Characterization of metallic pollution in leachate from the Ouled Berjal landfill in Kenitra, Morocco, and treatment by coagulation and filtration

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ABSTRACT

Elevated levels of contaminants, such as organic chemicals, nitrogen, phosphorus, and heavy metals, are present in landfill leachate and pose serious dangers to both human health and the environment. The main objectives of this study were to evaluate the presence of heavy metals and characterize the leachate from the Oulad Berjal landfill in Kenitra. It also aimed to compare the effectiveness of leachate treatment using coagulation combined with filtration (using red brick waste as the filter material) and coagulation alone. The originality of this work lies in its treatment of leachate for the first time, combining filtration with red brick waste and coagulation. The combination of these two processes for leachate treatment has never been addressed in the literature. The efficacy of a coagulation-filtration method for red brick waste was assessed. The results showed that the leachate from the Kenitra landfill had significant metal contamination. With concentrations of 1.08 mg/L and 100 mg/L, respectively, Cr and Zn are the most concentrated metals. The concentrations of Pb and Cu are moderate, ranging from roughly 0.45 to 0.79 mg/L and 0.35 to 0.70 mg/L, respectively. Ni was present at an intermediate concentration of about 0.07 to 0.32 mg/L, while Cd remained low at 0.03–0.05 mg/L. When the leachate was treated by coagulation followed by filtration, COD, ammonium, turbidity, and heavy metals were significantly reduced. Coagulation-flocculation, which eliminated 81% of COD, 65% of NH_4^+, 83% of Pb, and 70% of Cr, was primarily responsible for the reduction. Filtration greatly reduced turbidity (71%), COD (50%), and ammonium (31%), further improving the treatment. Because of its high porosity and specific surface area, the discarded red brick can absorb and filter sewage.

Keywords: leachate, ammonium, coagulation, filtration, manhole.

INTRODUCTION

Population growth, rising consumption rates, and the development of industrial processes are contributing to increased municipal solid waste generation [Chen et al., 2020]. The most widespread method of solid waste disposal in most countries is landfilling, which allows waste to decompose into a stable material at a lower cost than other methods, such as incineration [Babaei et al., 2021]. One of the main problems associated with municipal waste disposal is the production of leachate, which results from the decomposition of organic waste and the percolation of

precipitation [Cherni et al., 2021]. There are two categories of leachate: fresh leachate and stabilized leachate [Farsad et al., 2022]. The young leachate exhibits the following characteristics: high levels of biodegradable organic matter, a high BOD/COD ratio, and elevated nitrogen concentrations. Conversely, the stabilized leachate exhibits limited biodegradability, a more alkaline pH, and the presence of mineral compounds [Tałałaj et al., 2021]. These leachates typically contain significant levels of heavy metals and hazardous and carcinogenic compounds. The composition of the waste typically determines the extent of the harm caused by these leachates.

Leachates from landfills containing hazardous industrial waste are the most toxic. Ammonia and alkalinity are the primary constituents that render these leachates toxic. The toxicity of these leachates is likely to affect ecology and human health [Daniel et al., 2021]. Using composite samples of leachate, a study was conducted on the environmental impact of the leachate from the Amin Bazar landfill site. The research showed that the leachate exhibited physicochemical parameters and heavy metal concentrations that far exceeded permitted limits. It was discovered that all of the soil, vegetation, groundwater, and surface water were contaminated with heavy metals; the plants had elevated levels of Pb, Cd, Cr, and Co. Additionally, the leachate's As content was higher than allowed. Leachate from the landfill site is a significant source of environmental metal contamination, as indicated by spatial analysis using ArcGIS [Hredoy et al., 2022]. Leachate is typically treated using a combination of physical-chemical and biological techniques, including advanced oxidation, membrane bioreactor treatment, denitrification, biofilm reactor treatment, and electrocoagulation treatment [Cherni et al., 2021]. Particularly for colloidal particles, the coagulation-flocculation procedure is an economical and dependable method of treating leachate. Heavy metals and non-biodegradable organic substances can be eliminated by allowing the particles to flocculate. The process is particularly effective for young leachate or as a pre-treatment for biological treatment. If the ideal coagulant dose is applied and the coagulant is compatible with the leachate pH, the procedure is successful [Djeffal et al., 2021]. The objective of this study is to characterize the composition of leachate, particularly its heavy metal content, and to assess the associated pollutant load. It aims to evaluate the effectiveness of leachate treatment by coagulation combined with filtration through red brick waste. These red bricks, characterized by high porosity and a large specific surface area, enable leachate absorption and filtration. According to the literature, this leachate treatment, combining filtration through red brick waste with coagulation, has not previously been tested. No previous study has used this combination of physicochemical treatment and red brick filtration. It is expected that the use of red brick waste as a filter material will enhance coagulation efficiency, particularly in removing turbidity, organic matter, and heavy metals.

MATERIALS AND METHODS

Study area

The Ouled Berjal landfill, situated some 3 km northwest of the city center on the secondary road to Sidi Allal Tazi, extends over 20 hectares and treats almost 330 tons of domestic and other waste daily, or about 120,450 tons per year [Bakraouy et al., 2017]. Although it is relatively far from the port and the industrial area, its location creates difficulties: prevailing winds from the west and northwest carry smoke, odors, and light waste toward the neighboring agricultural and residential areas. The landfill has a waste-disposal area with a 4-hectare cell, divided into four compartments, with drainage pipes for leachate and rainwater. One reserve basin and three sizable leachate collection basins are present. The first basin, with a capacity of 21,945 m³, was constructed in 2010. The fourth reserve basin was constructed in 2014 with a capacity of 19,200 m³, the third basin was constructed in 2013 with a capacity of 19,220 m³, and the second basin was constructed in 2012 with a capacity of 7,363 m³.

Figure 1 shows basins 1, 2, and 3, as well as the inlet of the Kenitra landfill.

Sampling

To assess leachate quality, two sampling methods were used to obtain representative samples for treatment.
- Method 1: manually collecting 1 L of leachate (B1, B2, B3) at hourly intervals for eight consecutive hours. This collected leachate was then homogenized to obtain a 2-liter sample for analysis.
- Method 2: collecting 10 liters of leachate per hour for eight hours from the inspection chamber serving six compartments. This leachate was then used for treatment tests.

