Comparative analysis of hospital laboratory wastewater treatment techniques in Syrian Arab Republic

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Abstract

Background: Hospital wastewater poses a significant threat to human health due to the presence of difficult-to-degrade organic compounds, active pharmaceutical ingredients and multiple inorganic substances that can pollute water resources and ecosystems.

Aim: To compare the effectiveness of different techniques for removing organic load from hospital laboratory wastewater in Aleppo, Syria.

Methods: We treated wastewater samples from hospital laboratories at Aleppo University Hospital, Syria, using several techniques, including biological treatment with the rotating biological contactor, adsorption with Syrian natural clay, coagulation with aluminium sulphate, advanced oxidation with ultrasound, and a combined treatment using natural clay and ultrasound. We assessed the organic load removal efficiency for each technique under different conditions.

Results: The most effective technique was the combination of natural clay and ultrasound. Applying natural clay at a concentration of 1 g/L of wastewater along with ultrasound at 40 kHz for 30 minutes achieved chemical oxygen demand and biochemical oxygen demand values suitable for irrigation, in accordance with the Syrian standard. The chemical oxygen demand value decreased to 212 mg/L with 94% removal rate, and the biochemical oxygen demand value decreased to 82 mg/L with 87% removal rate.

Conclusion: Based on our findings, techniques that combine different methods of hospital wastewater treatment, such as combining adsorption with advanced methods like ultrasound, are more effective than those that use single methods. Such techniques should be promoted.

Keywords: Hospital wastewater, treatment methods, laboratory, irrigation, pollution, Syria

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Background

Appropriate waste management in hospital discharge systems is complicated due to the presence of uniquely emergent contaminants. Hospital wastewater also has a lower biodegradability index than municipal wastewater, making it more challenging to treat with conventional biological systems. Many recalcitrant organic compounds in hospital wastewater, such as pharmaceutically active compounds (PhACs), are highly toxic and have very low drinking water equivalent limit (DWEL) values, posing a significant threat to the environment (*19*). Besides PhACs, several microorganisms, including antibiotic-resistant bacteria, antibiotic-resistant genes, and anti-viral resistant viruses reside in hospital wastewater. (*1–3*). Viruses, antibiotic resistant bacteria, and antibiotic resistant genes continue to survive even after the treatment of hospital wastewater, and their release to the aquatic ecosystem imposes a significant threat to the environment (*6-10*).

Treatment of hospital wastewater is not an easy feat, considering that the vast quantities of wastewater generated have high chemical oxygen demand, nitrogen, and PhAC content (*11,12*). Hospital wastewater often contains high levels of biochemical oxygen demand, chemical oxygen demand, ammonia, and nitrogen, which are significantly higher than in domestic wastewater (*4,5*). Biochemical oxygen demand measures the oxygen consumed by microorganisms to break down organic matter under aerobic conditions, while chemical oxygen demand measures the total oxygen required to oxidize both biodegradable and non-biodegradable organic matter (*6,7*). Biochemical oxygen demand represents the biodegradable fraction, and chemical oxygen demand includes all organic compounds. The ratio of biochemical oxygen demand to chemical oxygne demand is called the wastewater biodegradability index (*8,9*).

Average chemical oxygen demand concentrations in hospital wastewater were 613 mg/L in Europe, 1074 mg/L in South America, and 591 mg/L in Asia. High chemical oxygen demand levels of 2480 mg/L, 2464 mg/L, and 1142 mg/L were reported in Brazil, Spain, and India, respectively (*13*). South American countries had higher average chemical oxygen demand concentrations than Europe and Asia. The global average biochemical oxygen demand: chemical oxygen demand ratio for hospital wastewater was 0.29–0.34 in Asia and Europe, which was lower than the ratio seen in municipal wastewater, making hospital effluent more challenging to treat. Median, 25th percentile, and 75th percentile values for the biochemical oxygen demand: chemical oxygen demand ratio were 0.27, 0.20, and 0.57, respectively, with high values of 0.75, 0.64, and 0.85 observed in Iran, Thailand, and Brazil (*14*).

