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Assessment of the Quality of Effluent from the Zanjan Urban Wastewater Treatment Plant for Potential Reuse in Agricultural and Industrial **Applications**



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ABSTRACT

Background: Every year, a significant amount of water is consumed worldwide and converted into wastewater. This wastewater can be reused by treating and transforming it into reliable and sustainable water resources for various purposes. The purpose of this study was to assess the viability of reusing the effluent from the Zanjan wastewater treatment plant for agricultural and industrial uses in Group 4.

Methods: In order to assess the quality of treated wastewater for agricultural and Group 4 industrial purposes, various parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), and coliforms were measured. The results were then compared to the quidelines in Iran, and the quality of the effluent was ultimately interpreted using the Wilcox diagram.

Results: The findings showed that the treated wastewater met the required quality standards for both agricultural and industrial Group 4 uses, with no restrictions for reuse. The wastewater was classified in the Wilcox diagram as C₃S₁, indicating moderate quality for agricultural applications.

Conclusion: The average parameters measured in the wastewater fall within the acceptable ranges for agricultural irrigation and industrial use in Group 4. However, the utilization and reutilization of this wastewater necessitate careful planning and consideration of its environmental impacts. Through meticulous planning and effective wastewater management, substantial water resources can be accessed for industrial and agricultural purposes without incurring extra costs.

1. Introduction

The scarcity of water resources and increasing demand in many parts of the world have made water supply a constant challenge. As a result, overuse of groundwater has significantly reduced its levels in many areas, while climate change and pollution have led to excessive depletion of surface water in numerous countries (Akhoundi & Nazif, 2018). Water is considered one of the most essential factors for the development of human societies. Iran is one of the countries where providing water for various uses is considered a significant concern for sustainable development in the country (Ghaneian & Dehvari, 2019). Iran is situated in an arid and semi-arid region. Despite covering only about 1.1% of the world's land area, it has access to just 0.36% of the total water available globally (Hatami et al.,

2018). The 50-year average long-term rainfall in Iran was approximately 250 mm. In the 2000-2001 water year, it reached 172.1 mm. In the 2020-2021 water year, it reached 137.5 mm, and in the 2023-2024 water year, it reached 234.5 mm (Iran Meteorological Organization, 2024). In 2001, total water consumption was 78 billion cubic meters, with the agricultural, industrial, and residential sectors accounting for 71.8, 1.2, and 5 billion cubic meters, respectively. However, by 2021, water consumption had increased to 92.7 billion cubic meters. The agricultural, industrial, and residential sectors accounted for 82, 2.4, and 8.3 billion cubic meters, respectively (Ministry of Energy, 2021).

The availability of water is quickly diminishing, while the number of water users in residential, commercial, industrial, and agricultural sectors is steadily rising worldwide (Faramarzi et al., 2010; Mishra et al., 2021; Vollmer &



Harrison, 2021). Climate change, severe droughts, population growth, increasing demand, and poor management in recent decades have further highlighted the scarcity of freshwater resources worldwide (Jafari Shalamzari & Zhang, 2018; Khatibi & Arjjumend, 2019; Orimoloye et al., 2021; Procházka et al., 2018). Overexploitation of freshwater resources threatens food security and the overall well-being of humanity in many parts of the world (Al Hamedi et al., 2023; Falkenmark, 2013). Water scarcity is a problem that both developing and developed countries face, reflecting the complexity and unpredictability of the issue (Alsup & Alsup, 2021). It is predicted that by 2050, 3.6 billion people will not have access to adequate water (Aghababaei, 2020).