It was stored in opaque polyethylene containers sterilized at 4°C to prevent any alteration of its composition by light or secondary chemical reactions. The leachate samples intended for treatment by coagulation and filtration were collected at the main inlet of the landfill, which collects the leachate produced in eight cells. A pump installed at the inlet provides a flow rate of 20 m³/h. Heavy metal samples were taken from basins B1, B2, and B3. The tests were conducted between March

Figure 1. Basins 1, 2, and 3, as well as the Kenitra discharge manhole

23 and 24, 2023. The analyses were performed in the laboratory two days after sampling. The analyses were carried out three times to ensure reproducibility of the results.

Coagulation-flocculation (CF)

Before implementing the combined treatment at the Kenitra landfill, preliminary small-scale laboratory tests were conducted to determine the optimal FeCl₃ concentration (Figure 2). The coagulation process combined rapid agitation at 150 rpm for 5 minutes and slow agitation at 40 rpm for 30 minutes. The supernatant was then collected after 30 minutes of decontamination (Figure 3). Leachate treatment tests were subsequently carried out at the Kenitra public landfill site. A 100 L reactor was used (Figure). Leachate samples were collected from basins B1 and B3. The pH was adjusted to 7 using sulfuric acid. A 40% ferric chloride (FeCl₃) solution at a concentration of 12.5 g/L was used to treat the samples. This reactor was operated with mechanical agitation. The same agitation speeds applied at the laboratory level were applied on site to maintain the same processing conditions.

Filtration treatment

Filtration on red brick (F)

At the Kenitra landfill, immediately after treating 100 L of leachate by coagulation-flocculation, the treated samples underwent a filtration step. This filtration was carried out using a pilot filter made of red bricks with an average pore size of 100 μm. This step allowed for the separation of the flocs formed during coagulation-flocculation and the production of clarified leachate.

Figure 4 illustrates the pilot plant used onsite for leachate treatment, including the coagulation-flocculation and filtration steps. Figure 5 presents a visual comparison between the raw leachate and the leachate treated by coagulation-flocculation (CF) followed by filtration (F). Removal efficiencies were calculated using the following formula:

$$Removal\ efficiency\ (\%) = \frac{Ci - Cf}{CI} \cdot 100 \quad (1)$$

where: Ci – initial concentration; Cf – final concentration.

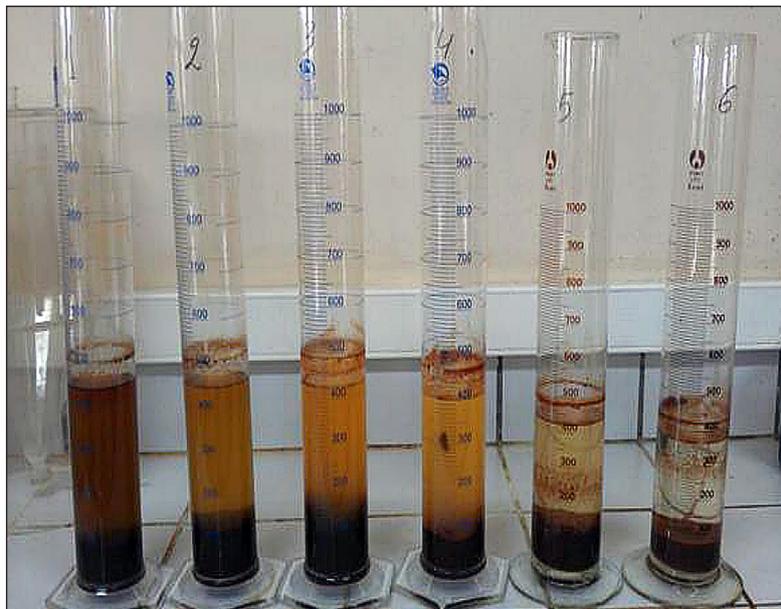**Figure 2.** Leachate CF tests performed on a laboratory scale using a jar-test type device

Figure 3. Results of the settling of leachate treated by coagulation-flocculation

Analysis techniques

The physical and chemical parameters and equipment used to measure them are as follows:

- The pH was measured using OHAUS START-ER 3100 equipment according to standard NF EN ISO 10523.
- The electrical conductivity was measured using Jenco 3177 MB equipment according to standard NF T-90-111.
- The turbidity was measured using Hach 2100N equipment according to standard NF EN ISO 7027-1.

The spectral absorption coefficient (SAC) values at three distinct visible spectrum standard wavelengths (436, 525, and 620 nm) were used to calculate the color. According to the established procedure EN ISO 7887:1994, which measures the absorbance of the sample at three wavelengths in the visible spectrum and calculates the absorbance using equation (2), the color intensity of the leachates was examined using a Jenway 6705 UV-Vis Spectrophotometer (Aouni et al. 2012).

$$Color = \frac{A^2_{(\lambda=436nm)} + A^2_{(\lambda=525nm)} + A^2_{(\lambda=620nm)}}{A_{(\lambda=436nm)} + A_{(\lambda=525nm)} + A_{(\lambda=620nm)}} \quad (2)$$

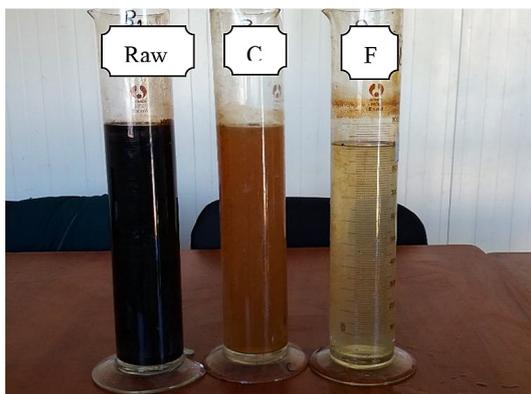**Figure 4.** Pilot combines coagulation and filtration

Figure 5. Leachate and leachate treated by coagulation-flocculation (CF) followed by filtration (F)

where: the absorbance values recorded at the various standard wavelengths (436 nm, 525 nm, and 620 nm) are represented by A.

