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Review

A Review on Pharmaceutical Wastewater Characteristics, Treatment Techniques and Reusing

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Abstract: Pharmaceuticals are chemicals that are bioactive and can have potential effects on living systems. After being used or excreted by wastewater (WW) and sewage treatment systems, various types of pharmaceuticals enter the environment. There should be no underestimation of the complexity of these hazards. More than 3,000 different substances are used in modern drugs, including painkillers, antibiotics, contraceptives, and many more. Therefore, it is important to find out the characteristics and treatment methods for pharmaceutical wastewater (PWW), because the disposal of raw PWW causes human and environmental problems. According to the current literature, various treatment options have been investigated for the removal or reduction of medicines in PWW, such as the up-flow anaerobic sludge blanket (UASB) reactor, carbon filtration through activated carbon, membrane bioreactor (MBR), microalgal bioremediation, ultraviolet-free surface reactor (UV-FSR), solar or ferrioxalate photocatalysis, etc. Removal efficiencies for chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), and total dissolved solids (TDS) in the PWW ranged between 20% and 95%. In light of the inadequacy of water resources, it's necessary to know and develop methodologies for the treatment of pharmaceutical effluent as a part of water management.

Keywords**:** characteristics, pharmacy, treatment, wastewater, reusing

1. Introduction

There is no question that the success of countries and their progress are measured by the degree to which they are involved in the protection of humans and the environment. The spread of diseases and epidemics, however, made the manufacture and production of medicines and medical preparations unavoidable, although these factories, whether chemical or biological, would produce very dangerous waste. So, the trend is to treat industrial wastewater (WW) arising from these industries, and laws were enacted to regulate the location of these facilities so as not to harm humans and the environment.

This article addresses a basic overview of industrial WW treatment for medicines. Industrial WW varies from one industry to another in its characteristics and also differs from day to day and from hour to hour in the same plant depending on the current activities at the time of WW flow to the industrial wastewater treatment plants (WWTPs). Because of this distinction, the nature of the industrial WWTP will vary depending on the form and characteristics of the WW being handled by the plant. It should be remembered that the industrial WW generated by the pharmaceutical

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industry is processed in batches during processing, e.g., the fermentation processes take several days to several weeks. In this case, industrial WW is not produced until after the end of the process. During manufacturing and for cleaning the devices and laboratories used, the pharmaceutical industries use a variety of solvents, disinfectants, and additives, which vary entirely from one industry to another, product to product, and country to country.

The increase in population, propagation of disease, and pandemics such as coronavirus disease 2019 (COVID-19) lead to people using more drugs. Therefore, more drugs are produced. The production of medicines in the factory generates WW. Disposal of fresh pharmaceutical wastewater (PWW) without treatment causes problems for humans and the environment. Therefore, it is very much essential to create effective and efficient treatment methods for the removal of substances from PWW. Numerous tools and techniques are studied for the removal and treatment of PWW, but the most effective removal mechanism in recent times has been treated by the WWTP using biological approaches. Some of the biological treatment schemes include a waste stabilization pond (WSP), a membrane bioreactor (MBR), an activated sludge treatment plant (ASTP), a constructed wetland (CW), a rotating biological contactor (RBC), an algal photobioreactor (AP), etc. [1, 2].

In literature, many researchers studied PWW treatment. Rizzo et al. [3] and Gadipelly et al. [4] identified the best available tools to remove pharmaceutically active compounds from WW. Additionally, Rashid et al. [5] designed a unique paraboloid graphite-created microbial cell for bioelectrogenesis and PWW treatment. Meanwhile, Feng [6] analyzed the technology and researched the progress of pharmaceutical sewer water treatment and hoped to push the extent of chemical treatment and chemical treatment of organic chemistry treatment. Also, Guo et al. [7] studied the performance of antibiotic resistance genes under enormously high levels of antibiotic collection pressure in PWW treatment plants. Furthermore, Zhao et al. [8] investigated the effects of different PWW types and compared the bacterial composition and diversity of PWW treatment plants. Moreover, the possibility to recycle and return the treated water was also considered. Likewise, photocatalysis titanium dioxide (TiO_2) has been used for PWW treatment technology [9].

In Iraq, several authors published their research on PWW treatment. Mahmood et al. [10] assessed the participation of antibiotics in consumable water from two treatment plants in Baghdad City. The results of this study indicated the presence of antibiotic drugs in raw and finished water and ought to be included within the Iraqi standard for drinking water quality evaluation. Furthermore, Al-Khazrajy and Boxall [11] investigated a risk-created prioritization method connected to 99 of the most prominently parceled-out prescription drugs in the cities of Baghdad, Mosul, and Basrah. Additionally, Ismail and Habeeb [12] studied the potential of mechanical PWW treatment going with bioelectricity generation in microbial fuel cells utilizing blended cultures immobilized on a stuffed bed within the anode compartment. Moreover, the persistent consecutive biological anaerobic or aerobic treatment of the Samarra Drugs PWW plant was assessed under distinctive operation conditions of hydraulic retention time (HRT) considered by Al-Hashimi and Abbas [13].

The current research aims to review many papers on PWW to study the characteristics, treatment techniques, and reusing the treated water in irrigation.

2. PWW production and quantity

Roughly 3,000 pharmaceutical materials are used in the European Union. The most extensively used molecules are antibiotics for human and veterinary medicine; their intake has reached 12,500 tons per year over the past decade [14]. In reality, while pharmaceutical residues are tossed into the surroundings by untreated WW having special harmful pills, human beings might be especially exposed via the intake of flora, which can be as of now irrigated, or through the intake of infected fish, as proven in Figure 1.

