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Physicochemical Analysis of Leachates from the Public Landfill of Guercif City Before Restoration and Impact on the Tafrata Water Table, Soil, and River Moulouya in Morocco

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ABSTRACT

The leachate from the landfill of the city of Guercif (Morocco) is considered to be a major source of pollution. The present study is aimed to carry out physico-chemical analyses following Rodier's methodology in order to determine the degree of pollution of leachate from this landfill on the water table of Tafrata, the soil, and the Moulouya River. Six sampling stations in the province of Guercif were selected for the study. The method of Rodier, which distinguishes between in situ measurements and laboratory analyses, was used for the physicochemical analyses. The results revealed chemical pollution of the leachates with a BOD_5 of 860 mg O_2/L, a COD: 86678.19 mg O_2/L, a NO_2: 5.086 mg/L, a NO_3^-: 61.07 mg/L, and an NH_4^+: 30.953 mg/L. However, Moulouya river water had a BOD_5: 150 mg O_2/L, a COD: 168.51 mg O_2/L, NO_2^-: 0.660 mg/L, NO_3^-: 31.27 mg/L and NH_4^+ of 0.45 mg/L. The Tafrata water table presented at the level of P1 (BOD_5: 45 mg O_2/l, COD: 131.97 mg O_2/L, NO_2^-: 0.126 mg/L, NO_3^-: 25.6 mg/L, NH_4^+: 0.52 mg/L), and the landfill soil after leachate percolation had S1 (Al: 1 mg/L, Cd: 1 mg/L, Co: 1 mg/L, Cr: 3.4 mg/L and Pb: 2.9 mg/L) and S2 (Al: 383 mg/L, Cd: 1 mg/L, Co: 1 mg/L, Cr: 3.3 mg/L, Pb: 1 mg/L). The conclusion indicates that the landfill has negative impacts on groundwater, river Moulouya water and soil.

Keywords: Leachates, Tafrata water table, River Moulouya, Guercif, Morocco.

Introduction

The generation of waste in Morocco is increasing at a faster rate as a result of population growth,[1] technical, industrial, and agricultural development. The landfill is the most appropriate method for removing this waste. However, it harms the environment. Some of the negative effects include the release of offensive odors,[2] the production of biogas with a greenhouse effect,[3] and the contamination of the ground by leachates, which is the most polluting source of surface and groundwater. Pollution can develop as a result of leachate percolating through the bedrock and contaminating the water table,[4] or as a result of waste being discharged into the surface water system. These two types of pollution have the potential to be harmful to both humans and the environment. Morocco, like many other countries, has uncontrolled landfills in the cities of Saidia,[5] al Jadida, sidi Kassem, Oujda, Meknes,[6] Fez (until 2012), and Guercif. A study of the city of Guercif's landfill before and after its development and restoration project was conducted as part of environmental protection and enhancement. The environmental impact of this landfill was investigated by identifying leachate infiltration through natural barriers, which results in deterioration of groundwater and surface water quality.

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Physicochemical characterization of leachate, groundwater, surface water, and landfill soil before and after restoration was also used to investigate physical and chemical perturbations in the receiving environment. These studies were carried out in accordance with Rodier's[7] water quality assessment techniques and Moroccan standards of 2013.[8] Temperature, pH, electrical conductivity, dissolved oxygen, turbidity, Suspended solids (SS), Biochemical oxygen demand (BOD_5), Chemical oxygen demand (COD), nitrate, nitrite, sulphate, orthophosphate, metals (Fe, Ni, Pb, Al, Mn, Cr, Co, Cd), trace elements (Na, K, Ca, Mg) are examples of these standards.

The aim of this study was to provide an assessment of the main physicochemical characteristics of leachates on groundwater, soil, and surface water of Moulouya before rehabilitation, to quantify the degree of contamination of the Guercif landfill and its environment.

Materials and Methods

Study area

The landfill of the city of Guercif is a wild, open-air dumping ground with rubbish dumped recklessly and in a disorganized manner over a 44 hectare area.[4] It is located in the province of Guercif, which is a subdivision of the Oriental region, bounded to the north by the provinces of Nador and Driouach, to the west by the province of Taza, to the east by the province of Taourirt, and to the south by the province of Boulemane. The study location is 3.5 km from the urban perimeter (6 km from the city center), on the territory of the rural commune of Houara Ouled Rahou (Figure 1). It is strategically located on the national route N°6 connecting Rabat-Oujda and the national road N°15 connecting Guercif-Nador, Guercif-Midelte, and Er-Rachidia. The region has a legal population of 216.717 inhabitants.[9]

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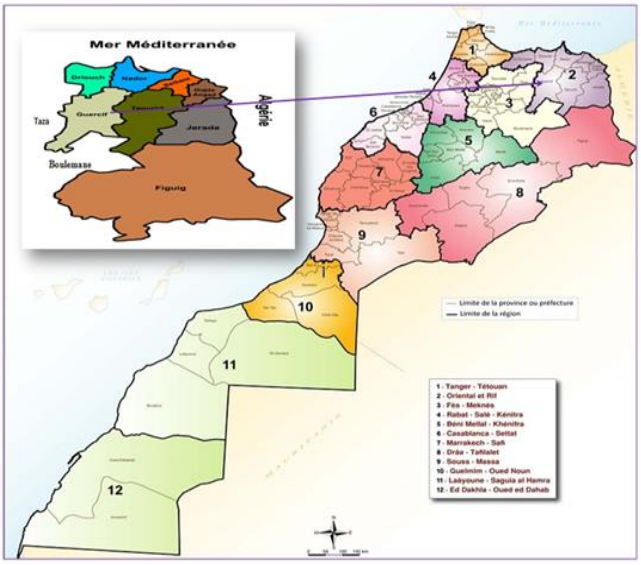