The suspended solids (SS) were also measured using a filtration and analytical balance according to standard NF EN 872.

In accordance with AFNOR standard NF T90-101 of February 2001 (T90-101), the COD was calculated by back titration, oxidizing the organic matter in the sample with an excess of potassium dichromate ($K_2Cr_2O_7$) at 120 °C, in the presence of sulfuric acid (H_2SO_4), mercuric sulfate ($HgSO_4$), and silver sulfate ($AgSO_4$) as catalysts.

The biological oxygen demand (BOD_5) ((EN 1899 May 1998) (T90-103)) was measured using the gauge method with BOD counterbrand VELP.

The Folin-Ciocalteu reagent was used in the colorimetric method to determine the phenolic compounds, as explained by [Singleton and Rossi, 1965]. Ten milliliters of the sample were extracted, Following the addition of 0.5 ml of FC, the solution was mixed with sodium carbonate five minutes later. The thoroughly mixed concoction was left in the dark for one hour. At 725 nm, a spectrophotometer measures the wavelength.

A liquid-liquid extraction was used to separate low molecular weight sulfonates, such as toluene sulfonate, from detergent-type sulfonates.

According to NFT 90-023, phosphorus was measured using the ascorbic acid approach using a spectrophotometer at longer wavelengths of about 700–880 nm. In an acidic environment, the interaction among potassium tartrate, ammonium molybdate, and antimony yields phosphomolybdic acid, which forms a vivid blue complex [Bicanic et al., 1989].

A measurement of the NH_4^+ was made according to AFNOR NF T 90-015 January 1997, using the spectrophotometric technique indophenol blue. 10 mL of the sample was mixed with 0.5 mL of the phenol nitroprusside solution and 0.5 mL of the alkaline solution. The combination was left in the dark. The spectrophotometer measured the absorbance at 630 nm after six hours.

Finally, total Kjeldahl nitrogen (TKN) was analyzed using the complete Kjeldahl method in accordance with standard NF EN 25663.

Heavy metal analyses

The concentrations of heavy metals in the leachates, including Cd, Cr, Cu, Pb, Ni, and Zn, were determined using plasma atomic emission spectroscopy (ICP-AES) after sample preparation. The glassware was washed with distilled water and then rinsed with 1% nitric acid solution. Calibration standards and experimental blanks were used for validation. The results were expressed in mg/L.

RESULTS AND DISCUSSION

Physico-chemical characterization, leachate volumes, and pollutant loads

The average values of the physicochemical parameters of the leachate from the landfill in Kenitra, as well as the amounts of waste generated, the volume of the generated leachate, and the corresponding pollutant load, are given in Table 1. The waste generated at the landfill in Kenitra amounts to 165,349 tons per year. Based on a factor of 0.26 m³/ton of waste, it is estimated that the annual volume of the generated leachate is 42,991 m³. The pH of the leachate is slightly basic, at 8.43, while the conductivity of the solution is high, at 14.2 mS/cm. The pH of the

leachate depends on the degradation of organic matter, which produces carbon dioxide and ammonium, resulting in the formation of carbonic acid and bicarbonate ions. The partial pressure of CO_2, as well as the presence of materials and gases, affects the environmental pH [Naveen et al., 2017]. The values obtained are comparable to those reported by [Naveen et al., 2017]. Electrical conductivity reflects the total concentration of dissolved ions (anions and cations) and inorganic salts. High conductivity is generally associated with high levels of ions and total dissolved solids [Mohd-Salleh et al., 2020]. However, the values measured in this study remain lower than those reported by [Mohd-Salleh et al., 2020], who recorded a conductivity of 7,857.8 µS/cm. The high values for turbidity (450 NTU), suspended solids (0.38 g/L), absorbance at 254 nm, and color indicate a high presence of organic matter and dissolved compounds. These results remain lower than those reported by [Ogedey and Oguz, 2024] for intermediate leachates from a sanitary landfill, for which a turbidity of 228 NTU was measured. This turbidity is primarily due to suspended solids and colloidal particles, both organic and mineral, resulting from the degradation of waste [Sarkar et al., 2023]. In addition, landfill leachate contains a large quantity of dissolved organic matter, which exhibits high absorbance in the ultraviolet region at 254 nm due to the presence of aromatic compounds [Sato et al., 2023]. The results show a very high average COD concentration of approximately 50,300 mg/L and a BOD_5 concentration of 992.5 mg/L, corresponding to annual pollutant loads of 372,689 t/yr and 42,776 t/yr, respectively. These results, particularly during the summer, can be explained by increased biological activity [Ančić et al., 2020]. The COD/BOD_5 ratios, ranging from 3.95 to 5.0, indicate low biodegradability. Similar results were found by [Nidheesh et al., 2023]. The phenol concentration of approximately 869 mg/L confirms the toxicity of the leachate. Nitrogen compounds are also highly concentrated, with significant amounts of ammonium (910 mg/L), nitrates (364 mg/L), and total Kjeldahl nitrogen (820 mg/L), resulting in high annual pollutant loads. Total phosphorus (26.6 mg/L) and detergents (29.2 mg/L) also contribute significantly to the overall leachate pollutant load. [Turki et al., 2025] demonstrated that the leachate composition, even after treatment, still had a large concentration of total nitrogen nutrients (NTK). However, the values measured in this

study remain lower than those reported by [Charki et al., 2024], who reported an ammonium concentration of 2,159 mg/L. Finally, in the treatment of municipal solid waste leachate, excessive foaming is a serious problem, as it reduces process efficiency and increases costs. This foam is primarily caused by surfactants (detergents) in the leachate, whose concentrations range from 0.16 to 4,230 mg/L, depending on the source and geographical location. Even at low concentrations (< 20 mg/L), these substances can contribute largely to the formation of foam [Zhang et al., 2023].