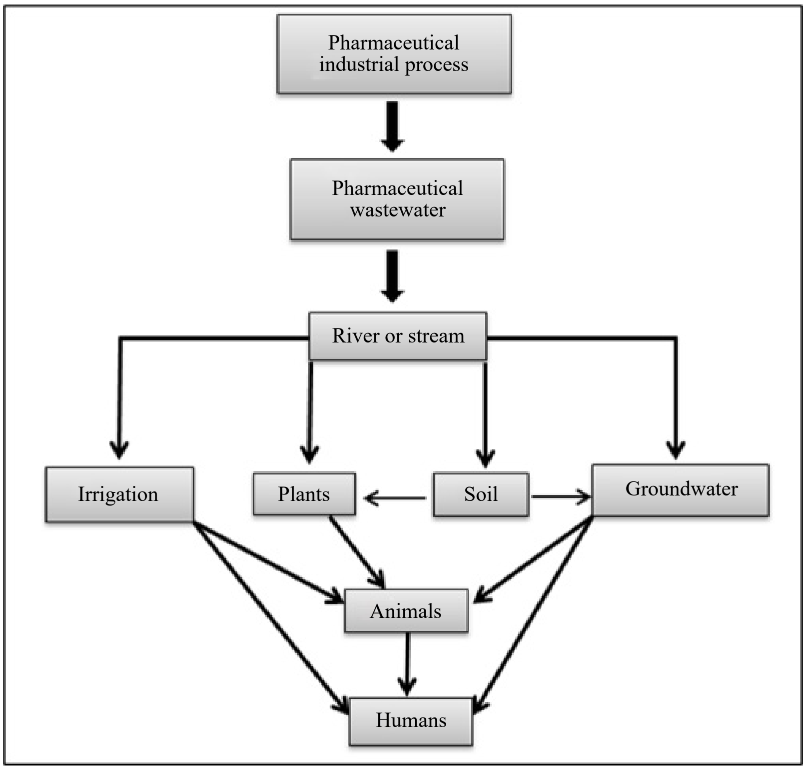

Figure 1. Conveyance of pharmaceutical compounds from PWW to the environment and humans

Pharmaceutical industries discharge an assortment of exceedingly harmful and diligent organics in their WW. Consequently, fruitful expulsion of these organics is essential [15]. Based on the production forms, the pharmaceutical industry can be separated into five categories: specific maturation, normal item extraction, chemical amalgamation, definition, and investigation and development [16]. Many researchers studied production and quantity for PWW. Al-Khazrajy and Boxall [11] investigated PWW dumping for the primary exceedingly in the cities of Baghdad, Mosul, and Basrah. The researchers stated that the quantity of PWW produced in Baghdad, Mosul, and Basrah was 1.6 x 106 m^3/day, 0.5 x 106 m^3/day, and 0.331 x 106 m^3/day, respectively [11]. Correspondingly, Al-Hashimi and Abbas [13] considered the PWW features and expository strategies of the factory, which lies in Samarra City, approximately 120 km to the north of Baghdad. This plant delivered around 300 types of pharmaceutical formulae (antibiotics and distinctive drugs). The average PWW discharged from the factory was 18.7 m^3/hour.

3. Characteristics of PWW

Table 1 demonstrates the characterization of PWW. Using direct and indirect methods, pharmaceuticals can be introduced into the environment. It is possible to classify pharmaceutical development processes as physical, chemical, and biological [17]. In several environmental matrices worldwide, pharmaceutical residues have been found (such as in waters, WW, sediments and sludge). The hydrophobicity that can pass in the aquatic environment or stay adsorbed on rock-solid elements mainly depends on these compounds. Households, WWTPs, hospitals, manufacturing units, and intensive animal husbandry are the greatest common foundations of such combinations in the environment. Industrial and domestic waste must be handled effectively to meet the demands of growing populations, strict regulatory standards, and ageing water treatment facilities. Unique analytical approaches are available to track the chemical compounds in WW to meet these challenges. However, due to the complexity of the sample matrix, several analytical methods are required in the dissolved and suspended phases to determine polar and non-polar organic compounds, which may have an impact on water quality [18]. Pharmaceutical waste is not a single stream of waste but many distinctive streams of waste that can affect the integrity and uniformity of pharmaceutical chemicals. PWW can result from a variety of actions within a healthcare facility, including general compounding, breakages, partially used ampoules, needles and intravenous (IV) therapy, obsolete and unused preparations, doses of unused units, personal drugs, and outdated pharmaceutical products [19]. The general approaches used for the treatment of PWW are flotation or sedimentation, physio-chemical therapy, the MBR technique, and biological treatment [20]. Common characteristics of PWW are given in Table 2. Further PWW quality parameters are shown in Tables 3 and 4.

Table 1. Studies on PWW and characteristics

Type of study	References	Year
In the evaluation of the elimination performance of pharmaceutical merchandise from WW in sewage remedy plants, the researcher observed that the chemical oxygen demand (COD) was 3,173 ± 1,528 mg/L and the biochemical oxygen demand (BOD) was 1,206 ± 397 mg/L	Kodom et al. [21]	2021
Based on the analysis of the PWW treatment technology, the COD concentration was 20,000 mg/L	Feng [6]	2019
Based on the study of a sustainable approach for PWW treatment, the researcher observed that the COD was 3,200 mg/L, the BOD was 1,690 mg/L, and the total suspended solids (TSS) were 296 mg/L	Fawzy et al. [22]	2018
The origin and character of PWW were summarized in this paper. The researcher found that the range of COD was 2,000 mg/L to 10,000 mg/L, the five-day biochemical oxygen demand (BOD_5) was 1,000 mg/L to 2,500 mg/L, pH 4 to pH 8, and total nitrogen (TN) was 500 mg/L to 1,500 mg/L	Fazal et al. [23]	2015
The researcher observed that the total dissolved solids (TDS) were 2,450 ± 1.09 mg/L in the study of the PWW of antibiotics	Ng et al. [24]	2015
The researcher found a COD of 1,565 ± 114 mg/L in the study of antibiotic waste	Ng et al. [25]	2014
The study of PWW fermentation	Chen et al. [26]	2014
From the assessed hazards of the WWTP of the pharmaceutical industry, the researcher observed a pH range of 5.8 to 7.8, TSS was 230 mg/L to 830 mg/L, TDS was 650 mg/L to 1,250 mg/L, BOD was 20 mg/L to 620 mg/L, and COD was 128 mg/L to 960 mg/L	Choudhary and Parmar [27]	2013
From the assessed biodegradability of PWW treated by ozone, the researcher observed a rate of pH 6.9, TSS of 370 mg/L, TDS of 1,550 mg/L, BOD of 120 mg/L, and COD of 490 mg/L	Gome and Upadhyay [28]	2013
In the study of mixed PWW treatment, the researcher observed a rate of pH 7.2 to pH 8.5, TSS of 48 mg/L to 145 mg/L, BOD of 480 mg/L to 1,000 mg/L, and COD of 2,000 mg/L to 3,500 mg/L	Wei et al. [29]	2012
Based on the study of the production of bulk drug TDS, the researcher found that TDS was 15,000 mg/L	Deshpande et al. [30, 31]	2010, 2012
The researchers observed rates of pH 3.69 to pH 6.77, TSS of 280 mg/L to 1,113 mg/L, TDS of 1,770 mg/L to 4,009 mg/L, BOD of 995 mg/L to 1,097 mg/L, and COD of 2,268 mg/L to 3,185 mg/L based on the study of the toxicity of heavy metal contaminants in WW discharge samples gathered from Taloja Industrial Estate in Mumbai, India	Lokhande et al. [32]	2011
The researcher observed rate parameters in PWW of pH 6.2 to pH 7.0, TSS of 690 mg/L to 930 mg/L, TDS of 600 mg/L to 1,300 mg/L, BOD of 1,300 mg/L to 1,800 mg/L, and COD of 2,500 mg/L to 3,200 mg/L	Saleem [33]	2007
The researchers found that the pH value ranged from 5.2 to 6.8 in the study of WW in the pharmaceutical brewery industry	Chelliapan et al. [34, 35]	2006 2011
The researchers observed a TSS rate of 871 ± 87 mg/L in penicillin industry waste	Rodríguez et al. [36]	2005
Chemical synthesis studies in the pharmaceutical industry	Degirmentas and Deveci [37]	2004

