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First Assessment of Water Quality Impact from a New Landfill in Tangier, Morocco – Microbial and Metal Contamination

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ABSTRACT

This research provides the first assessment of the leachate impact on water sources near the newly installed Landfill and Recovery Center (LRC) in Tangier, Morocco, which has been operational since the beginning of 2021. The investigation involved the analysis of microbiological and chemical parameters in water samples from four community wells and five surface water sources in the M'harar and Tahaddart Wadis during the dry season. Chemical analysis focused on detecting heavy metals, which were quantified using Atomic Absorption Spectrometry. Microbiological analysis involved assessing the presence of Fecal Indicator Bacteria utilizing the membrane filtration method. The findings reveal alarmingly high levels of fecal bacteria and distinct spatial water quality patterns, with a notable gradient of bacteriological contamination in groundwater sources surrounding the LRC. The highest concentrations were noted at well P.1, located about 3.6 meters from the LRC, while at well P.4, located 1 km away, there is a regression in bacterial and metal concentration, suggesting leachate percolation, likely due to construction faults and inadequate waste management. The heavy metal concentrations remained below the World Health Organization's maximum acceptable values. Nevertheless, the overall results of the M'harar and Tahaddart Wadis waters show no leachate runoff. The study highlights the urgent need to improve the installation of proper leachate collection tanks and treatment systems as well as robust environmental monitoring, to protect the ecological integrity of the Biological and Ecological Interest Site (SIBE) of the Tahaddart region and safeguard public health. This study is limited by its focus on a specific geographic area and the timing of sampling, which restricted the groundwater analysis to only four wells. Future research should include sampling across different seasons and a broader range of wells to provide a more comprehensive understanding of water quality dynamics.

Keywords: landfill and recovery center, leachate, percolation, groundwater contamination, landfill management, biological and ecological interest site.

INTRODUCTION

Morocco is a semi-arid Mediterranean country. Rainfall is scarce and irregular; the country is considered water poor (Kadi and Ziyad, 2018). However, these resources are under increasing pressure from population growth, economic expansion, and, decreasing rainfall caused by climate change (Milewski et al., 2020). In addition to water scarcity, Morocco suffers from the deterioration of ground and surface water quality. 30% of which is affected by anthropogenic pollution (fertilizers, wastewater, leachate). The groundwater and surface water resources are largely threatened by a combination of chemical and microbiological contamination (Lotfi et al., 2020). Traditionally, groundwater sources are considered free from pathogenic germs due to the inherent filtration processes within the subsurface environment and the considerable distance microbes would need to traverse to reach these sources. Despite the natural barriers, contaminants can infiltrate groundwater through various pathways. These include insufficient wastewater treatment, improper waste disposal, leaks from underground storage septic tanks or landfills, and other factors (Kumar et al., 2016). Unsystematic landfilling of solid waste affects water resources by generating leachate; a liquid filtered by the moisture and water present in the residues of the organic matter, resulting the biological degradation (Abiriga et al., 2020; Mor et al., 2018; Peng, 2017). Leachate is usually a dark-colored liquid with a strong odor, which carries a high organic and inorganic load. One of its characteristics is an aqueous solution in which five groups of pollutants may be present; dissolved organic matter, macro-inorganic and organic compounds, infectious germs, and heavy metals (Ighalo and Adeniyi, 2020; Vahabian et al., 2019). Infectious germs such as bacteria can cause various epidemics. The most common are cholera, typhoid, diarrhea, skin rashes, etc. (Daniel et al., 2021; Zulić et al., 2019). However, pathogenic organisms are difficult to isolate and analyze directly. Thus, bacterial water quality can be determined using fecal indicator bacteria (FIB). These bacteria are mainly thermotolerant total coliforms, *Escherichia Coli*, *Enterococci*, and *Clostridium perfringens* (Matejczyk et al., 2011; Moravia et al., 2013). The most common heavy metals (HM) in landfill leachate are zinc, cadmium (Cd), lead (Pb), mercury (Hg), nickel, and chromium (Al-Yaqout and Hamoda, 2003; Harahap and Lubis, 2018). The persistence of these metals in ecosystems and their biodegradability pose a particular problem. They are considered potential carcinogens associated with the etiology of various pathologies, such as cardiovascular, renal, blood, nerve, and bone diseases (Alam et al., 2020).

