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Assessment of water quality in wells and springs across various districts of Taza City, Morocco

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ABSTRACT

The aim of this study is to assess groundwater pollution in the city of Taza, Morocco. This was accomplished through hydrochemical and biological investigations, focusing on analyzing the physicochemical and bacteriological parameters of groundwater. Water samples were collected from wells and sources within Taza City on a monthly basis during the spring and summer of 2023. These samples were subjected to analysis to identify physicochemical and bacteriological characteristics. The findings revealed multiple contaminations, primarily stemming from two sources: significant microbial pollution observed in 100% of samples due to runoff percolation and discharge of domestic and industrial wastewater, and varying degrees of chemical pollution observed across all samples. The results underscored deviations from national standards, notably in parameters such as dissolved oxygen, nitrate, and nitrite concentrations. These parameters exhibited values either lower or higher than the established norm.

Key words: bacteriological, groundwater, physicochemical, water quality, Taza, wastewater

HIGHLIGHTS

- Groundwater Quality Assessment:This study provides a comprehensive analysis of groundwater pollution specifically in Taza, Morocco, contributing valuable data to the understanding of local water quality issues.
- Microbial Pollution Findings: The discovery of significant microbial contamination in all samples highlights critical public health concerns related to runoff and wastewater discharge.
- Chemical Contaminants Analysis: The investigation reveals concerning levels of key chemical pollutants (dissolved oxygen, nitrate, nitrite) that exceed national standards, signaling environmental and health risks.
- Monthly Sampling Approach: The research utilizes a rigorous monthly sampling schedule, ensuring robust data collection and analysis during crucial seasonal periods, and enhancing the reliability of the findings.
- Call for Improved Management: The results advocate for urgent improvements in wastewater management and monitoring practices, aiming to protect groundwater resources and ensure public health in Taza.

INTRODUCTION

The quality of water resources in Taza City is strongly influenced by the rational and sustainable management of solid and liquid wastes that end up in the aquatic receiving environment without any prior treatment (Sghiouer *et al.* 2024). Indeed, it is regrettable that many Moroccan cities have grown considerably, the number of habitats has risen sharply, and the development of socio-economic activities and changes in lifestyles and consumption have led to an additional waste deposit increasingly, without having the time to acquire modern sanitation networks and wastewater treatment units (Nguyen *et al.* 2020; Axon *et al.* 2023).

The 'Julien' landfill is installed on a common site, a site chosen at random without any impact study. It is an uncontrolled dump, which receives all kinds of solid waste in its raw state (household, industrial, hospital, and agricultural). Pollutant emissions emanate permanently from the landfill, uncontrolled surface flow, or leachate infiltration in the subsoil, as well as biogas produced by the decomposition of organic matter. In addition, frequent fires and the development of smoke as well as general misuse (waste disposal, ragpickers, grazing cattle, and hygienic aspects) are still to be named, leading to significant risks and serious ecological nuisances.

An organoleptic diagnosis made it possible to note certain observations concerning the water quality of the wells and springs close to the sewage flow of Taza City: high salinity and sometimes a bad odor. A preliminary physicochemical study of most of the wells on both banks of Oued Larbaa showed the possibility of groundwater contamination by sewage infiltration (Abouabdallah *et al.* 2023).

Taza Province is recognized as one of the regions at a high risk of water-borne diseases, according to Mahmoud *et al.* (2023). The primary diseases of concern in this area are typhoid and hepatitis A, which are especially prevalent in large urban agglomerations that suffer from partial or inadequate sanitation infrastructure. The lack of comprehensive sanitation facilities leads to the contamination of water sources, making it easier for these diseases to spread among the population.

In addition, a significant contributing factor to the health risks in Taza Province is the practice of using untreated sewage for the irrigation of vegetable crops in the vicinity of Taza City. This method of irrigation introduces pathogens from the raw sewage into the food supply, posing a substantial threat to public health. When these contaminated vegetables are consumed, the risk of spreading water-borne diseases, such as typhoid and hepatitis A, increases dramatically. Ben Abbou *et al.* (2013) highlight that this practice not only affects those who consume the contaminated produce but also has the potential to disseminate these diseases more widely, exacerbating the public health crisis in the region.

The combination of poor sanitation and the use of raw sewage for irrigation creates a dangerous environment for the spread of water-borne diseases in Taza Province. Addressing these issues is crucial for improving the overall health and safety of the population, necessitating urgent interventions in sanitation infrastructure and agricultural practices.

The purpose of this study is to determine the extent of groundwater degradation in various districts of Taza City, Morocco. This evaluation is essential for understanding the impact of pollution originating from multiple sources, particularly landfill leachate, and streams that receive direct discharges of municipal wastewater. By analyzing water quality data from wells and springs, we aim to identify the contaminants present and their concentrations. This study will provide a comprehensive assessment of how these pollution sources affect groundwater quality, highlighting areas of concern and contributing valuable information for the development of effective water management and pollution mitigation strategies. Furthermore, the findings will help in raising public awareness and guiding policy decisions to ensure the safety and sustainability of the city's water resources.

MATERIALS AND METHODS

Study area

Taza, situated in the northeastern region of Morocco, experiences a subhumid climate. Its rainfall pattern is characterized by two distinct seasons: a lengthy rainy period spanning nearly 8 months from October to May, with an average precipitation of about 510 mm, and a dry season from June to September, marked by average maximum temperatures nearing 35 °C (Ben Abbou *et al.* 2013).

