
PO_4^{3-} (mg/l)	0.2–1	1	1	0.1861
DBO_5 (mg/l)	3–5	5	0.2	0.0372
		Σ(1/*Si*)	5.375	
		k=1/ Σ (1/*Si*)	0.186	

Sediments analysis by X-ray diffractio

The analysis of the sediments forming the solid load of the tanks by X-ray diffraction has raised the presence of different minerals which have been classified into the following main groups: Aluminosilicates, Phyllosilicates, Tecto-silicates, and Inosilicates. The qualitative determination of the existing minerals is represented in Table 6.

Analysis of sediments by scanning electron microscope

The mineralogical study of the solid load of TRST was then refined by SEM analysis whose results show a diversification of the mineralogical constitution of the samples. The spectra obtained are illustrated in Figures 2:

DISCUSSION

According to the results of the study, the quality of water collected and stored by the rural population in traditional tanks (TRST) is unsatisfactory. It is characterized by the presence of pathogens indicating fecal pollution. Several anthropogenic activities are thought to be responsible for this pollution [Amuah et al., 2022; Bekoe et al., 2021]. The rainwater flowing into storage tanks carries pathogens and other undesirable substances present in livestock.

excrement [Palamuleni & Akoth, 2015]. The same observation is reported by Vialle [Wright et al., 2004] who confirms that runoff is accompanied by a degradation of the physicochemical and microbiological quality of the water and fecal contamination increases due to the presence

Table 6. Results of XRD analysis of sediments collected at the TRST

Mineral	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
Chlorite	3.96	6.12	4.61	5.45	3.38	10.47	9.9	4.12	2.41	4.89
Illite	12.8	8.9	11.3	16.97	14.6	8.1	6.96	4.35	8.59	13.7
Kaolinite	7.42	11.13	8.17	8.9	5.86	8.12	5.08	4.78	5.61	4.15
Palygorskite	2.88	1.99	6.9	4.39	1.94	3.94	2.66	1.99	1.08	3.07
Smectite	8.6	13.4	8.7	15.7	27.2	10.7	13.79	11.6	7.1	5.76
Vermiculite	1.37	0.69	0.76	0.05	0.77	0.05	0.99	0.67	0.04	0.51
Albite	5.92	2.04	5.03	3.51	3.93	1.9	3.04	0.53	1.32	1.58
Anorthite	5.72	3.54	6.91	6.48	3.99	7	8.95	3.96	3.1	3.12
Biotite	1.92	1.62	4.01	2.64	3.08	2.39	2.07	1.55	1.33	2.1
Calcite	9.5	2.14	13.76	11.38	2.74	4.21	7.94	40.92	20.59	35.82
Dolomite	3.45	10.23	0.94	0.76	1.13	4.83	9.22	1.87	9.85	0.62
Enstatite	4.12	2.84	3.19	0	0	3.69	1.65	4.06	5.86	3.18
Muscovite	7.3	16.4	11.9	10.04	9.9	14.9	10.16	9.39	9.69	11.7
Quartz	24.98	18.92	13.75	13.76	21.44	19.78	17.59	10.17	23.43	9.81
Total %	99.94	99.96	99.93	100	99.96	100	100	99.96	100	100

of animal excrement. The presence of livestock in the vicinity of the storage container showed a significative correlation with the concentration of fecal bacteria in the stored drinking water [Daniel et al., 2020].

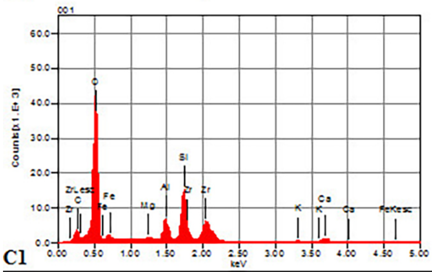
The microbiological processes that occur in storage containers are complex, given the interaction of biota in the collected water with biofilms in the containers and/or recontamination by the means of drawing water from the tank (bucket, rope...) [Wright et al., 2004].

Furthermore, the filling rate recorded in the different tanks studied is 30% as an average (min 9%; max 58%). This result is explained by the fact that the study is conducted at the end of the dry season in this region. If it is admitted that microbiological pollution is significantly higher in the rainy season compared to the dry season as reported by Kapembo et al. [2022], the waters analyzed would be more loaded with bacteria.