Table 2. Common PWW physicochemical properties [38]

COD (mg/L)	BOD_5 (mg/L)	TN (mg/L)	Total PO_4 (mg/L)	TSS (mg/L)	Chromaticity (times)	Temperature (°C)	pH
1,000 to 10,000	500 to 2,500	500 to 1,500	50 to 250	200 to 500	500 to 1,000	25 to 80	1 to 8

Table 3. Results of filtering technology for PWW [39]

Test	Filter 3	Filter 2	Filter 1	Blank
pH	7.5	7.3	7.54	5.93
Electrical conductivity (EC; μmhos/cm)	690	830	715	727
Temperature	25	25	25	25
Turbidity (NTU)	22	35	32	80
COD (mg/L)	135	316	246	432
TS (mg/L)	520	710	685	1,160
TSS (mg/L)	38	225	210	375
PO_4 (mg/L)	1.19	2.3	2.8	5.2
NO_3 (mg/L)	0.29	0.56	0.41	2.89
Total hardness (mg/L)	100	180	160	270
Ca^{++} (mg/L)	47	61	58	72.2
Mg^{++} (mg/L)	4.8	4.88	4.98	8.96

Table 4. PWW characteristics [39]

Parameter	Range
pH	5.93 to 6.75
EC (μmhos/cm)	727 to 1,625
Turbidity (NTU)	80 to 95
COD (mg/L)	432 to 1,536
TS (mg/L)	1,160 to 1,750
TSS (mg/L)	375 to 504
PO_4 (mg/L)	5.2 to 8.6
NO_3 (mg/L)	0.15 to 2.98
Total hardness (mg/L)	270 to 400
Ca^{++} (mg/L)	72.2 to 136.4
Mg^{++} (mg/L)	8.96 to 13.4

There are many types of pollutants in PWW, consisting of nitrogen, organic material, dissolved material, etc. Conventionally, specific toxicity assays based on methanogenic activity are commonly used in anaerobic processes. Table 5 illustrates the severe toxicity of PWW.

Table 5. Severe toxicity of PWW

Indicator strain	Sample category	The concentration of acute toxicity	References	Year
Folic acid inhibitors	Trimethoprim	26,100 ng/L	Dalahmeh et al. [40]	2020
Antimicrobials	Metronidazole	7,400 ng/L	Giebułtowicz et al. [41]	2020
	Ciprofloxacin	4,300 ng/L		
	Vancomycin	3,200 ng/L		
	Sulfamethoxazole	3,000 ng/L		
Rifamycins	Rifampicin	2.9 ng/L	Alygizakis et al. [42]	2019
	Rifaximin	12 ng/L		
Thioamides	Ethionamide	9.3 ng/L	Faleye et al. [43]	2019
Azoles	Fluconazole	170 ng/L	Yilmaz et al. [44]	2017
	Metronidazole	3,000 ng/L		
	Tinidazole	12 ng/L		
Penicillins	Ampicillin	790 ng/L	Kimosop et al. [45]	2016
Vibrio	Amoxicillin	3.99 g/L	Ji et al. [46]	2013b
	Ciprofloxacin	5.63 g/L		
	Lincomycin	4.32 g/L		
	Kanamycin	5.11 g/L		
Fischeri	Aureomycin	12.06 mg/L	Ji et al. [47]	2013a
	Chloromycetin	429.90 mg/L		
	Polymyxin	6.24 mg/L		
	Acetate	20.71 g/L		
	Butyrate	12.17 g/L		
	Ethanol	19.40 g/L		
	Propionate	10.47 g/L		
Photobacterium phosphoreum	Kemicetine	95 mg/L	Sponza and Demirden [48]	2010

4. Treatment technologies for PWW

Table 6 shows the technologies used for pharmaceutical waste treatment. According to the current literature, the general characterization of PWW is that it is produced by several production plants. Although most WW sources contain high COD concentrations, it has been found that the change among different production actions can still be enormous, with COD values ranging from 4,410 mg/L to 40,000 mg/L [38].

