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The Effect of Scale on the Performance of an Integrated Poultry Slaughterhouse Wastewater Treatment Process

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Abstract: The efficiency of a wastewater treatment process may be affected by several factors including the scale at which the system is operating. This study aimed at investigating the influence of scale on a poultry slaughterhouse wastewater treatment process. The process is comprised of several units including electrolysis, membrane filtration, and ultraviolet irradiation. The results of the industrial-scale wastewater treatment plant of the Izevski poultry farm slaughterhouse in Kazakhstan were compared with those of a lab-scale wastewater treatment process under the same conditions. The traditional and water quality index (WQI) approaches were used to present the results and the drinking water quality standards of Kazakhstan were used as a reference. The industrial and lab-scale plants showed high purification efficiency for most of the studied water quality parameters. The comparative analysis based on the WQI showed that the industrial-scale wastewater treatment plant outperforms the lab-scale wastewater treatment process.

Keywords: scale-up; poultry wastewater; water quality index; integrated wastewater treatment

1. Introduction

The poultry industry is recognized as one of the largest and rapidly growing agro-based sectors around the world. This is attributed to the increasing demand for poultry meat and egg products due to urbanization, population rise, and income increases [1]. However, the poultry industry is facing many challenges including the large amounts of waste produced, which accumulate and may pose disposal and pollution problems unless sustainable management methods are implemented [2]. The wastewater generated from a poultry industry contains large amounts of proteins, fats, and carbohydrates resulting

from meat, blood, skin, and feathers, which in turn lead to high biological oxygen demand (BOD) and chemical oxygen demand (COD). The majority of the soluble and suspended materials of this wastewater have to be removed before recycling or discharge [3]. In general, wastewater from a poultry production process is considered to be polluted water, making it unsuitable for certain uses such as drinking, irrigation, or swimming [4].

Previous studies have indicated the potential of integrated treatment systems for poultry slaughterhouse wastewater [5–7]. The removal of pollutants with integrated wastewater systems is achieved by utilizing multi-stage treatment systems. By the utilization of integrated systems, several parameters such as heavy metals, grease and oils, color, biochemical oxygen demand (BOD), total suspended solids (TSS), and chemical oxygen demand (COD) can be handled within one system with multiple stages [8,9]. To develop more efficient poultry slaughterhouse wastewater treatment technologies, research studies are also of great importance towards understanding the performance of different technologies in terms of their efficiency to treat poultry slaughterhouse wastewater [10]. Lab-scale processes can be developed to simulate full-scale wastewater treatment plants [11]. However, the level at which the lab-scale processes represent the full-scale plants should be considered case by case as this depends on the composition of wastewater, the required effluent water quality, and the combination of technologies used [12]. Therefore, research studies on the comparison between lab-scale and full-scale systems are of particular importance.

Laboratory scale treatment processes are characterized by low capacity and high flexibility [13]. Lab-scale treatment plants are part of the preliminary stages towards designing a full-scale integrated treatment plant; however, the degree at which lab-scale may be a good representative of a full-scale plant for treating poultry slaughterhouse wastewater has not been comprehensively studied. Lab-scale plants are normally used during the first stage of a process design, especially when a high number of experiments is required before designing the industrial-scale treatment plant to meet industry-specific requirements [14]. The poultry slaughterhouse production processes exhibit significant variations in organic matter content which accounts for a large part of the pollutants in the wastewater [15]. The presence of large amounts of biodegradable substances such as fat, loose meat, colloidal particles, soluble proteins, undigested food, and suspended solids contribute to the high organic loading in poultry slaughterhouse wastewater [16]. This means that the treatment of such wastewater before discharge is necessary to avoid severe environmental problems.

In the last few decades, several treatment technologies for slaughterhouse wastewater have been studied [15,17]. However, aerobic and anaerobic treatment systems seem to be dominant, which are also subjected to some limitations. For instance, to implement the aerobic treatment approach, high energy is required for aeration while generating a high amount of sludge [18]. Additionally, the anaerobic wastewater treatment process of poultry slaughterhouse wastewater often faces some challenges or is slowed down because of the tendency of accumulating suspended solids and floating fat in the reactors, leading to the reduction in methanogenic activity and biomass washout [19]. Anaerobic wastewater treatment technologies are regarded as more suitable in treating high organic loading wastewater [20]. Electrochemical wastewater treatment technologies are also attractive due to their flexibility and effectiveness [21,22]. Poultry producers need to adopt the latest technologies that will help in reducing the consumption of fresh water while increasing recycling practices and achieve almost zero effluent discharges [23].