Various treatment technologies, including the biological methods, such as activated sludge process, membrane bioreactor, moving bed bioreactor, constructed wetlands, the advanced oxidation processes, such as photocatalysis, Fenton process, etc. have been implemented to treat hospital wastewater for use in irrigation and/or disposal into sewage systems. Hospital wastewater is typically treated using conventional treatment plants, which achieve contaminant removal rates of 20–50% for primary treatment, 30–70% for secondary, and over 90% for tertiary (*15*). However, these methods are ineffective for removing contrast media drugs, psychiatric drugs, and recalcitrant antibiotics. Advanced methods such as ozonation, advanced oxidation, photo-Fenton oxidation, nano remediation, and hybrid technologies need further study for complete contaminant removal (*16*).

Ozonation can remove up to 93% of recalcitrant antibiotics but is ineffective against X-ray contrast media. Advanced oxidation processes effectively remove antibiotics and pathogens, while nanocomposites can improve biodegradability and assist in photodegradation (*17*). Electrocoagulation and photocatalytic methods showed up to 99% removal efficiency. Integrated approaches combining biological methods and advanced oxidation processes achieve over 98% removal of pharmaceuticals and antibiotic resistance genes. Membrane bioreactors paired with advanced oxidation processes are also promising for pre-treatment. However, high energy and cost requirements limit their scalability (*18,19*).

In a full-scale treatment plant, sequential anaerobic filtration after eight-hour upflow anaerobic sludge blanket (UASB) digestion reduced chemical oxygen demand by 82%, biochemical oxygen demand by 90%, and ammonia by 74%. Waste stabilization ponds reduced total suspended solid, chemical oxygen demand, and biochemical oxygen demand by 87%, 86%, and 94%, respectively, over 29 days, although ammonia concentrations remained high due to pH-related ammonia gas formation (*20*). An ozone reactor followed by an aerated fixed film biofilter in Indonesia resulted in almost complete elimination of PhACs. Treatment combining ozone, ultraviolet and adsorption in various studies showed ozone as the most effective (*21-23*). The objective of our study was to compare the effectiveness of different remediation technologies for the removal of organic load from hospital laboratory wastewater in Aleppo, Syria.

Methods

Wastewater sampling

We collected samples of wastewater from laboratories at Aleppo University Hospital, Syria. We mixed samples from different laboratories in the same hospital to form a composite sample and stored each sample in a tightly sealed polyethylene container at low temperature. We determined the characteristics of each composite wastewater sample according to standard wastewater composition methods as provided in Table 1.

Biological treatment of wastewater

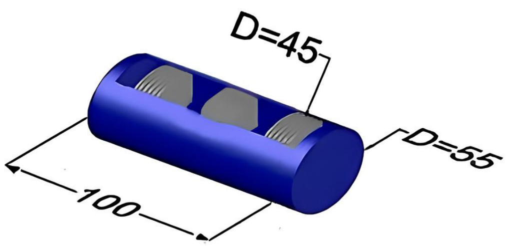
We used a rotary biological disk reactor to measure the effectiveness of biological management of hospital wastewater. A rotary biological disk reactor is a cylindrical treatment basin with a length of 1 m, a diameter of 55 cm and a capacity of 80 litres containing 18 disks. Each disk had a diameter of 45 cm; the spacing between disks was 1 cm; the thickness of the disk was 3 mm; and the length of the axis was 1 m. The rotary inlet was 38 cm as well as the exit (Figure 1). We controlled the number of cycles with a disk immersion rate of 35%. We then collected sediments in a special post treatment basin. We operated the rotary biological disk reactor at temperatures of 25±2°C . We added composite samples of wastewater daily to encourage bacteria growth on the surface of the rotary disks.

Adsorption method for wastewater treatment

We used natural clay from Tal Ajar, Aleppo, Syria, to test the effectiveness of adsorption treatment of wastewater with the following elemental composition: SiO_2 (47.44%), Al_2O_3 (19.25%), Fe_2O_3(8.5%), MgO (1.79%), CaO (6.18%), Na_2O (0.19%), K_2O (2.35%), SO_3(0.97%), L.O.I (13.05%).

For the adsorption study, we used 8- 1 litre composite water samples. We added clay in different quantities

Figure 1 Rotating biological contactor rotary disk biological reactor



with 3 distinct granularities and processed for different treatment times according to a structured sample-based process.

