

(RESEARCH ARTICLE)



WASTEWATER TREATMENT AT THE NIAMEY GENERAL REFERENCE HOSPITAL (HGR) USING ZINC- AND ALUMINUM-BASED LAYERED DOUBLE HYDROXIDES (Zn-Al-LDH)

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World Journal of Advanced Research and Reviews, 2026, 31(03), 1902–1908

Publication history: Received on 19 August 2026; revised on 24 September 2026; accepted on 26 September 2026

Article DOI: <https://doi.org/10.30574/wjarr.2026.31.3.2398>

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ABSTRACT

This study is part of the effort to combat environmental pollution by removing pollutants. The objective of this study was to use zinc (Zn)- and aluminum (Al)-based double lamellar hydroxides (HDLs) to treat wastewater by adsorbing contaminants generated by the activities of the Niamey General Reference Hospital (HGR). The experimental results obtained under operating conditions of 0.7 g of double-layered hydroxide (Zn-Al-HDL), a 25 mL volume of wastewater, at room temperature, and a contact time of 24 hours show that the removal efficiencies of micropollutants, as measured by conductivity, total dissolved solids (TDS), and chemical oxygen demand (COD) are 84.85%, 82.02%, and 6.86 mg/L, respectively.

Keywords: Wastewater, General Reference Hospital, Niamey, Zn-Al-HDL, Adsorption.

1 INTRODUCTION

The scientific community places great emphasis on water quality on Earth—that is, on environmental preservation—which is being compromised by gaseous, liquid, and solid emissions generated by natural disasters and human activities [1]. The impact of these emissions, which are minimally or not at all biodegradable, on the environment and the health of living organisms has become a cause for concern [2,3]. The presence of pharmaceutical residues in the environment is a significant indicator of pollution. These compounds are classified as “micropollutants” because they are generally

detected at very low concentrations, ranging from micrograms to nanograms per liter [3]. Despite these low concentrations, their potential effects on the environment should not be overlooked [3]. Several techniques have been developed for wastewater treatment, including physical separation processes using adsorbent materials such as zeolites, activated carbon, and clays; membrane processes (reverse osmosis); and chemical processes (oxidation advanced (e.g., ozonation, ion exchange) and biological [2]. Among these methods, adsorption is one of the most widely used techniques due to its effectiveness, simplicity, and relatively low implementation cost [4]. Lamellar materials known as double-layer hydroxides (DLHs) are attracting growing interest in wastewater treatment. These materials are rare in their natural state but can be easily synthesized in the laboratory at low cost [5]. HDLs can be used directly or after calcination, depending on the intended application [5]. They possess several remarkable properties, such as a large specific surface area, a two-dimensional structure, a positive surface charge, good thermal stability, and excellent anion exchange capacity [5]. The structure of double-layered hydroxides consists of positively charged hydroxide layers, balanced by interlayer anions. Their general formula can be expressed as follows: $[M^{II}_{1-x}M^{III}_x(OH)_2]^{x+}[A^{m-}_{x/m}.nH_2O]^{x-}$ [6]. In natural compounds, the molar ratio MII/MIII is generally close to 3, whereas in synthetic materials, the value of x typically ranges from 0.20 to 0.33 [6]. Divalent cations can be Zn^{2+} , Ni^{2+} , Mn^{2+} , Fe^{2+} , Co^{2+} , and Ca^{2+} , while trivalent cations include Al^{3+} , Cr^{3+} , Mn^{3+} , Fe^{3+} , Co^{3+} and V^{3+} [2,6]. The interlayer anion is often carbonate CO_3^{2-} [6]. Double-layered hydroxides have numerous applications in various fields such as catalysis, air and water purification, medicine, and nuclear waste treatment [7].

The objective of this study is to contribute to solving the problem of purifying polluted water through the use of HDLs based on transition metals such as zinc.

Specifically, the aim is to evaluate the effectiveness of Zn-Al-HDLs in adsorbing pollutants generated by the HGR.

2 MATERIALS AND METHODS

2.1 Adsorption Tests

Adsorption tests were conducted at room temperature by bringing a mass of Zn-Al-HDL into contact with 25 mL of aqueous solution. The contact time was set at 24 hours, in accordance with protocols used in similar studies [18]. The parameters monitored are chemical oxygen demand (COD), electrical conductivity, and total dissolved solids (TDS). The pH of the solutions is adjusted using diluted HCl or NaOH solutions prior to testing in order to study the influence of pH on the adsorption process [19].

2.2 Wastewater Parameters from the Niamey General Reference Hospital (HGR)

Table 1: Physicochemical parameters of wastewater from the Niamey HGR prior to treatment.

Parameters	Raw water
Temperature (°C)	26.6
pH	6.66
Conductivity (μs/cm)	480
TDS (ppm)	245
DCO (mg/L)	110

2.3 Variation in HDL Mass

The experimental conditions used to study the effect of mass on adsorption capacity are summarized in Table 2.