Geographically, the Taza region is primarily located between two watersheds: the Moulouya Basin to the east and the Sebou Basin to the west (Benzougagh *et al.* 2020). Hydrologically, Taza city is intersected by an extensive network of watercourses, primarily consisting of the main river, Oued Larbâa, and its tributaries – Oued Taza, Oued Dfali, Oued Laghouireg, and Oued Jaouna.

From a hydrogeological perspective, Taza features two types of aquifers: a deep aquifer comprised of limestone formations and a shallow water table that gives rise to numerous water sources within the city.

The sanitation network in the city is unitary and covers almost the entire city with a total linear of 80 km. This network is made up of a group of five main collectors (Larbaâ, Taza, Rhouireg, Dfali, and Jaouna) ensuring the sanitation of most of the districts of the city. These collectors discharge the wastewater into the various points of the Oued crossing the city without any prior treatment (Abba *et al.* 2021).

Experimental protocol

Physicochemical analyzes

A monthly sampling frequency was adopted during the period from May to October 2013, with a representative choice of the sampling sites.

Twenty parameters were measured, including nine (ONEP 2019) carried out *in situ*: temperature, conductivity, pH via a multi-parameter analyzer Type CONSORT-Model C535, turbidity with a turbidimeter Type HACH-Model 2100P, and dissolved oxygen (DO) by the Winkler titration method (ONEP 2019) and bicarbonates, calcium, and magnesium by titrimetric assay.

The sampling, transport, and storage of water samples refer to the protocol and procedures defined by the National Office for Drinking Water (Rodier & Legube 2009; ONEP 2019). The methods used in the Laboratory of Natural Resources and Environment of the Polydisciplinary Faculty of Taza are volumetry for chlorides and oxidability; molecular absorption spectrophotometry for sulfates, nitrates, nitrites, ammonium ions, and orthophosphates and flame spectrophotometry for sodium and potassium (Rodier & Legube 2009). The determination of the trace elements (Cd, Co, Cu, Fe, Ni) was carried out using induced plasma emission spectrometry at the Fez innovation center.

Bacteriological analysis

The samples were taken, considering no contaminating or modification of samples, in sterile bottles and transported in a cooler immediately to the laboratory where they were stored at 4 °C until the bacteriological analysis. The analysis was done within a maximum of 6 h after the sample was collected.

The study of bacteriological parameters has focused on the detection and enumeration of pollution indicators germs: coliforms, *Escherichia coli* (*E. coli*), intestinal enterococci (IE), total aerobic mesophilic flora (TAMF), anaerobic sulfate-reducing clostridium spores (ASRCS), *Staphylococci* and *Pseudomonas*. For seven germs searched, six replicates were performed on the 84 samples taken, for a total of 588 analyzes.

The samples were taken according to the Office National de l'eau potable (ONEP) sampling and analysis procedure (ONEP 2019) with a monthly frequency. Fecal coliforms (FC), total coliforms (TC), and fecal staphylococcus (FS) were counted using the indirect method of multiple tube fermentation in a lactose broth; the number was then statistically deduced using the most probable number method (Rodier & Legube 2009). The filtration is carried out on a vacuum filtration stage. Isolation and enumeration were performed in a solid medium (Table 1).

RESULTS AND DISCUSSION

The results are presented by discussing the measured parameters, in particular the measurements carried out *in situ* and those carried out in the laboratory. Average results for groundwater will be cited.

Table 1 | Analysis method of the various bacteriological parameters

Germs	Used medium	Incubation temperature and time	References
TC (Coliforms)	Tryptose Lauryl sulfate broth; Brilliant green lactose-bile broth	37 + 1 °C/48H	(ISO-9308-2-2012)
EC (*Escherichia coli*)	Tryptose Lauryl sulfate broth; EC medium	37 + 1 °C/48H ; 44 + 0.5 °C/24H	(ISO-9308-2-2012)
FS (Entérocoques intestinaux)	Glucose broth with azide; Bile agar with Esculin and Azide	37 + 1 °C/48H; 44 ± 0.5 °C/ 48H	(ISO-7899-2-2000)
TAMF	Plate count agar (PCA)	36 ± 1 °C/ 24 à 48 H	(ISO-6222-1999)
ASRCS	Incorporation of Sodium-Polymixin Sulfite Agar	36 ± 1 °C/ 24 à 48 H	(ISO-6461-2-1986)
Staphylococcus aureus	Baird-Parker agar	36 ± 1 °C/ 48 H	Rodier & Legube (2009)
PA	Cetrimide medium	42 ± 1 °C/ 48 H	(ISO-16266-2-2018)

Bacteriological analysis

Coliforms and *E. coli*

The obtained coliform content in the different sources varies between 1.15 log10/100 mL as the minimum value recorded in source S7 and 3.42 log10/100 mL as the maximum value recorded in source S14. The mean concentration is of the order of 2.02 log10/100 mL (Figure 1).

Significant differences in the *E. coli* content were noted in the various sources: absence of *E. coli*. *E. coli* is recorded at sources S9, S10, and S13, while the minimum value is recorded at source S8 (0.85 log10/100 mL) and the maximum value at source S14 (2.99 log10/100 mL). The mean concentration is of the order of 1.68 log10/100 mL.

The same content of *E. coli* is noted at S3 and S12 (1.09 log10/100 mL), and close values were recorded at S1 and S14; S5 and S11; S6 and S10; S7 and S8, with standard deviations of up to: 0.26; 0.03; 0.17 and 0.15 log10/100 m (Figure 2).