Coagulation method for wastewater treatment

We used hydrated aluminium sulphate, $Al_2(SO_4)_3.18H_2O$, with a purity of 98%, produced by Sigma-Aldrich, to study the effectiveness of coagulation in treating wastewater. We adjusted the pH to 7 using diluted sodium hydroxide and hydrochloric acid solutions until reaching the desired value. Treatment conditions are detailed in Table 1.

Ultrasonic treatment of wastewater

We used an ultrasonic wave generating device (model WUC-D 3.3) with a frequency of 40 kHz, produced by Witeg Labortechnik GmbH, to study the effectiveness of ultrasonic treatment. We applied different frequencies (20, 30, 40 kHz) and exposure times (15, 30, 45 minutes) to reduce organic pollutants in the water sample. Each test was repeated 3 times, and we measured the chemical oxygen demand and biochemical oxygen demand after treatment.

Combined clay adsorption and ultrasound treatment of wastewater

Treatment was carried out with clay and in the presence of ultrasound. Sample was coded with the symbol AU and stirred mechanically, the best conditions from results of this study were applied.

Bacterial tests

We used 2 different bacterial culture media to grow our sample colonies: i) Total count plate and ii) MacConkey agar. We used total plate count to enumerate the number of germs in each composite sample and MacConkey Agar (HIMEDIA) to detect the presence of *Enterobacteriaceae*– an important indicator of contamination in hospital wastewater.

We conducted bacterial analyses on treated samples by plating 1 ml of the sample on both types of media and incubating it at 37°C for 48 hours. After colonies developed, we calculated the number of bacteria per millilitre by multiplying the number of colonies by the reciprocal of the dilution factor.

Results

Biological treatment of wastewater

Table 3 presents the elemental composition standards of water for irrigation and the specifications of wastewater. The development process took 35 days for the biological layer to form on the surface of the discs, with a membrane thickness of approximately 0.5 mm. Afterward, we conducted processing experiments. Table 4 presents the results from the reactor start-up phase.

Table 4 shows that as the start-up time increased, the efficiency of COD removal improved, likely due to the exponential growth of biomass feeding on organic materials and breaking them down to obtain the energy needed for growth and development.

After completion of the reactor start-up process (biological membrane development), we carried out treatment of wastewater samples by adding batched water samples to the treatment basin at a flow rate of 2 L/h and a rotation speed equivalent to 6 rpm. We collected treated samples from the sedimentation basin after treatment at one hour time intervals, up to 12 hours. We then calculated the chemical oxygen demand and biochemical oxygen demand to determine

Table 1 Coagulation with aluminium sulphate to treat wastewater

Sample	Aluminium sulphate (gr/L)	Treatment time (mins)
A0.5	0.5	120
A1	1	120
A1.5	1.5	120
A2	2	120

Table 2 Wastewater treatment samples

Sample	Clay size (gr)	Particle size (µm)	Processing time (mins)
A	0.5	500	30
B	1	500	30
C	2	500	30
D	3	500	30
E	2	300	30
F	2	100	30
G	2	100	60
H	2	100	120

Table 3 Elemental composition of treated wastewater samples

Element (mg/L)	Syrian standard for irrigation /2752/ of 2008	Sample Averages (mg/L)
pH	6-9	7.1
S.S	ND	8.1785
T.S.S	150	465
SO_4	500	540
NH_4-N	5	30
PO_4	20	122
Cr	1	0.5
Cu	5	4
BOD	150	635
COD	300	3600
T.D.S	1500	4300
Cl	350	3944
F	15	40.2

Table 4 **Rotary disk reactor start-up measured in COD (mg/L)**

Start-up (day)	COD (mg/L)
0	3600
5	1523
10	1342
15	924
20	575
25	437
30	263
32	251
33	245
35	240

the effectiveness of treatment by time, as illustrated in Table 5.

We observed that as the treatment time increased, the chemical oxygen demand value decreased. At a treatment time of 12 hours, the chemical oxygen demand reached 147 mg/l, while at 10 hours, the Syrian standard for irrigation of agricultural lands (2752 of 2008) was met with a chemical oxygen demand concentration of 294 mg/l. Similarly, with increasing treatment time, the biochemical oxygen demand value also decreased. At 12 hours, the biochemical oxygen demand value was 124 mg/l, and at 10 hours, it met the Syrian standard for irrigation, decreasing to 135 mg/l. These results suggest that the ideal treatment time to obtain water suitable for irrigation is 10 hours.