Monitoring and reporting the efficiency of a wastewater treatment plant is essential. One of the widely used methods for presenting water quality data is the water quality index (WQI) approach [24–26]. A WQI is a summary of different water quality parameters, resulting in a single unitless number [27,28]. A WQI helps in defining the general quality status of water—using a simplified meaning such as “poor”, “good”, or “excellent” [29]. Water quality indices have been one of the most effective tools to provide feedback on the quality of water to a wide range of experts including engineers, managers, policymakers, and the general public. Depending on the source being investigated, WQI indices can be developed using different water quality parameters. For instance, Şehnaz Şener, Erhan Şener and

Ayşen Davraz [30] used a total of 24 water quality parameters such as pH, temperature, turbidity, total phosphorus, sodium, calcium, COD, and others to develop a WQI for the evaluation of water quality in Aksu River (SW Turkey). Apart from rivers, WQIs have also been used for evaluating various types of waters, such as groundwater [31], aquaculture effects on aquatic bodies [32], and drinking water [33].

In this work, industrial and lab-scale wastewater treatment plants are compared in terms of their efficiency, and the influence of scale on the treatability of poultry slaughterhouse wastewater is studied. The research question was whether a lab-scale treatment plant can be a good representative of a full-scale industrial plant. For this purpose, samples were collected from the Izevski PC poultry farm slaughterhouse wastewater treatment plant, located in Izhevskoye village 70 km from the capital city, Nur-Sultan, and compared with the effluent of a lab-scale treatment process under the same conditions installed in the Water and Environmental Management laboratory at L.N. Gumilyov Eurasian National University (Kazakhstan, Nur-Sultan). The integrated wastewater treatment plant is comprised of electrolysis, membrane filtration, reverse osmosis, and ultraviolet irradiation as main processes. The traditional and WQI approaches were used to present the results.

2. Materials and Methods

2.1. Description of the Case Study and Wastewater Characteristics

The Izevski poultry farm is located in Izhevsk village (70 km from the capital city, Nur-Sultan), Arshalinsky district, in the Akmola region of the Republic of Kazakhstan. The production capacity of the Izevski poultry farm is 280 million eggs per year. The new imported cage used for the production of eggs is capable of accommodating 1 million laying hens. The production setup is composed of 10 sets of equipment for the maintenance of young chickens. Meat production capacity of the poultry farm is 3000 tons per year, while the production of hatchery sets is 4 million pullets per day. The poultry products are daily delivered to the capital city, Nur-Sultan, as well as other cities of Kazakhstan and Russia.

To analyze the wastewater constituents for the water quality parameters of interest, a number of wastewater samples were collected from the farm over two years. The samples used in this study were mainly from the mixture of de-feathering and cooling sections wastewaters. In total, 17 parameters were studied as shown in Table 1; the guidelines set by the Kazakhstan government for drinking water quality standards are also presented. From the raw wastewater characteristics, it can be observed that the poultry slaughterhouse generates wastewater characterized as highly polluted, as seen by COD and BOD measures, as well as the microbial parameters.

Table 1. Poultry wastewater characterization.

Parameter	Concentration (Average)	Kazakhstani Guidelines	Unit
pH	7.4	6.5–8.5	
Turbidity	68.7	Clear	FAU
Color	552	500	mg/dm ³
TSS	116	Clear	mg/dm ³
Chlorine-free	0.08	0.3–0.5	mg/dm ³
Chlorine total	0.07	3.5	mg/dm ³
Nitrite-nitrogen	0.09	3.0	mg/dm ³
Nitrate-nitrogen	18.3	45	mg/dm ³
Phosphates	5.16	2	mg/dm ³
Ammonium	1.12	3.5	mg/dm ³
Iron total	1.33	0.3	mg/dm ³
Aluminum	0.89	0.5	mg/dm ³
COD	2042	1000	mg/dm ³
BOD ₅	653		mg/dm ³
Total microbial number	1365	0	(CFU/1 mL)
Total coliform bacteria	1122	0	(CFU/100 mL)
Thermo-tolerant bacteria	659	0	(CFU/100 mL)