Fecal coliforms come exclusively from the intestines of warm-blooded animals, including humans, and their presence is the most accurate indicator of fecal contamination. Although the presence of *E. coli* bacteria in water indicates fecal contamination, it does not identify the precise source of fecal matter. There are several possible sources: manure, grazing, septic

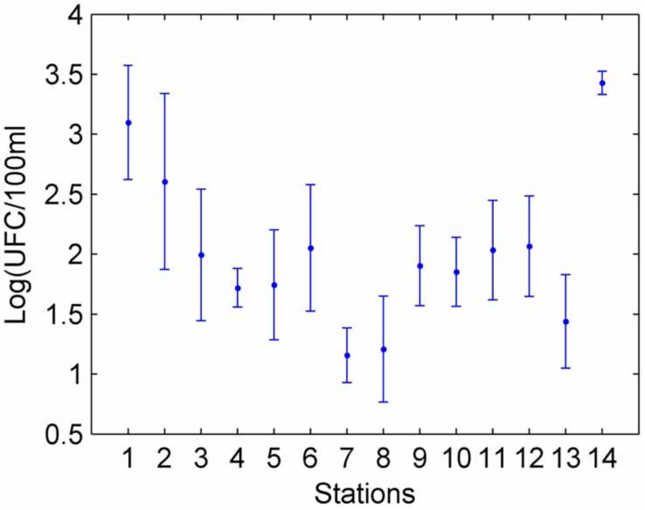

Figure 1 | Spatial evolution of mean values and standard deviations of total coliforms (N/100 mL).

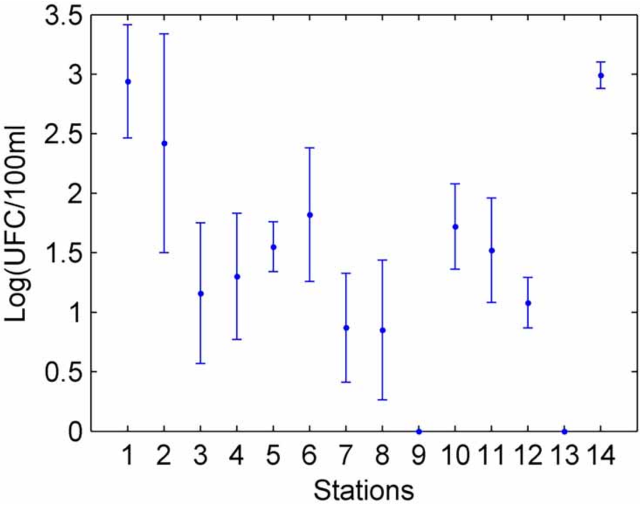

Figure 2 | Spatial evolution of mean values and standard deviations of fecal coliforms (N/100 mL).

tanks, latrines, and other sources such as wild animals. According to our health surveys in the vicinity of the wells and sources that were the subject of our physicochemical and bacteriological analyzes, we noticed the existence of waste of all kinds in neighboring land and a direct release without any prior treatment in the streams of Taza City.

The health risk associated with the presence of total coliform bacteria is often low, with the exception of some strains of *E. coli* and some opportunistic bacteria that can cause serious illness in debilitated patients. Thus, *Klebsiella pneumoniae* can cause respiratory and genito-urinary tract infections and septicemia (Yang *et al.* 2022). There are, however, cases where an association between the detection of total coliforms and the appearance of water-borne epidemics has been demonstrated (Mabvouna *et al.* 2020; Some *et al.* 2021), although water without coliforms may also be responsible for gastroenterological problems (Alam & Abdullah 2022).

The presence of fecal coliforms may be an indication of the presence of enteropathogenic microorganisms (Hammad *et al.* 2022), such as *Salmonella* and Norwalk virus (Jain & Rajesh 2016; Lucero *et al.* 2021).

Intestinal enterococcus (IE)

The content of IE varies between 0.46 log10/100 mL as a minimum value and 2.91 log10/100 mL as a maximum value for S13 and S1, respectively, with an average concentration of 1.56 log10/100 mL. Almost the same IE content is recorded between S9 and S10 and a reconciliation of contents is noted between S2 and S6; S4 and S5; and S8 and S11, with, respectively, a deviation of 0.02; 0.25; 0.10 and 0.11 log10/100 mL (Figure 3).

The detection of enterococci in a groundwater table or in wells must seriously suspect fecal contamination and the presence of enteropathogenic microorganisms (Lotfi *et al.* 2020) thus showing a correlation between the presence of enterococci and fecal coliforms in untreated drinking water. More convincingly, Chique *et al.* (2021) clearly demonstrated that the detection of enterococci was strongly associated with the presence of *E. coli* in distribution systems supplied by groundwater. As for Xiong *et al.* (2021), they showed an increased risk of developing gastroenteritis with a relatively small number of fecal streptococci (3–10 bacteria/100 mL). OMS (2000) (OMS 2000) suggests that groundwater should not be consumed in which *Enterococci* have been identified.

Total aerobic mesophilic flora

The content of TAMF varies slightly between the different sources; it reaches a minimum value (1.96 log10/100 mL) in the source S11 and a maximum value (3.05 log10/100 mL) in the source S14, the mean value is 2.31 log10/100 mL.