Clay adsorption treatment of wastewater

The effectiveness of clay adsorption treatment was found to increase with the number of added pollutants, with the optimal amount being 2 grams per litre of polluted water. Adding more than this amount did not enhance treatment effectiveness. Additionally, the treatment's efficiency improved with the reduction in the granular size of the clay used, due to the increased specific surface area.

Table 5 **Organic load after biological treatment**

Treatment Time (h)	COD (mg/l)	BOD (mg/l)
Raw water	3600	635
1	2683	530
2	2119	466
3	1709	326
4	1366	301
5	1095	278
6	894	251
7	724	231
8	528	227
9	388	206
10	294	191
11	186	135
12	147	124

Table 6 **Organic load after clay adsorption treatment**

Water sample	COD (mg/l)	BOD (mg/l)
Raw water	3600	635
A	610	225
B	436	198
C	410	172
D	380	150
E	312	131
F	277	112
G	252	91
H	240	85

The best results were achieved with a particle size of 100 microns, although smaller sizes were not studied due to the difficulties and high costs associated with grinding to those dimensions. The effectiveness also increased with longer treatment times, with 120 minutes being the optimal duration. However, a treatment time of 60 minutes was sufficient if the goal was only to dispose of the water into the sewage system.

Coagulation (aluminium sulphate) treatment of wastewater

Aluminium sulphate coagulation treatment was less effective than treatment with clay adsorption agents (Table 7). This result can be explained by the type of pollutants in the studied water, which had a weak tendency to aggregate and settle due to their high solubility. We observed that clay adsorption was more effective at capturing and collecting highly soluble organic pollutants.

Ultrasonic treatment of wastewater

Table 8 shows that treatment effectiveness increased with both the applied frequency and the duration of application, with frequency having a greater impact than application time. Therefore, it can be concluded that applying a frequency of 40 kHz for 30 minutes is sufficient to achieve an organic content level suitable for irrigating crops.

Table 7 **Organic load after coagulation with aluminium sulphate**

Water sample	COD (mg/L)	BOD (mg/L)
Raw water	3600	635
A0.5	2198	379
A1	1755	341
A1.5	1689	330
A2	1630	310

Table 8 **Organic load after ultrasonic treatment**

Water sample		COD (mg/l)	BOD (mg/l)
Raw water		3600	635
kHz	**min**		
20	15	3120	592
20	30	2833	500
20	45	2773	432
30	15	2688	401
30	30	2430	344
30	45	2332	312
40	15	2312	378
40	30	1934	284
40	45	1885	255

Combined clay adsorption and ultrasound treatment of wastewater

To reduce the amount of clay required for treatment and achieve effective results in a short time, we conducted treatment using a combination of clay and ultrasound. Table 9 shows that the double treatment method, using ultrasound (advanced oxidation) alongside natural clay (adsorption), was highly effective under the following conditions: 0.5 g/L clay, 30 minutes of treatment, and a frequency of 40 kHz. This approach resulted in a low organic content, suitable for irrigation, with relatively short treatment time and lower clay usage than experiments using only natural clay. The chemical oxygen demand value reached 212 mg/L with a 94% removal rate, and the biochemical oxygen demand value reached 82 mg/L with an 87% removal rate. These results confirm the effectiveness of this combined treatment method for hospital wastewater, highlighting that sequential techniques are necessary, as a single treatment technique alone is insufficient for achieving optimal results.