Heavy metal characterization

Presence of cadmium (Cd) and chromium (Cr)

Figure 6 shows that the cadmium concentration was low in all samples, ranging from 0.03 to 0.05 mg/L. These concentrations exceed the FAO standard of 0.01 mg/L and the WHO standard of 0.003 mg/L [Borjac et al., 2019]. In contrast, Figure 7 shows that Cr concentration was highest, ranging from 0.62 mg/L in basin B1 to 1.08 mg/L in basin B3. These concentrations exceed the WHO recommended value of 0.05 mg/L [Afolabi et al., 2022]. The leachates generally had lower cadmium (Cd) concentrations than those reported by [Beinabaj et al., 2023] at the wastewater treatment plants they studied, whereas chromium (Cr) concentrations

were relatively high. [Kusumaningrum et al., 2025] reported high cadmium and chromium concentrations at the Putri Cempo final treatment site in Surakarta. The cadmium level of 0.1246 mg/L exceeded the permitted limits, while the chromium level of 0.3986 mg/L was concerning, despite the absence of a regulatory threshold. [Talbi et al., 2020] also showed that chromium was the most abundant metal in the leachate studied. In general, [Sulistyowati et al., 2023] indicated that landfill leachates contain high levels of heavy metals, such as cadmium, and other toxic elements. These elements, primarily of human origin, are mobile and can pose a serious threat to soils and groundwater. Soils contaminated by leachate also accumulate cadmium levels 2.7 to 3 times higher than the control value, with the highest accumulation in wheat, where cadmium is present in the highest concentrations in the roots, followed by the stems and grains. Cadmium transfer is influenced by soil properties, such as the availability of cadmium, iron (II) oxides (Fe_2O_3) and aluminium(II) oxides (Al_2O_3), salinity, and organic matter content [Rezapour et al., 2022].

Presence of nickel (Ni) and copper (Cu) in leachate

Figures 8 and 9 illustrate the concentrations of heavy metals Ni and Cu in the leachates of basins B1 and B3, as well as an overview of

Table 1. Physicochemical parameters, leachate volumes, and pollutant loads at the Kenitra landfill

Parameter	A1	A2	A3	Average values	Quantity of waste (T/an)	Quantity of leachate (m³/an) 0,26 m³/ tonne (Bouyakhsass et al. 2023a)	Polluting load (T/an)
pH	8.45	8.44	8.40	8.43			***
Conductivity (mS/cm)	14.12	14.2	14.3	14.2			***
Turbidity (NTU)	440	460	450	450			***
254nm (FD=200)	0.167	0.166	0.169	0.167			***
Couleur (FD=20)	0.364	0.365	0.372	0.367			***
TSS (g/L)	0.32	0.35	0.47	0.38			***
COD (mg/L)	50200	50300	50400	50300	165349	42991	2162.5
BOD$_5$ (mg/L)	992.5	991.4	993.6	992.5			42.65
Phenol (mg/L)	860	869	878	869			37.36
NH$^+_4$ (mg/L)	910	909	911	910			39.12
NO$_3^-$(mg/L)	360	364	368	364			15.65
NTK (mg/L)	820	819	821	820			35.25
Ptotal (mg/L)	26.5	26.4	27	26,6			1.14
Detergents (mg/L)	28	30	29.2	29.1			1.25

Note: *FD* – dilution factor, A1 – analysis 1, A2 – analysis 2, A3 – analysis 3.
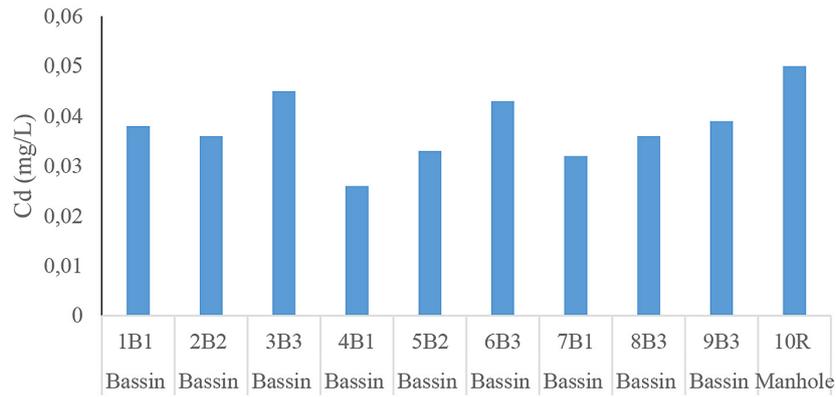
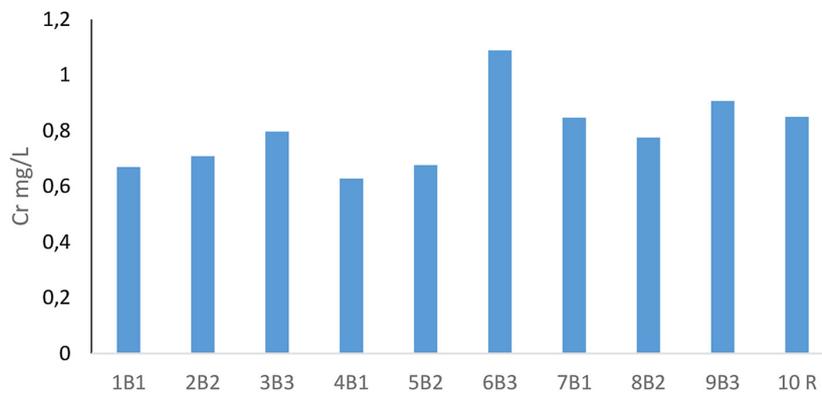**Figure 6.** Cadmium concentrations in the Ouled Berjal landfill (Kenitra)