On the other hand, the study noted a deficit in the monitoring and disinfection of water stored in these tanks. Residual chlorine concentrations in all samples studied were zero. This results in an increased risk of infection if the residual chlorine concentration is not sufficient. According to WHO [2017], the chlorine disinfection of drinking water supplies is widely regarded as one of the most important public health interventions, reducing the incidence of waterborne disease worldwide. Disinfection of water results in the inactivation or elimination of microorganisms and the maintenance of a chlorine residual to avoid bacterial recontamination. For human consumption water, the objective is a chlorine residual (free chlorine) that must be maintained between 0.3 and 0.5 mg/L during storage [WHO, 2017]. Therefore, all water supplies must be checked regularly to ensure that satisfactory water quality is maintained. This helps to prevent water-related diseases [Ferreira et al., 2021] which are one of the common problems in developing countries, mainly in rural communities that consume rainwater without proper microbiological quality [Gougueni et al., 2021]. The water that is contaminated with total mesophilic aerobic flora and germs due to hygiene failures is a major risk of gastroenteritis for consumers [Sokegbe et al., 2018]. Contaminated water sources should not be used for consumption until the situation is cleaned up and the cause of the fecal contamination is eliminated [Edberg et al., 1997].

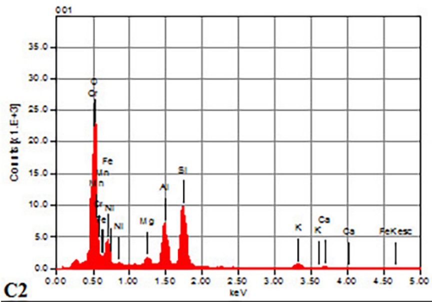
The values of the physicochemical parameters of the water are within the limits described by the WHO and the Moroccan standard for the quality of drinking water. The pH ranged from 7.33 to 8.26. No water sample showed values below 6.5 or above 8.5, i.e. the lower and upper limits allowed for drinking water by the guide values, respectively. Nitrates NO_3 and nitrites NO_2 are the result of the degradation of organic matter and degrade the quality of drinking water. Abnormal concentrations of NO_3 and NO_2 can be explained by the excessive use of nitrogenous fertilizers and by the drainage of wastewater and human or animal excrement [Adamou et al., 2020]. In the

(a) Spectra — EDS Pure — EDS Oxide



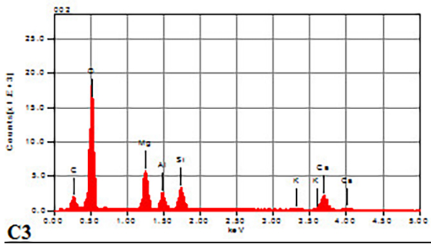
C1

Formula	mass%	Atom%	Formula	mass%	mol%
C	4.00	7.88			
O	42.34	62.52	C	4.68	23.81
Mg	0.60	0.58	MgO	1.09	1.65
Al	5.58	4.88	Al2O3	11.63	6.97
Si	14.68	12.34	SiO2	34.75	35.37
K	1.43	0.87	K2O	1.93	1.25
Ca	3.32	1.96	CaO	5.18	5.64
Fe	10.45	4.42	FeO	14.32	12.19
Zr	17.61	4.56	ZrO2	26.42	13.11
Total	100.00	100.00	Total	100.00	100.00



C2

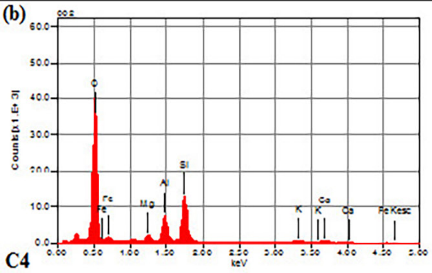
Formula	mass%	Atom%	Formula	mass%	Atom%
O	23.13	43.86	O	23.13	43.86
Mg	1.58	1.98	Mg	1.58	1.98
Al	8.35	9.38	Al	8.35	9.38
Si	13.36	14.44	Si	13.36	14.44
K	2.22	1.72	K	2.22	1.72
Ca	1.16	0.88	Ca	1.16	0.88
Cr	13.42	7.83	Cr	13.42	7.83
Mn	1.18	0.65	Mn	1.18	0.65
Fe	32.75	17.79	Fe	32.75	17.79
Ni*	2.84	1.47	Ni*	2.84	1.47
Total	100.00	100.00	Total	100.00	100.00