Figure 1: Geographical locations of the studied region. (https://www.challenge.ma/Les-fonds-regionaux-au-maroc-une-experience-peu-concluante-78868/)

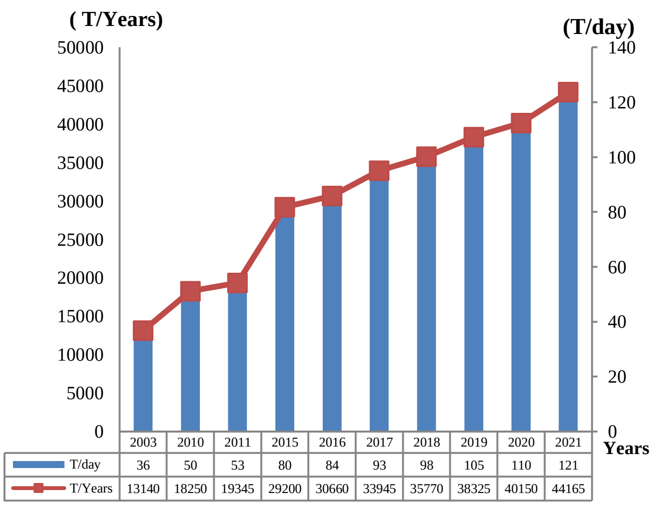

Figure 2: Evolution of the quantity of tonnage of the landfill of the city of Guercif.

The province of Guercif is divided into nine rural communes and one urban commune (the town of Guercif) as illustrated in Figure 1. The geological environment of the landfill is characterized by flat ground with a conglomerate and sandy cover, as well as a limestone structure that enables leachate percolation towards the water table and groundwater pollution.[4] The study area has a semi-arid climate with harsh and cold winters, hot and dry summers, and low and irregular rainfall that does not exceed 200 mm/year.[4]

Quantity of waste produced

According to the Municipal Park Service of Guercif, the amount of waste produced per individual per day is about 1 kg/inhabitant/d, with a daily production of household and similar waste of approximately 80 T/d in 2015, and 121 T/d in 2021 (Figure 2). The number of household waste increases in parallel with the evolution of the population.[4] For example, between 2013 and 2020, the quantity of household waste at the level of the rural commune of Houara Oulad Rahou increased from 4.3 to 5.5 T, with an estimated population of 34.147 to 43.445 (Table 1).

Types of waste

The public dump in Guercif comprises many sorts of waste, including solid, liquid, and industrial liquid waste. Industrial waste such as agro-industrial, textile and cooking chemistry, and parachemistry, olive industry, hospital waste that is neither incinerated nor sterilized, handicrafts waste, and souk waste that is collected once a week by the municipal park service and contains waste from chickens, fish, trade, plastics, and glasses (Table 2). The extraction of olive oil by oil mills increases the amount of liquid waste, the majority of which is discharged regularly in the rural commune of Houara Old Rahou and the center of Guercif, where the dump is located (Table 3). Industrial liquid waste comprises the discharge of liquid waste, which is done most of the time by the textile industry and other industries present at the city level.

Sampling methods

Six sampling stations were chosen for the study (Figure 3). Samples were collected at two groundwater stations (P1 and P2), a station corresponding to samples of surface water from Moulouya (OM), a station corresponding to samples of leachate (Lx) from the landfill, and samples obtained from two landfill soil stations (S1 and S2) for heavy metals and trace element analysis. The characterization of the quality of groundwater, surface water, leachate, and soil was carried out over five months, from February to June 2017, with several samples collected at each station.

Physico-chemical analyses

The Rodier methodology,[7] which distinguishes between in situ measurements and laboratory analyses, was employed for the physicochemical analyses.

Table 1: Evolution of the population and household garbage of the Houara Oulad Rahou center by 2055 discharging into the Guercif landfill (Source: Moulouya Hydraulic Basin Agency)

Designations	YEARS											
	2004	**2013**	**2015**	**2017**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**
Population of CR Houara Oulad Rahou	25055	34147	36580	39185	43445	51599	61284	72786	86447	102671	121941	144828
Population of the Houara O Rahoucenter		6829	7316	7837	8689	10320	12257	14557	17289	20534	24388	28966
Growth rate / Pop-%	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Daily OM production (T)		4.3	4.6	4.9	5.5	6.5	7.7	9.2	10.9	12.9	15.4	*18.8*

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Table 2: Composition of solid waste from Guercif (Source: Moulouya Hydraulic Basin Agency, 2011).