2.2. Wastewater Treatment Plant Setup

The wastewater treatment plant is an integrated system indented for wastewater recycling. Both industrial and lab-scale processes have the same design (Figures 1 and 2). The plant consists of three main components, namely electrolysis, membrane filtration, and ultraviolet disinfection. There are also several other sub-components connected in series including storage tanks, feather and fat catchers, a coarse mechanical filter, and ultra-filtration (Figure 2). The process of electrolysis in the treatment system begins with applying a unipolar voltage to the metal plates-electrodes from a power unit. The mechanical ultra-filtration plays an important role in preparing the water for reverse osmosis as it removes some particles remaining from the previous steps. In general, the membrane filtration technology in the treatment system is used to separate the biomolecules and particles larger than $0.4 \mu\text{m}$ in diameter and it is a pre-treatment unit before the reverse osmosis unit. The reverse osmosis system is designed to reduce the total salinity of water, which is achieved by filtration of water at high pressure through semipermeable membranes that can pass water and trap ions of dissolved salts. The ultraviolet disinfection unit in the integrated wastewater treatment plant is designed to disinfect water with ultraviolet (UV) radiation. It destroys harmful microorganisms contained in the water and makes the water safe for use.

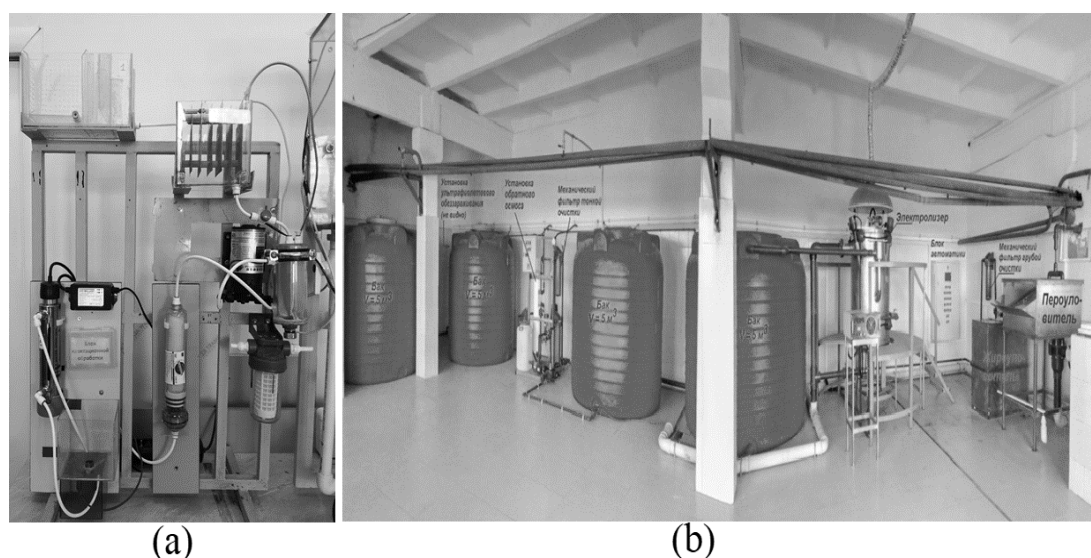


Figure 1. Treatment plant setup showing (a) the lab-scale plant and (b) industrial-scale plant.

The inflow to the lab-scale treatment plant was 0.08% of the industrial-scale inflow, while the outflow from the lab-scale plant was approximately 0.07% of the industrial-scale outflow (Table 2). The lab-scale feather catcher volume was $2.4 \times 10^5 \text{ mm}^3$, which is approximately 0.02% of the industrial-scale treatment plant with a volume of $1.27 \times 10^9 \text{ mm}^3$. Fat catcher unit volume for the lab-scale plant was estimated to be 0.06% of the industrial-scale treatment plant. Additionally, the volume of the lab-scale electrolysis chamber was around 0.06% of the industrial-scale treatment plant. In general, the lab-scale plant was characterized by less hydraulic retention time (HRT) in comparison to the industrial-scale treatment plant.