Table 6. PWW treatment technology

Type of study for treatment technology	References	Year
A novel paraboloid-formed graphite-based microorganism electric cell (MFC) configuration has been designed to treat PWW; the outcomes are rumored to be a big reduction in COD (80.55%) and TDS (35.62%) for PWW by MFC	Rashid et al. [5]	2021
The researcher used physicochemical, biochemical, and blended techniques for PWW treatment methods. The results showed a big drop in COD (95%); also, the common elimination charges of ammonia and overall phosphorus in natural pollution can attain 80% and 65% to 99%, respectively.	Feng [6]	2019
The researcher used the activated sludge process (ASP) in incorporation with the ultraviolet-free surface reactor (UV-FSR) process for the treatment of PWW; the highest BOD removal ranged between 95.65% and 99.98% and TSS was 98.33% to 98.31%	Fawzy et al. [22]	2018
The applications of a novel Fe-TiO_2 composite that can comprise in situ dual impacts (photocatalysis and photo-Fenton) were used for the treatment of PWW; the reduction in COD was 83%	Bansal et al. [49]	2018
The researchers studied the chemical synthesis of PWW by MBR, and they found that 90% of COD removal was from PWW.	Kaya et al. [50]	2017
The researchers treated the WW from the pharmaceutical industry by using anaerobic MBR technology; the highest COD elimination of as much as 97% was detected, while the influent awareness was expanded with the aid of methanol addition	Svojitka et al. [51]	2017
The researchers used a combination of an up-flow anaerobic sludge blanket (UASB) reactor followed by an MBR system for the complete removal of the PWW residues; they found that the COD was reduced from 1,100 mg/L to 10 mg/L, the BOD from 735 mg/L to less than 10 mg/L, and the TSS from 290 mg/L to 15 mg/L. The pharmaceuticals had been eliminated from raw WW at a charge ranging from 94% to 99.2%	Abdel-Shafy and Mansour [52]	2017
The researchers used the cyclic activated sludge procedure (CASS) and MBR for treating PWW; excessive concentrations of antibiotics remain from 0.14 mg/L to 92.2 mg/L	Wang et al. [53]	2015
The researchers studied the waste treatment of synthetic antibiotics. In the experiment, the COD was reduced from 2,500 mg/L to 62 mg/L	Aydin et al. [54]	2014
The researchers investigated manufacturing and cleaning treatment equipment and observed a 52.2% COD reduction	Chen et al. [55]	2011a
The researchers studied the treatment of amoxicillin waste by clarification and found that 97% of COD was removed	Chen et al. [56]	2011b
The researchers studied the use of a multi-media filter (activated carbon, ceramic and sand) in the treatment of wastes from the pharmaceutical factory in Mosul, as it is one of the industries that contain a high percentage of chemicals. The PWW was passed through the filter to find out the efficiency of its removal through a procedure. The filter with three media (activated carbon, ceramic and sand) showed that it was the most efficient in removing waste	Abawee et al. [39]	2010
The researchers showed that ceramics were used to purify PWW in Cambodia. Ceramic is a lightweight, easy-to-use material that is also economical and free of chemicals, so it is considered a safe material. It is harmful to use as well as being very efficient at reducing a high percentage of pollutants. The study relied on ceramics in various forms, including annular, circular, and cylindrical. The results showed a possible reduction of 96% of E-pathogenic bacteria and viruses and 99.99% of L-bacteria. The turbidity in the water was reduced by 95%, as well as other pollutants.	Brown et al. [57]	2008
For PWW to be used again, the researcher used activated carbon to get rid of as much phenol as possible. Adsorption of activated carbon can also lower phenol, TDS, TSS, BOD, and COD up to 99.9%, 99.1%, 21.4%, 81.3%, and 71.1%, respectively	Saleem [33]	2007
The researchers studied pharmaceutical industry waste treatment by sequential batch reactors (SBR) and the removal of pollutants was 94.7% to 99.4%	Amin et al. [58]	2006
The researchers studied the treatment of ampicillin WW by anaerobic baffled reactor (ABR). COD levels were reduced to 89.6 mg/L from 1,300 mg/L to 14,000 mg/L	Zhou et al. [59]	2006
Sand and carbon filter activators were used for the treatment of PWW in Basrah City, Iraq. According to the results, the treatment processes removed 100% of the lead, 50% of the manganese, 55% of the iron, 23% of the cadmium, 3% of the nickel, and 55% of the iron	Al-Imarah et al. [60]	2006
Researchers investigated the waste pharmaceutical treatment and discovered that the COD decreased by 93%	Chelliapan et al. [61]	2006
SBR was used for the treatment of PWW. The WW contained COD of 250 mg/L to 500 mg/L, BOD of 130 mg/L to 280 mg/L, ammonia of 80 mg/L to 200 mg/L, TN of 90 mg/L to 240 mg/L, total phosphorus of 1 mg/L to 2 mg/L, and a pH of 8.8 to 9.6. At 23 °C, a reduction efficiency of 99% was achieved for atomic number seven.	Peng et al. [62]	2004
Mulhern activated carbon was used to treat well water that had been contaminated with industrial WW containing organic matter and contaminants. The researchers discovered that lead was removed by 80%, copper by 93%, and organic matter by 70% to 95%	Mulhern et al. [63]	2020

The research applied Tabbal ceramics with a diameter of 6 cm and a length of 25 cm for the treatment of PWW mixed with river water. The removal efficiency of turbidity was 85%, and the removal of *E. Coli* suspended matter was 95%	Dies et al. [64]	2003
Researchers conducted a study on the characteristics of pharmaceutical plant discards used to treat excreta and the treatment processes. The results of the treatment process showed the filter's efficiency in removing a high percentage of toxicities in addition to organic material, as the removal efficiency reached about 67% of the organic matter. As for the bacteria, the efficiency of their removal reached about 96%	Ibigbami et al. [65]	2016
Fiberglass was used as a filter medium for PWW treatment. The researcher used p to get rid of the water's bacteria and turbidity. The study demonstrated the candidate's capability of removing 70% of turbidity and suspended solids based on a combination of factors, including cycle time and the dose or continuous flow regime, the most important of which are the types of inputs that passed through it.	Rizzo [66]	1972

5. PWW management and reusing

Proper WW management and reuse are becoming more important in ensuring a sustainable environment by protecting public health, sustaining aquatic habitats, and preserving water resources. The significance of water reuse may be examined by comparing water reuse potential to total water usage. Currently, water recycling and reuse are relatively small compared to overall water usage, but they are predicted to grow dramatically in the future [67]. Pharmaceuticals are often manufactured in multi-stage batch methods that generate extremely complicated WW courses with varying chemical configurations, poisonousness, and volume [20]. Such variations in the waste material amount and quality will produce shock and overload in treatment systems, leading to bad or maybe failures of treatment operations, together with biological treatment [68]. To achieve successful treatment of pharmaceutical effluents, production operations must deal with different types of WW individually, identify extremely hazardous and dense streams, and provide pre-treatment if needed. WW biocompatibility and toxicity, along with the concentration of particular contaminants in various batch streams, must all be considered when determining the best treatment approach. The assessment and separation of pharmaceutical batch streams primarily based on the type of impurity is now a prime mission not only for figuring out the high-quality remedy method but for determining the possibility of healing or reuse of additives in effluents [68].