A resemblance of the TAMF contents is noted on the one hand between S1, S2, S3, S4, S5; S12 and on the other hand between S6, S7, S8, S9, S10, S11, S13 with a deviation of 0.25 and 0.15 log10/100 mL, respectively (Figure 4).

The total germs at 22 °C are bacteria of residual origin (environmental), while the total germs at 37 °C are bacteria of intestinal origin (human or animal). The high contamination of wells by total germs could be due to poor protection of wells (open pits), ignorance of basic hygiene rules, neighboring pollution (agricultural land, livestock breeding, existence of septic tanks

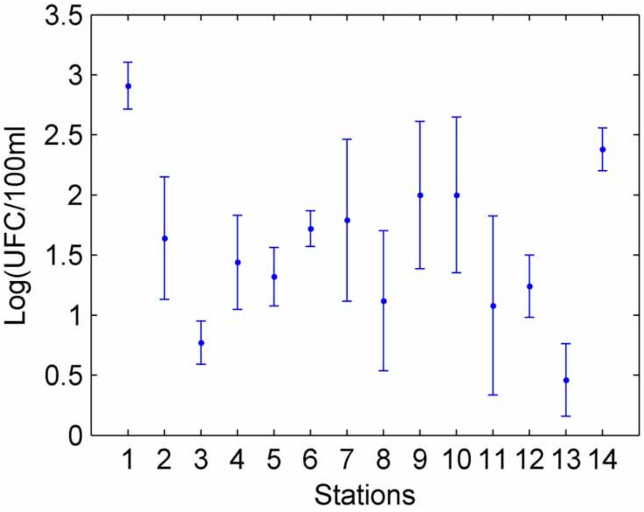

Figure 3 | Spatial evolution of mean values and standard deviations of IE (N/100 mL).

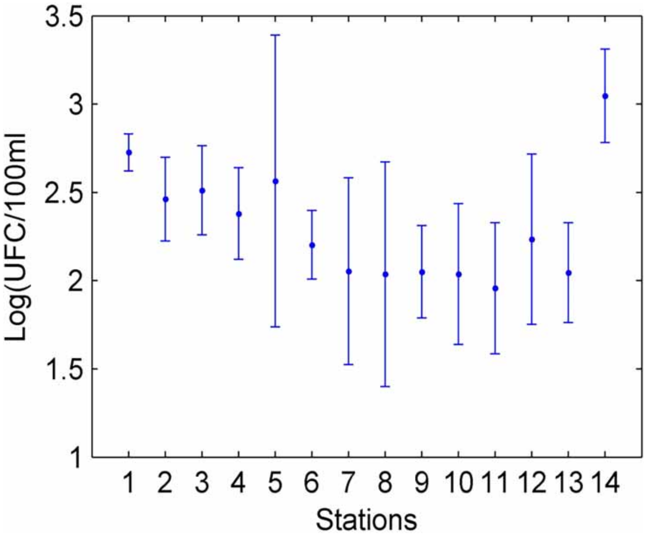

Figure 4 | Spatial evolution of mean values and standard deviations of the TAMF load (CFU/100 mL).

and latrines), and the absence of liquid sanitation. The count of mesophilic aerobic germs is used as an indicator of pollution and as an indicator of treatment efficiency, in particular physical treatments such as soil filtration, which should lead either to a very great decrease in bacterial concentration compared to the entry, or even an absence of bacteria. The soil of the wells studied does not filter enough microorganisms.

Anaerobic sulfite-reducing clostridium spores (ASRCS)

The sources S5, S7; S8; S9, and S13 are free from ASRCS. The minimum and maximum levels of ASRCS are recorded at source S3 (0.07 log10/100 mL) and source S14 (2.34 log10/100 mL), this value could be explained by old fecal contamination; the mean value is 1.06 log10/100 mL (Figure 5).

It should be noted that anaerobic sulfite-reducing bacteria are often considered as controls of fecal pollution. The spore form, which is much more resistant than the vegetative forms of fecal coliforms and fecal streptococci, would thus detect old or intermittent fecal pollution.

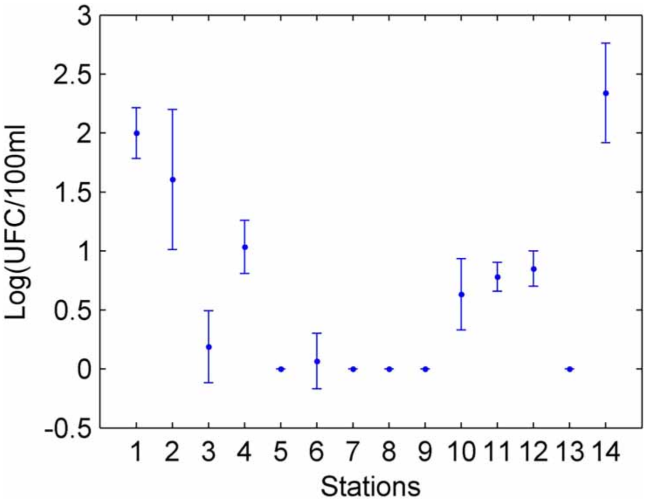

Figure 5 | Spatial evolution of mean values and standard deviations of the ASRCS content (CFU/100 mL).

Staphylococcus (STAPH)

The studied sources contain *Staphylococcus* contents which oscillate between 1.15 log10/100 mL as the minimum value in the source S3 and 3.13 log10/100 mL as the maximum value in the S1 source, while the mean concentration is 2.03 log10/100 mL.