Reduced rainfall, shortages, and overexploitation of freshwater resources have made the management and use of unconventional waters a necessity for the country (Ghaneian & Dehvari, 2019; Kama et al., 2023; Procházka et al., 2018). Wastewater treatment and recycling are among the most important solutions in the current conditions of the country for developing water resources. It is also one of the most effective, sustainable, and always available factors that can reduce the pressure on the quantity of water resources (Farhadkhani et al., 2018; Heidarpour et al., 2007; Jeong et al., 2016; Khodabakhshi et al., 2022). Reusing wastewater not only creates new water resources and preserves existing water resources but also helps prevent environmental pollution (Orimoloye et al., 2021). The first regulations on wastewater reuse for agriculture and irrigation were established in California, USA, in 1918 (Angelakis et al., 2018; Olivieri et al., 2020; Shoushtarian & Negahban-Azar, 2020). World Health Organization (WHO) standards were published in 1973 (Jeong et al., 2016), followed by United State Environmental protection agency (USEPA) in 1980 and Food and Agriculture Organization (FAO) in 1987 (Shoushtarian & Negahban-Azar, 2020).

Wastewater can be utilized for various purposes such as urban, agricultural, recreational, environmental, industrial, and groundwater recharge (USEPA, 2012). Water used in industries is generally classified into four categories based on the required water quality and the amount of purification needed to achieve the desired quality. The fourth group of industrial waters includes water used in processes that are less sensitive than those in other groups. The main uses of water in this group include disposable and open-cycle cooling waters, surface washing water, water used in chemical industries for preparing adhesives, process water in petrochemicals, process water in cement factories, water used for transporting materials, irrigation, and water used in firefighting (Ministry of Energy, 2009).

In a study conducted in 2008, the performance of the Zanjan wastewater treatment plant was evaluated to assess the quality of the effluent for potential reuse in agricultural applications and discharge into receiving waters. The results of the study indicated that the activated sludge system utilized in the treatment plant was effective, producing effluent that met Standards for key parameters such as biochemical oxygen demand (BOD₅), chemical oxygen

demand (COD), and total suspended solids (TSS). As a result, the effluent was deemed suitable for agricultural reuse and discharge into receiving waters (Bagheri Ardebilian et al., 2011).

In a study conducted in 2011 to investigate the quality of wastewater from the Zanjan wastewater treatment plant, various parameters such as turbidity, pH, BOD₅, COD, TSS, and coliforms were measured. The results indicated that the wastewater met suitable conditions for agricultural use based on general indicators. However, in terms of bacteriology, the average data exceeded the environmental standard limit, indicating that the wastewater did not meet the required criteria (Gharibi & Akbarzadeh, 2014).

In a study conducted in 2011, the feasibility of using the effluent from the Zanjan treatment plant as water required by industries was assessed. The study evaluated the current degree of purification and compliance with environmental standards. The results indicated that the effluent fell into the third group of industrial waters. As a result, it was deemed suitable for use in cement industries without any restrictions. For petrochemical industries, the addition of a sand filter to remove additional TSS would make the effluent usable (Assadi et al., 2014).

In this study, we will evaluate the quality of wastewater from the Zanjan Wastewater Treatment Plant (ZWTP) to determine its suitability for reuse in agricultural and Group 4 industrial purposes. Water quality indicators will be compared to the guidelines in Iran for assessment. When comparing the output values of the parameters with their permissible limits in the guidelines, the quality of wastewater for agricultural uses is also determined based on the Wilcox diagram. Finally, according to FAO guidelines, potential irrigation issues are examined across various values of the parameters mentioned.

2. Materials and Methods

Zanjan Province is situated in the northwest of Iran (Figure 1), between 35°33' to 37°15' north latitude and 47°10' to 49°26' east longitude from the Greenwich meridian. The total area of Zanjan Province is 21,773 Km², with a population of 430,871 people in Zanjan City, the province 's center, according to statistics from 2016.



Figure 1. Map of Zanjan Province, Iran

ZWTP is located 5 km southwest of Zanjan city. Wastewater enters ZWTP by gravity. The existing ZWTP was put into operation as the first module in 2007 with a capacity of 125,000 people. Since 2017, work has been underway to

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upgrade the first module to accommodate 220,000 people by the target year 2019, with a flow rate of 40,000 cubic meters per day. This upgrade was completed and ready for operation by the end of the summer of 2019. A second module has been constructed for the target year 2022, with a total capacity of 410,000 people and a total flow rate of 75,000 cubic meters per day. The wastewater treatment process in the first module is an Extended Aeration Activated Sludge system, while in the second module, it is a sequencing batch reactor (SBR).