Reusing water in the industry is critical for sustainability since it can reduce the amount of freshwater needed and increase production without exceeding water discharge limits [20]. Due to the high risk of consequence contamination, which may be harmful to human health, the possibilities for recycling wiped-clean PWW as a secondary aid in pharmaceutical manufacture are extremely restricted [68]. Certain countries (Switzerland, the United States of America, Singapore, and Australia) where WW after treatment is reused for agricultural irrigation or dumped into aquifers that simultaneously supply drinking water should include certain medications in their water monitoring systems [69]. Furthermore, the pretreatment and healing of numerous useful byproducts, including solvents, acids, heavy metals, and numerous key active pharmaceutical ingredients that make their way into waste streams, represent an important waste management approach for pharmaceutical factories [70]. Recovering a pharmaceutical product could minimize or even eradicate waste disposal expenses for the main process system as well as raw water needs for the secondary unit procedure, rapidly offsetting waste-treatment working costs and boosting process economics. The retrieved waste circulate may be utilized someplace else inside the function, and the water also can be used for boiler feed, cooling towers, and other activities, decreasing raw water usage and substantially lowering operating costs [71].

6. Water quality standards

Water quality standards imply statements and numeric values that describe water quality and fall within the following three components:

- Designated uses of the water body as related to water supply, aquatic life, agriculture, or recreation.
- Water quality criteria, general statements that describe good water quality, and specific numerical concentrations for various parameters.
- Anti-degradation policy designed to maintain and protect the existing water uses for each water body.

The standard used for a particular type of water is a function of the expected use of the water. Table 7 presents some of the established standards for some water quality parameters. This means that the established drinking water standard is only used to determine the Drinking Water Quality Index, whereas the Aquatic Water Quality Index standards are used to protect aquatic life.

Table 7. Iraq [72] and the World Health Organization (WHO) [73] standards

	Iraq standard		WHO standard
Parameter	Maximum desired values	Maximum allowed value	
Temperature (℃)	13 to 35	-	13 to 35
EC (µS/cm)	1,000	-	1,000
TDS (mg/L)	500	1,500	1,000
TSS (mg/L)	60	-	30
Turbidity (NTU)	5	25	1 to 5
pH	7 to 8.5	5.2 to 6	6.5 to 8.5
COD (mg/L)	-	-	100
BOD (mg/L)	5	-	-
Mg (mg/L)	50	150	125
Ca (mg/L)	75	200	75
Total hardness (mg/L)	100	500	250 to 500
NO_3 (mg/L)	20	40	10
SO_4 (mg/L)	200	400	250
Chloride (mg/L)	200	600	250
Alkaline (mg/L)	170	200	125
Fluoride (mg/L)	-	1	0.5 to 1.5

7. Conclusion

According to the literature review for the PWW treatment, there are large amounts of waste that contain toxic materials, nitrogen, and organic materials. Some pollutants in the PWW exceeded the standards for the disposal of WW. Therefore, treatment processes are essential for the PWW before disposal into the natural environment or water sources. Several techniques were applied for the treatment of the PWW, which led to the removal of organic and nitrogen compounds, TSS, turbidity, toxic materials, PO_4, etc. Commonly, treated PWW can be reused through methods such as the UASB reactor, carbon filtration through activated carbon, MBR, microalgal bioremediation, UV-FSR, solar or ferrioxalate photocatalysis, etc. The removal efficiencies for COD, BOD, TSS, and TDS in the PWW ranged between 20% and 95%.

Conflict of interest

There is no conflict of interest in this study.

References

[1] Deegan AM, Shaik B, Nolan K, Urell K, Oelgemöller M, Tobin J, et al. Treatment options for wastewater effluents

from pharmaceutical companies. *International Journal of Environmental Science & Technology*. 2011; 8(3): 649-666. https://doi.org/10.1007/BF03326250

[2] Samal K, Mahapatra S, Ali MH. Pharmaceutical wastewater as emerging contaminants (EC): Treatment technologies, impact on environment and human health. *Energy Nexus*. 2022; 6: 1-18. https://doi.org/10.1016/j.nexus.2022.100076

[3] Rizzo C, Marullo S, D'Anna F. Carbon-based ionic liquid gels: Alternative adsorbents for pharmaceutically active compounds in wastewater. *Environmental Science: Nano*. 2021; 8(1): 131-145. https://doi.org/10.1039/D0EN01042A

[4] Gadipelly C, Pérez-González A, Yadav GD, Ortiz I, Ibáñez R, Rathod VK, et al. Pharmaceutical industry wastewater: Review of the technologies for water treatment and reuse. *Industrial & Engineering Chemistry Research*. 2014; 53(29): 11571-11592. https://doi.org/10.1021/ie501210j

[5] Rashid T, Sher F, Hazafa A, Hashmi RQ, Zafar A, Rasheed T, et al. Design and feasibility study of novel paraboloid graphite based microbial fuel cell for bioelectrogenesis and pharmaceutical wastewater treatment. *Journal of Environmental Chemical Engineering*. 2021; 9(1): 1-36. https://doi.org/10.1016/j.jece.2020.104502

[6] Feng H. Research progress in pharmaceutical wastewater treatment technology. In: Weng C-H, Weerasinghe R, Wu J. (eds.) *2019 4th International Conference on Advances in Energy and Environment Research (ICAEER 2019)*. France: EDP Sciences; 2019. p.1-4.

[7] Guo X, Yan Z, Zhang Y, Xu W, Kong D, Shan Z, et al. Behavior of antibiotic resistance genes under extremely high-level antibiotic selection pressures in pharmaceutical wastewater treatment plants. *Science of The Total Environment*. 2018; 612: 119-128. https://doi.org/10.1016/j.scitotenv.2017.08.229

[8] Zhao F, Ju F, Huang K, Mao Y, Zhang XX, Ren H, et al. Comprehensive insights into the key components of bacterial assemblages in pharmaceutical wastewater treatment plants. *Science of The Total Environment*. 2019; 651: 2148-2157. https://doi.org/10.1016/j.scitotenv.2018.10.101

[9] Kanakaraju D, Glass BD, Oelgemöller M. Titanium dioxide photocatalysis for pharmaceutical wastewater treatment. *Environmental Chemistry Letters*. 2013; 12: 27-47. https://doi.org/10.1007/s10311-013-0428-0

[10] Mahmood AR, Al-Haideri HH, Hassan FM. Detection of antibiotics in drinking water treatment plants in Baghdad City, Iraq. *Advances in Public Health*. 2019; 2019: 1-11. https://doi.org/10.1155/2019/7851354