Composition		Percentage (%)	
Organic material		74.65	
Glass		2.22	
PET		0.42	
Plastic materials	PVC	2.08	10.45
	Plastic bags	8.37	
Textile Paper		11.87	
Metals		0.35	

Table 3: Quantity of liquid industrial discharge from the province of Guercif (Source: Moulouya Hydraulic Basin Agency, 2011).

Municipalities	Liquid discharge volume (m^3/year)	Liquid discharge volume	Receiving medium
Houara Old Rahou	2930	4	Sol
Guercif	1 244	1	Sol

In situ physicochemical measurements

Some physicochemical parameters, such as the potential of hydrogen (pH), electrical conductivity, temperature, and dissolved oxygen, were measured in the field during sampling following Moroccan standards 03.7.059 of 2013 (5.5).[8]

Laboratory physicochemical analyses

The samples were transported to the laboratory in coolers, following national and international standards to avoid accelerating the biological and physicochemical processes. The analyses of the chemical parameters were carried out in the Laboratory of Biotechnology, Department of Biology, Faculty of Science, Dhar El Mehraz Fez, following the methodology of Rodier[7] (Table 4). The physicochemical parameters include turbidity, suspended solids (SS), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), nitrogenous compounds: nitrate (NO_3), nitrite (NO^-_2), ammoniacal nitrogen (NH_4^+), phosphate compounds: orthophosphates (PO_4^{3-}), sulphate anion (SO_4^{2-}). However, the heavy metal and trace element measurements were carried out at the City of Innovation in Fez by inductively coupled plasma (ICP) atomic emission spectroscopy.

Statistical analysis

All the results obtained were processed using descriptive statistical methods (mean, standard deviation, coefficient of variation, p-value), and presented in summary tables, in order to determine the pollution situation of each site.

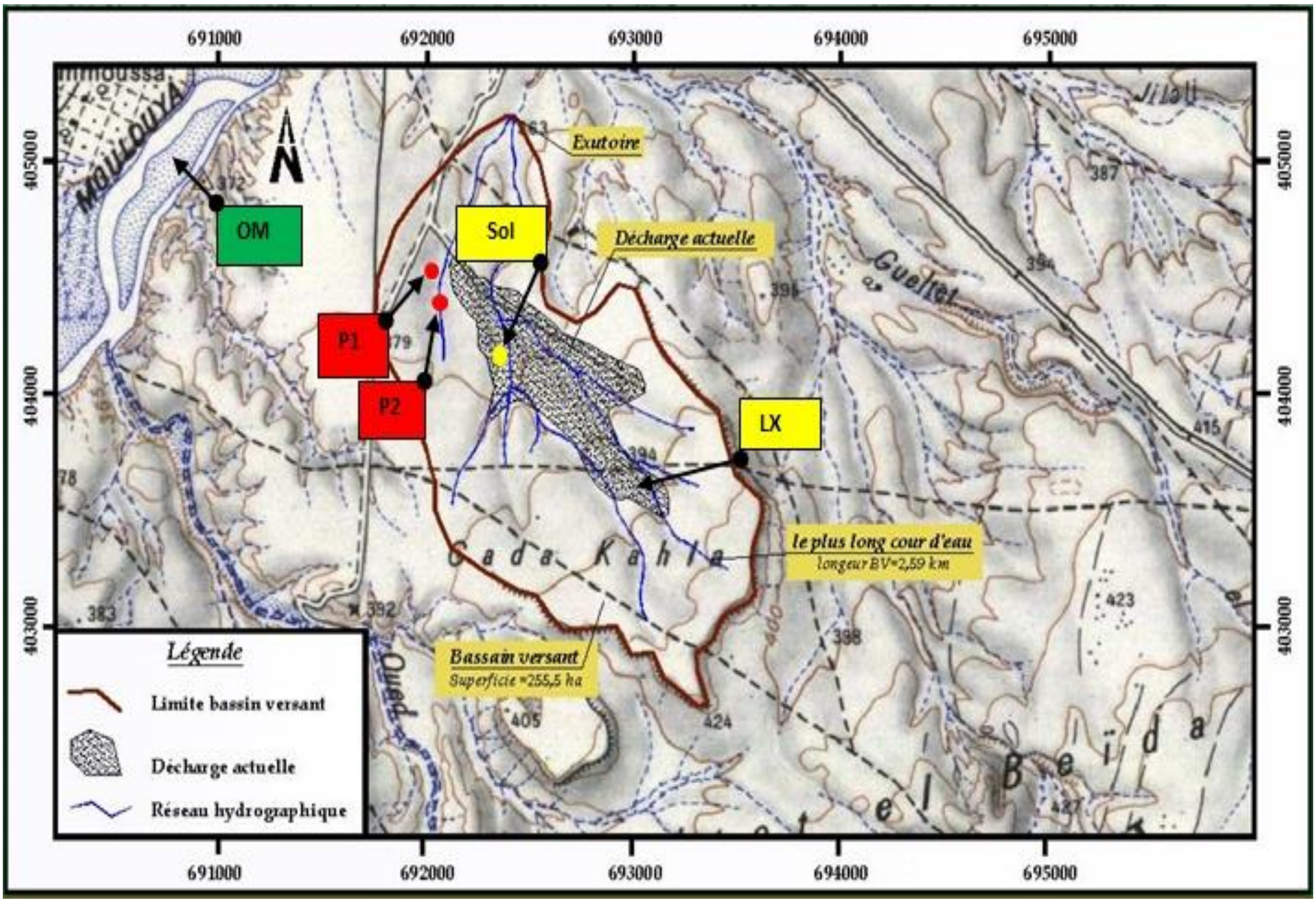

Figure 3: Situation map of the uncontrolled Guercif landfill (Source: Moulouya Hydraulic Basin Agency). Various sampling points in the landfill area of the city of Guercif (Nora Zamani).

