EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2022, 23(3), 138–147
https://doi.org/10.12912/27197050/147450
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Received: 2022.02.28
Accepted: 2022.03.15
Published: 2022.03.25

Groundwater Quality Assessment for Human Drinking in Rural Areas, Al-Hoceima Province (Northern Morocco)

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ABSTRACT

The aim of this study is to assess the quality of water for drinking in the rural area of the city of Al-Hoceima, in order to measure the health risks to which people who use it for their needs are exposed. A cross-sectional, descriptive, and analytical study was carried out on 60 households selected randomly. Well and spring water samples (8 wells and 8 springs) were collected in November and December 2019 and analyzed according to the standard methods of water analysis. The survey indicated that water consumed by 80.00% of households does not receive any prior treatment. With the lack of a collective excreta and wastewater management system in the municipality, 99.00% of households have latrines, 50.00% of which are installed within 15meters of the water source. The bacteriological analyses indicate that all the sampled points are contaminated by fecal contamination germs. This poor quality may be due to various anthropogenic activities, and the presence of non-standardized septic tanks. Therefore, protecting and improving water sources must be accompanied by adequate measures of disinfection of these waters before their use.

Keywords: Al-Hoceima rural area, anthropogenic activities, fecal contamination, health risk, water source.

INTRODUCTION

Access to drinking water is a vital condition for human health, for that reason, the importance of water, sanitation, and hygiene for health and development is highlighted in the conclusions of a series of international forums, such as the World Water Conference in Argentina (UN 2006).

The World Health Organization (WHO) estimates that the population dependent on unimproved water sources is 884 million people, the majority of which is in sub-Saharan Africa, where the rate of access to safe water, sanitation, and hygiene is the lowest in the world. In 2006, according to the United Nations, only 46.00% of the rural population and 81.00% of the urban population had access to drinking water (UN, 2006). The WHO in 2013, considers an improved source is one that, by the nature of its construction, protects water source adequately from contamination, particularly fecal matter (WHO/UNICEF, 2013). The protection of the water source is one of the safety measures but it doesn't account for the actual contamination, in 2011, the WHO defined safe drinking water as "water that doesn't pose a significant health risk (WHO, 2011), and the major risk to public health is fecal contamination (WHO/UNICEF, 2010).

Several reviews have found that 38.00% of papers on water quality about improved water sources in low-income areas reported a quarter or more of the water samples as containing fecal material (Kostyla et al., 2015; Bain et al., 2014; Wolf et al., 2013).

In Morocco, groundwater is an important part of the country's hydraulic heritage (Oubalkace, 2007). Traditionally, groundwater has been the preferred water resource for drinking water in rural areas, as it is considered to be safer from pollutants than surface water. In Al Hoceima province and in our study area, groundwater has been considered as an important source of drinking water for the local population, and surface water is used for watering animals and for irrigation. The challenge facing all regions of Morocco, and particularly rural areas, is the protection of the quality of groundwater resources.

The pollution of groundwater is one of the most worrying aspects and the use of this water for food purposes could represent in some cases a certain danger for human health (Gaudreau et al., 1997). Little data is available today on the sanitary status of water sources in the rural communes of Al-Hoceima province. The majority of the communes use water from wells and springs to satisfy their needs for water. These water wells can be constructed or not, as also water can be treated or not. These conditions increase the risk of contracting waterborne diseases. Based on a report by the Service and Network of Health Facilities (SRES) of Al Hoceima in 2018, the cases of diarrhea recorded in children under 5 years during the period 2016, 2017, and 2018, in the province of Al-Hoceima in rural areas, are 1273, 2076 and 3665 respectively (SRES, 2017).

The purpose of this study is to evaluate the water quality of drinking water (wells and water sources), using the principal component analysis (PCA), in rural areas of Al-Hoceima province (northern Morocco), to measure the health risks to which are exposed the people who use this water for their needs.

MATERIALS AND METHODS

Study area

The Al Hoceima province is located in the central part of the Rif chain. This ensemble of mountains heterogeneous and compartments is the highest (Jbel Tidghine 2456 m) and widest (80 km) part of the Rif. Al Hoceima has an area of 3550 km², a population of around 400,000 inhabitants and, a large rural population representing 65.60% of the population compared to only 34.40% in urban areas, and urbanization rate that is lower than the national average (60.30%) (RGHP, 2014).