[11] Al-Khazrajy OSA, Boxall ABA. Risk-based prioritization of pharmaceuticals in the natural environment in Iraq. *Environmental Science and Pollution Research.* 2016; 23: 15712-15726. https://doi.org/10.1007/s11356-016-6679-0

[12] Ismail ZZ, Habeeb AA. Pharmaceutical wastewater treatment associated with renewable energy generation in microbial fuel cell based on mobilized electroactive biofilm on zeolite bearer. *Journal of Engineering*. 2015; 21: 35-44. https://www.iasj.net/iasj/download/ecae2e666fda24f6

[13] Al-Hashimi MAI, Abbas AH. Sequential anaerobic/aerobic treatment of pharmaceutical wastewater. *Tikrit Journal of Engineering Sciences*. 2007; 14: 1-31. https://doi.org/10.25130/tjes.14.2.01

[14] Mansouri F, Chouchene K, Roche N, Ksibi M. Removal of pharmaceuticals from water by adsorption and advanced oxidation processes: State of the art and trends. *Applied Sciences*. 2021; 11(14): 1-35. https://doi.org/10.3390/app11146659

[15] Chen YF, Ng WJ, Yap MGS. Performance of upflow anaerobic biofilter process in pharmaceutical wastewater treatment. *Resources, Conservation and Recycling*. 1994; 11(1-4): 83-91. https://doi.org/10.1016/0921-3449(94)90080-9

[16] Ince BK, Selcuk A, Ince O. Effect of a chemical synthesis-based pharmaceutical wastewater on performance, acetoclastic methanogenic activity and microbial population in an upflow anaerobic filter. *Journal of Chemical Technology & Biotechnology*. 2002; 77(6): 711-719. https://doi.org/10.1002/jctb.629

[17] Shi X, Leong KY, Ng HY. Anaerobic treatment of pharmaceutical wastewater: A critical review. *Bioresource Technology*. 2017; 245: 1238-1244. https://doi.org/10.1016/j.biortech.2017.08.150

[18] Renita AA, Kumar PS, Srinivas S, Priyadharshini S, Karthika M. A review on analytical methods and treatment techniques of pharmaceutical wastewater. *Desalination and Water Treatment*. 2017; 87: 160-178. https://doi.org/10.5004/dwt.2017.21311

[19] Babu MA. A short review on pharmaceutical waste disposal and management. *Journal of Pharmaceutics and Nanotechnology*. 2016; 4(2): 1-7. https://www.rroij.com/open-access/a-short-review-on-pharmaceutical-waste-disposal-and-management-.php?aid=82745.

[20] Gadipelly C, Pérez-González A, Yadav GD, Ortiz I, Ibáñez R, Rathod VK, et al. Pharmaceutical industry wastewater: Review of the technologies for water treatment and reuse. *Industrial & Engineering Chemistry Research*. 2014; 53(29): 11571-11592. https://doi.org/10.1021/ie501210j

[21] Kodom K, Attiogbe F, Kuranchie FA. Assessment of removal efficiency of pharmaceutical products from wastewater in sewage treatment plants: A case of the sewerage systems Ghana limited, Accra. *Heliyon*. 2021; 7(11): 1-9. https://doi.org/10.1016/j.heliyon.2021.e08385

[22] Fawzy ME, Abdelfattah I, Abuarab ME, Mostafa E, Aboelghait KM, El-Awady MH. Sustainable approach for pharmaceutical wastewater treatment and reuse: Case study. *Journal of Environmental Science and Technology*. 2018; 11(4): 209-219. https://doi.org/10.3923/jest.2018.209.219

[23] Fazal S, Zhang B, Zhong Z, Gao L, Chen X. Industrial wastewater treatment by using MBR (membrane bioreactor) review study. *Journal of Environmental Protection*. 2015; 6: 584-598. https://doi.org/10.4236/jep.2015.66053

[24] Ng KK, Shi X, Ng HY. Evaluation of system performance and microbial communities of abioaugmented anaerobic membrane bioreactor treating pharmaceutical wastewater. *Water Research*. 2015; 81: 311-324. https://doi.org/10.1016/j.watres.2015.05.033

[25] Ng KK, Shi X, Tang MKY, Ng HY. A novel application of anaerobic bio-entrapped membrane reactor for the treatment of chemical synthesis-based pharmaceutical wastewater. *Separation and Purification Technology*. 2014; 132: 634-643. https://doi.org/10.1016/j.seppur.2014.06.021

[26] Chen Z, Wang Y, Li K, Zhou H. Effects of increasing organic loading rate on performance and microbial community shift of an up-flow anaerobic sludge blanket reactor treating diluted pharmaceutical wastewater. *Journal of Bioscience and Bioengineering*. 2014; 118(3): 284-288. https://doi.org/10.1016/j.jbiosc.2014.02.027

[27] Choudhary S, Parmar N. Hazard assessment of liquid effluent treatment plant in pharmaceutical industry. *VSRD International Journal of Technical & Non-Technical Research*. 2013; 4(9): 209-214. https://www.vsrdjournals.com/pdf/VSRDIJTNTR/2013_9_September/1_Sanjay_Choudhary_2693_Research_Article_VSRDIJTNTR_September_2013.pdf

[28] Gome A, Upadhyay K. Biodegradability assessment of pharmaceutical wastewater treated by ozone. *International Research Journal of Environment Sciences*. 2013; 2(4): 21-25. http://www.isca.me/IJENS/Archive/v2/i4/5.ISCA-IRJEvS-2013-054.pdf

[29] Wei X, Li B, Zhao S, Wang L, Zhang H, Li C, et al. Mixed pharmaceutical wastewater treatment by integrated membrane-aerated biofilm reactor (MABR) system – A pilot-scale study. *Bioresource Technology*. 2012; 122: 189-195. https://doi.org/10.1016/j.biortech.2012.06.041

[30] Deshpande AM, Satyanarayan S, Ramakant S. Treatment of high-strength pharmaceutical wastewater by electrocoagulation combined with anaerobic process. *Water Science & Technology*. 2010; 61(2): 463-472. https://doi.org/10.2166/wst.2010.831

[31] Deshpande AM, Satyanarayan S, Ramakant. Kinetic analysis of an anaerobic fixed-film fixed bed-reactor treating wastewater arising from production of a chemically synthesized pharmaceutical. *Environmental Technology*. 2012; 33(11): 1261-1270. https://doi.org/10.1080/09593330.2011.618952