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Table 4: Measurement equipment and methods of analysis of chemical parameters according to the methodology of Rodier.[7]

Settings	Methods - Experimental Equipment
pH	Multi 3430 WTW pH meter
Conductivity	Lovibond conductivity meter type: Turbi Direct
Temperature	Multi 3430 WTW type analyzer
DCO	COD meter. COD REACTOR model
DBO_5	BOD meter type Oxi TOP®
Dissolved oxygen	Multi 3430 WTW type analyzer
PO_4	are characterized according to Rodier (1996) by the colorimetric method which is based on the formation.in an acidic medium.of a complex with ammonium molybdate and double antimony and potassium tartrate.
NO_3^-	are reduced to nitrites in the presence of sulfo-salicylic acid. Followed by colorimetric assay according to Rodier (1996).
NO_2^-	are assayed by the Zambelli reagent method, then colorimetric assay according to Rodier (1996).
NH_4^+	NH^+_4 ions treated with a solution of chlorine and phenol give indophenol blue capable of colorimetric determination according to Rodier (1996).

Results and Discussion

pH in the study locations

The pH measurement results show that the evolution of the pH level at well N°1 is acidic (Figure 4). This acidity could be due to the impact of leachate, which has an acidic pH (pH = 5.5 ± 0.1) due to its proximity to the landfill site (almost 50 m). In comparison to other landfills, it was discovered that the pH values of leachate from the city of Guercif were higher than those of Abobo-Dokoui (Ivory Coast) (pH = 3.69),[10] and lower than values recorded in some Moroccan cities such as Meknes (pH = 7.48),[6] Larache (pH = 7.87),[11] and Agadir (Morocco) (pH = 6.2),[12]. The acidic properties of this leachate could be because the landfill was more recent than other landfills.

Electrical conductivity of the study locations

Changes in electrical conductivity indicate changes in the chemical composition of the water, as well as changes in the mineralization of organic matter by bacterial activities. The electrical conductivity measurements obtained during the study revealed important mineralization that exceeded the Moroccan standards of 2013 (2700 µs/cm),[8] in the leachates (12300±130.5 µs/cm). This observation could be attributed to the nature of discharges such as domestic, artisanal (dyes), agro-alimentary, industrial, particularly the textile industry (washing of jeans). Surface water and groundwater (P1, P2) both had extremely high conductivity values (Figure 5). This could be explained by the percolation of leachate, which is highly polluted due to the presence of these wells near the dump. This leachate has a p-value (< 0.00001) which means that the hypothesis is statistically significant ($p < 0.05$).The average electrical conductivity of leachate from the Guercif landfill was much lower than in Kenitra (22792 µs/cm),[13] Larache (64600 µs/cm),[11] Essaouira (39983 µs/cm),[14] and Meknes (30805 µs/cm).[6]

Temperature and dissolved oxygen of the study stations.

The results indicated that temperature does not show a big change from one station to the next, with a slight increase in leachate temperature (27.9±2.005°C) when compared to the other stations (Figure 6). The amount of dissolved oxygen was low in the leachate (0.51±0.14 mg/L) as shown in Figure 7 compared to the Niamey (Niger) leachate (2.7 mg/L).[15] This amount was also low in the surface water (1.31±0.37 mg/L), and in the wells: P1 (5.67±0.82 mg/L) and P2 (5.88±0.80 mg/L) which are closer to the landfill. This can be explained by the presence of microorganisms that consume oxygen by degrading organic matter.

Turbidity of the study locations

Turbidity is a critical optical property for light distribution through water. It varies depending on the amount of suspended matter.

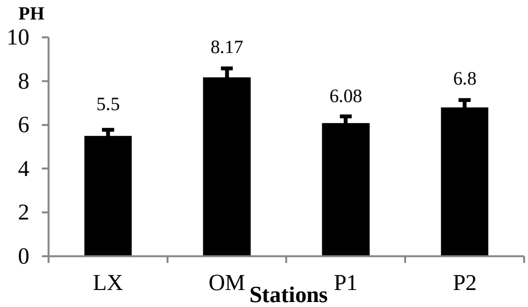

Figure 4: Spatial variation of the means and standard deviations of pH of study locations. LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

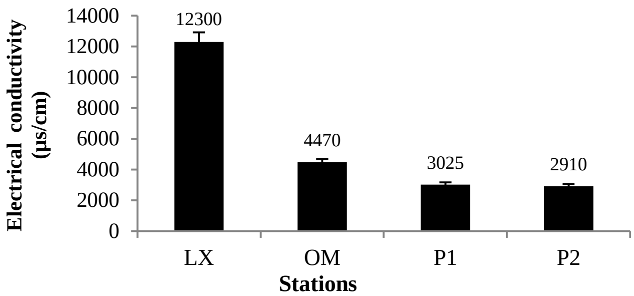

Figure 5: Spatial variation of the means and standard deviations of electrical conductivity at the study stations.
LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