C3

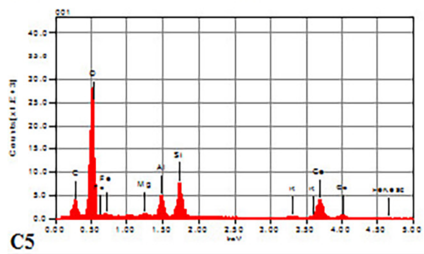
Formula	mass%	Atom%	Formula	mass%	mol%
C	4.15	7.39			
O	42.83	57.27	C	4.82	18.92
Mg	11.33	9.97	MgO	20.86	24.41
Al	5.00	3.96	Al2O3	10.52	4.87
Si	7.93	6.04	SiO2	19.02	14.94
K	1.79	0.98	K2O	2.42	1.21
Ca	26.98	14.40	CaO	42.37	35.65
Total	100.00	100.00	Total	100.00	100.00

(b)



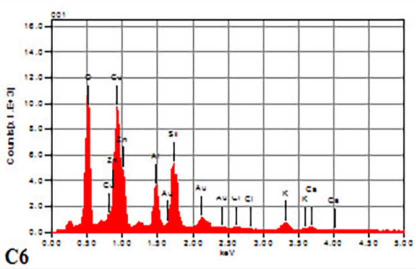
C4

Formula	mass%	Atom%	Formula	mass%	mol%
O	46.27	63.67	O		
Mg	2.16	1.96	MgO	3.79	6.30
Al	10.54	8.60	Al2O3	21.06	13.84
Si	21.28	16.68	SiO2	48.23	53.79
K	3.29	1.85	K2O	4.20	2.99
Ca	4.87	2.68	CaO	7.23	8.64
Fe	11.58	4.57	FeO	15.49	14.44
Total	100.00	100.00	Total	100.00	100.00



C5

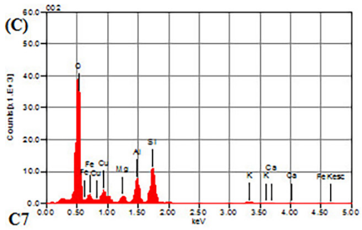
Formula	mass%	Atom%	Formula	mass%	mol%
C	6.08	10.98	C	7.47	29.82
O	43.48	58.94			
Mg	1.22	1.09	MgO	2.34	2.78
Al	5.72	4.60	Al2O3	12.54	5.90
Si	10.48	8.09	SiO2	26.09	20.83
K	1.35	0.75	K2O	1.91	0.97
Ca	21.27	11.51	CaO	34.83	29.79
Fe	10.40	4.04	FeO	14.83	9.90
Total	100.00	100.00	Total	100.00	100.00



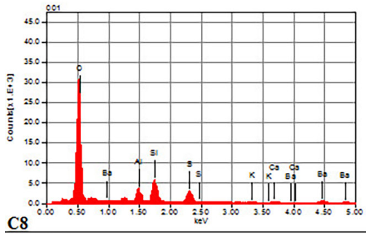
C6

Formula	mass%	Atom%	Formula	mass%	mol%
O	20.13	44.01	Al2O3	11.68	9.41
Al	7.25	9.39	SiO2	22.37	30.56
Si	12.25	15.26	Cl	0.43	1.00
Cl	0.51	0.50	K2O	4.34	3.78
K	4.23	3.78	CaO	1.50	2.20
Ca	1.26	1.10	CuO	35.63	36.78
Cu	31.41	17.29	ZnO*	14.33	14.46
Zn*	12.82	6.86	Au2O3	9.70	1.80
Au	10.15	1.80	Total	100	100
Total	100.00	100.00			