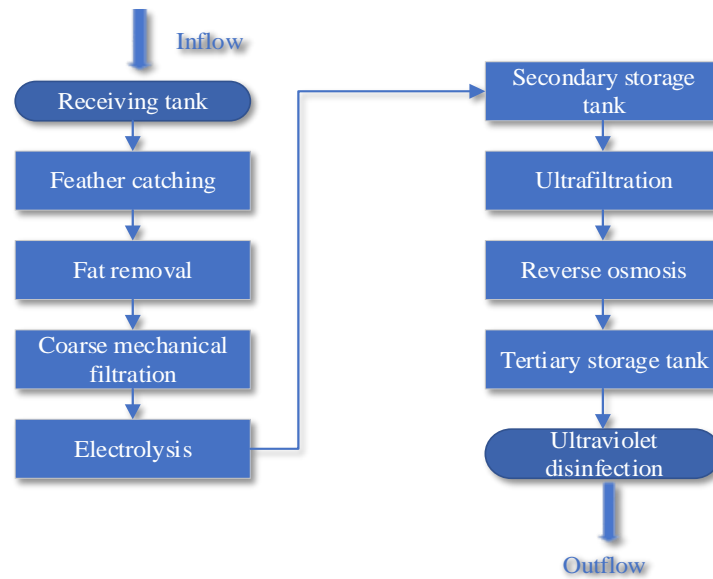


Figure 2. Process flow diagram.

Table 2. Technical specifications.

Parameter	Unit	Lab-Scale	Industrial-Scale
Influent	m ³ /h	0.001	1.25
Effluent	m ³ /h	0.00055	0.75
Drainage	m ³ /h	0.00045	0.5
Total power supply	kW	0.3–0.6	3.8
Feather catcher			
Length	mm	80	1040
Width	mm	60	790
Height	mm	50	1540
Fat catcher			
Length	mm	100	1000
Width	mm	40	540
Height	mm	80	1040
Electrolysis			
Length	mm	100	1030
Width	mm	100	820
Height	mm	100	2030
Cathode	Material	Titanium	Titanium
Anode	Material	Aluminum	Aluminum
Supply voltage	V	12–24	380
HRT	min	10	24
Mechanical filter for fine cleaning			
Nominal filtration fineness	µm	0.02	0.02
Pump supply voltage	V	24	220
Pump power	kW	0.2–0.4	0.44–0.7
UV lamp for disinfection			
Power	W	30	40
Operating pressure	bar	1.1	8
Supply voltage	V	220	220
HRT	min	10	24

2.3. Analysis of the Samples

The water samples were collected in 5L plastic bottles thoroughly rinsed with deionized water before use. The chemical parameters were analyzed using a spectrophotometer (Hach DR3900, HACH/LANGE, Germany) and colorimeter (Hach DR900), with standard reagents as well as test kits. Standard operating procedure for measuring GLNPO (the U.S. Environmental Protection Agency Great Lakes National Program Office) turbidity was used for the analysis of turbidity, the American Public Health Association 4500-Nor method was used for the analysis of total phosphorous and a lab pH-meter (Hach Co) was used for pH measurements. For the microbiological analysis the water samples were passed through a membrane filter with a pore size of 0.45 μm and incubated on an agar plate at 37 °C for 48 h. Generally, the analyses of the samples were accomplished following the APHA's Standard Methods for the Examination of Water and Wastewater [34].

2.4. Process Efficiency Quantification

The WQI method was used to present the analysis results from the lab and industrial-scale treatment plants. In total, 15 water quality parameters, namely pH, turbidity, color, TSS, chlorine-free, chlorine total, nitrite nitrogen, nitrate nitrogen, phosphates, ammonium, iron total, aluminum, COD, BOD₅, and total coliforms (100 mL) were used to develop the WQIs. The WQI method was used to aggregate 15 water quality parameters into a single index. This helped in getting an overall picture of the general performance of the lab and industrial-scale wastewater treatment plants. The step-by-step procedure for the development of the WQIs is summarized in Equations (1)–(4).