The deterioration of water quality by microbiological and metallic contamination has been the subject of numerous studies in Morocco, (Abbou et al., 2014) confirmed organic, metallic, and microbiological pollution of surface and groundwater due to the influence of leachate discharge in the city of Taza (El Atmani et al., 2018) evaluated the environmental impact of landfill leachate "Oum Azza" in Rabat on the environment. The study revealed that the areas around the landfill site are affected by chemical and organic pollution that puts groundwater contamination below the site at risk (Lekhal et al., 2018) have shown significant pollution of the Wadi of "Boufekrane" and agricultural land adjacent to the landfill of Meknes City due to the flow of leachate that does not undergo any treatment. Another impact study carried out in Kenitra on water sources highlighted the presence of a gradient of metallic contamination of groundwater near the "Ouled Berjal" landfill (Mrabet et al., 2019). Physic-chemical analyses conducted by (Asouam et al., 2021) on surface waters and different wells (often used as a source of drinking water) sampled in the vicinity of the "Tamellast" landfill in Agadir, showed significant contamination due to leachate percolation. (Benaddi et al., 2022) found that the direct discharge of leachate from three different landfills in the Marrakech region into the natural environment without any treatment led to microbiological and metallic pollution of wells downstream of the studied landfills. Despite the efforts of the authorities, the proposed solutions have proven insufficient. The improvement of water management has taken on additional urgency due to climate change and the overuse of water (Legrouri et al., 2019).

Although controlled landfills operate under the protection of a bottom line with leachate collection, it has been shown that the percolation of this liquid into water resources can occur even with these precautions (Fernández et al., 2014). High and moderate subsoil permeability allow infiltration and diffusion of leachate into the groundwater, consequently altering the water resources (El Kharmouz et al., 2013; Laghzal et al., 2018). Despite careful site selection and the installation of geomembrane layers, landfill leakage has repeatedly impacted groundwater quality (Talalaj and Biedka, 2016). In a second sense, due to construction faults, sudden or progressive leachate overflows through site geomembranes can lead to water resource contamination (Grugnaletti et al., 2016).

Therefore, the National Program for Management of Municipal Solid Waste (PNDM) was developed with the support of the World Bank in 2008 and aims to improve solid waste management at national level. The city of Tangier, Morocco, has implemented at the beginning of 2021 a new sanitary Landfill and Recovery Center (LRC) in parallel with the installation of a transfer and reconversion center at Ain Mechlaoua and an intermediate waste depot at Deradeb (Tangier-city district) as part of the PNDM.

The landfill is still in its initial phase, dedicated to receiving and depositing waste without any treatment into the first of designated "cells" within the LRC. These cells are designed and lined to prevent any leakage of toxins (leachate) into the soil or groundwater. It comprises a biogas recovery unit and a leachate treatment system utilizing flocculation and coagulation methods. The leachate is intended to undergo biological treatment in an aerated lagoon. A subsequent phase is currently underway, which involves the establishment of a composting facility and a sorting center aimed at recovering recyclable waste.

The landfill is installed in the central part of Sguedla village a rural area near local inhabitants, agricultural lands, and the Biological and Ecological Interest Site (SBEI) of the Tahaddart region. Approximately 28 km south of Tangier, it covers an area of 157 hectares (Fig. 1).

The total solid waste generated was approximately 400,000 tons in 2019, averaging 0.71 kg per inhabitant per day (Gueriri et al., 2023). The solid waste collected from Tangier city and, from other surrounding areas is managed in two ways:

- waste from three communes (Tangier, Gueznaia, and Laaouama) is compacted at the Transfer Center before being transported and deposited at the CEV.
- waste from nine communes (Al Bahraoyene, Hjar Ennhal, Jbel Lahbib, Assilah, Aguwass Briech, Sahel Chamali, Had Gharbia, Sidi Lyamani, and Dar Chaoui) is transported directly and deposited at the CEV.

This study aims to assess the impact of leachate on water sources near the newly operational Landfill and Recovery Center (LRC) in Tangier, Morocco. We will analyze microbiological and chemical parameters in water samples from community wells and surface water sources in the M'harar and Tahaddart Wadis. Using Atomic Absorption Spectrometry for HM and membrane filtration for FIB. The findings will provide essential insights for policymakers and environmental managers to implement more effective waste management practices. Stations selected for this study have never been examined for bacteriological or metallic quality.