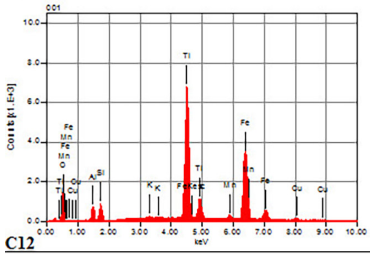
Figure 2. Spectra obtained by SEM analysis of TRST sediments: (a) Chtouka Ait Baha; (b) Tiznit



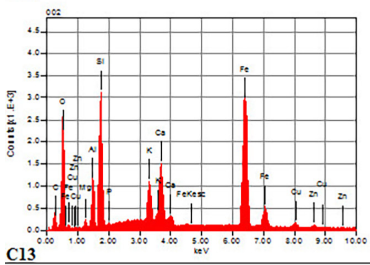
Formula	mass%	Atom%	Formula	mass%	mol%
O	39.06	59.24	MgO*	4.02	6.92
Mg*	2.44	2.44	Al2O3	19.89	13.53
Al	10.60	9.53	SiO2	37.86	43.70
Si	17.81	15.39	K2O	3.07	2.26
K	2.56	1.59	CaO	1.60	1.98
Ca	1.15	0.70	FeO	25.15	24.28
Fe	19.63	8.53	CuO	8.41	7.33
Cu	6.75	2.58	Total	100	100
Total	100.00	100.00			



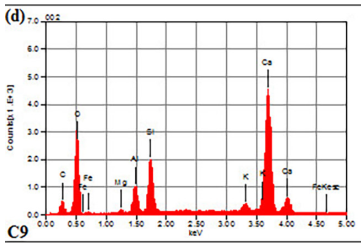
Formula	mass%	Atom%	Formula	mass%	mol%
O	35.05	63.77	Al2O3	10.43	9.29
Al	5.64	6.09	SiO2	21.78	32.94
Si	10.41	10.79	SO3	24.38	27.68
S	9.99	9.07	K2O	1.44	1.39
K	1.22	0.91	CaO	3.73	6.04
Ca	2.72	1.98	BaO	38.25	22.67
Ba	34.98	7.41	Total	100.00	100.00
Total	100.00	100.00			



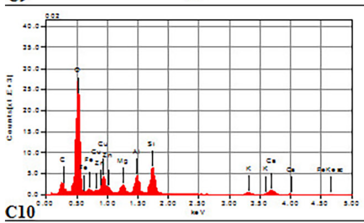
Formula	mass%	Atom%	Formula	mass%	mol%
O	6.21	17.30	Al2O3	1.82	1.35
Al	1.36	2.25	SiO2	2.43	3.07
Si	1.60	2.55	K2O	0.34	0.27
K	0.39	0.44	TiO2	49.63	47.12
Ti	41.06	38.21	MnO	1.84	1.97
Mn	1.99	1.61	FeO	42.22	44.58
Fe	45.50	36.31	Total	100.00	100.00
Cu	1.89	1.33			
Total	100.00	100.00			



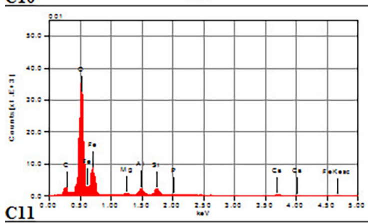
Formula	mass%	Atom%	Formula	mass%	mol%
C	2.07	6.56	C	1.55	8.42
O	8.86	21.05	MgO	0.81	1.31
Mg	0.63	0.98	Al2O3	4.97	3.18
Al	3.38	4.77	SiO2	14.50	15.74
Si	8.71	11.79	P2O5	0.39	0.18
P	0.22	0.27	K2O	4.34	3.01
K	4.60	4.47	CaO	8.57	9.97
Ca	7.78	7.38	FeO	57.38	52.11
Fe	56.20	38.26	CuO	4.25	3.49
Cu	4.29	2.57	ZnO	3.23	2.59
Zn	3.27	1.90	Total	100.00	100.00
Total	100.00	100.00			



Formula	mass%	Atom%	Formula	mass%	mol%
C	1.62	3.85	C	1.38	6.43
O	21.40	38.21	MgO	0.54	0.75
Mg	0.37	0.44	Al2O3	5.00	2.74
Al	3.03	3.21	SiO2	13.41	12.49
Si	7.21	7.34	K2O	3.49	2.08
K	3.35	2.45	CaO	73.80	73.65
Ca	60.96	43.45	FeO	2.38	1.85
Fe	2.06	1.05	Total	100	100
Total	100	100			