The study rural area is located between 34°57’30” & 34°52’30” North Latitude and between 3°57’00” & 3°47’40” West longitude (Fig. 1). It is traversed by the Nekor wadi and the Ghiss wadi.

The study area was chosen because the population uses exclusively water from wells and springs due to the lack of connection to the drinking water supply network (ONEE branch water). Transversal and analytical studies were conducted during the period between November and December 2019 on 60 households previously selected. In each household, the person in charge of the drinking water supply was interviewed. Socio-sanitary conditions were determined using a questionnaire and an observation checklist. The following data were collected: (i) socio-economic characteristics of the households, (ii) source of water supply and usage, (iii) hygiene, sanitation, environment, and health.

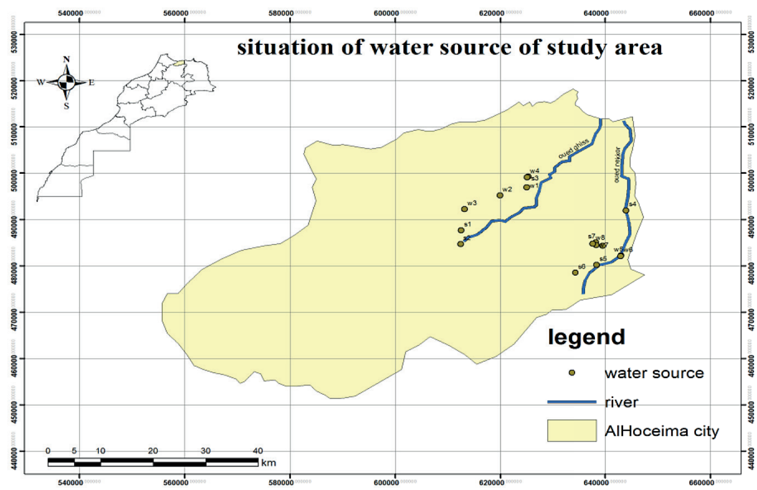

Fig. 1. Map of the location of water samples in study area, Al-Hoceima city

Characterization of water collective points

Sixteen collective water supply points were selected and sampled (8 wells and 8 springs). All these water points are categorized in (Table I). The samples were taken during the wet season, they are spread between periods of the month November and December 2019, the water samples were collected in sterile glass bottles of 500 ml, labeled and placed in a cooler, stored and sent to the laboratory for analysis within 24 hours.

Physico-chemical parameters analysed

Physico-chemical factors are measured in situ with a multi-parameter meter (HANNA HI 9829) and concerned temperature T°C, pH, electrical conductivity EC, total dissolved solid TDS, salinity, dissolved oxygen, percentage of oxygen saturation and other parameters odor, color, flavor by visual and olfactory observations.

Analysis of microbiological contamination

Fecal contamination of drinking water is monitored using the fecal indicator (WHO, 2011). *Escherichia coli* (*E coli*) is commonly recognized by the WHO as the best indicator for monitoring drinking water contamination (WHO/UNICEF, 2010). Guidelines from the WHO on water safety indicate that thermotolerant coliforms shouldn't be present in 100 mL of a sample (WHO, 2006). Thermotolerant coliforms (TTC) in drinking water are an indication of the potential presence of fecal matter and an intestinal pathogen (WHO, 2011).

In this study, we made the necessary analyses for the identification of fecal contamination indicator germs:

- Coliform bacteria (CB) at 37 °C,
- *Escherichia coli* (*E coli*) at 44 °C,
- Intestinal Enterococcus (IE) at 37 °C.

The bacteriological analysis was performed by the membrane filtration method (Rodier et al., 2009). This technique consists of filtering 100 mL of water into a cellulose membrane with a uniform pore size of 0.45 µm; this membrane is placed in a culture medium (lactose agar with TTC and tergitol 7 for Coliform Bacteria as well as *Escherichia coli*, and Slanetz and Bartely agar for Intestinal Enterococcus).

Statistical analysis

The statistical analysis is based on the principal component analysis (PCA). PCA is a statistical method (initially descriptive statistics) that allows classifying samples and examining the correlation between different qualitative and quantitative variables and is widely used in scientific research (Aslouj et al., 2007; Kanohin et al., 2017, Merzoug et al., 2011).