Figure 7. Chromium concentrations in the Ouled Berjal landfill (Kenitra)
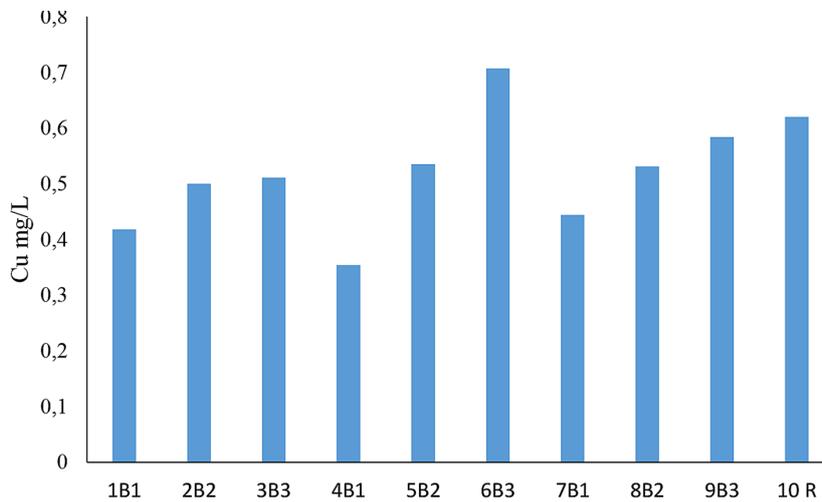

Figure 8. Copper concentrations in the Ouled Berjal landfill (Kenitra)

the different sampling campaigns. Copper (Cu) is present in moderate to high concentrations, between 0.35 mg/L (B1-2) and 0.70 mg/L (B3-2). These concentrations exceed the FAO and WHO standards, which set the value at 0.20 mg/L [FAO/WHO]. Nickel (Ni) is present at intermediate concentrations, between 0.07 mg/L (B1-1) and 0.32 mg/L (B3-2), exceeding the WHO standard, which requires a value of 0.02 mg/L [Afolabi et al., 2022]. The values obtained are lower than those reported by [Jhamnani and Singh, 2009], who analyzed the nickel content
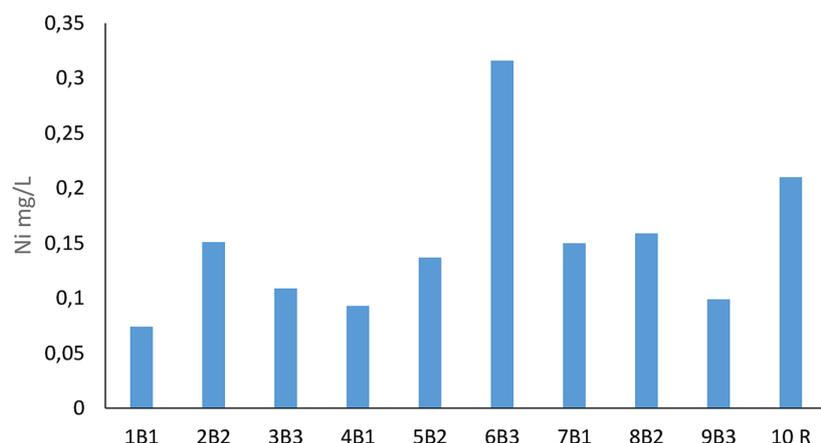
Figure 9. Nickel concentrations in the Ouled Berjal landfill (Kenitra)

in the leachate of landfills and reported values below 3 mg/L. This element is toxic and carcinogenic and is classified as a pollutant, often present in hazardous waste, particularly landfills, which receive urban, clinical, and industrial waste [Haque, 2016]. The concentrations of copper identified in this study are lower than those reported by [Delgado Arroyo et al., 2014], which was 77.65 µg/L in poultry manure leachate. [Kabala et al., 2014] identified that the concentration of copper in litter leachate depends on the location and season of the year. The concentration of copper peaks in the spring but can also peak in autumn and winter. The concentration of copper increases with the concentration of dissolved organic matter, regardless of rainfall, temperature, or pH.

Presence of lead (Pb) and zinc (Zn) in leachates

The progression of Zn contents in the leachates of the three basins B1, B2, and B3 for the several sample campaigns is shown in Figure 10. Zn levels ranged from 58 mg/L to 100 mg/L. These results show that the concentrations of this metal in the leachates are high. The minimum concentrations of Zn in the leachates of the three basins were observed during the second campaign in basin B1, i.e., 2B1 = 58 mg/L. The maximum concentration of Zn was observed during the second campaign in basin B3, i.e., 2B3 = 100 mg/L. The concentrations of Zn in the leachates of basin B1 varied between 63 mg/L (1B1) and 62 mg/L (3B1). In the leachates of basin B3, the concentrations of Zn varied between 73 mg/L (1B3) and 83 mg/L (3B3). The concentrations of Zn in the leachates of the three basins increase