A resemblance of the *Staphylococcus* contents is noticed between the sources S1 and S14; S2 and S8; S4 and S10, respectively, with a deviation of 0.05; 0.02, and 0.01 log10/100 mL (Figure 6).

The maximum value of *Staphylococci* in the source waters is 3,100 colony forming unit (CFU)/100 mL at source S1 (Figure 6). However, WHO standards (2000) set a 'zero' value for the presence of staphylococci in water intended for human consumption, given the pathogenicity of these microorganisms. The French and Canadian standards also require the total absence of these bacteria in any water intended for direct or indirect human consumption because some forms can withstand high temperatures (Rodier & Legube 2009).

Pseudomonas aeruginosa (PA)

For PA, is noted their absence in the S11 and S13 sources and their presence in the other sources with variability of the contents. The minimum value is recorded at source S10 (0.24 CFU/100 mL) and the maximum value is recorded at source S6 (1.56 CFU/100 mL).

The same level of PA was observed at the sources S8 and S9 (0.3 CFU/100 mL) and at S4 and S12 (0.24 CFU/100 mL). A similarity of the PA contents is noted between the sources S2, S3, and S14 with a deviation that does not exceed 0.12 CFU/100 mL (Figure 7).

The presence of PA in the studied waters represents a health risk for weakened and immunocompromised persons. As an opportunistic pathogen, this germ is responsible for a wide variety of infections: atrial, ocular, urinary, and infections of the skin or respiratory tract (Rossi *et al.* 2024).

The results of the germs sought in the waters of Taza City confirm the presence of an important source of pollution and that is the origin of the establishment of environments favorable to bacterial development.

The adverse effect of wastewater on groundwater quality and human health has been demonstrated by some studies (Zhang *et al.* 2020; Mora *et al.* 2022). Urban wastewater contains a lot of nutrients (macronutrients N, P, K, Ca, Mg, and micronutrients: iron) which are strongly solicited by bacterial populations (Jayakumar *et al.* 2021).

Determination of the origin of fecal contamination

The ratio of fecal coliforms to IE can indicate the origin of fecal contamination (animal or human) at contaminated sources.

The results show that:

- 14.28% of the fecal contamination is of human origin,

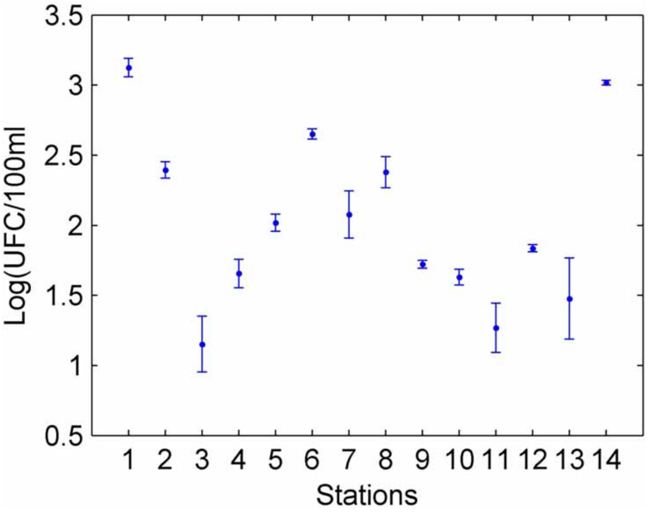

Figure 6 | Spatial evolution of mean values and standard deviations of the STAPH content (CFU/100 mL).

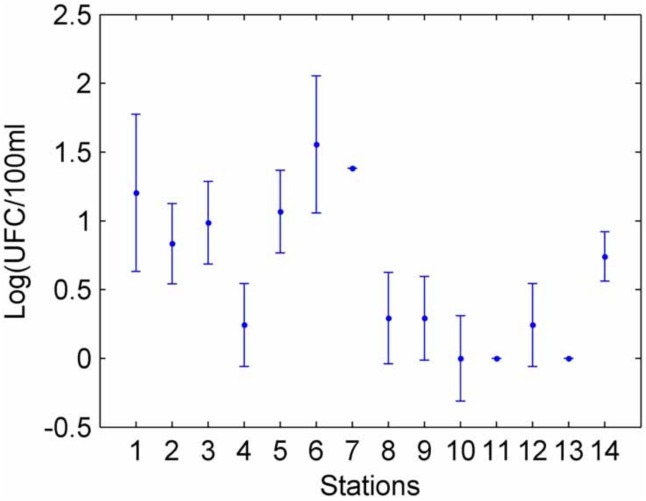

Figure 7 | Spatial evolution of mean values and standard deviations of the PA content (CFU/100 mL).

- 42.85% of the fecal contamination is of strictly animal origin,
- 7.14% of the fecal contamination is of mixed origin, predominantly animal,
- 14.28% of fecal contamination is of mixed origin, predominantly human,
- 21.42% of the points show fecal contamination of uncertain origin. (Only the source S13 that was revealed is not affected by fecal contamination among the fourteen sources analyzed (7 and 14%).)

The majority of the studied points present a contamination by the IE whose origin could be human or animal. Human fecal flora contains more fecal coliforms than streptococci (Khan & Gupta 2020). The FC/FS ratio is greater than 1 suggesting that fecal pollution is of human nature (Bisimwa *et al.* 2022). According to this report, 95% of fecal streptococci (SF)-contaminated sites have fecal contamination of animal origin, whereas only source 7 with fecal contamination of human origin ($FC/FS > 1$).