MATERIAL AND METHODS

Study area

The region of Tangier-Tetouan-Al Hoceima has a renewable water potential estimated at 4 billion m^3 per year as an average interannual contribution. Surface water constitutes the bulk of these resources (Direction Générale des Collectivités Locales, 2015). Hydrographic features of the Tangier peninsula include dense Wadis with low and unstable flow (Laghzal and Salmoun, 2014). The region adheres to a subhumid climate (Ouassini and Ouassini, 2021). The interannual rainfall average amounts to 900 mm (Elmaghnougi et al., 2022). The study area borders the commune Hjar Nhal in the west, Al Manzla commune in the southeast, and Wadi M'harar in the north. The Wadi is the main tributary of Tahaddart Wadi in the Tangier basin. It has an average annual contribution of about 450 m^3/year. The studied perimeter is in a rural area characterized by agricultural soils, a weak sewerage network with

Figure 1. Landfill and recovery center of Tangier site design

several septic tanks, and a lack of a drinking water network. The annual average of leachate production is estimated at 110 m^3 per day.

Sampling and analysis

Initially, a preliminary diagnosis was conducted to determine the water quality of wells near the LRC in Sguedla village. Sampling sites were selected based on the groundwater's use for irrigation, livestock watering, and drinking purposes, noting that its quality unknown. The direction of water flow and proximity to the LRC were considered to evaluate potential contamination pathways and associated health risks, ensuring the safety and well-being of the local community and environment.

Heavy metals like Pb, Cd, and Hg were estimated by Atomic Absorption Spectrometry. Graphite furnace atomic absorption spectrometry concerns Pb and Cd. Their wavelengths are 283.3 nm and 228.8 nm, successively. Mercury is determined by cold-vapor atomic absorption spectrometry (CVAA). The CVAA is used to obtain excellent measurement accuracy for Hg concentrations at ultra-trace levels. Microbiological analyses are assessed by detecting FIB. Although these organisms are not directly pathogenic, their presence indicates a risk to consumer health. It is based on the research of *Escherichia coli* (EC), total coliform bacteria, intestinal *Enterococci* (IE), sulfite reducing anaerobic (SRA) bacteria (Cabral, 2010). The samples were collected using sterile polyethylene bottles and placed in a cooler where the temperature was maintained between 2–4 °C and sent directly to the laboratory. The membrane filtration method was used for the bacteriological analysis. This method has the advantage of allowing the use of a larger volume to determine both the concentration and diversity of bacteria, providing quantitative and qualitative data. Colonies that showed shading were counted and expressed as Colony Forming Units (CFU/100 ml). The number (N) of CFU is deduced according to the formula 1:

$$N = \frac{\sum c}{1.1 \times d} \quad (1)$$

where: $\sum c$ represents the sum of colonies counted on the dilution, and d represents the dilution factor.

Nine samples were collected during the dry season (September 2022) from four community wells and five surface water sources in the M'harar and Tahaddart Wadis. This distribution allows for a comprehensive assessment of water quality across the project area. The geographical coordinates of the sample collection sites were recorded using the Global Positioning System