from basin B1 to basin B3. The maximum concentrations of Zn were observed in basin B3 during the second campaign. These concentrations are higher than those defined by the WHO and FAO standards, which require a concentration of 2 mg/L [Chaoua et al., 2019]. The presence of this heavy metal in the leachate indicates that the waste is of industrial origin [Jantunen et al., 2021]. [Jantunen et al., 2021] found that zinc levels in the leachate at the Okhla landfill site fluctuated irregularly, decreasing and then increasing. The concentration of zinc in the leachate at the Narela-Bawana landfill site was found to be significantly higher in 2016 and 2017 than that at the Okhla landfill site, i.e., above 5 mg/L. Figure 11 shows the lead concentration in the Kenitra landfill. The results indicate that lead (Pb) is also present at high levels, ranging from 0.45 mg/L (B1-1 and B1-2) to 0.79 mg/L (B3-2). These concentrations are below the FAO standard (5 mg/L) and above the WHO standard of 0.01 mg/L [Borjac et al., 2019]. These results are lower than those reported by [Ogundiran et al., 2012], who found a lead concentration in the leachate of 8.81 ± 0.06 mg/L. Animal and human exposure to heavy metals occurs primarily through the ingestion of contaminated water and plants. Analysis of the abundant forage grasses at the sites (Sporobolus pyramidalis, Imperata cylindrica, Panicum maximum, Andropogon tectonum) shows high levels of lead, confirming that the cattle ingest contaminated plants. These results highlight that poor management of metallurgical waste can lead to contamination of forage plants and exposure of animals to lead [Ogundiran et al., 2012].
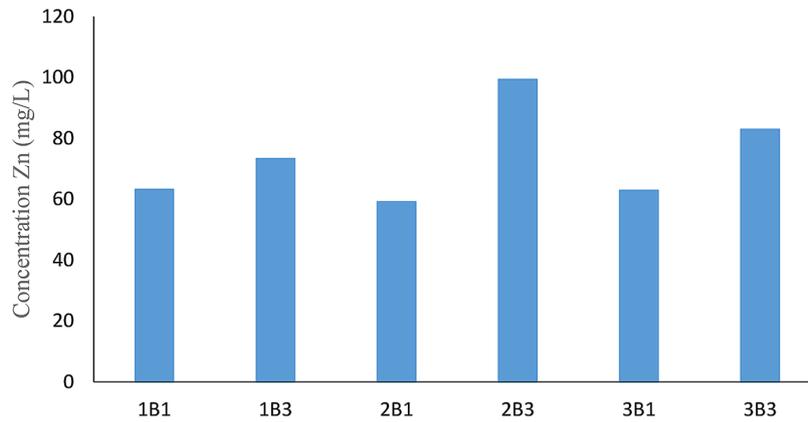
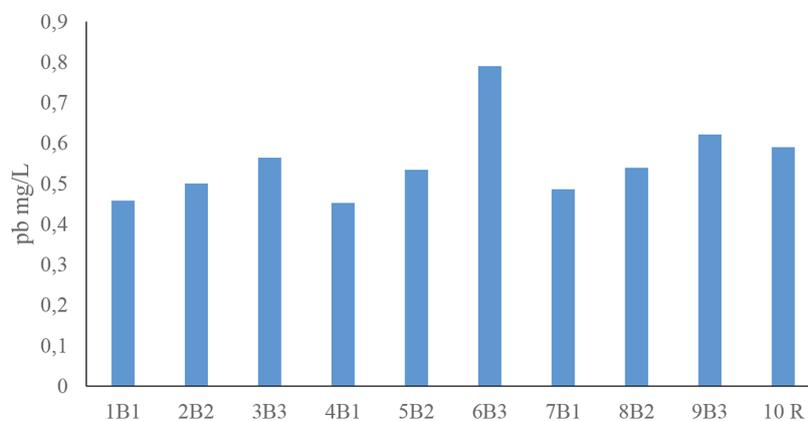**Figure 10.** Zinc concentrations in the Ouled Berjal landfill (Kenitra)

Figure 11. Lead concentrations in the Ouled Berjal landfill (Kenitra)

Efficiency of leachate treatment by coagulation and filtration

Optimal FeCl$_3$ concentration

Table 2 shows the optimal FeCl$_3$ concentration for leachate treatment and its effect on sludge production. The optimal concentration used is 12.5 g/L. After treatment, the amount of sludge produced is 14.4 g per 100 liters of leachate. These results are similar to those reported by [Chaouki et al., 2017], who showed that the optimal coagulation concentrations for mature leachate were 12 g/L for ferric chloride. Generally, these results are explained by the fact that leachate composition is influenced by several factors. Among the most important factors are the age of the landfill, which influences biological and chemical processes over time; the depth of the waste, which affects degradation conditions; and the local climate and seasonal variations, which influence leachate production and dilution. The nature and composition of the deposited waste are also determining factors, as different types of waste release a variety of chemical and organic substances during degradation [Moody and Townsend, 2017].

Turbidity removal

Figures 12 and 13 show the turbidity of the leachate from the manhole before and after treatment by coagulation-flocculation and filtration. The raw leachate has a high turbidity of approximately 450 NTU. After treatment by coagulation-flocculation, the turbidity decreases to nearly 300 NTU, with a removal efficiency of approximately 33%. [Assou et al., 2016] showed that the FeCl$_3$ + Superfloc combination offers the best performance, with turbidity removal efficiencies of 66%. The filtration step allows for a much more significant reduction in turbidity, reaching a value close to 90 NTU, which corresponds to an overall removal efficiency of approximately 71%. The turbidity removal percentages by coagulation alone are lower than those reported by [Bouyakhsass

Table 2. Optimal concentrations during the use of FeCl$_3$

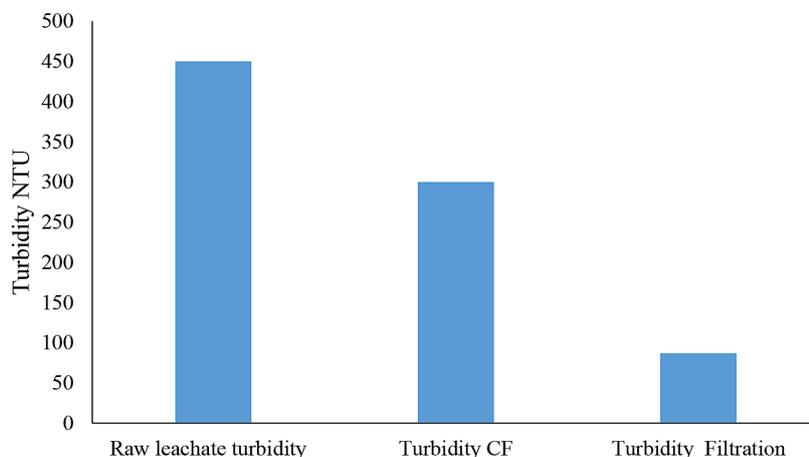| Leachate	Optimal Concentration g/L FeCl$_3$	Sludge produced l/100 liters leachate
Manhole	12.5	14.4

Figure 12. Turbidity (NTU) of raw and coagulation-flocculation and filtration-treated leachates

et al., 2023b], which achieved reductions of approximately 90.38% using both the coagulant and the flocculant. The effectiveness of coagulation is highly dependent on the initial pollutant load of the leachate, which explains the results obtained in this study. The coagulation-flocculation method is commonly used to remove suspended particles from wastewater. It works by neutralizing negatively charged particles, which then clump together to form larger flocs [Cheng et al., 2021]. [Almi et al., 2025] have shown that coagulation using a combination of aluminum sulfate (AS) and Moringa oleifera extract (MOS) achieves the highest turbidity removal efficiencies, reaching up to 91%, while simultaneously reducing sludge production and chemical consumption. These results

indicate that coagulation-flocculation effectively reduces turbidity, particularly in basins B1 and B3, while filtration allows for near-complete removal of suspended solids, especially in the basin with initially higher turbidity. Filtration using red bricks has proven effective. This effectiveness is attributed to their large specific surface area and porosity, which enable them to absorb and filter wastewater [Wang et al., 2020](Figure 13).