The priority parameters to be considered in any drinking water quality assessment, as

Table I. Characterization of the water supply points in the study area

Samples	Source type	Protection	Presence of pump	Pump type	Source-latrine distance (meter)	Chlorination treatment
w1	well	yes	yes	electric	≤15	Yes
w2	well	yes	yes	electric	≤15	No
w3	well	no	no	-	> 15	No
s1	spring	no	no	-	> 15	No
s2	spring	no	no	-	> 15	No
s3	spring	no	no	-	> 15	No
w4	well	yes	yes	electric	≤15	No
w5	well	yes	yes	electric	≤15	No
w6	well	yes	yes	electric	≤15	No
s4	spring	no	no	-	≤15	No
s5	spring	no	no	-	> 15	No
s6	spring	no	no	-	> 15	No
s7	spring	no	no	-	> 15	No
s8	spring	no	no	-	> 15	No
w7	well	no	no	-	≤15	No
w8	well	no	no	-	≤15	No

defined by the WHO, are those that have the greatest impact on health and are most often detected at significant concentrations in drinking water (WHO, 2006).

The microbiological parameters are included in this categorical classification. Therefore, seven parameters were selected in this study (pH, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), Coliform Bacteria (CB), *Escherichia coli* (*E coli*) and Intestinal Enterococcus (IE).

RESULTS AND DISCUSSIONS

Household socio-economic characteristics

About 20.00% of the interviewees had a primary school level and 69.00% had no schooling. The high rate of analphabetism in the study area may contribute to poor water management and hygiene practices by users (Table 2).

Supply and use of water

As noted above, households collect water exclusively from wells or springs, or even from the surface water of the Nekor River, as the area does not have a drinking water supply system. In addition, the majority of families consume water without treatment. Of the more than 60 households that use water for drinking, approximately 85% use water from wells, and 15.00% use spring water. As for the sanitation systems installed, the majority of households (99.00%) have non-standard septic tank latrines. Additionally, about 50.00% of latrines are located less than 15 meters (the minimum distance, recommended by the WHO, between water source and latrine). To protect a water source, it is necessary to respect this minimum distance source-latrine, it is also suggested to build the septic tanks downstream (and not upstream) of the water supply points.

Several scientific works have been able to identify guidelines for the location of latrines (Cadwell et al., 1937). The latrine to water

Table 2. Health risk variables related to the consumption of groundwater in the study area.

Variable	Modality	Percentage
Educational level	- unschooled - primary - secondary - academic	69% 20% 10% 1%
Socio-economic level	- household - commercial - farmer	50% 20% 30%
Source of water supply	- well - spring - river water and rain water	80% 15% 5%
Drinking water	- well - spring	85% 15%
Well condition, protection devices	- protected well - no cover	40% 60%
Drinking water treatment	- well - spring	20% 00%
Drinking water treatment type	- boiling - filtration - chlorination	6% 8% 86%
Management of excreta, wastewater and household waste	- existence of septic tank type latrines - source-latrine distance ≤ 15 meters	99% 70%
Household waste disposal method	- landscaped dump - wild dumping ground - pre-collection in garbage bins - landfill and incineration	0.5% 70% 14.5% 15%
Location of wastewater discharges	- street - sump - hole - stream	85% 5% 2% 3%
Manual fecal sludge discharge location	- behind house - burial and digging a pit	8% 92%
Presence of pollution sources	- atmospheric pollution - accidental pollution Fall of animals and objects	

source distance should be at least 30.00 meters and the latrine bottom should be at least 1.5 meters above the water table (Damerell, 2011). Other researchers (Banks et al., 2002) suggested a 15 m to 30 m distance, and another (Wright et al., 2013) has recommended a distance over 100.00 m. A study of the assessment of the impact of latrines on groundwater contamination (Ndoziya et al., 2019), showed a strong association between the level of water contamination by coliform bacteria and the density of latrines located adjacent to water sources.

In many cases, access to water points that are far from households can generate practices that expose people to risks by using dirty containers or unclean hands that can contaminate the water, at the time of supply (collection), or during transport through canals or plastic pipes and this is well represented in A Seasonal Cohort Study in Malawi of Household Practices in Accessing Drinking Water and Post-Collection Contamination (Cassivi et al., 2021). In reality, the majority of households do not have any collection system for water, domestic waste, or wastewater.