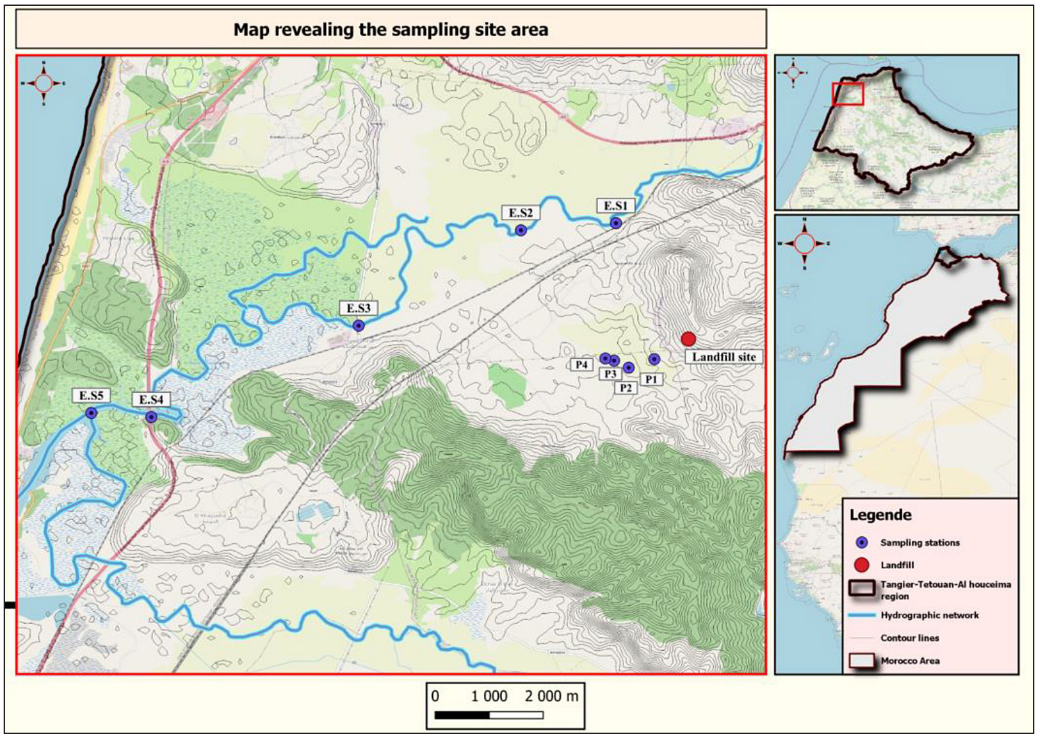


Figure 2. Map revealing the sampling site area

(Table 1), and the mapping of these sites was established using QGIS (Fig. 2).

The sampled public supply wells, designated specifically for domestic use, serve as the primary water source for a representative population. To ensure accuracy, a considerable volume of water was pumped before sampling to avoid stagnation. The wells were labeled as P.1, P.2, P.3, and P.4, respectively (Fig. 3). Additionally, three springs from M'harar Wadi and two springs from Tahaddart Wadi were sampled, labeled E.S1, E.S2, E.S3, E.S4, and E.S5, respectively (Fig. 4). Before filling the bottles were rinsed three times with the sampling water. The samples were then collected in triplicate using sterile polyethylene bottles and kept at 4 °C until transported to the laboratory.

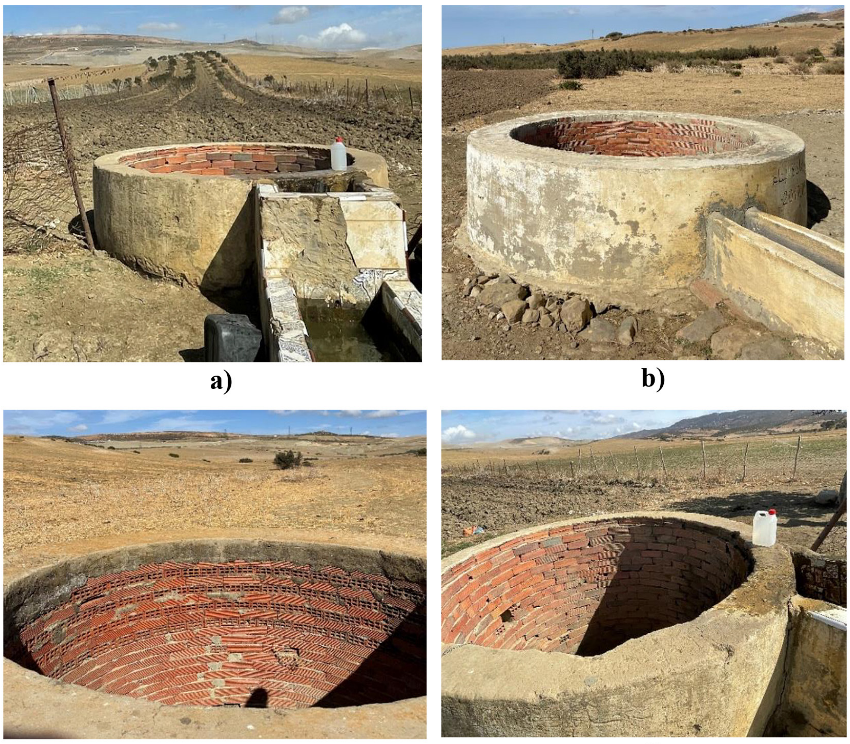
Table 1. Geographical coordinates of samples

Sample code	Geographical coordinates	Distance from landfill (km)
P.1	35.60839, N -5.85845W	0.36
P.2	35.60722, N -5.86472W	0.95
P.3	35.60829, N -5.86687W	0.97
P.4	35.60887, N -5.86745W	1
E.S1	35.63551, N -5.86649W	2.69
E.S2	35.6346, N -5.88457W	3.78
E.S3	35.61529, N -5.91754W	5.98
E.S4	35.59701, N -5.9605W	10
E.S5	35.59861, N -5.97275W	11