The first step was to assign a weight (w_i) to each parameter on a scale of 0 to 6, where 0 is for the lowest effect and 6 is for the highest effect on water quality. The weighting process was based on the perceived effects of the water quality parameters on the intended use. The parameters' weighting was done according to the United States National Sanitation Foundation Water Quality Index (NSFWQI). Then the relative weight (W_i) was computed as a result of an individual weight divided by the summation of all the weights as shown in Equation (1):

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i} \quad (1)$$

where

W_i is the relative weight,
 w_i is the weight of individual parameters,
 n is the number of parameters studied.

The third step was to calculate a quality rating scale (q_i) for each parameter. This was done by dividing the concentration of each parameter by its respective recommended standard according to the Kazakhstan standards, and the result was multiplied by 100:

$$q_i = \frac{C_i}{S_i} \times 100 \quad (2)$$

where

q_i is the quality rating,
 C_i is the concentration of individual parameters, and
 S_i is the recommended water standard (drinking water) for each parameter as recommended by the Kazakhstan standards.

For the calculation of the general WQI, the sub-index (SI) for each parameter had to be determined as shown in Equation (3):

$$SI_i = W_i \times q_i \quad (3)$$

Lastly, the general WQI was calculated by summing up all the sub-indices from each of the studied parameters:

$$WQI = \sum_{i=1}^n SI_i \quad (4)$$

where

SI_i is referring to sub-index of an i th parameter,

q_i accounts for the quality rating based on the concentration of i th parameter,

W_i (with capital W) is referred to as relative weight

n is the number of chemical parameters.

The definition of the calculated WQIs was based on the status value categories: <50 “excellent water”, 50–100 “good water”, 100–200 “poor water”, 200–300 “very poor water”, >300 “water unsuitable for drinking” [35,36]. All the assigned weights and relative weights are summarized in Table 3.

Table 3. Weights and relative weights of the studied parameters.

Parameter	Weight (w_i)	Relative Weights (W_i)
pH	4	0.06
Turbidity	4	0.06
Color	4	0.06
TSS	4	0.06
Chlorine free	5	0.07
Chlorine total	5	0.07
Nitrite nitrogen	5	0.07
Nitrate nitrogen	5	0.07
Phosphates	4	0.06
Ammonium	4	0.06
Total iron	4	0.06
Aluminum	4	0.06
COD	5	0.07
BOD ₅	5	0.07
Total coliform (100 mL)	6	0.09
Total	68	1.00

The statistical analysis of the results presented in this study was accomplished with the help of Microsoft Excel 2019.