COD elimination

Figures 14 and 15 show the results of the treatment of the leachate at the Ouled Berjal landfill manhole by following the evolution of the chemical oxygen demand (COD) during two treatment
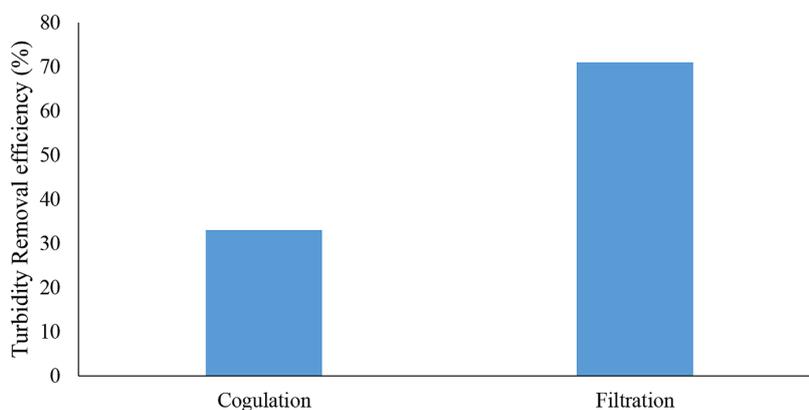

Figure 13. Percentage of turbidity removal after coagulation-flocculation and filtration

steps: coagulation-flocculation (CF) and filtration. The raw leachate has very high initial COD values, exceeding 50,000 mg/L. As shown in the figures, after coagulation-flocculation, a significant COD removal is observed, and the values are below 10,000 mg/L. Then, filtration refines the treatment and further reduces the COD values, which are below 5,000 mg/L. As for the efficiency of each treatment step, coagulation-flocculation seems to be the most efficient treatment step, as its removal rate is approximately 81%. Filtration further reduces the organic load, with an efficiency of approximately 50% compared to the effluent obtained after coagulation-flocculation. The results obtained in the present study are superior to those reported by [Boumechhour et al., 2013], who showed that CF followed by

Fenton oxidation achieved a COD reduction of 63.62%. [Ogedey and Oguz, 2024] showed that SBR alone reduced COD by 58–70%, while the coagulation-flocculation step improved these

results, with reductions reaching 74% with alum and 77% with ferric chloride. The combined SBR-coagulation/flocculation treatment led to an overall COD removal of up to 89–90%, meeting international rejection standards. The effectiveness of ferric-rich steel industrial wastewater (SIWW) as a coagulant for the treatment of stabilized leachate was evaluated by [Anouzla et al., 2022]. A dosage of 8 mL/L of SIWW at pH 2.75 was found to be the ideal setting after the coagulation-flocculation process was optimized using a response surface approach. Under these conditions, the COD was reduced by 55.43%, while turbidity was eliminated by 87.55%, with a sludge production of 19 mL/L.

Ammonium removal

Figures 16 and 17 analyze the effectiveness of ammonium treatment for the leachate collected at the manhole. At 910 mg/L, the initial ammonium concentrations are extremely high. Elevated
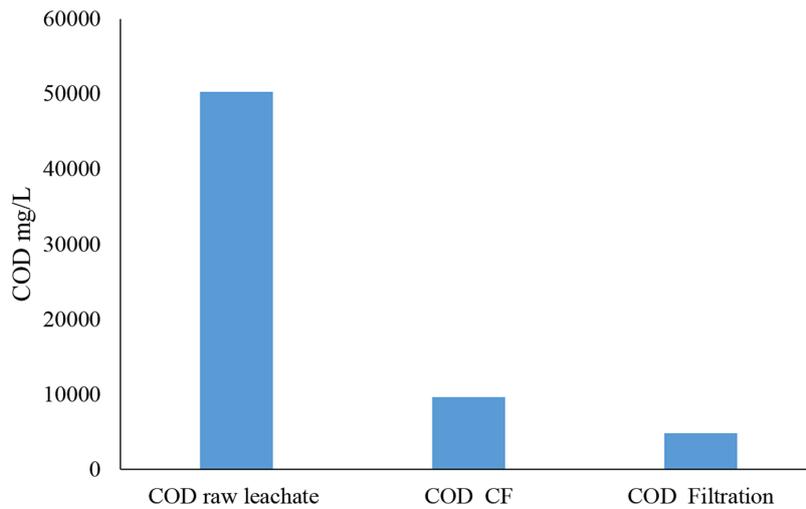

Figure 14. COD in (mg/L) of raw and treated leachate by coagulation–flocculation and filtration
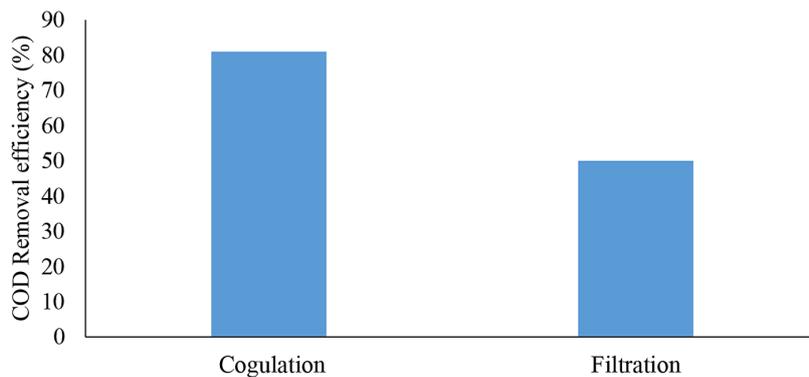