RESULTS AND DISCUSSION

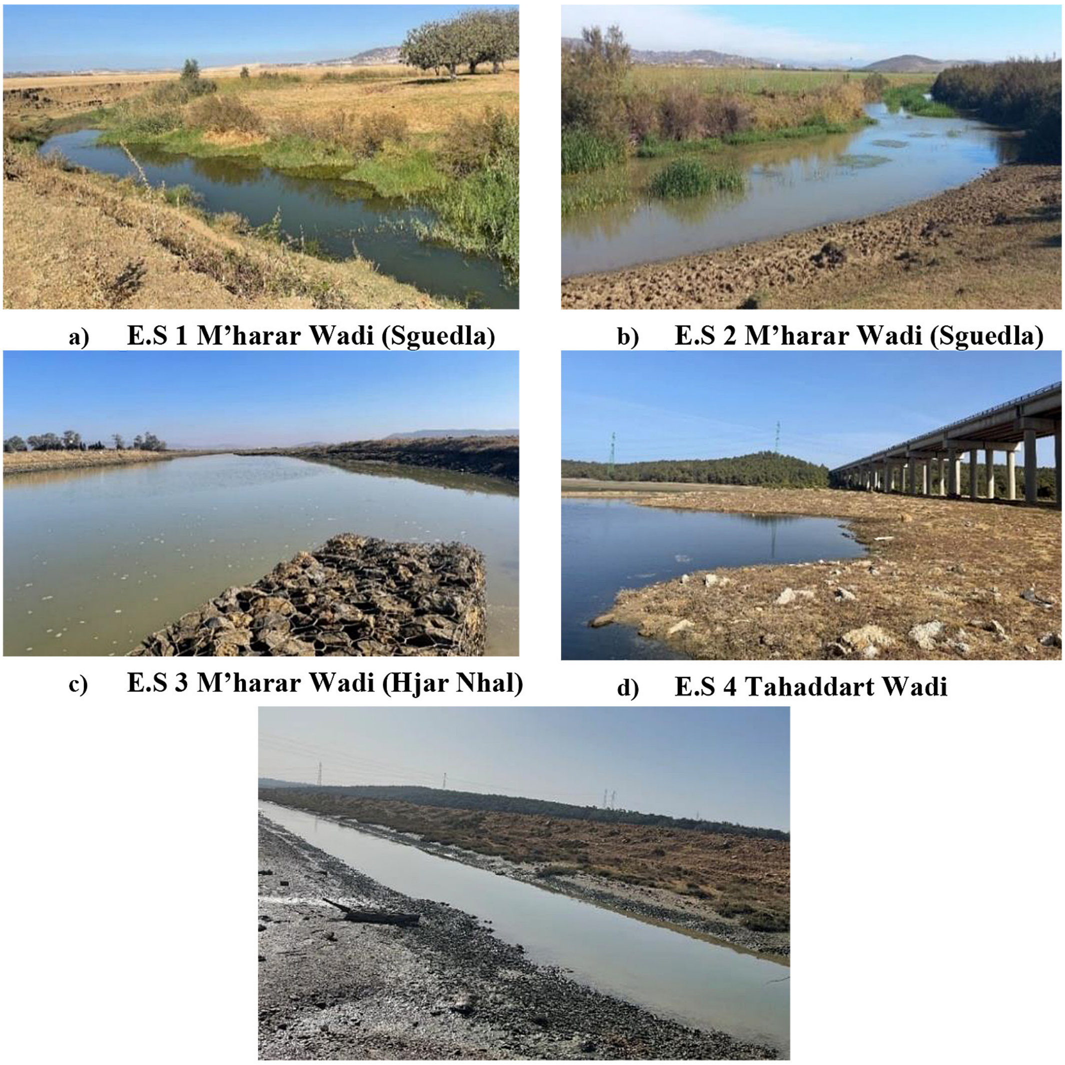
Bacteriological and chemical analyses of water collected from wells adjacent to the LRC

Table 2 provides a summary of the bacteriological concentrations in well samples near the landfill site. The results show alarmingly high levels of TC, EC, IE, and SRA. Specifically, TC concentrations range from 5.1×10^5 to 8.4×10^5 CFU/100 ml, E.C, concentrations range from 2.8×10^2 to 5.6×10^4 CFU/100 ml, I.E concentrations range from 2.9×10^3 to 6.2×10^4 CFU/100 ml, and SRA concentrations range from 100 to 200 CFU/100 ml. These values far exceed the maximum limit of 1000 CFU/100ml set by national standards for water intended for irrigation (NM, 2006). Furthermore, according to the WHO, water intended for human consumption must not contain any pathogenic germs (OMS, 2017). The natural topography of the LRC site facilitates the gravity drainage of leachate and stormwater,



a) b) c) d)

Figure 3. Wells sampled near the landfill and recovery center: (a) P.1, (b) P.2, (c) P.3, (d) P.4



a) E.S 1 M'harar Wadi (Sguedla)

b) E.S 2 M'harar Wadi (Sguedla)

c) E.S 3 M'harar Wadi (Hjar Nhal)

d) E.S 4 Tahaddart Wadi

e) E.S 5 Tahaddart Wadi

Figure 4. Sample collection stations in M'harar and Tahaddart Wadis

potentially leading to contaminated water flowing downstream to nearby wells. The exceedingly high concentrations of these contaminants render the water undrinkable and unsuitable for agricultural use. Despite this, the local inhabitants currently use this water primarily for watering livestock and irrigation, activities that can pose significant health risks due to the contaminated nature of the water. This underscores the necessity for water treatment before it is used for human consumption or irrigation purposes.