Bacteriological water quality

The water bacteriological analysis results revealed that all the sampled points are contaminated with fecal indicator germs (Fig. 2). The sanitary survey alone does not reflect the quality of the water (Parker et al., 2010) and must always be complemented by testing for fecal indicators such as Coliform bacteria, *Escherichia coli* and Enterococcus.

The most dominant germs in the groundwater sampled were Coliform bacteria (CB) and *Escherichia coli* (*E. coli*) in 100% of the water points, 34 to 2700 colony-forming unit cfu/100 mL and 1 cfu/100 mL to 400 cfu/100 mL respectively.

These findings correlate with the results of several researches. Indeed, researchers (Kostyla et al., 2015) have shown that seasonal variation in groundwater contamination by fecal indicators is highly significant in wet periods.

Intestinal Enterococcus (IE) is less abundant in the analyzed waters. Their concentrations vary from 1 cfu/100 mL to 80 cfu/100 mL with an average of 18 cfu/100 mL. They are also good fecal contamination indicators.

The water from well w1 is treated by chlorination monthly. However, there is recent fecal contamination which was revealed by the presence of coliform bacteria and *E. coli* bacteria. Based on the sanitary score, and considering the presence of a poultry farm, the open-air wastewater and the nauseating odors, all this can explain the results found, which are judged to influence the quality of the groundwater in well w1.

The water supply at w2, w4, w5 and w6 is contaminated, and yet they are protected wells. This may be explained by the storing of the water after electric pumping in the cement tanks and without any treatment before use. Furthermore, the latrine water source distance is less than 15 m. All of these factors contribute to the prediction of unsafe water. Our results are confirmed by relatively recent studies (Foster et al., 2018) that showed the corrosion of pumps, which are used in wells, can increase the contamination rate by thermo-tolerant bacteria.

In addition, according to other studies classifying sources of water by bacteriological quality (Parker et al., 2010) they could identify that borehole water is better bacteriological quality than water from protected hand-dug wells and that

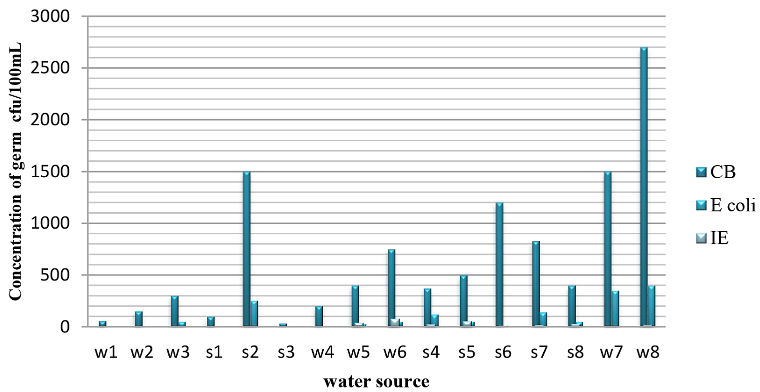

Fig. 2. Result of bacteriological analysis of the various water samples of the study area, (colony-forming unit (cfu) /100 mL)

roof rainwater is better than water from unprotected wells and springs.

Several factors could explain the bacteriological pollution recorded in sampled groundwater in the area of study:

- Environmental factors and the behavior of the poulation, due to the lack of a collection, treatment and disposal system for wastewater and household waste;
- Inadequate hygiene and inappropriate containers, which makes the presumed safe water at risk of contamination;
- Nearby water sources for septic tanks and latrines, and soil disposal of sludge, are all potential causes of pollution by infiltration into the water table.

The causes are in accordance with those detected in the studies conducted on the pollution of groundwater in Fez (El Haissoufi et al., 2011). Other researchers noted in their study of the water quality of Martil that contamination of water results from unhygienic behavior of users and/or use of unclean equipment (buckets, rope, cover, etc.) (Benajiba et al., 2013).

The bacteriological quality study of groundwater in the Tadla plain (Hafiane et al., 2020) showed that the spatial variation in the concentration of fecal indicator germs may be related to the location of wells, the presence of sources of contamination, the sampling period (wet or dry season), and also to anthropogenic activity.

The deterioration of groundwater quality by anthropogenic and geological pollution is proved by several studies on the evaluation of the physico-chemical and bacteriological groundwater quality (Mehdaoui et al., 2019; Benyoussef et al., 2021). Groundwater vulnerability is well demonstrated in the study mapping groundwater pollution risks in parts of the Hail region of Saudi Arabia (Ahmed et al., 2018).