In this study, sampling of effluent from the ZWTP after the chlorination unit was conducted after the chlorination unit to determine the quality characteristics of the effluent over a 6-month period, from September 2023 to February 2024. After collection, the samples were transferred to the laboratory of the School of Public Health at Zanjan University of Medical Sciences.

The first step in investigating the reuse of effluent from the ZWTP is to determine water quality indicators. Therefore, to evaluate the quality of treated wastewater for agricultural purposes and Group 4 industrial uses, parameters such as electrical conductivity, BOD, COD, TSS, TDS, Na, Ca, Cd, Cl, Fe, Mg, Mn, SO₄, SiO₂, Pb, alkalinity, hardness, pH, turbidity, color, MPN and parasite eggs were measured and compared with estalished standards. All sampling conditions and tests were carried out according to the instructions outlined in the book "Standard Methods for Water and Wastewater Testing" (Rice & Bridgewater, 2012).

Excel software was used to analyze the data and draw graphs. Various standards for the use of wastewater in different fields have been established by international organizations such as WHO, FAO and USEPA. In Iran, the Environmental Protection Organization has set standards for the use of wastewater in agriculture and irrigation (IRNDOE Standard), while the Ministry of Energy has established guidelines for industrial uses (IRNMOE guideline). These standards will be considered in this study.

While comparing the output values of the parameters with their permissible limits according to guidelines, the quality of the effluent for agricultural use was also determined using the Wilcox diagram (Figure 2). This diagram is a common method for interpreting agricultural waters, based on electrical conductivity and the sodium absorption ratio (SAR). The horizontal axis represents electrical conductivity (EC) in $\mu\text{S/cm}$, while the vertical axis represents SAR. If the calcium, magnesium, and sodium levels in the water sample are known in terms of meq/l, the sodium absorption can be calculated using the following equation:

$$\mathsf{SAR} = \frac{Na^{+}}{\sqrt{\frac{1}{2}[ca^{2^{+}} + Mg^{2^{+}}]}}$$

In the Wilcox diagram, water is divided into 16 classes. Excellent quality water is in class C_1S_1 , good water quality is in classes S_1C_2 , S_2C_1 , and S_2C_2 . Moderate water quality is in classes S_3C_1 , S_3C_2 , S_2C_3 , S_1C_3 , S_3C_3 , with the remaining classes indicating poor water quality. In these terms, S represents the sodium absorption ratio (SAR) and C represents the electrical conductivity (Wilcox, 1955).

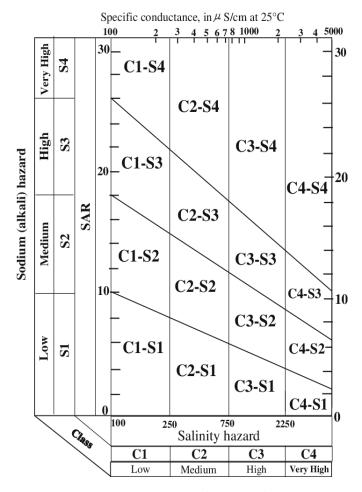


Figure 2. Wilcox diagram (Wilcox, 1955)

Table 1 presents the FAO guidelines for water quality for irrigation. It outlines potential irrigation issues associated with various parameter values. Electrical conductivity and total dissolved solids are used to determine water availability to crops, while electrical conductivity and SAR are used to assess water infiltration rate into the soil. Sodium and chlorine levels are evaluated for toxicity to sensitive crops in surface and sprinkler irrigation, and elements like nitrate and bicarbonate are considered for their impact on susceptible crops. The FAO guidelines also analyze the sensitivity of different agricultural products to water salinity (Ayers & Westcot, 1985).