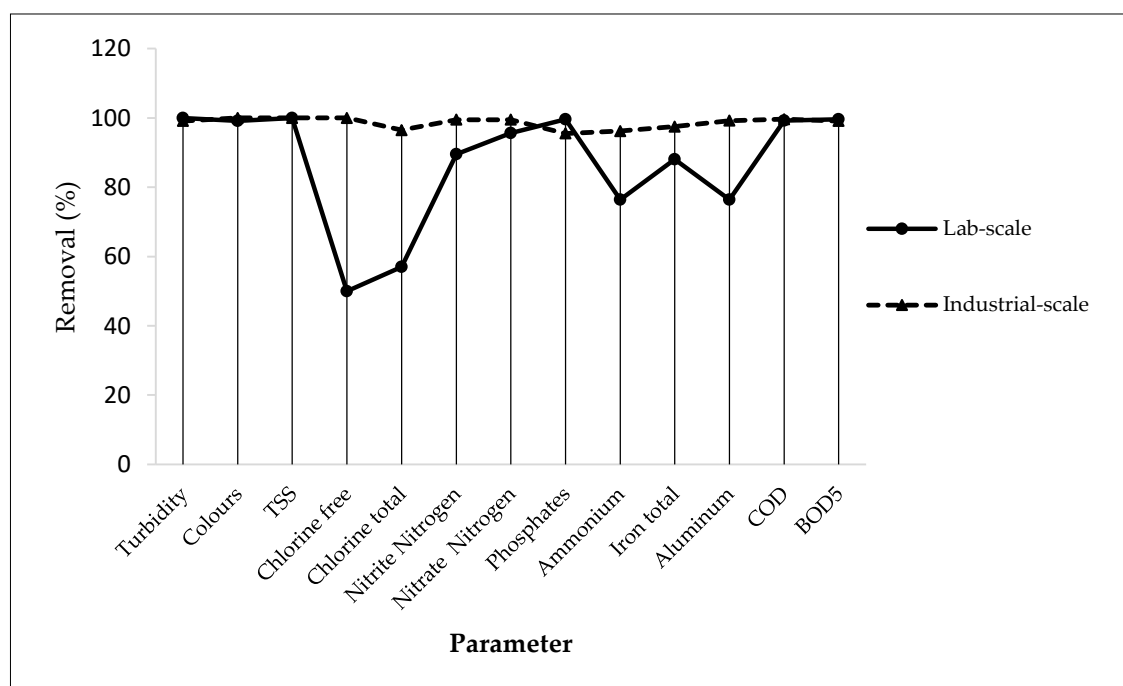
3. Results and discussion

From Table 4, it can be observed that the industrial-scale treatment plant achieved an efficiency higher than 95.5% for all parameters. The industrial-scale treatment plant achieved an efficiency of 100% for color, TSS, and free chlorine, and most of the other parameters were successfully purified with the range of efficiency from 99 to 100%. The lowest efficiency of 95.5% can be observed from the phosphates with 0.025 mg/dm³, which is considerably lower than the Kazakhstani guidelines (3.5 mg/dm³). The lab-scale treatment plant achieved 100% efficiency for turbidity and TSS. High efficiency was also observed for other parameters, i.e., color (99.1%), nitrite (89.5%), nitrate (95.6%), and TSS (100%). Thus, the lab-scale process was less efficient than the industrial plant. Some studies [37,38] have attempted to identify potential relationships of bacterial behavior between different plant scales. In this study, the lab-scale treatment plant faced a challenge in total coliform removal (Table 4), while 100% coliform removal was observed for the industrial-scale treatment plant. Total coliform has been used as the main indicator for defining the quality of water [39].

Table 4. Analysis results for all the studied water quality parameters.

Indicator	Before Purification (mg/dm ³)	Lab-Scale		Industrial-Scale	
		After Combined Purification (mg/dm ³)	Efficiency (%)	After Combined Purification (mg/dm ³)	Efficiency (%)
pH	7.4	7.7		8.14	-
Turbidity	68.7	0	100	0.62	99.1
Color	552	5	99.1	5	100
TSS	116	0	100	0	100
Chlorine free	0.08	0.04	50	0.0	100
Chlorine total	0.07	0.03	57	0.0	96.5
Nitrite nitrogen	0.09	0.009	89.5	0.003	99.5
Nitrate nitrogen	18.3	0.8	95.6	0.1	99.5
Phosphates	5.16	0.02	99.6	0.025	95.5
Ammonium	1.12	0.12	76.4	0.05	96.2
Total iron	1.33	0.16	88.0	0.05	97.5
Aluminum	0.89	0.21	76.4	0.022	99.2
COD	570	4.68	99.2	4.68	99.6
BOD ₅	1409	5.5	99.6	5.5	99.1
Total coliforms	1122	298	73.4	0	100

From Figure 3, almost a horizontal line can be observed for the lab-scale and industrial-scale graphs showing the 100% removal efficiency for the physical water quality parameters (turbidity, color, and TSS), as well as for some of the chemical parameters such as BOD and COD. A huge deviation can be observed in the free and total chlorine, where low-efficiency values are observed from the lab-scale treatment plant.

**Figure 3.** Lab-scale and industrial-scale processes' efficiency.

An average removal efficiency of 59.85, 73.44, and 70.26% was achieved for total microbial number, total coliform, and thermo-tolerant coliform when the wastewater was subjected to the lab-scale treatment plant as shown in Figure 4. However, the performance of the lab-scale treatment was lower than that of the industrial-scale treatment plant. This observation can be attributed to the lower HRT in the lab-scale treatment plant. According to Curtis [40], there are essentially two factors that determine

pathogen removal in a wastewater treatment plant, which are the residence time of the pathogen in the system (HRT), and its life expectancy, which depends on the reactor's operation. In this study, the UV disinfection unit was the main unit designed for microbial removal and the lab-scale treatment plant UV disinfection unit had lower HRT (10 min) than that of the industrial-scale treatment plant (24 min). Additionally, apart from the HRT, the performance of the lab-scale treatment plant for microbial removal may have been affected by the power of the UV light, which was lower than that of the industrial-scale treatment plant. Moreover, the small HRT of the electrolysis and membrane filtration processes may have contributed to the low microbial removal of the lab-treatment plant.