[32] Lokhande RS, Singare PU, Pimple DS. Toxicity study of heavy metals pollutants in waste water effluent samples collected from Taloja Industrial Estate of Mumbai, India. *Resources and Environmen*t. 2011; 1(1): 13-19. http://article.sapub.org/10.5923.j.re.20110101.02.html

[33] Saleem M. Pharmaceutical wastewater treatment: A physicochemical study. *Journal of Research (Science).* 2007; 18: 125-134. https://www.bzu.edu.pk/jrscience/vol18no2/8.pdf

[34] Chelliapan S, Wilby T, Sallis PJ. Performance of an up-flow anaerobic stage reactor (UASR) in the treatment of pharmaceutical wastewater containing macrolide antibiotics. *Water Research*. 2006; 40(3): 507-516. https://doi.org/10.1016/j.watres.2005.11.020

[35] Chelliapan S, Wilby T, Yuzir A, Sallis PJ. Influence of organic loading on the performance and microbial community structure of an anaerobic stage reactor treating pharmaceutical wastewater. *Desalination*. 2011; 271(1-3): 257-264. https://doi.org/10.1016/j.desal.2010.12.045

[36] Rodríguez MJ, Garza GY, Aguilera CA, Martínez ASY, Sosa SGJ. Influence of nitrate and sulfate on the anaerobic treatment of pharmaceutical wastewater. *Engineering in Life Sciences.* 2005; 5(6): 568-573. https://doi.org/10.1002/elsc.200520101

[37] Degirmentas I, Deveci N. Anaerobic treatment of antibiotic production wastewater and kinetic evaluations. *The Journal of Biochemistry*. 2004; 136(2): 177-182. https://doi.org/10.1093/jb/mvh110

[38] Guo Y, Qi PS, Liu YZ. A review on advanced treatment of pharmaceutical wastewater. In: *2017 International Conference on Environmental and Energy Engineering (IC3E 2017)*. IOP Publishing Ltd; 2017. p.1-7.

[39] Abawee SA, Al-Hashimi ZF, Shihab MS. استخدام اوساط مختلفة في ازالة الملوثات من مطروحات نينوى ادوية لمعمل [The use of multi media filter for removing pollutants from Nineveh drugs industry]. *Iraqi Academic Scientific Journals*. 2010; 28(13): 627-641. https://www.iasj.net/iasj/article/27779

[40] Dalahmeh S, Björnberg E, Elenström A-K, Niwagaba CB, Komakech AJ. Pharmaceutical pollution of water

resources in Nakivubo wetlands and Lake Victoria, Kampala, Uganda. *Science of The Total Environment*. 2020; 710: 1-8. https://doi.org/10.1016/j.scitotenv.2019.136347
[41] Giebułtowicz J, Nałęcz-Jawecki G, Harnisz M, Kucharski D, Korzeniewska E, Płaza G. Environmental risk and risk of resistance selection due to antimicrobials' occurrence in two Polish wastewater treatment plants and receiving surface water. *Molecules*. 2020; 25(6): 1-22. https://doi.org/10.3390/molecules25061470
[42] Alygizakis NA, Besselink H, Paulus GK, Oswald P, Hornstra LM, Oswaldova M, et al. Characterization of wastewater effluents in the Danube River Basin with chemical screening, in vitro bioassays and antibiotic resistant genes analysis. *Environment International*. 2019; 127: 420-429. https://doi.org/10.1016/j.envint.2019.03.060
[43] Faleye AC, Adegoke AA, Ramluckan K, Fick J, Bux F, Stenström TA. Concentration and reduction of antibiotic residues in selected wastewater treatment plants and receiving waterbodies in Durban, South Africa. *Science of The Total Environment*. 2019; 678: 10-20. https://doi.org/10.1016/j.scitotenv.2019.04.410
[44] Yilmaz G, Kaya Y, Vergili I, Gönder ZB, Özhan G, Celik BO, et al. Characterization and toxicity of hospital wastewaters in Turkey. *Environmental Monitoring and Assessment*. 2017; 189: 1-19. https://doi.org/10.1007/s10661-016-5732-2
[45] Kimosop SJ, Getenga ZM, Orata F, Okello VA, Cheruiyot JK. Residue levels and discharge loads of antibiotics in wastewater treatment plants (WWTPs), hospital lagoons, and rivers within Lake Victoria Basin, Kenya. *Environmental Monitoring and Assessment*. 2016; 188: 1-9. https://doi.org/10.1007/s10661-016-5534-6
[46] Ji JY, Xing YJ, Ma ZT, Cai J, Zheng P, Lu HF. Toxicity assessment of anaerobic digestion intermediates and antibiotics in pharmaceutical wastewater by luminescent bacterium. *Journal of Hazardous Materials*. 2013; 246-247: 319-323. https://doi.org/10.1016/j.jhazmat.2012.12.025
[47] Ji JY, Xing YJ, Ma ZT, Zhang M, Zheng P. Acute toxicity of pharmaceutical wastewaters containing antibiotics to anaerobic digestion treatment. *Chemosphere*. 2013; 91(8): 1094-1098. https://doi.org/10.1016/j.chemosphere.2013.01.009
[48] Sponza DT, Demirden P. Relationships between chemical oxygen demand (COD) components and toxicity in a sequential anaerobic baffled reactor/aerobic completely stirred reactor system treating Kemicetine. *Journal of Hazardous Materials*. 2010; 176(1-3): 64-75. https://doi.org/10.1016/j.jhazmat.2009.10.127
[49] Bansal P, Verma A, Talwar S. Detoxification of real pharmaceutical wastewater by integrating photocatalysis and photo-Fenton in fixed-mode. *Chemical Engineering Journal*. 2018; 349: 838-848. https://doi.org/10.1016/j.cej.2018.05.140
[50] Kaya Y, Bacaksiz AM, Bayrak H, Gönder ZB, Vergili I, Hasar H, et al. Treatment of chemical synthesis-based pharmaceutical wastewater in an ozonation-anaerobic membrane bioreactor (AnMBR) system. *Chemical Engineering Journal*. 2017; 322: 293-301. https://doi.org/10.1016/j.cej.2017.03.154
[51] Svojitka J, Dvořák L, Studer M, Straub JO, Frömelt H, Wintgens T. Performance of an anaerobic membrane bioreactor for pharmaceutical wastewater treatment. *Bioresource Technology*. 2017; 229: 180-189. https://doi.org/10.1016/j.biortech.2017.01.022
[52] Abdel-Shafy HI, Mansour MSM. Treatment of pharmaceutical industrial wastewater via anaerobic/aerobic system for unrestricted reuse. *Indian Journal of Scientific & Industrial Research*. 2017; 76: 119-127. http://nopr.niscpr.res.in/bitstream/123456789/39820/1/JSIR%2076%282%29%20119-127.pdf
[53] Wang J, Mao D, Mu Q, Luo Y. Fate and proliferation of typical antibiotic resistance genes in five full-scale pharmaceutical wastewater treatment plants. *Science of The Total Environment*. 2015; 526: 366-373. https://doi.org/10.1016/j.scitotenv.2015.05.046
[54] Aydin S, Ince B, Cetecioglu Z, Ozbayram EG, Shahi A, Okay O, et al. Performance of anaerobic sequencing batch reactor in the treatment of pharmaceutical wastewater containing erythromycin and sulfamethoxazole mixture. *Water Science & Technology*. 2014; 70(10): 1625-1632. https://doi.org/10.2166/wst.2014.418
[55] Chen Z, Wang H, Chen Z, Ren N, Wang A, Shi Y, Li X. Performance and model of a full-scale up-flow anaerobic sludge blanket (UASB) to treat the pharmaceutical wastewater containing 6-APA and amoxicillin. *Journal of Hazardous Materials*. 2011; 185(2-3): 905-913. https://doi.org/10.1016/j.jhazmat.2010.09.106
[56] Chen Z, Wang H, Ren N, Cui M, Nie S, Hu D. Simultaneous removal and evaluation of organic substrates and NH3-N by a novel combined process in treating chemical synthesis-based pharmaceutical wastewater. *Journal of Hazardous Materials*. 2011; 197: 49-59. https://doi.org/10.1016/j.jhazmat.2011.09.053
[57] Brown J, Sobsey MD, Loomis D. Local drinking water filters reduce diarrheal disease in Cambodia: A randomized, controlled trial of the ceramic water purifier. *The American Journal of Tropical Medicine and Hygiene*. 2008; 79(3): 394-400. https://doi.org/10.4269/ajtmh.2008.79.394
[58] Amin MM, Zilles JL, Greiner J, Charbonneau S, Raskin L, Morgenroth E. Influence of the antibiotic erythromycin on anaerobic treatment of a pharmaceutical wastewater. *Environmental Science & Technology*. 2006; 40(12): 3971-