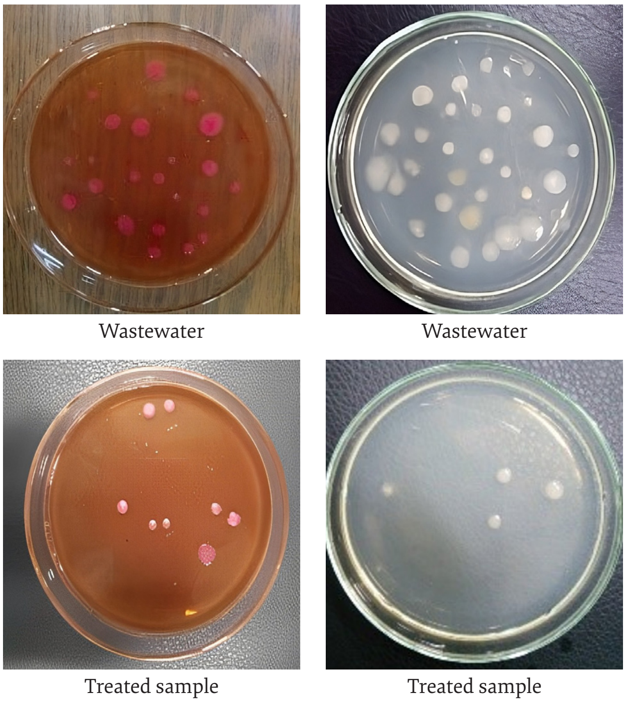
Table 9 **Organic load after clay and ultrasound treatment**

Water sample	COD (mg/l)	BOD (mg/l)
Raw water	3600	635
AU	212	82

Bacterial tests showed that the untreated sample contained 3100 cfu/ml on plate count agar and 2200 cfu/ml on MacConkey agar. After treatment, the number of bacterial colonies decreased significantly to 80 cfu/ml on plate count agar and 40 cfu/ml on MacConkey agar, as shown in Figure 2, indicating the effectiveness of the double treatment process.

The combined treatment method, using clay and ultrasound, achieved excellent results both chemically and microbiologically. Ultrasonic waves effectively broke down complex toxic organic compounds into simpler, less toxic substances that were easier to treat. The presence of clay directly adsorbed pollutants destroyed by the ultrasonic waves. Compared to other single treatment techniques, this hybrid method proved to be the most effective and shows promise for treating this type of wastewater.

Figure 2 **Results of bacterial analysis of the raw sample treated with natural clay and ultrasound**



Conclusion

Our practical research strategy clearly identified several effective methods for treating laboratory wastewater for grey water irrigation. Using the rotating biological disk method, a 10-hour treatment, reduced chemical oxygen demand to 294 mg/l and biochemical oxygen demand to 135 mg/l, meeting Syrian Standard 2752 of 2008 for irrigation.

Optimal conditions for natural clay adsorption involved using 2 g of clay per litre of polluted water, with a granular size below 100 microns. This treatment required 120 minutes to achieve irrigation standards and 60 minutes for disposal into the public sewer.

Aluminium sulphate treatment was less effective than adsorption due to the weak ability of pollutants to aggregate and settle, highlighting adsorption as a more suitable method for capturing these contaminants.

The most effective approach combined natural clay with ultrasonic treatment. Applying 1 g of clay per litre along with ultrasound waves at 40 kHz for 30 minutes achieved a chemical oxygen demand reduction to 212 mg/l (94% removal) and biochemical oxygen demand to 82 mg/l (87% removal). This combined technique demonstrated the best performance in reducing organic pollutants, making the treated water suitable for irrigation.

These results underscore the effectiveness of hybrid treatment techniques over single method approaches for treating complex wastewater. Combining adsorption with advanced methods like ultrasound can significantly enhance treatment efficiency, contributing to sustainable water reuse and better environmental compliance.

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Competing interests: None declared.

Analyse comparative des techniques de traitement des eaux usées dans les laboratoires hospitaliers en République arabe syrienne

Résumé

Contexte : Les eaux usées des hôpitaux constituent une menace importante pour la santé humaine en raison de la présence de composés organiques difficiles à dégrader, de principes actifs pharmaceutiques et de nombreux polluants inorganiques susceptibles de contaminer les ressources en eau et les écosystèmes.

Objectif : Comparer l'efficacité de différentes techniques d'élimination de la charge organique des eaux usées des laboratoires hospitaliers à Alep (République arabe syrienne).