Formula	mass%	Atom%	Formula	mass%	mol%
C	4.42	8.79	C	4.69	21.65
O	36.77	54.96	MgO	5.59	7.68
Mg	3.23	3.17	Al2O3	13.83	7.52
Al	7.00	6.21	SiO2	27.02	24.93
Si	12.08	10.29	K2O	2.81	1.65
K	2.23	1.36	CaO	12.41	12.27
Ca	8.49	5.06	FeO*	12.56	9.69
Fe*	9.51	4.07	CuO	16.13	11.24
Cu	12.43	4.68	ZnO*	4.96	3.38
Zn*	3.84	1.41	Total	100	100
Total	100.00	100.00			



Formula	mass%	Atom%	Formula	mass%	mol%
C	3.16	5.86	C	2.31	12.39
O	44.31	61.66	MgO	0.75	1.19
Mg	1.22	1.12	Al2O3	5.92	3.73
Al	9.39	7.75	SiO2	6.41	6.86
Si	14.16	11.22	P2O5	1.03	0.47
K	4.13	2.35	CaO	2.26	2.59
Ca	3.92	2.18	FeO	81.33	72.78
Fe	19.71	7.86	Total	100.00	100.00
Total	100.00	100.00			

Figure 2. Spectra obtained by SEM analysis of TRST sediments: (c) Taroudant; (d) Agadir Ida Outanane

present study, the NO_3 and NO_2 values are below the MAV, since the samples studied are from storage tanks in mountainous regions where there is no wastewater drainage and agricultural activities using nitrogen fertilizers are almost absent.

Regarding chloride, the maximum value found in samples does not exceed 18 mg/l. According to WHO [WHO, 2017], no health-based guide value has been proposed for chloride in drinking water. However, concentrations above about 250 mg/l can give it a detectable taste.

In all samples analyzed, the biochemical oxygen demand remained below 5 mg O2/l, indicating unpolluted surface water. High BOD concentrations reduce oxygen availability. They also reduce biodiversity and impair water use. In addition, high BOD loads in freshwater systems are mainly due to anthropogenic sources, including domestic and livestock wastes, industrial emissions and combined sewer overflows [Vigiak et al., 2019]. The COD/BOD_5 ratio is around 1, indicating that the inflow is highly biodegradable. In addition, the conductivity values show good mineralization in K^+, Ca^{2+}, and Mg^{2+} giving the water its softness. Indeed, as it is most often a crystalline substrate, the waters are not very loaded with CaMg (CO_3) carbonates, and the average mineralization is about 150 µg/l.

The analysis of the sediments forming the solid load of the tanks by X-ray diffraction has raised the presence of different minerals which have been classified into the following main groups: Aluminosilicates, Phyllosilicates, Tectosilicates, and Inosilicates.

The sediments collected in tanks C9, C10, and C11 are characterized by the dominance of carbonates composed of calcite and dolomite with percentages that vary between 30% and 43%. On the other hand, in the other tanks, the percentage of carbonates remains low, ranging from 3% to 17%. This difference is related to the geological substratum formed by Jurassic limestone in the surroundings of these tanks.

The question is whether there is any relationship with the mineral load of the water. Indeed, water being the main liquid that affects the dissolution of rocks plays an important role in the exchange of cations and anions in the substrates that are subject to runoff.

Overall, the water is of low hardness due to the presence of below-average carbonate constituents (calcite and dolomite). In addition, the presence of swelling clay (Smectite), known for its purifying role, was noted. Silica, the least hydrolyzable element, is also little present with values around 20%.

SEM analyses led to the determination of mass and molar percentages of major geochemical elements. The results confirm the dominance of clay minerals. Indeed, in almost all samples the chemical elements contained in clays (Si, Al, Mg, Fe, K, S, O, Ca, C) were found [Qlihaa et al., 2016]. Similarly, the presence of silicon in significant quantities is mainly due to the presence of Quartz.

The analysis of the distribution of clay minerals in the different samples shows the presence of six minerals in variable quantities (Figure 3).