This contamination could be caused by the infiltration or percolation of untreated sewage of domestic or agricultural origin, livestock waste, proximity to latrines and septic tanks of these water points, use of fertilizer excreta as fertilizers, or poor maintenance of water points and noncompliance with hygiene and protection rules, as evidenced by other authors (Mothapo 2020; Luong 2021).

The consumption of these waters exposes the population using them to serious health risks. The cohabitation of the other pathogens with the indicators of fecal contamination enumerated will have an impact on the health of the users because the consumption of water containing germs of fecal origin increases the number of intestinal flora already varied (Parker *et al.* 2020). That causes metabolic imbalances (Giordano-Kelhoffer *et al.* 2022). Indeed, risk of developing gastroenteritis with a limited number of SF (3–10 bacteria/100 mL) has been demonstrated (Karakan *et al.* 2021).

Assessment of water use of analyzed sources

We have classified the waters of the sources analyzed according to the microbiological parameters, in order to know their conformity to be used by the consumer (drinking water, irrigation waters, and bathing waters), in compliance with the required standards.

According to the microbiological results and the compliance of the source water, no water from the analyzed sources was found to be suitable for use as drinking water, the maximum permissible value is 0/100 mL. For *E. coli* and IE (Bancessi *et al.* 2020). All the waters of the springs exceeded this value.

Source S1 is the only source whose waters are declared as non-compliant with bathing waters by presenting a 7.14% share of all the sources analyzed. However, the 92.86% were found to be suitable for bathing (NM.03.7.200-1998).

However, all the sources analyzed have waters complying with irrigation water standards with a limit value of 1,000 *E. coli*/100 mL (SEEE 2007).

Principal component analysis

In the course of this work, principal compound analysis (PCA) was performed on centered variables reduced using MATLAB software. The data covers all fourteen sources of Taza City. Seven variables were treated: Coliforms, *E. coli*, IE, TAMF, ASRCS, STAPH, and PA.

The use of principal component analysis (PCA) for the overall study of source water allows differentiation of their microbiological characteristics, a determination of their overall variations (factors) along the main axes, and especially a characterization of different poles of pollution.

Analysis of this correlation matrix shows that a good correlation has been established between coliforms, *E. coli*, TAMF, ASRCS, and STAPH.

The analysis of the factorial planes F1 and F2 shows that more than 89.68% of the total variance is expressed (we have a good quality of representation), the F1 axis makes it possible to explain 72.96% of the total variance and the F2 axis accounts for 16.72% of the total variance (Figure 8). The PCA was carried out on a matrix of data composed of fourteen lines representing the studied sources and seven columns representing the bacteriological parameters studied.

TAMF, coliforms, *E. coli*, STAPH and ASRCS are positively correlated with the F1 axis, which accumulates 72.96% of inertia, and IE and PA is positively correlated with the F2 axis, which accumulates 16.72% of inertia (Figure 8).

The projection of the individuals on the factorial planes F1 and F2 made it possible to distinguish four different groups (Figure 8):

- Group 1: Includes source S14, which contains very polluted and poor-quality waters in germs indicative of bacteriological pollution.
- Group 2: It contains only the source S6 which presents water more contaminated by PA compared to the other sources.
- Group 3: It contains only station S1, which also contains polluted water, but is relatively more contaminated by IE compared to other sources.
- Group 4: It brings together the sources S2, S3, S4, S5, S7, S8, S9, S10, S11, S12, and S13 which present less polluted source waters in germs indicative of bacteriological pollution.

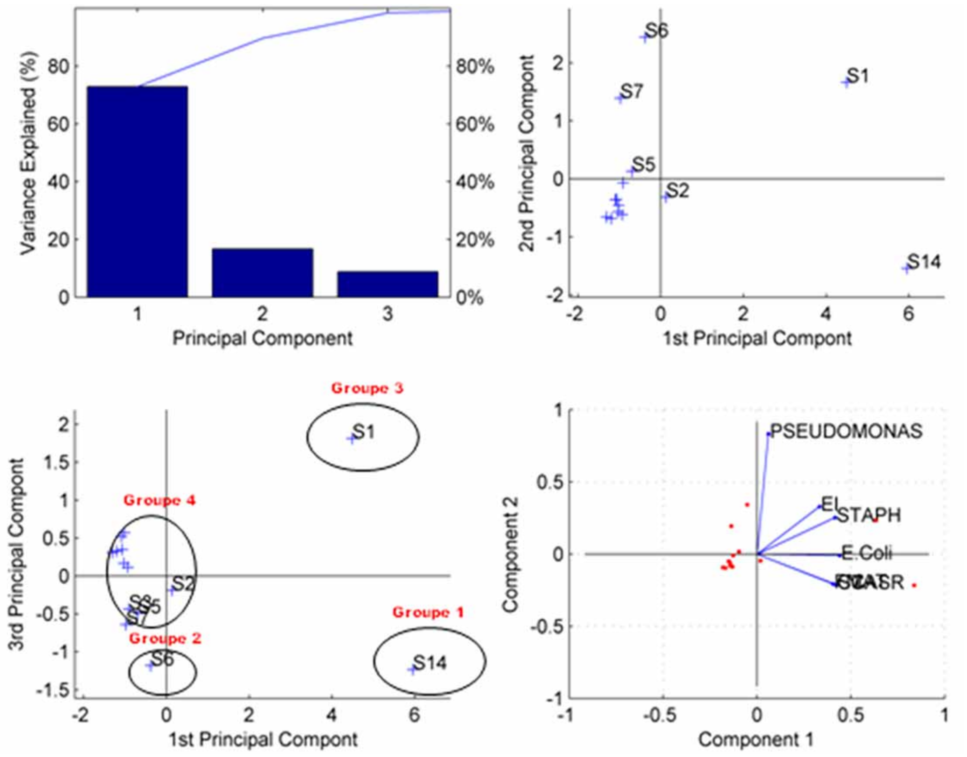

Figure 8 | Projection of the variables and representation of the sources on the factorial planes F1 and F2.