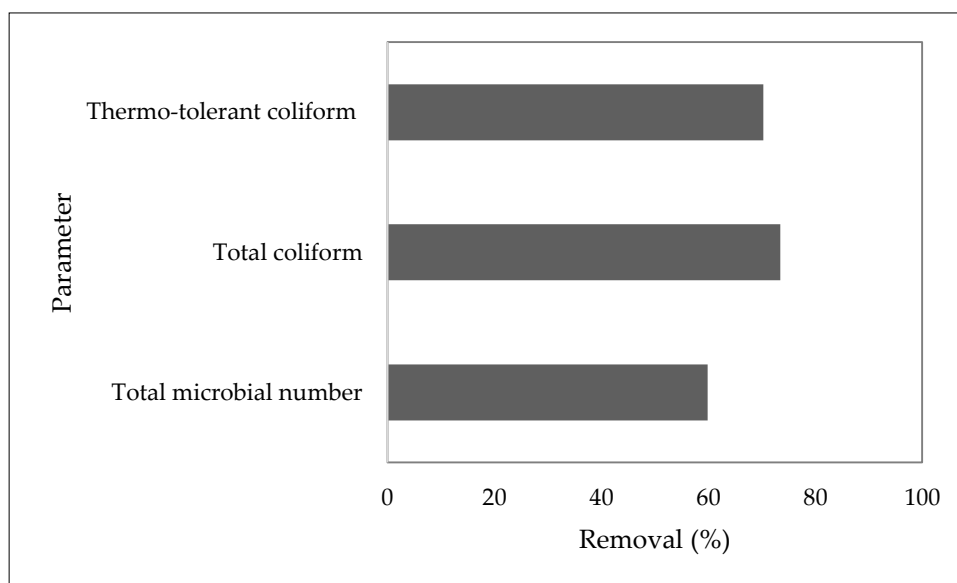


Figure 4. Lab-scale plant microbial results.

An average of 100% removal efficiency was achieved for the wastewater samples treated by the industrial-scale treatment plant for total microbial number, total coliform, as well as thermo-tolerant coliform. The impressive microbial results from the industrial-scale treatment plant are well reflected in the aggregated WQI, presenting excellent water quality status for drinking standards.

The results for quality rating (q_i), parameters' sub-indices (SI_i) and total WQI for the lab and industrial-scale treatment plants are shown in Tables 5 and 6 respectively. From the calculated sub-indices, it can be observed that total coliform had considerable influence on the WQI values for the lab and the industrial-scale plants. The total coliform sub-index of 82.59 out of 104.57 (Table 5) of the total WQI from the lab-scale treatment plant indicates that the presence of total coliform in the final effluent under drinking water standards had significant influence. Such a presence of total coliform potentially affected the general water quality of the final effluent. The absence of total coliform in the final effluent for the wastewater subjected to the industrial-scale treatment plant led to a 0 value of the total coliform sub-index that in turn influenced the smaller value of 21.64 of the total WQI (Table 6). Generally, the values of q_i were highly affected by the parameter sensitivity and its concentration in the final effluent for water intended for drinking purposes. However, both treatment plants showed high performance for most of the studied parameters. From Tables 3 and 4, it can be observed that a 0 sub-index value was achieved from the calculated SI_i for TSS, as well as a value of less than 1 for most of the other studied water quality parameters for both lab-scale and industrial-scale treatment plants.

Table 5. WQI for the lab-scale treatment plant.

Parameter	Quality Rating (q_i)	Sub-Index (SI_i)
pH	90.59	5.33
Turbidity	0	0
Color	25	1.47
TSS	0	0
Chlorine free	3.33	0.25
Chlorine total	2	0.15
Nitrite itrogen	0.30	0.02
Nitrate nitrogen	1.60	0.12
Phosphates	1	0.06
Ammonium	6	0.35
Total iron	4	0.24
Aluminum	42	2.47
COD	46.80	3.44
BOD ₅	110	8.09
Total coliforms (100 mL)	936	82.59
Total		104.57

Table 6. WQI for the industrial-scale treatment plant.