3977. https://doi.org/10.1021/es060428j

[59] Zhou P, Su C, Li B, Qian Y. Treatment of high-strength pharmaceutical wastewater and removal of antibiotics in anaerobic and aerobic biological treatment processes. *Journal of Environmental Engineering*. 2006; 132(1): 129-136. https://doi.org/10.1061/(ASCE)0733-9372(2006)132:1(129)

[60] Al-Imarah FJM, Al-Ta MK. Environmental parameters of discharged effluents from diary and soft drinks industries in Basra City and their effect upon water properties of Al-Jubailah Creak and Shatt Al-Arab River. *Iraqi Academic Scientific Journals*. 2006; 6(1): 188-200. https://www.iraqjournals.com/article_129136_0.html

[61] Chelliapan S, Wilby T, Sallis PJ. Performance of an up-flow anaerobic stage reactor (UASR) in the treatment of pharmaceutical wastewater containing macrolide antibiotics. *Water Research*. 2006; 40(3): 507-516. https://doi.org/10.1016/j.watres.2005.11.020

[62] Peng YZ, Li YZ, Peng CY, Wang SY. Nitrogen removal from pharmaceutical manufacturing wastewater with high concentration of ammonia and free ammonia via partial nitrification and denitrification. *Water Science & Technology*. 2004; 50(6): 31-36. https://doi.org/10.2166/wst.2004.0356

[63] Mulhern R, Gibson JM. Under-sink activated carbon water filters effectively remove lead from private well water for over six months. *Water*. 2020; 12(12): 1-19. https://doi.org/10.3390/w12123584

[64] Dies R, Pincus M, Flores X, Tabbal G. *Final project report: Point-of-use water treatment technology investigations in Nepal*. Master's degree thesis. Massachusetts Institute of Technology; 2003.

[65] Ibigbami TB, Dawodu FA, Akinyeye OJ. Removal of heavy metals from pharmaceutical industrial wastewater effluent by combination of adsorption and chemical precipitation methods. *American Journal of Applied Chemistry*. 2016; 4(1): 24-32. https://doi.org/10.11648/j.ajac.20160401.15

[66] Rizzo JL. Adsorption/filtration: A new unit process for the treatment of industrial wastewaters. In: *American Institute of Chemical Engineers (AIChE)*. Chemical Engineering Symposium Series; 1971.

[67] Zimmo OR, Imseih N. Overview of wastewater management practices in the Mediterranean region. In: Barceló D, Petrovic M. (eds.) *Waste Water Treatment and Reuse in the Mediterranean Region*. Berlin, Heidelberg: Springer; 2010. p.155-181.

[68] Strade E, Kalnina D, Kulczycka J. Water efficiency and safe re-use of different grades of water-Topical issues for the pharmaceutical industry. *Water Resources and Industry*. 2020; 24: 1-42. https://doi.org/10.1016/j.wri.2020.100132

[69] Miarov O, Tal A, Avisar D. A critical evaluation of comparative regulatory strategies for monitoring pharmaceuticals in recycled wastewater. *Journal of Environmental Management.* 2020; 254: 1-12. https://doi.org/10.1016/j.jenvman.2019.109794

[70] Welton T. Solvents and sustainable chemistry. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 2015; 471(2183): 20150502. https://doi.org/10.1098/rspa.2015.0502

[71] Raymond MJ, Slater CS, Savelski MJ. LCA approach to the analysis of solvent waste issues in the pharmaceutical industry. *Green Chemistry*. 2010; 12(10): 1826-1834. https://doi.org/10.1039/c003666h

[72] Iraqi Criteria and Standards for Drinking Water, Chemical Limits (ICSDWCL). IQS:417/2001. *Drinking-water Standard*. Iraq: Council of Ministers, Republic of Iraq; 2001.

[73] World Health Organization (WHO). *Guidelines for drinking-water quality (4th ed)*. https://www.paho.org/en/documents/guidelines-drinking-water-quality-4o-ed-2011 [Accessed 30th November 2022].