The water samples were analyzed to determine the concentrations of lead (Pb), cadmium (Cd), and mercury (Hg). The heavy metal concentrations in well water samples collected near the landfill are presented in Table 3. The results indicated that the concentrations of these heavy metals did not exceed the maximum acceptable value (MAV) according to Moroccan standards (NM, 2006), and those set by WHO (OMS, 2017). The absence of metallic contamination can be attributed to the landfill's relatively recent establishment (less than five years) and the composition of the leachate. Typically, young leachate contains relatively low concentrations of heavy metals and undergoes significant attenuation through processes like precipitation and sorption (Samadder et al., 2017). The age of a landfill is crucial in determining the quality of leachate, which in turn influences the degree of groundwater pollution (Abiriga et al., 2020).

To better understand the quality of wells-water near the landfill, Figure 5 shows the spatial variations of pathogens and HM in the surveyed wells-water samples. The highest concentrations were noted at well P.1, located about 3.6 meters

Table 2. Germ concentration in well-waters in CFU/100 ml

Wells	Germes (CFU/100 ml)			
	T.C	E.C	I.E	S.R.A
P.1	8.4×10^5	5.6×10^4	6.2×10^4	200
P.2	7.8×10^5	4.6×10^4	4.2×10^4	180
P.3	6.2×10^5	3.3×10^4	3.5×10^4	120
P.4	5.1×10^5	2.8×10^2	2.9×10^3	100

Table 3. Heavy metals concentration in wells-water samples in µg/L

Parameter (µg/L)	Samples				MAV	
	P.1	P.2	P.3	P.4	MS*	WHO
Pb	1.009	0.798	0.292	0.083	50	10
Cd	0.237	0.043	0.067	0.035	5	3
Hg	N.D	N.D	N.D	N.D	1	1

Note: *(MS 03.07.001, 2006) N.D: non detected.