Smectite, illite, kaolinite, and chlorite dominate the clay fraction of the sediments studied. Palygorskite is found with a significant percentage (17%) in the sediments of the C4 tank. The Upper Cretaceous-Eocene is a favorable period for the development of palygorskite in this part of Morocco. It represents on average 10 to 20% of the clay fraction in the clayey-sandstone levels of the substrates. It is associated with illite and smectite which represent (20 to 25%) and (25 to 50%), respectively [Daoudi, 2004].

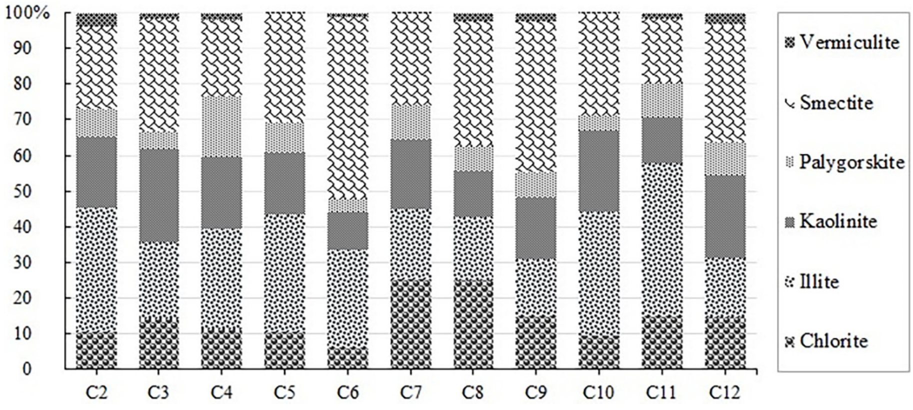


Figure 3. Distribution and percentage of clay minerals in each sample

Moreover, smectite is among the most abundant clay minerals, especially in recent marine and continental sediments. Several origins are possible for the case of these tanks, the reworking of soils developed under hydrolyzing conditions or alteration products seem to be the most plausible mechanism of their presence [Rousset, 2002]. As for the origin of the kaolinite, it can only be a product of inheritance, since the current climatic conditions do not allow their neogenesis.

Finally, it is important to recall the beneficial effect of certain clays on health and the human body, and their capacity to trap water molecules (swelling clays) and to take on a gel-like texture, which can transport ions or active molecules. This property is the basis of the technologies of dressings for the digestive tract (smectite, attapulgite...). Clays have a purifying role by absorption of toxins, viruses, bacteria, antibiotics, organic acids, intestinal gases, and alkaloids which will then be eliminated in the stool.

CONCLUSIONS

This study focused on the quality of water stored in traditional rainwater harvesting and storage tanks in semi-arid areas. This ancestral technique is very popular in the rural regions of southwestern Morocco and provides a water resource to counter the recurrent water shortages of the long dry season. The assessment of the quality of the water stored in these tanks showed a bacteriological non-conformity with the guidelines and quality requirements for drinking water. Microbiological analyses showed contamination by germs indicative of fecal contamination induced by pastoral activities. Hence, the need to undertake appropriate measures to prevent health risks related to this pollution.

Concerning the physicochemical parameters, the analyses performed are below the limits described by the WHO and the Moroccan standard for the quality of drinking water. It is a neutral, odorless water of average mineralization (Mg^{2+}, Ca^{2+}, K^{+}) and easily biodegradable. The water quality index is in the range 0–25 justifying an excellent quality as well as allowing the intra and extra-domestic uses of water without risk to the health of the consumer.

The analysis of the sediments by X-ray diffraction and SEM revealed the presence of silicate and carbonate minerals in the lithology of the soils forming the substrates of the water flows. Swelling clays such as smectites are suspected to have a self-purifying role in these tanks. On the other hand, the detection of heavy metals in their solid load incites to push the study towards the search for toxic metals in solution.

Acknowledgments

The authors would like to thank Pr. Belkacem Kabbachi (Ibn Zohr University) for his help and his precious orientations for the realization of this work and Pr. Ahmed Algouti (Cadi Ayad University) for the help provided in the determination of the mineralogical composition of the sediments. We also thank Mr. Mustapha Agnaou (Ibn Zohr University) for his contribution to the realization of the SEM and RXD analyses.

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