3. Results and Discussion

The effluent from the ZWTP has been tested three times, and the average parameter values measured are shown in Table 2 to determine its suitability for use in agriculture compared to the IRNDOE Standard (Environmental Protection Agency of Iran, 2018).

According to Table 2, all measured parameters are within the standard range for reuse in agricultural uses. A sand filtration unit can be utilized to eliminate any potential parasite eggs.

Table 1. FAO guidelines for water quality for irrigation (Ayers & Westcot, 1985)

Possible Irrigation Problem	Units		Degree of Restriction on Use		
		None	Slight to Moderate	Severe	
Salinity (Affects Crop Water Availabili	ty)				
EC_w	dS m ⁻¹	< 0.7	0.7-3	>3	
(or)					
Total dissolved solids (TDS)	mg L ⁻¹	<450	450-2000	>2000	
Infiltration (affects infiltration rate of	water into the soil. Evaluate using EC _w and S	AR together)			
SAR =0-3 a	nd EC	>0.7	0.7-0.2	<0.2	
=3-6	···	>1.2	1.2-0.3	<0.3	
=6-12		>1.9	1.9-0.5	<0.5	
=12-2	0	>2.9	2.9-1.3	<1.3	
=20-4	0	>5	5-2.9	<2.9	
Specific Ion Toxicity (affects sensitive	crops)				
Sodium (Na)					
Surface irrigation	SAR	<3	3-9	>9	
Sprinkler irrigation	me L ⁻¹	<3	>3		
Chloride (CI)	1-1		4.40	10	
Surface irrigation	me L ⁻¹	<4	4-10	>10	
Sprinkler irrigation	me L ⁻¹	<3	>3	2	
Boron (B) Trace Elements	mg L ⁻¹	<0.7	0.7-3	>3	
Miscellaneous Effects (affects suscepti		<5	5-30	>30	
Nitrogen (NO₃-N)²	mg L ⁻¹ me L ⁻¹	<o <1.5</o 	5-30 1.5-8.5	>30 >8.5	
Bicarbonate (HCO3) (overhead sprinkling only)	me L ·	<1.5	1.5-8.5	>8.5	
pH		Normal Range 6.5-8.4			

Table 2. Values of measured effluent parameters and the IRNDOE Standard for agriculture

Paramrter	Unit	effluent	agriculture
			agriountare
EC	μs/cm	1148 ± 9.89	-
BOD	mg/l	8.23 ± 0.1	100
COD	mg/l	67.6 ± 10.07	200
TSS	mg/l	37.26 ± 4.72	100
Na	mg/l	88.56 ± 7.82	-
Ca	mg/l	75.56 ± 2.65	-
Cd	ppb	2.27 ± 0.2	0.05
CI	mg/l	118.11 ± 3.04	600
Fe	mg/l	0.118 ± 0.006	3
Mg	mg/l	16.51 ± 1.22	100
Mn	mg/l	0.032 ± 0.002	1
Pb	ppb	0.43 ± 0.07	1
SO ₄	mg/l	136.43 ± 0.56	500
pН	-	8.17 ± 0.14	6-8.5
Turbidity	NTU	1.08 ± 0.11	50
Color	Pt-Co	<5	75
MPN	n/100 mL	153.3 ± 4.7	1000
parasite eggs (after sand filtration)	n/1 lit	ND	<1

Since the units of the parameters measured in this study were different, it was necessary to convert them to a common scale to draw a graph comparing the measured values to the standard. The graphs were plotted in percentage terms. In Figures 3 and 4, the standard level of each parameter was set at 100 percent, and the concentration of each parameter in the wastewater was calculated as a percentage compared to its standard level.

Figure 3 displays the levels of parameters measured in wastewater intended for agricultural reuse compared to the Iran Standard, as a percentage.