Physicochemical analysis

The pH and temperature values of the studied groundwater are found in the Moroccan potability standards, with average values varying from 6.77 to 7.60 for pH and from 14.50 to 25 °C for temperature. For turbidity (Figure 9), only the sources S2, S4, and S14 exceed the Moroccan standard successively with values of 36.7, 10.1, and 19.0 Nephelometric Turbidity Unit (NTU) and have a low content of DO with an average value of 1.68 mg/L (Figure 9).

This is mainly due to the sewage infiltration of the Oued Larbaâ (wastewater collector of Taza City, the distance between this collector and the S3 does not exceed 2 m).

The mean values of electrical conductivity (Figure 10) vary between 433.50 and 5,420 μS/cm, with high values at the source S1 located next to the discharge and the wells located immediately downstream of the discharge wastewater. These important values appear to be the result of the inputs from the drainage of the Oued by the alluvial water table, due to the absence and inadequacy of the rainy period and/or leaching of the reservoir rock where the waters stay.

The mean values of the chloride content (Figure 10) evolve in parallel with those of the conductivity for all the measurement points. The chlorides could come from industrial discharges, water percolation through saline grounds (the chloride concentration upstream of Oued Larbaâ equal to 2.584, 14 mg/L), and the flow of irrigation water.

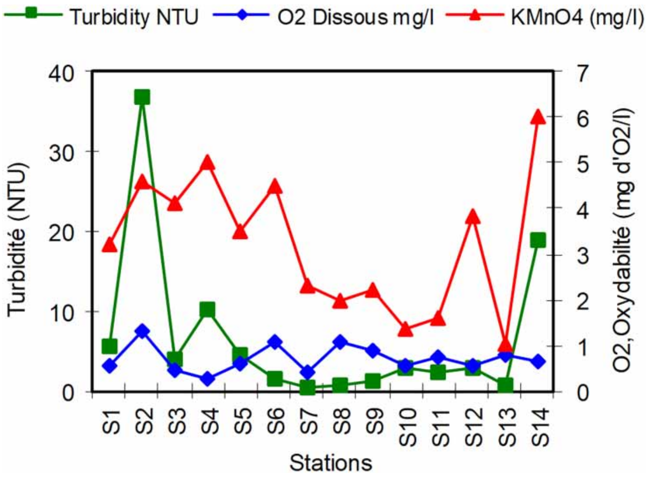

Figure 9 | Spatial evolution of turbidity averages (NTU), DO (O_2), and oxidability at $KMnO_4$ (mgO_2/L) as a function of sampling stations.

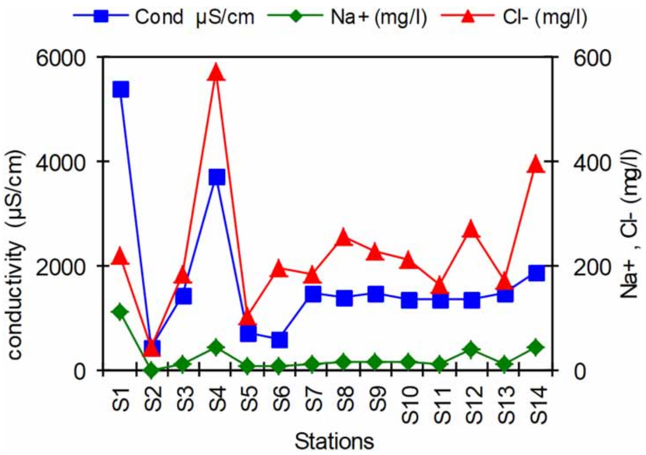

Figure 10 | Spatial evolution of conductivity averages (μS/cm), chlorides, and sodium (mg/L) as a function of sampling stations.

On the hydrochemical level, the waters are highly mineralized and very hard (147–325 mg/L of Ca^{2+}, 8.8–112.20 mg/L of Mg^{2+}, and 66.67–1,230.9 mg/L of Na^{+}).

The measured heavy metals showed metallic pollution of the studied groundwater compared to the Moroccan norm of potability (PNM 2022). In fact, the concentration of lead reached 0.02 mg/L in wells S10, S14, and source S3, the latter also having an iron concentration of 0.875 mg/L, while the content of aluminum reached a value of 0.558 mg/L at source S2 (Figure 11). This would indicate a percolation of wastewater and leachate through the different layers of the soil depending on their degree of permeability.

Nitrogen elements (Figure 12) increase in the studied groundwater near wastewater and landfills. Their existence in large quantities indicates recent contamination resulting from the infiltration of wastewater and a deficiency in oxygen.

Similarly, the water quality is poor compared to the nitrate parameter since only the sources S1, S2, S3, S6, and S12 respect the Moroccan standard of 50 mg/L. The maximum mean value reached 147.9 mg/L in well S8. This result shows pollution by nutrients, the origin of which is probably related to the oxidation of nitrites by nitrification bacteria following the infiltration of wastewater.