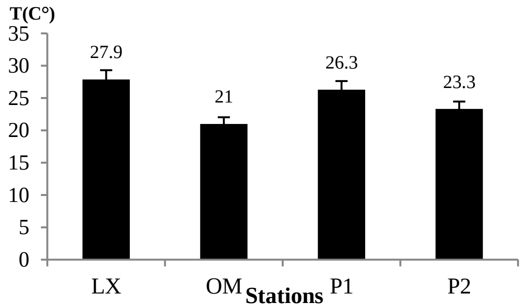

Figure 6: Average temperature variation of the study stations.
LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

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Figure 8 highlights that turbidity reaches its peak at the level of leachate (1058.2±115.6 NTU), indicating the presence of a high pollutant load, and at the level of surface water (618.7±269.6 NTU), but decreases at the level of groundwater (P1: 0.48±0.16 NTU, P2: 0.42±0.39 NTU).

Suspended solids content in the study locations

The leachates from the city of Guercif's landfill have a high concentration of suspended matter (461.2±74.6 mg/L), reflecting a large amount of waste discharged (Figure 9). These values remained high at the surface water level (OM: 39.3±11.24 mg/L), giving the water a cloudy appearance. However, the groundwater has a very low amount of suspended solids (P1: 0.63±0.33 mg/L; P2: 0.87±0.24 mg/L). The average concentration of suspended solid in Guercif's leachate is higher than that recorded in Essaouira (146 mg/L),[14] but remains lower than those recorded in Agadir's landfill (12560 mg/L),[16] and Meknes (832 mg/L).[6] These significant concentrations represent an indicator of the high organic and mineral load due to the nature of the waste. The average concentration of suspended solids in Guercif's leachate is higher than that recorded in Essaouira (146 mg/L),[14] but remained lower than that recorded in Meknes' landfill (832 mg/L).[6] These significant concentrations represent an indicator of the high organic and mineral load due to the nature of the waste. The leachate's high turbidity (1085.2±115.6 UNT), high SS content (461.2±74.6 mg/L), and low dissolved oxygen concentration indicate that it is highly polluted.

Biochemical oxygen demand of the study stations

Biochemical oxygen demand (BOD_5) values peaked at the leachate level (860±110 mg O_2/L), exceeding the average value of 40 mg O_2/L established by Moroccan standards of 2013 (Figure 10) for surface water and similarly for groundwater (P1: 45±19 mg O_2/L, and P2: 41±17.24 mg O_2/L). The average BOD_5 levels in the Guercif landfill leachate (860±110 mg O_2/L) were higher than in Meknes (598 mg O_2/L),[6] and Essaouira (632 mg O_2/L), but lower than in Agadir (18062 mg O_2/L),[12] and Jawaharnagar in India (996 mg O_2/L).[17]

Chemical oxygen demand of the study locations

Chemical oxygen demand (COD) values (Figure 11) were high at the leachate level (86678.19±11117.72 mg O_2/L) and at the surface water level. This amount exceeded the Moroccan standards (2013) value of 120 mg O_2/L and in well water (P1: 131.97±59.71 mg O_2/L and P2: 121.19±53.49 mg O_2/L). The COD values were very high at the level of leachate, which explains the very high pollution load caused by the various types of discharges, and quite high at the level of surface water, and P1, P2 compared to Moroccan standards of 2013. This observation indicates that these waters have pollution potential because they are present in the vicinity of the landfill, and they should be treated before use, fils p-value (< 0,00001) is Statistically Significant (p<0,05). The average value of COD in the Guercif landfill leachate (86678.19±11117.72 mg/L) exceeded the limit value of direct discharge, which is estimated at 500 mg/L. This value was much higher than those of the landfills of Agadir (38135 mg/L),[12] and Meknes (3346 mg/L),[6] indicating the significance of pollution in the Guercif landfill leachate.

Nitrate (NO_3^-) content in the study locations

In both surface and groundwater, nitrates are the most prevalent form of nitrogen. They are generally formed as a result of the decomposition of organic matter by bacterial oxidation of nitrites and thus form a nitrification product. The histogram of average nitrate concentration (Figure 12) shows very high levels of leachate (61.07±7.66 mg/L). This trend can be explained by the fact that it is very rich in organic matter, as well as relatively high values for the river Moulouya OM: 31.27±10.67 mg/L, P1: 25.6±5.71 mg/L, and a slight variation of this content at the level of the other P2 well, which attains 15.1±4.35 mg/L. However, these values remain lower than the admissible value by Moroccan standards (50 mg/L), indicating that the water studied is not at risk of nitrate pollution. This can be explained by the fact that the form of nitrate studied is an unstable form that is dependent on the physical and biological conditions of the environment.