Figure 15. Percentage of COD removal after coagulation-flocculation and filtration
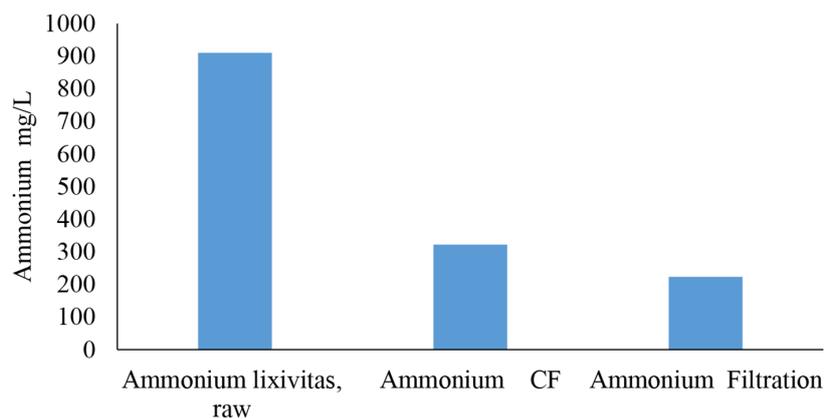
Figure 16. NH$_4^+$ in (mg/L) of raw and treated leachate by CF and filtration
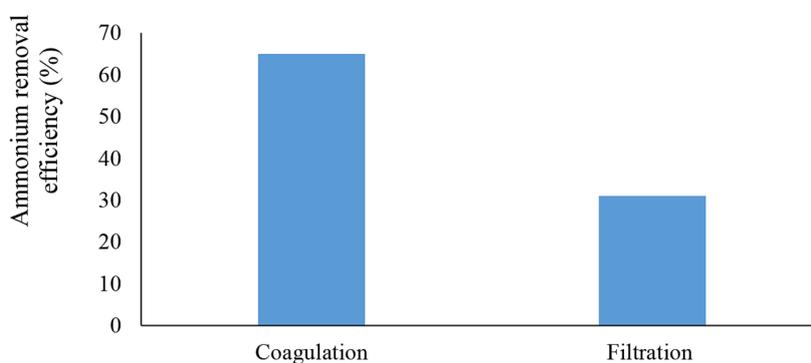

Figure 17. Percentage of NH$_4^+$ elimination after coagulation-flocculation and filtration

ammonia levels can raise free ammonium (FA), which in turn encourages nitrite buildup and the production of free nitrous acid (FNA) [Miao et al., 2019]. Ammonium concentrations also significantly decrease after coagulation-flocculation, reaching about 320 mg/L. Following filtration, the concentration reaches its lowest value of approximately 220 mg/L. With a removal efficiency of about 65%, coagulation-flocculation appears to be the most efficient step. The efficiency achieved by coagulation-flocculation is increased by about 31% through filtration. The results obtained in this research are similar to those presented by [Mosanefi et al., 2021], who found that the efficiency in the removal of ammonium from leachates using natural zeolites was optimal at a pH level of 7, with the zeolites concentrated to 80 g/L and a contact time of 30 minutes, achieving the highest efficiency of 44.49%. [Poveda et al., 2016] found that among various physicochemical methods of leachate treatment, air stripping is the most effective method for the removal of ammonium, yielding 86% of the total amount. In comparison, advanced oxidation using sodium ferrate resulted in

16% yield, while chemical coagulation and electrocoagulation resulted in yields of less than 10%. Ammonium removal reached 85% when chemical coagulation and air stripping were combined.

Removal of lead (Pb) and chromium (Cr) by CF

Figure 18 depicts the coagulation-flocculation removal efficiency of chromium (Cr) and lead (Pb). As demonstrated in the results, lead (Pb) is removed with an efficiency of 83%, while chromium (Cr) is removed with an efficiency of approximately 70%. Ferric salts have generally been shown to be efficient coagulants for heavy metal removal. In this context, ferric chloride has been shown by [Pang et al., 2011] to be an effective coagulant for removing arsenic, lead, and zinc from water. [Amuda et al., 2006] studied the effectiveness of the addition of polymer to the coagulation process in the treatment of wastewater from the beverage industry and the removal of specific trace metals such as lead and total chromium. The findings demonstrated that 300 mg/L FeCl$_3$ and 65 mg/L polymer effectively removed chromium,
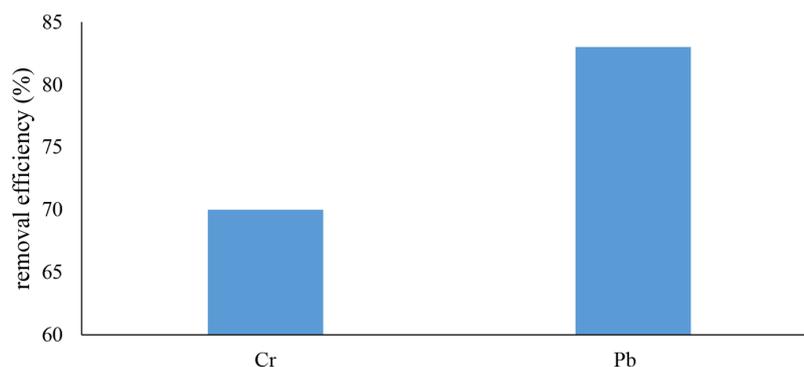
Figure 18. Efficiency of Cr and Pb elimination by CF

with 91% removal by $FeCl_3$ alone and 95% by the polymer. This removal was enhanced to 97% when $FeCl_3$ and the polymer were combined. The coagulation and adsorption method for handling nickel mining wastewater containing hexavalent chromium was investigated by [Sawali et al., 2024]. Cr(VI) removal from 100 mg/L to 12.15 mg/L was achieved with alum, $FeSO_4$, and fly ash. The maximum Cr(VI) removal reached 87.9%, with an adsorption capacity of 0.087 mg/g.

CONCLUSION

The study characterized the leachate from the Ouled Berjal landfill, highlighting the presence of heavy metals and the associated pollutant load. The combined use of $FeCl_3$ coagulation and filtration through red brick waste was shown to be effective in reducing turbidity, organic matter, and heavy metals. This represents a novel treatment strategy, never previously tested, that leverages the porosity and large specific surface area of red bricks to enhance coagulation efficiency. The study fills a gap in the literature regarding the combined use of physicochemical treatment and red brick filtration. Future work should focus on optimizing the process for different types of leachate and evaluating its applicability at a larger scale for industrial and municipal wastewater treatment.

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