Physicochemical measurements in situ

The water collected during the period of our sampling between November and December 2019, has a clear appearance and a taste that varies between sweet and salty. The results of the physicochemical parameters are summarized in the following Table 3.

The water temperature presents fluctuations between the different water points sampled with a minimum of 12.09 °C and 19.77 °C.

As for dissolved O_2, which is a very crucial parameter for aquatic life, dissolved oxygen shows significant fluctuations between points; from 2.53 to 8.28 mg/L. In general, the results show that the waters of the wells are slightly under oxygenated. Approximately 38% of the points examined (s1, s2, s3, w4, w5 and w6) have a level of dissolved O_2 less than or equal to 3 mg/L and a percentage of oxygen saturation less than 30%, so these waters can be classified as a poor quality based on Moroccan standards.

Table 3. The variation of physic-chemical parameters of water samples taken in the study area

Source water	Temperature	pH	Dissolved oxygen mg/L	% oxygen saturation	Electrical conductivity µs/cm	TDS ppm	Salinity psu
s4	19.33	7.44	3.6	41.5	4979	2244	2.42
s5	12.41	7.59	4.02	41.3	2852	1427	1.5
s6	12.09	6.24	4.22	43.7	599	301	0.29
s7	17.55	6.94	3.53	40.7	1640	824	0.84
s8	13.37	6.83	4.07	42.6	1760	879	0.9
w7	18.66	6.82	3.47	40.8	6354	3199	3.74
w8	15.83	7.27	3.98	42.3	6332.3	3157	3.46
w1	19.77	6.95	3.7	41.1	1680	622	0.57
w2	19.4	6.84	8.28	93.2	1122	562	0.56
w3	19.18	7.12	3.77	43.6	1499	774	0.75
s1	16.13	8.08	2.68	29.3	1929	973	1
s2	13.62	8.05	2.82	29.2	1303	652	0.66
s3	16.4	7.09	3	33.5	1084	535	0.53
w4	13.34	7.97	2.75	29	738	476	0.48
w5	16.18	8.35	2.53	29	742	371	0.37
w6	14.97	7.81	2.57	29	518	257	0.25

The only good quality point according to dissolved O_2 values, which is 8.28 mg/L and 93.2% oxygen saturation, is the well w2, it is located near the Wadi Nekor which appears to improve the oxygen level of groundwater by the contribution of oxygenated water to the water table. The detected decrease in dissolved O_2 can be interpreted as sign of biological growth by the multiplication of organisms, including bacteria.

All the water points are relatively close to the wastewater, which is released to open air and lost pit, keeping a permanent organic matter supply and favoring the micro-organism development, thus affecting the dissolved oxygen level. These results are similar to those of other researchers who have studied the same problem. Indeed, a study that was conducted on the community of Mzamza (Chaouia, Morocco), showed the impact of pollution on groundwater quality (Aslouj et al., 2007). The low percentage of dissolved oxygen saturation is not only due to the absence of photosynthetic plants but also to the potential infiltration of wastewater. Dissolved oxygen can be reduced by the bacterial activity of decomposing organic matter in the water. The survey on the anthropogenic impact on groundwater quality in the commune of Ajdir (Ait Benichou et al., 2017) revealed that these waters are charged with chemical elements that can be of geological or anthropogenic origin. Therefore the presence of local pollution near a water source can contaminate the aquifer by infiltration or direct discharge; the contamination will be highest when the well is not protected.

The electrical conductivity of the water gives an overall idea of its mineralization. The values recorded during the study period vary from 518 to 6354 µs/cm, the waters of the points (s4, w7, and w8) do not respect the Moroccan norms of quality fixed at 2700 µs/cm (NM03.7.001 2006). These results are confirmed by the Moroccan water quality report, which classified the quality of groundwater in the Nekor aquifer as poor to very poor based on the conductivity problem (MEEE, 2007).

Water pH indicates its acidity or alkalinity, in the majority of the natural waters, the pH is between 6 and 8.5 (Chapman, 1996). In the case of the study area, there is slight alkalinity of the water and the pH ranges from 6.24 to 8.35. The waters analyzed in all the points are in conformity with the standards of drinking water in Morocco (NM03.7.001).