These sources also have significant bacterial contamination which confirms the superficial flow of wastewater to the alluvial water table in the study area.

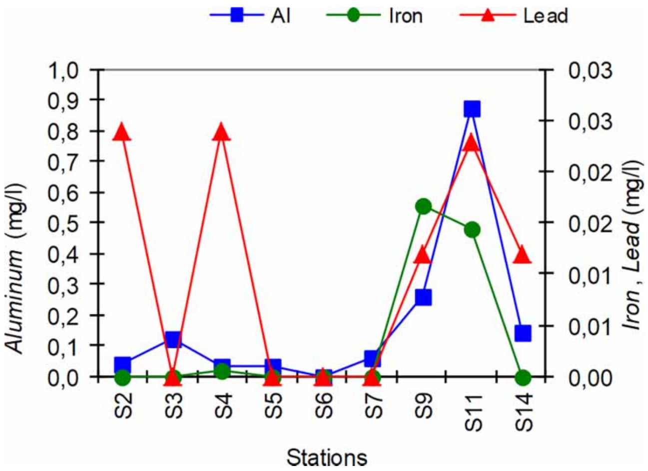

Figure 11 | Spatial evolution of heavy metals (in mg/L) (lead, aluminum, and iron) as a function of sampling stations.

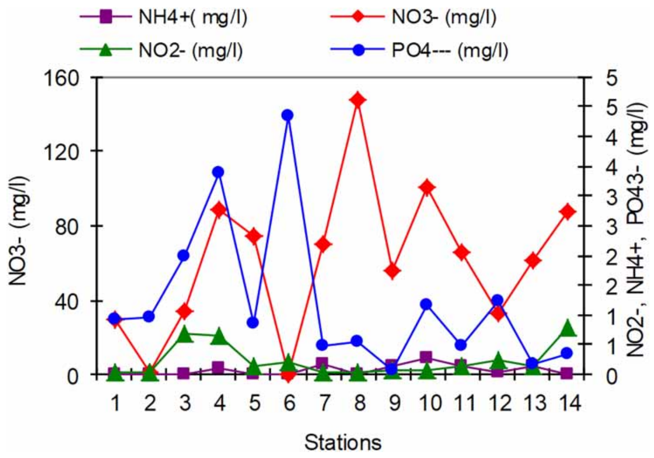

Figure 12 | Spatial evolution of the average scores of nitrates (NO_3^-), nitrites (NO_2^-), ammoniums (NH_4^+), and orthophosphates (PO_4^{3-}) as a function of sampling stations.

CONCLUSION

Furthermore, the findings from this observation underscore the oblique repercussions of unregulated landfill practices and wastewater disposal on groundwater pleasant. The unrestricted dumping of waste, coupled with insufficient wastewater control, has brought about a situation wherein water percolates via crevices, facilitating the infiltration of pollution into groundwater reservoirs. Particularly regarding the area of the landfill on an alluvial plain, which exacerbates the leaching of contaminants and wastewater into the groundwater, resulting in profound pollutants in the aquifer system.

The quality of water is influenced by a variety of pollutants from sources such as industrial, agricultural, and urban waste, as well as uncontrolled discharges, posing risks to human health and the environment. The concentration of DO is critical for aquatic life, with insufficient levels leading to reduced biodiversity and harmful anaerobic conditions. Nitrate (NO^{3-}) and ammonium ions (NH^{4+}) indicate pollution from nitrates and ammoniums, often associated with intensive agriculture and wastewater, affecting water potability and human health. Heavy metals such as Al^{3+}, Fe, and Pb, toxic in the long term to living organisms, originate from industrial sources and ageing infrastructure. The presence of pathogens in groundwater underscores the need for rigorous monitoring and treatment to ensure the safety of drinking water against microbiological risks.

In light of those findings, pressing intervention and complete control techniques are vital to mitigate, in addition, the deterioration of groundwater pleasant withinside the observed area. Also, if no measures are taken to address these issues, the situation could worsen significantly, leading to several dire consequences. Continuous exposure to contaminated groundwater can lead to serious health problems for the local population, including gastrointestinal illnesses, neurological disorders, and increased cancer risk due to heavy metal exposure. Persistent pollution will lead to the degradation of aquatic ecosystems, affecting biodiversity and the overall health of the environment. This could disrupt local flora and fauna and harm agricultural productivity due to contaminated irrigation water. The cost of dealing with advanced-stage groundwater contamination is significantly higher than preventive measures. The local economy could suffer due to decreased agricultural yields, increased healthcare costs, and potential loss of tourism if the region becomes known for its polluted water. As the quality of groundwater deteriorates, the availability of safe drinking water will decrease, leading to water scarcity. This can cause conflicts over water resources and necessitate the import of potable water, further straining economic resources. Prolonged neglect of groundwater contamination can lead to irreversible damage to aquifer systems, making it impossible to restore them to their original state. This would have a lasting negative impact on the region's water security and ecological balance.

To prevent these outcomes, immediate action is needed. Authorities must enforce stricter regulations on waste disposal and landfill management, upgrade wastewater treatment facilities, establish monitoring systems, and initiate cleanup projects. Public education and engagement in groundwater conservation efforts are also crucial. These steps will help protect groundwater quality in Taza and similar regions, ensuring a healthier and more sustainable future.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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