Table 2: Variation in Adsorbent Mass

pHi	6.66
Temperature (°C)	Room temperature
Mass (g)	0.01 to 1
Volume of solution (ml)	25
Time (h)	24

2.4 Effect of pH on Removal Efficiency

The experimental conditions used in the study on the effect of pH are summarized in Table 3.

Table 3: Experimental conditions for the effect of pH

Change in pH	3 to 11
Temperature (°C)	Room temperature
Mass (g)	0.3
Volume of solution (ml)	25
Time (h)	24

2.5 Kinetic Effect: Influence of Time on Removal Efficiency

The experimental conditions used for the kinetic study of HGR wastewater treatment via Zn-Al-HDL adsorption are summarized in Table 4.

Table 4: Experimental conditions for the effect of time

pH	6.66
Temperature (°C)	Room temperature
Mass (g)	0.3
Volume of solution (ml)	25
Time (h)	0 to 24

3 RESULTS AND DISCUSSION

3.1 Results of the Application of Zn-Al-HDL Double-Layered Hydroxide

3.1.1 Effect of Adsorbent Mass (Zn-Al-HDL)

Figures 1 and 2 shows the results for conductivity and total dissolved solids (TDS), respectively.

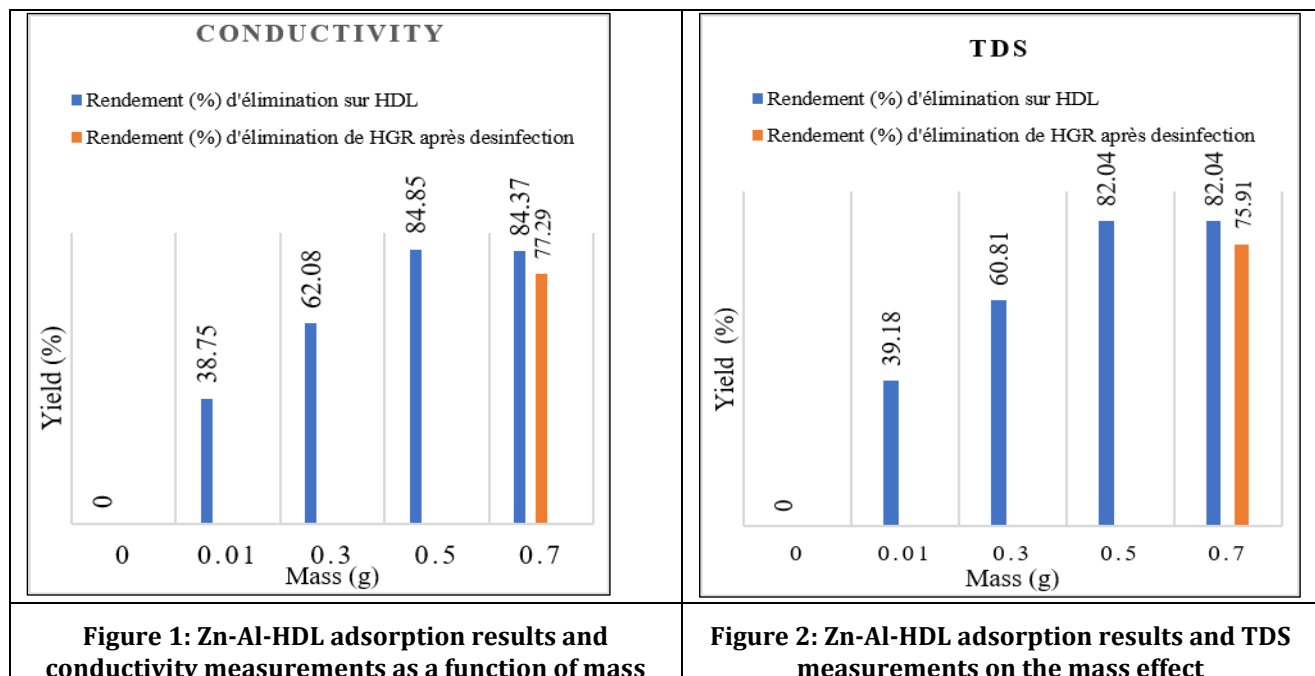


Figure 6 shows a significant increase in conductivity removal efficiency as the mass of Zn–Al–HDL increases. The efficiency rises from approximately 38% at a mass of 0.01 g to over 84% at 0.7 g. This trend is attributed to the increase in the number of active sites available on the adsorbent's surface, which promotes the adsorption of the ionic species responsible for water conductivity. After disinfection, a slight decrease in efficiency is observed, which can be explained by the introduction of additional ions from the disinfectant, leading to competition with the ions adsorbed on the material's active sites. This behavior is typical of double-layered hydroxides, as reported by Cavani et al. (1991) [8] and Rives (2001) [9].