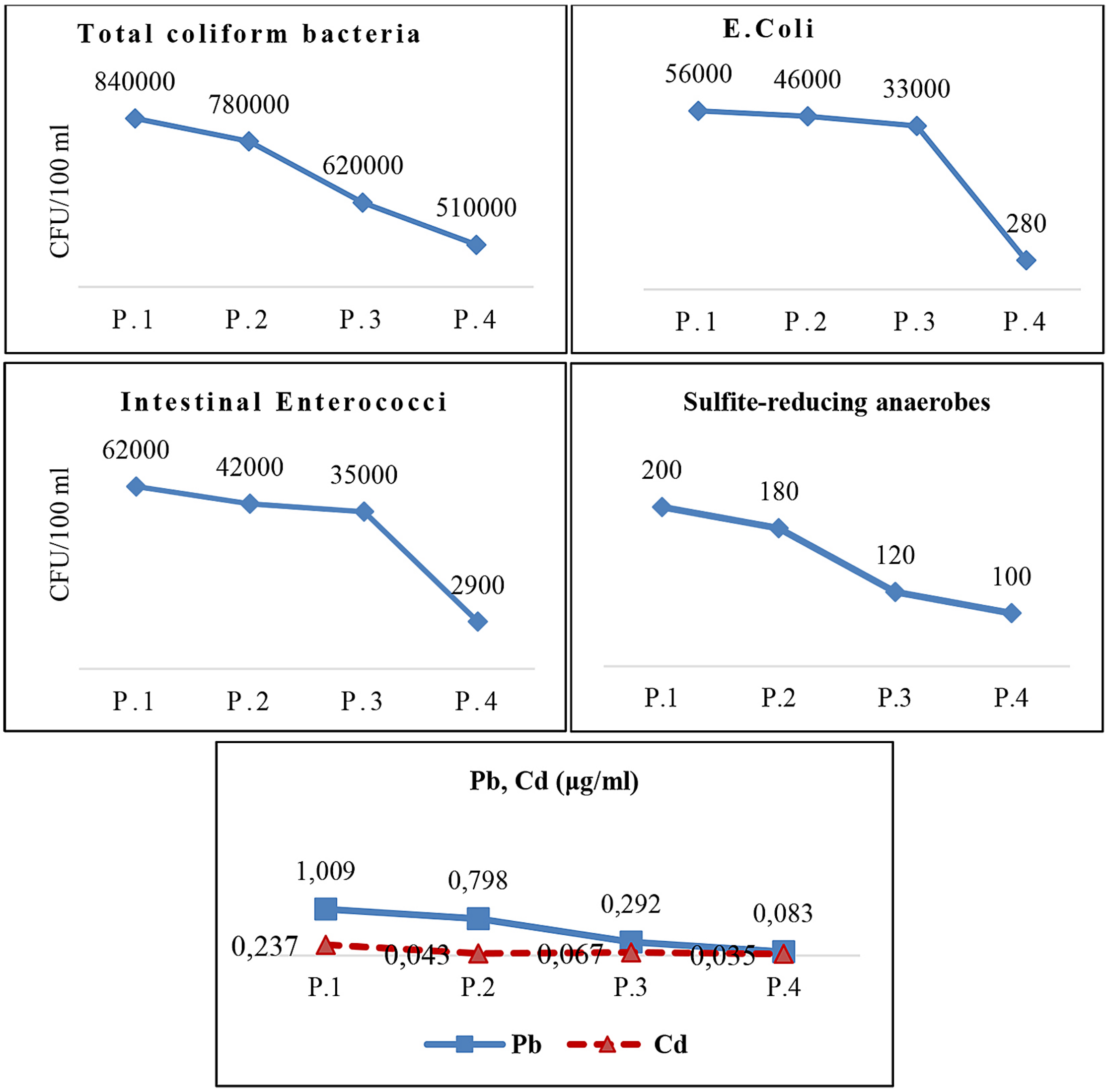


Figure 5. Spatial variation of total coliform bacteria, *Escherichia coli*, intestinal *Enterococci*, sulfite-reducing anaerobes, lead, and cadmium in wells-water samples

from the LRC, while at well P.4, located 1 km away, there is a regression in HM and bacterial concentration. The points closest to the LRC where the highest values of FIB contamination are reported.

This finding, coupled with residents' reports of changes in well watercolor and odor since the installation of the LRC, strongly suggests that leachate has likely contaminated the water in these wells. The high bacteriological concentrations observed in wells near the landfill further indicate leachate contamination. Researchers have identified two main routes for sanitary landfill leachate migration (Zeng et al., 2021). The first route is through advective and dispersive transport, where leachate spreads with the water flow. The second route involves diffusive transport, where contaminants migrate through defects in the geomembrane seams or through the clay layer under the geomembrane. These distinct pathways emphasize the complexity of leachate migration within landfill systems (Zeng et al., 2021). The LRC site has a natural topography suitable for gravity drainage of leachate and stormwater, noting that the soil is marly clay of low permeability and not impermeable. These characteristics are favorable to leachate flow under the effect of the slope when the collection basin is submerged; the water containing contaminants can flow downstream along wells in the vicinity. Thus, small pockets of water that feed the wells around the landfill may be polluted. Immediate and effective measures are needed to manage and treat leachate from the landfill to prevent further pollution. This includes the installation of proper leachate collection tanks and treatment systems.

Bacteriological and chemical analysis of M'harar and Tahaddart Wadis

In this section, we discuss the results of the water quality of M'harar Wadi, one of the most important rivers in the Tangier basin, and its main watershed Tahaddart (Table 3). The national environmental quality standards distinguish between surface waters by five quality classes. The surface waters of Wadi M'harar are classified as good to medium bacteriological quality according to MS at different collection points (ES.1, ES.2, ES.3). The samples ES.1 and ES.3, record a higher concentration of FIB contamination, these stations are near the settlements of the residents of Sguedla and Hjar Nhal villages, respectively, the households use mainly septic tanks from which the fecal contamination is higher. Bacteriological analyses of the Tahaddart Wadi revealed an excellent to good quality of surface water, and no detection of pathogens in point ES.4, nevertheless, TC and EC are present in ES.5 (5.4×10^3, 3.7×10^3 CFU/ml, respectively), the absence of I.E confirms a recent pollution of this point, perhaps of animal origin. The varying levels of bacteriological contamination at different sampling points underscore the influence of human settlements and agricultural activities on water quality. In particular, the higher FIB concentrations at ES.1 and ES.3 can be attributed to the inadequate waste management practices in nearby villages, where septic tanks are commonly used. In contrast, the excellent to good water quality at other points in the watershed, such as ES.4, highlights areas with lesser human impactfig (Table 4).