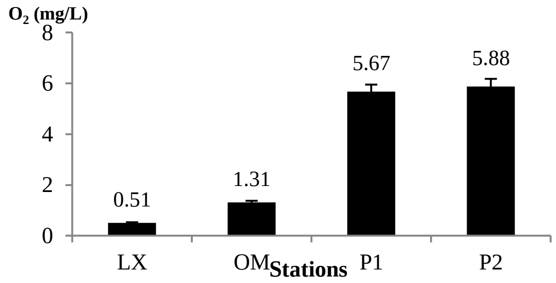

Figure 7: Change in dissolved oxygen at the study stations.
LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

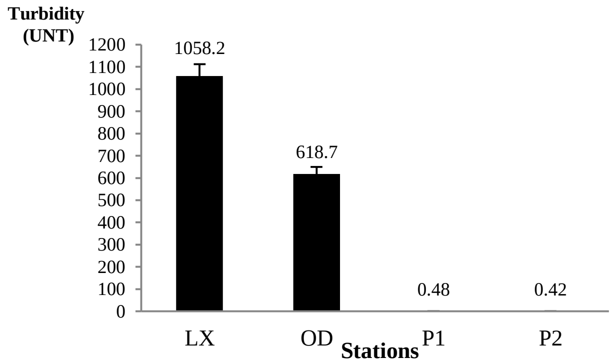

Figure 8: Average change in turbidity of the study stations.
LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

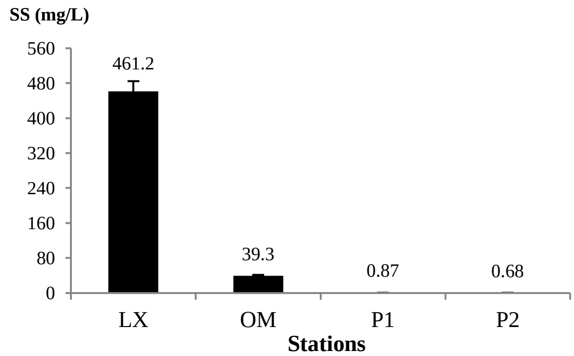

Figure 9: Average suspended solid concentration of the study stations. LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

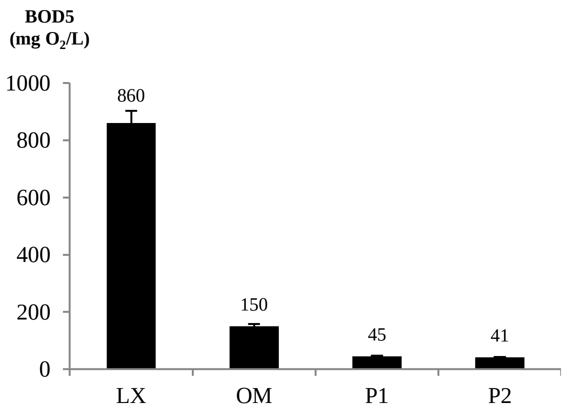

Figure 10: Average biochemical oxygen demand (BOD_5) content in the different study stations.
LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

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The presence of certain toxic elements of industrial origin, such as Cr, Ni, and Cd, inhibits the bacteria that cause the oxidation of NH_4 into nitrate and nitrite. The average nitrate value at the Guercif leachate level (61.07±7.66 mg/L) is much higher than the limit value for direct discharges into the receiving environment, which is estimated at 50 mg/L, and it is also higher than the value registered in Meknes (8.71 mg/L).[6]

Nitrite (NO_2^-) content in the study stations

The average nitrite concentration in leachate (5.086±3.61 mg/L) and surface water (0.66±0.57 mg/L) of the stations studied was high (Figure 13), with small variations ranging from (0.126±0.04 mg/L (P1) to 0.281±0.39 mg/L (P2) for groundwater.

Ammoniacal nitrogen (NH_4^+) content in the study locations

According to Figure 14, the concentration of ammoniacal nitrogen in leachate was very high (30.953±1.005 mg/L), and low in groundwater (P1: 0.53±0.17 mg/L; P2: 0.52±0.04 mg/L). Meanwhile, the Moulouya river falls within Moroccan standards (BO N° 6202)[8] by 0.45 mg/L. This observation is due to organic pollution of agricultural, domestic, or industrial origin, which results in the incomplete degradation of organic matter.

Orthophosphates (PO_4^{3-}) content in the study locations

The highest values were recorded at the leachate level (30.808±1.537 mg/L), as well as in wells P1 (1.092±1.05 mg/L) and P2 (0.692±0.07 mg/L) near the public dump as shown in Figure 15. This can be explained by the impact of percolate from various types of waste deposited on the landfill, as it can come from chemical fertilizers used by local farmers.

Sulphates (SO_4^{2-}) content in the study locations

The sulphate (SO_4^{2-}) determination results show very high concentrations at the level of leachate (4009.66±1.15 mg/L), even higher than the landfill of the city of Meknes (539 mg/L).[6] This trend could result from the strong industrial and household pollution at the level of landfills. The Oued Moulouya station (686.24±0.1 mg/l) and P1 well waters (574.77±0.94 mg/l) were rich in SO_4^{2-}, with concentrations that exceeded the Moroccan standards of 2013 (400 mg/l). This concentration was higher than that of groundwater in the Sidi Lahcen Algeria area (291 mg/l),[12] which could be due to leachate percolation.