Méthodes : Nous avons traité des échantillons d'eaux usées provenant des laboratoires hospitaliers de l'Hôpital universitaire d'Alep, en utilisant plusieurs techniques, notamment le traitement biologique à l'aide d'un contacteur biologique rotatif, l'adsorption avec de l'argile naturelle syrienne, la coagulation par sulfate d'aluminium, l'oxydation avancée par ultrasons et un traitement combiné à base d'argile naturelle et des ultrasons. Nous avons évalué l'efficacité de l'élimination de la charge organique pour chaque technique dans des conditions différentes.

Résultats : La technique la plus efficace était la combinaison d'argile naturelle et d'ultrasons. L'application d'argile naturelle à une concentration de 1 g/L d'eaux usées, combinée à l'utilisation d'ultrasons à 40 kHz pendant 30 minutes a permis d'obtenir des valeurs de demande chimique d'oxygène et de demande biochimique d'oxygène adaptées à l'irrigation, conformément à la norme syrienne. La valeur de la demande chimique d'oxygène a diminué pour atteindre 212 mg/L avec un taux d'élimination de 94 %, et la valeur de la demande biochimique d'oxygène a baissé à 82 mg/L avec un taux d'élimination de 87 %.

Conclusion : Selon nos constatations, les techniques combinant différentes méthodes de traitement des eaux usées des hôpitaux, comme l'adsorption associée à des méthodes avancées telles que les ultrasons, sont plus efficaces que celles qui n'utilisent qu'une seule méthode. Ces techniques devraient être encouragées.

تحليل مقارن لتقنيات معالجة مياه الصرف الصحي لمختبرات أحد المستشفيات في الجمهورية العربية السورية

عبد الرحمن تتان، فاطمة جعارة، نوزت النبغلي

الخلاصة

الخلفية: تشكل مياه الصرف الصحي الناتجة عن المستشفيات تهديدًا كبيرًا لصحة الإنسان، لاحتوائها على مركبات عضوية يصعب تحلُّلها، ومكونات صيدلانية فعَّالة، والعديد من الملوثات غير العضوية التي يمكن أن تلوث الموارد المائية والنُّظم الإيكولوجية.

الأهداف: هدفت هذه الدراسة الى مقارنة فعالية التقنيات المختلفة لإزالة الحمل العضوي من مياه الصرف الصحي لمختبرات المستشفى في حلب، الجمهورية العربية السورية.

طرق البحث: عالجنا عينات من مياه الصرف الصحي الناتجة عن مختبرات مشفى حلب الجامعي في الجمهورية العربية السورية بعدة تقنيات، من بينها المعالجة البيولوجية بالجهاز التلامسي البيولوجي الدوار، والامتزاز بالطمي السوري الطبيعي، والتخثُّر بكبريتات الألومنيوم، والأكسدة المتقدمة بالموجات فوق الصوتية، والمعالجة المشتركة بالطمي الطبيعي والموجات فوق الصوتية، ثم قيَّمنا كفاءة كل تقنية منها في إزالة الأحمال العضوية في ظل ظروف مختلفة.

النتائج: كان المزج بين الطمي الطبيعي والموجات فوق الصوتية التقنية الأكثر فعالية. فقد أدَّى استخدام الطمي الطبيعي بتركيز 1 جرام/ لتر من مياه الصرف الصحي، إلى جانب الموجات فوق الصوتية بتردد 40 كيلوهرتز لمدة 30 دقيقة، إلى ظهور قِيَم مناسبة للري من مطلوبية الأكسجين الكيميائية ومطلوبية الأكسجين البيوكيميائية، وذلك وفقًا للمعيار السوري. وانخفضت قيمة مطلوبية الأكسجين الكيميائية إلى 212 مليجرام/ لتر بمعدل إزالة بلغ 94٪، وانخفضت قيمة مطلوبية الأكسجين البيوكيميائية إلى 82 مليجرام/ لتر بمعدل إزالة بلغ 87٪.

الاستنتاجات: استنادًا إلى نتائج البحث، توصَّلنا إلى أن التقنيات التي تجمع بين طرق مختلفة لمعالجة مياه الصرف الصحي للمستشفيات، مثل الجمع بين الامتزاز والطرق المتقدمة، كالموجات فوق الصوتية مثلًا، أكثر فعالية من تلك التي تستخدم طريقة واحدة. وينبغي التشجيع على استخدام مثل هذه التقنيات.

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