We also measured the piezometric level of some wells in the study area (Arbaa Taourirt commune and Zaouia commune), the piezometric level is located between 2.80 m and 4.20 m indicating that the water table is very close to the surface (shallow depth 1–15 m). This shallow depth probably exposes the water table to several pollution sources.

Principal component analysis (PCA)

The PCA results give multiple tables, some of which are summarized in this study.

According to statistical analysis of the contamination of springs and wells with coliform bacteria in the study area, the concentration in wells is higher than in springs (Table 4), this may be due to the springs being far away from the population and so far from pollution sources.

The principal component analysis (PCA) (Fig. 3) reveals a correlation between the physic-chemical and bacteriological parameters of the studied waters. P1 is related to EC, TDS, salinity, CB and E. coli bacteria, while P2 is positively related to dissolved O2 and percent saturation and negatively related to pH and IE. The T°C is not related to conductivity. The circle indicates that there is an axis of pollution, this is the P1 axis, where we can say that points s4, w7, w8 are the most polluted, and the P2 axis is positively associated with dissolved oxygen and the percentage of saturation in which we clearly see that points w1, w2, w3 are more oxygenated than other points in the study area.

The ascending hierarchical classification (HAC) is used to group the different waters into three classes (Fig. 4; Table 5).

Table 4. Results of descriptive statistical analyze of contamination by coliform bacteria of spring and wells in the study area

Statistical	Coliform bacteria, well	Coliform bacteria, spring
Nb. observations	8.00	8.00
Minimum	57.00	34.00
Maximum	2700.00	1500.00
1st Quartile	187.00	302.00
Median	350.00	450.00
3rd Quartile	937.500	922.00
Average	757.125	6167.500
Variance (n-1)	833191.839	270558.786
Standard deviation (n-1)	912.793	520.153

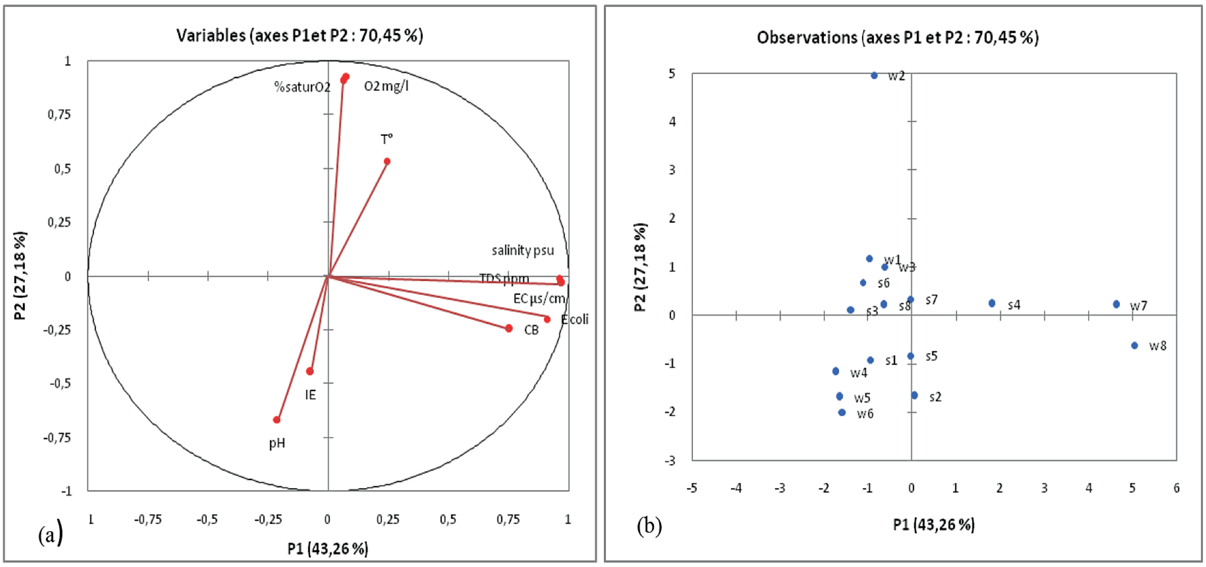

Figure 3. (a) P1/P2 correlation circle acute angle: positively related variables – Right angle: unrelated variables – Obtuse angle: negatively related variables (b) water point projections from the plane of the P1 and P2 spatial axis.