Heavy metal and trace element contents in the study locations

The Ni concentration did not exceed Moroccan standards, either at the groundwater or surface water levels. Conversely, the concentration of Cr was higher at the level of leachate (3.9 mg/L), which exceeded Moroccan standards of 2013 (0.5 mg/L). Meanwhile, this value was lower than that of leachate from the city of Fez (9 mg/L).[18] The high concentration can only be attributed to its anthropogenic origin in solid waste. The same is true for Pb, which reached its maximum in leachate (1 mg/L), but this concentration remained lower than that of leachate from Elelenwo (Nigeria) landfill (1.942 mg/L).[19] (Table 5) reveals that the concentration of Co in surface and groundwater was low in comparison to Moroccan standards (2013) but was very high at the leachate level, as is the concentration of Cd (1 mg/L). The Mn concentration in the leachate was very high (13.6 mg/L), but it did not exceed Moroccan standards (2013) for surface and groundwater. The concentration of Pb detected in the S1 surface layer of soil (2.9 mg/L) greatly exceeded the Moroccan standards of 2013 (1 mg/L) as shown in Table 5. The Pb found in the soil exists in two oxidation states, with the Pb^{2+} ion becoming less soluble under oxidizing conditions. This observation results from the fact that the Pb forms a complex with the organic matter. Higher levels of Pb can be attributed to the dumping of industrial and chemical wastes because the Ni concentration in the soil did not exceed Moroccan standards.

However, the concentration of Cr was higher at the soil level (S1: 3.4 mg/L and S2: 3.3 mg/L), which exceeded the Moroccan standards of 2013 (0.5 mg/L). This high concentration cannot be explained solely by its anthropogenic origin in solid waste, where approximately 30% of Cr comes from plastic bag packaging.

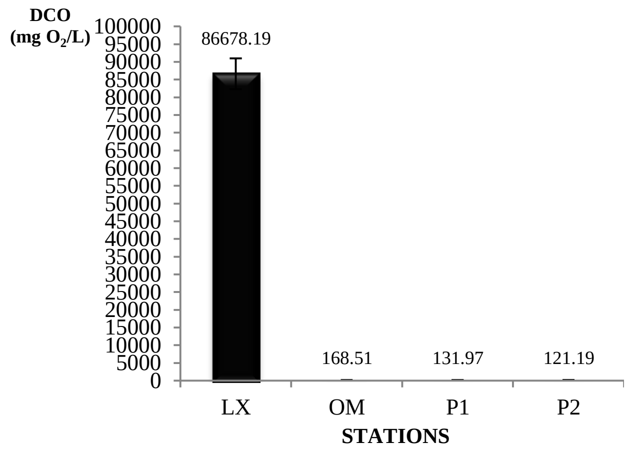

Figure 11: Average chemical oxygen demand (COD) concentration in surveyed stations. LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

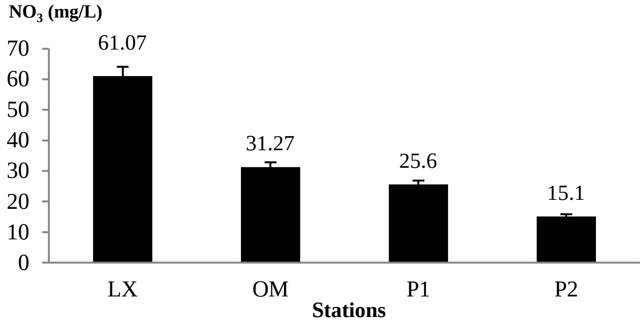

Figure 12: Average nitrate (NO_3^-) concentration of surveyed stations. LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

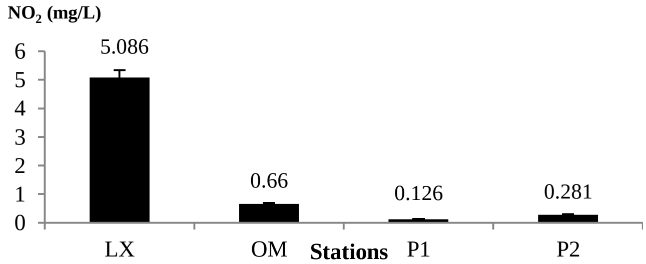

Figure 13: Average nitrite (NO_2^-) concentration at study station. LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

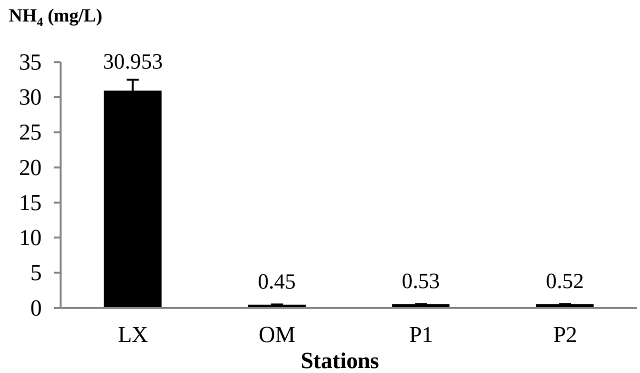

Figure 14: Average concentration of ammoniacal nitrogen (NH_4) in the study stations. LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