Parameter	Quality Rating (q_i)	Sub-Index (SI_i)
pH	95.76	5.63
Turbidity	41.33	2.43
Color	25	1.47
TSS	0	0
Chlorine free	0	0
Chlorine total	0	0
Nitrite nitrogen	0.10	0.01
Nitrate nitrogen	0.20	0.01
Phosphates	1.25	0.07
Ammonium	2.50	0.15
Total iron	1.25	0.07
Aluminum	4.40	0.26
COD	46.80	3.44
BOD ₅	110	8.09
Total coliform (100 mL)	0	0
Total		21.64

In Table 7 it can be observed that an “excellent” status with WQI of 21.64 was achieved for the industrial-scale wastewater treatment system. Additionally, the lab-scale water quality fell into “poor water” status. The difference in the two water quality statuses can be linked to the treatment efficiency of some parameters, such as total coliform. Total coliform is regarded as one of the principal water quality indicators such that any detection in drinking water is undesirable and may potentially affect the quality status of water [41].

Table 7. WQIs for the lab-scale and industrial-scale treatment systems.

Scale	WQI	Status for Drinking Standards
Laboratory	104.57	Poor water
Industrial	21.64	Excellent water

A WQI is a handy tool for rating overall water quality status. The aggregated numerical value can be very useful for the selection of appropriate treatment methods in order to meet the agreed requirements [42]. Although the WQI approach for a water quality assessment is widely used in

developed countries, it could be of particular interest for developing countries, as it offers an easy way of developing and interpreting results even with limited resources such as financial capacity and expertise [43]. From Table 4, it can be observed that water quality parameters are listed with their corresponding concentrations, which may have no meaning to non-experts in water quality. From Table 7, the “poor water” status recorded for the lab-scale treatment plant and “excellent water” status for the industrial-scale treatment plant provide an easy-to-understand approach of defining the quality of water. In that regard, water quality indices have been shown to be useful for the assessment of spatial and temporal variations of water quality [44].

Wastewater from the Izevski slaughterhouse subjected to lab-scale and industrial-scale analysis resulted in “poor” and “excellent” quality statuses respectively as derived from the WQIs under drinking water quality standards. Despite the fact that the lab-scale treatment plant underperformed in terms of microbial parameters, with 73.44% being the maximum average microbial removal efficiency, most of the physicochemical parameters were within the drinking water quality standards as recommended by the government of Kazakhstan. For the use of lab-scale result in large scale more detailed analysis may be required before a technology is adopted [45,46]. For instance, Hrad et al. [47], compared lab and full-scale applications of in situ aeration of an old landfill and showed that the full-scale plant performed differently after three years of operation in terms of leachate treatment efficiency. Nevertheless, lab-scale experiments are useful for the design of full-scale plants when conducted in conditions close to reality [48]. Future studies can focus on stepwise scaling and sensitivity analysis.

4. Conclusions

In this study, the impact of scale on the performance of an integrated poultry slaughterhouse wastewater treatment plant was investigated. Lab-scale and industrial-scale treatment plants were studied and compared towards wastewater treatment efficiency. Besides the evaluation of the processes by the use of removal efficiency of several substances, the WQI approach was used. The removal efficiency approach showed high efficiency from both treatment plants for most of the studied water quality parameters with efficiencies ranging from 73 to 100%. Turbidity, color, TSS, BOD, and COD showed the highest removal efficiency in both treatment plants. It was observed that the lab-scale process faced some challenges in some parameters such as total coliform, revealing that treatment plants with similar settings but with different scales may respond differently under the same conditions. However, in general, almost all the physical and chemical parameters were within the recommended standards set by the legislation. A WQI of 104.57 was achieved for the wastewater purified using the lab-scale wastewater treatment systems, which falls into the “poor water” water quality status when referencing the drinking water quality standards in Kazakhstan. In contrast, a WQI of 21.64 was obtained for the wastewater purified using the industrial-scale treatment plant, categorized as “excellent” quality status in reference to the drinking water quality standards of Kazakhstan. Future studies will focus on stepwise scale-up and on the comparison of the performance of individual units, such as electrolysis, membrane filtration, and reverse osmosis.

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