Class 1 groups the points (w2, s3, w4, w5, w6 and s6) that are moderately mineralized with conductivity (at 800 µs/cm), a percentage of oxygen saturation of 42% and a rate of CB and E. coli relatively lower than the two other classes with almost 4mg/l of dissolved oxygen and a percentage of oxygen saturation of about 43%. Class 2 includes the points of water (w1, w3, s1, s2, s5, s7 and s8) which have conductivity (to 1800 µs/cm). Class 3 is characterized by highly mineralized water (S4, w7 and w8) with high conductivity (>5000 µs/cm) and a significant concentration of germs, mainly coliform bacteria which exceed 1500 UFC/100 mL and Escherichia coli. The level of conductivity is influenced by several natural and anthropogenic factors such as the geology of the watershed (rock composition), as well as the contribution of contaminated water from human activities, which also increases water conductivity. PCA results show a correlation of conductivity with fecal contamination indicators.

In rural areas, the localities exploit the water table through wells and springs. With no access to sanitation and drinking water services, most people use traditional pit latrines, which generally reach the water table and pose a risk of microbiological contamination of groundwater. This confirms the results that reflect significant fecal contamination of water source; this deduction joins the results of the study of physicochemical and bacteriological characterization of groundwater in rural area (Kanohin et al., 2017; Adamou et al., 2020).

CONCLUSIONS

The principal component analysis and the hierarchical classification are helping to classify and characterize the waters of our study area. The results obtained from the bacteriological analysis of the collective water points of the study area show high concentrations of germs indicating fecal contamination in all the points, without exception, which would certainly pose a risk to the health of the local consumers and inhabitants, which requires treatment of these waters before consumption.

Table 5. Optimal classification of the groundwater studied based on several variables

Class	T °C	pH	O_2 mg/L	% satur O_2	EC µs/cm	TDS ppm	Salinity psu	CB	E coli	IE
1	16.004	7.366	3.513	38.257	1809.000	878.714	0.889	526.714	77.857	15.143
2	15.397	7.383	3.892	42.900	800.500	417.000	0.413	455.667	14.833	22.333
3	17.940	7.177	3.683	41.533	5888.433	2866.667	3.207	1523333	290.000	17.333

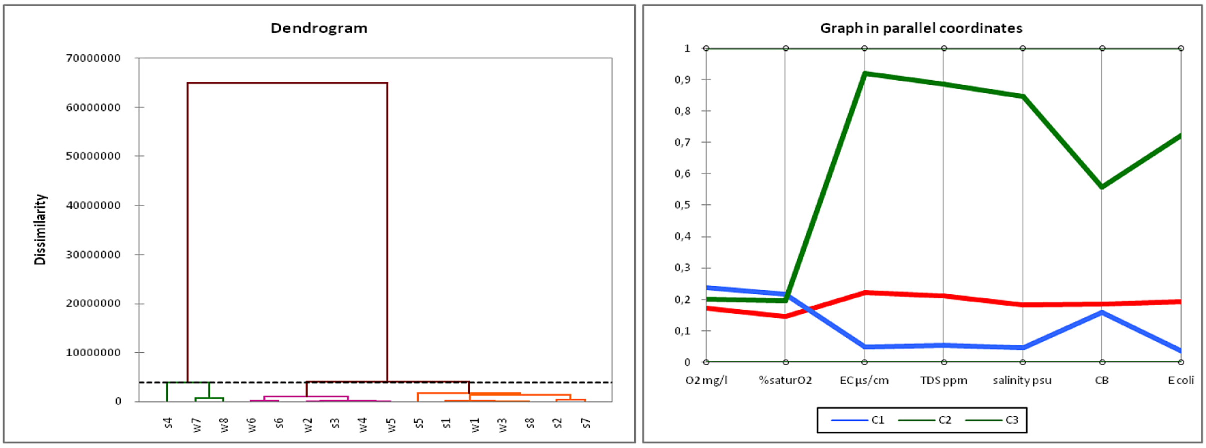

Figure 4. Hierarchical ascending HAC classification of the various water points in the study area.

Acknowledgments

We would like to thank in particular the Environmental Hygiene Technicians of the Al-Hoceima Health Delegation, the head doctor of the SRES, as well as anyone who has given support from near or far to the achievement of this work.

This work is part of the tasks of the research project PPR2/2016/05 funded by the CNRST and entitled “Biodiversity and groundwater quality in the Al Hoceima region (northern Morocco): Application to hygiene, monitoring and the protection of aquifers”.

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