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The concentrations of Fe (S1: 28.8 mg/L and S2: 29.3 mg/L), Al (S1: 1 mg/L and S2: 383 mg/L), and Mn (S1: 18 mg/L) were all high. This observation depicts the percolation of leachate through various soil layers based on their degree of permeability. Sodium (Na) is a highly soluble element that is often found naturally in groundwater. The sodium concentration is more or less high for wells P1, and P2 (poor quality, MS: 20 mg/L),[8] and rises for the soil (S1: 30578.7 mg/L, S2: 16444.4 mg/L), and leachate (1640.4 mg/L). An increase in sodium in groundwater at concentrations above the standards may indicate the presence of polluting agents. High sodium intake can cause problems in people on a low-salt diet due to high blood pressure, heart disease, or kidney disease. For Ca, high values (6256.3 mg/L) were recorded, which exceeded Moroccan standards at all stations (Table 6). Magnesium also had high values, particularly at the leachate level (439 mg/L), but this value was lower than that of station C1 in Bloemfontein (South Africa), with a value of 808 mg/L.[20] As a result, heavy metal and trace element analyses revealed metallic pollution of groundwater, leachate, and soil when compared to Moroccan standards.[8] Several authors have also demonstrated that the soil's high oxygenation allows for the formation of redox conditions favourable to the retention of metals.[5]

Conclusion

The results of this study reveal significant pollution caused by leachate from the wild landfills of the city of Guercif (BOD_5: 860 mg O_2/l, COD: 86678.19 mg O_2/l, NH_4^+: 30.953 mg/l) , on soil S2 (Al: 383 mg/l, Co: 1 mg/l, Cr: 3.3 mg/l, Pb: 1 mg/l), groundwater (BOD_5: 45 mg O_2/l, COD : 131.97 mg O_2/L, NO_2^-: 0.126 mg/L, NO_3^-: 25.6 mg/L, NH_4^+: 0.52 mg/L), and surface waters (BOD_5: 150 mg O_2/L, a COD: 168.51 mg O_2/L, NO_2-: 0.660 mg/L, NO_3-: 31.27 mg/L and NH_4^+ of 0.45 mg/L), it is therefore recommended to the competent authorities that the site be rehabilitated, a leachate collection network must be designed, and that a controlled landfill is established according to environmental standards.

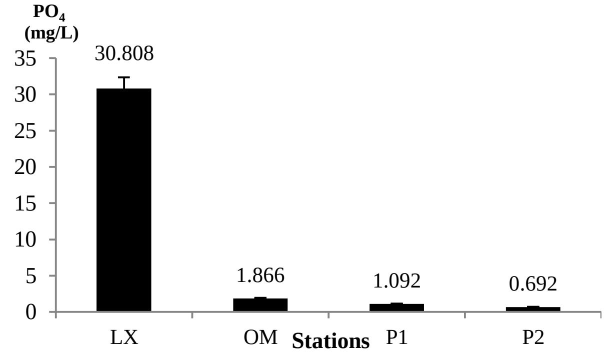

Figure 15: Average concentration of orthophosphates (PO_4^{3-}) in the study stations. LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

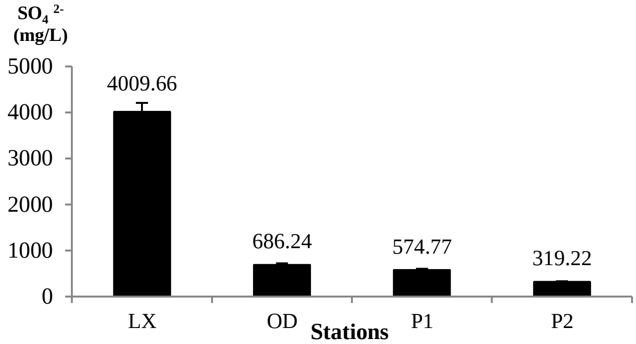

Figure 16: Average sulphate (SO_4^{2-}) concentration at study stations. LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2

Table 5: Concentration of heavy metals in the study stations

sample	Al mg/L	Cd mg/L	Co mg/L	Cr mg/L	Cu mg/L	Fe mg/L	Mn mg/L	Ni mg/L	Pb mg/L
Lx	1	1	1	3.9	1	233	13.6	1	1
od	0.1	< 0.01	< 0.01	0.048	< 0.01	0.284	0.016	< 0.01	< 0.01
P1	0.01	< 0.01	< 0.01	0.034	< 0.01	0.283	0.015	< 0.01	< 0.01
P2	0.01	< 0.01	< 0.01	0.032	< 0.01	0.283	0.016	< 0.01	< 0.01
S1	1	1	1	3.4	1.1	28.8	18	1	2.9
S2	383	1	1	3.3	1	29.3	1.5	1	1

LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2;
S1: Landfill soil station 1; S2: Landfill soil station 2

Table 6: Concentration of trace elements in the study stations

Sample	Ca mg/L	K mg/L	Mg mg/L	Na mg/L
Lx	6256.3	2484.7	439	1640.4
OM	183.721	1.634	15.35	25.359
P1	381.374	3.096	33.50	44.949
P2	407.806	3.101	34.33	45.563
S1	42679.3	2552.1	1	30578.7
S2	26572.9	834.6	1	16444.4

LX: Leachate; OM: Surface water from Moulouya; P1: Groundwater station 1; P2: Groundwater station 2;
S1: Landfill soil station 1; S2: Landfill soil station 2

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Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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