Figure 7 shows a similar trend for TDS, with a maximum removal efficiency of approximately 82% for a mass of 0.7 g of Zn–Al–HDL. This decrease in TDS confirms the material's ability to effectively adsorb total dissolved solids present in the water. The decrease observed after disinfection may be related to the formation of ionic byproducts that contribute to the residual TDS. These results confirm that Zn–Al–HDL is an effective adsorbent for improving the physicochemical quality of water (Miyata, 1983 [10]; Zhao et al., 2014 [26]).

The results clearly show that Zn–Al–HDL exhibits excellent adsorption capacity for the ionic species responsible for conductivity and TDS. Increasing the adsorbent mass significantly improves process performance, confirming that adsorption is highly dependent on the availability of active sites

3.2 Effect of pH on pollutant removal efficiency

pH is a very important factor in adsorption. The value for the binding of micropollutants depends on both the surface charge of the adsorbent and the structure of the micropollutants. Figures 3 and 4 show the results for conductivity and total dissolved solids (TDS), respectively.

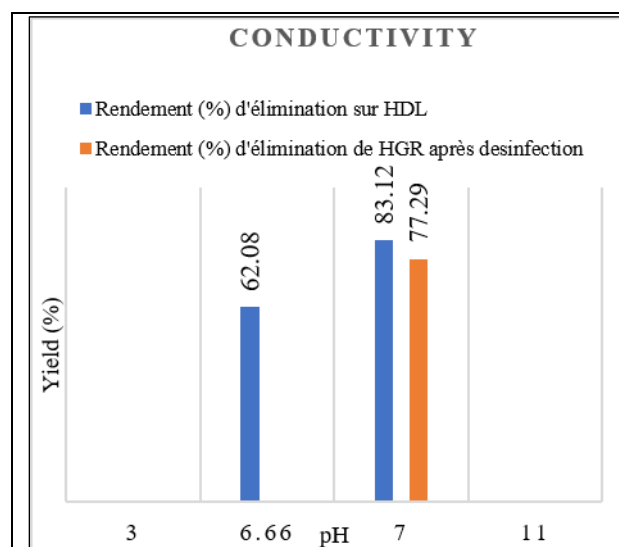


Figure 3: Zn-Al-HDL adsorption results and conductivity measurements as a function of pH

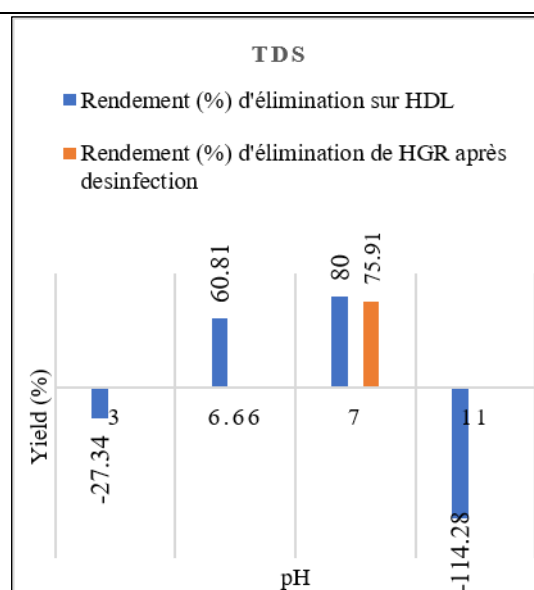


Figure 4: Zn-Al-HDL adsorption results and TDS measurements as a function of pH

The results in Figure 8 indicate that the maximum conductivity removal efficiency is achieved at pH 7, with a value of approximately 83%. At acidic pH (pH = 3), the efficiency decreases sharply, which can be attributed to structural instability of the Zn–Al–HDL and partial dissolution of the material. At neutral pH, the lamellar structure is more stable and promotes electrostatic interactions between the adsorbent and ions in solution. In a basic medium, the excessive presence of OH⁻ ions can cause competition with the adsorbed ions, slightly reducing the process efficiency, as reported in the work of Roy et al. (1992) [27].

Figure 9 shows that the TDS removal efficiency is highest at pH = 7 and decreases sharply at pH = 11. This decrease may be related to the dissolution of interlamellar carbonates and the partial release of metal ions into the solution, thereby contributing to an increase in TDS. These results confirm that pH is a key parameter influencing the stability of HDLs and their adsorption performance (Forano et al., 2006 [28]; Li et al., 2019 [29]).

pH strongly influences the adsorption mechanism, with maximum efficiency observed at neutral pH. This behavior is consistent with the surface properties of HDLs, whose structural stability is optimal around pH 7. In acidic or strongly basic environments, dissolution or ionic competition reduces the material's efficiency.