Not detected

The results of the determination of Hg in the analyzed samples indicate that there is no mercury contamination in any of the collected samples. This is likely due to mercury's propensity to evaporate easily at room temperature. In contrast, non-negligible levels of Pb and Cd were found.

According to Moroccan classifications, ES.1 and ES.2 are classified as having excellent quality, as there is no industrial activity in the vicinity of these points. However, points ES.3, ES.4, and ES.5 show high levels of Cd and Pb. The midstream of M'harar Wadi and the upstream of Tahaddart Wadi are considered to be of medium quality. The presence of Pb and Cd in ES.3 could be attributed to anthropogenic inputs such as agricultural soil leaching, livestock waste, or industrial discharges. Notably, an industrial fiber company is located a few meters from this sampling site.

The Pb content in ES.4 reaches a maximum value of 39.6 μg/L. This could be related to the station's location below a busy highway, as previous studies have documented significant concentrations of Pb in runoff from heavily trafficked road networks (Pratap et al., 2020). Pb is introduced into the road environment mainly through fuel combustion and is considered one of the most important contaminants of highways (Pereira et al., 2007). The impact of Pb on receiving environments, such as water, cannot be neglected due to the risks it poses to human health, especially the transmission of toxic elements via aquatic

Table 4. Bacteriological and chemical water quality of M'harar and Tahaddart Wadis

Wadi	Sample	Germs (CFU/100 ml)			Bacteriological quality	Parameter (µg/L)			Chemical quality
		T.C	E.C	I.E		Pb	Cd	Hg	
M'harar	E.S1	$7.4×10^4$	$1.3×10^3$	$1.2×10^3$	Medium	0.25	0.01	N.D	Excellent
	E.S2	$2.4×10^4$	$9.1×10^2$	$2.5×10^2$	Good	0.86	0.05	N.D	Excellent
	E.S3	$1.1×10^5$	$6.4×10^3$	$6.1×10^3$	Medium	15.3	5.4	N.D	Medium
Tahaddart	E.S4	N.D*	N.D	N.D	Excellent	39.6	6.9	N.D	Medium
	E.S5	$5.4×10^3$	$3.7×10^3$	N.D	Good	14.1	6.4	N.D	Medium

organisms that serve as food sources for humans (Chinwe et al., 2010). The region of Tahaddart is classified as a site of biological and ecological interest (SBEI). The anthropic pressure in the region is a real driver of the degradation of natural resources in the SBEI of Tahaddart Wadi (Zayoun et al., 2022). These results highlighted the direct impact of bacteriological contamination generated by raw domestic wastewater from the inhabitants and agricultural activity of this region, also we revealed significant metal pollution due to the highway network linking Tangier to Rabat. Nevertheless, the overall results of the waters of M'harar and Tahaddart Wadis, located at about 3 and 10 km, respectively, from the LRC, show that there was no leachate runoff during the dry season.

CONCLUSIONS

In conclusion, the comprehensive study revealed spatial differentiation of watercourses near the landfill site (LRC), indicating the presence of a gradient of bacteriological contamination in groundwater from wells P1, P2, P3, and P4. The natural topography of the LRC site facilitates the gravity drainage of leachate and stormwater, potentially leading to contaminated water flowing downstream to nearby wells. This finding, along with reports from residents about changes in well watercolor and odor since the LRC installation, suggests that the leachate has likely contaminated the water in these wells. As a result, the water is not suitable for drinking or irrigation purposes. While the leachates are collected and drained into a biological treatment lagoon, construction faults, inadequate management, and lack of environmental monitoring at the LRC pose a risk to natural resources and human health. The LRC is in a rural area near the agricultural lands and SBEI of the Tahaddart region, designed to prevent any contamination of water sources. Additionally, the study highlights those nearby Wadis showed no leachate runoff during the dry season, but bacteriological contamination from domestic wastewater and significant metal pollution from the highway network linking Tangier to Rabat were evident. To ensure sustainable development and preserve the environment, it is essential to adopt new policies and methods. This includes developing sewerage infrastructure in rural areas, continuous monitoring of water and effluent quality using various tools and implementing an LRC operating plan with regular internal and external audits. Moreover, environmental and safety certifications should be mandated for new activities, and strict measures must be taken against any illegal exploitation of water or activities that may compromise water quality. These steps are crucial to safeguarding the region's natural resources and human wellbeing. Future research should include sampling across different seasons and a broader range of wells to provide a more comprehensive understanding of water quality dynamics.

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