3.3 Kinetic Effect on the Removal of Micropollutants by HDL

The adsorption time determines the duration of micropollutant removal. This is a factor that depends on the choice of HDL. Figures 5 and 6 show the results for conductivity and dissolved salt concentration, respectively.

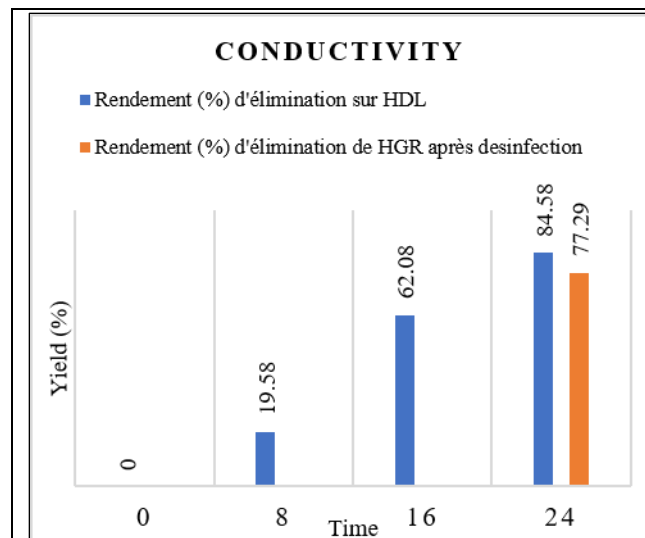


Figure 5: Zn-Al-HDL adsorption results and conductivity measurements on the effect of kinetics

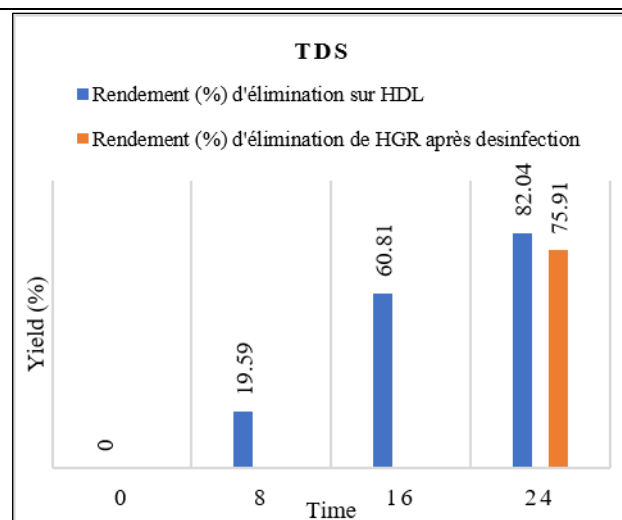


Figure 6: Zn-Al-HDL adsorption results and TDS measurements on the kinetic effect

Figure 10 shows a gradual increase in the conductivity removal efficiency with contact time. Rapid adsorption is observed during the first few hours, followed by stabilization after 24 hours, indicating that adsorption equilibrium has been reached. This trend suggests that adsorption is initially controlled by external diffusion, then by intralamellar diffusion of ions within the Zn–Al–HDL structure (Ho and McKay, 1999 [30]).

Figure 11 confirms the same trend for TDS, with a maximum removal efficiency of approximately 82% after 24 hours. This behavior is characteristic of a chemical adsorption mechanism well described by the pseudo-second-order kinetic model (Ho, 2006 [31]).

The adsorption kinetics show that equilibrium is reached after 24 h, indicating that Zn–Al–HDL has a relatively fast adsorption rate, compatible with water treatment applications. These results are consistent with several previous studies on HDLs used as adsorbents for inorganic pollutants (Wu et al., 2017 [32]; Liu et al., 2018 [33]).

3.4 Adsorption Performance (Conductivity, TDS, COD)

The experimental results show a significant decrease in COD, from 110 to 6.86 mg/L, as well as a notable reduction in conductivity and TDS. This high performance reflects the strong ability of Zn–Al–HDL to trap dissolved pollutants. This efficiency can be attributed to a combination of several mechanisms: surface adsorption, anion exchange, and electrostatic interactions between the pollutants and the positively charged layers of the material [4,20].

4 CONCLUSION

The objective of this study was to remove, using Zn–Al–HDL, contaminants generated by the activities of the Niamey General Reference Hospital (HGR). The experimental results demonstrate that Zn–Al–HDL is an effective adsorbent for reducing conductivity and TDS. Optimal conditions are achieved with a mass of 0.7 g, a pH close to neutrality, and a contact time of 24 hours. These results confirm the strong potential of Zn–Al–HDL for applications in water treatment, consistent with data from the scientific literature.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

We would like to thank Abdou Moumouni University in Niamey for providing us with the setting in which the work was carried out.

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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