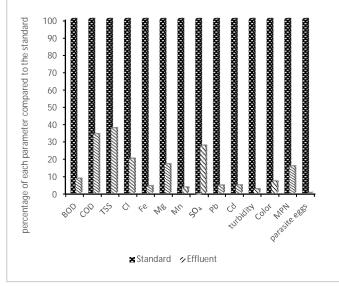


Figure 3. Comparison of ZWTP effluent and IRNDOE Standard for agriculture

In the ZWTP, the electrical conductivity and SAR were 1148 μ s/cm and 2.40, respectively. Therefore, according to the Wilcox diagram (Figure 2), the effluent falls into the C_3S_1 Class, which is considered a medium category. Table 3 displays the measurement results of the 6 parameters mentioned in Table 1, following the FAO guidelines for water quality for irrigation. According to the table, SAR and chlorine parameters in the effluent for surface irrigation fall within the range of having no effect, while the remaining parameters are within the range of having a slight to moderate effect on agricultural use.



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Table 3. Comparison of ZWTP effluent and FAO guidelines

Parameter	Effluent	None	Slight to Moderate	Severe
EC (ds/m)	1.14	<0.7	0.7-3	>3
TDS (mg/L)	607.6	<450	450-2000	>2000
SAR(meq/L) Surface Irrigation	2.40	<3	3-9	>9
SAR(meq/L) Sprinkler Irrigation	2.40	<3	>3	-
CI (meq/L) Surface Irrigation	3.33	<4	4-10	>10
CI (meq/L) Sprinkler Irrigation	3.33	<3	>3	-
NO₃ (mg/L)	28.14	<5	5-30	>30
HCO₃ (meq/L)	3.11	<1.5	1.5-8.5	>8.5

The average values of the measured parameters are shown in Table 4 to determine their suitability for Group 4 industrial uses compared to the IRNMOE guideline (Ministry of Energy, 2009).

Table 4. Quality of ZWTP effluent for industrial uses, Group 4

Parametre	Effluent	IRNMOE guideline	
pH	8.17 ± 0.14	5-10	
COD (mg/l)	67.6 ± 10.07	0-75	
TSS (mg/l)	37.26 ± 4.72	0-100	
TDS (mg/I)	607.6 ± 9.39	0-1000	
CI (mg/l)	118.11 ± 3.04	0-500	
SO ₄ (mg/l)	136.43 ± 0.56	0-500	
Fe (mg/l)	0.118 ± 0.006	0-1	
Mn (mg/l)	0.032 ± 0.002	0-1	
SiO ₂ (mg/l)	24.12 ± 1.33	0-50	
Alkalinity (mg/l CaCO3)	156 ± 6.48	0-500	
Hardness (mg/I CaCO3)	256.66 ± 8.67	0-500	

In Figure 4, the results of the ZWTP effluent are compared against the IRNMOE guidelines for Group 4 industrial uses, presented as percentages.

Based on the measurements of various parameters and the IRNMOE guidelines for Group 4 industries (Figure 4), all parameter values in the effluent from the ZWTP comply with the Group 4 industry guideline, indicating that no further treatment is necessary.

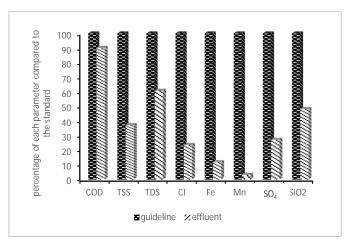


Figure 4. Comparison of ZWTP effluent and Group 4 industries

4. Conclusion

In this study, the quality parameters of the effluent from the ZWTP were measured and compared to the relevant guidelines in Iran to assess its suitability for agricultural and industrial use in Group 4. The results showed that the quality of the wastewater meets the standards for agricultural consumption and Group 4 according to the guidelines in Iran. Additionally, the Wilcox diagram classified the effluent from the ZWTP as C_3S_1 , indicating it is in the medium class.

Overall, it can be concluded that utilizing treated effluent from urban treatment plants to replace conventional water resources in agriculture and industries can significantly benefit valuable water resources and have positive economic and environmental impacts. However, careful planning and consideration of environmental impacts are necessary for its use and reuse.

Authors' Contributions

Mohammad Reza Mehrasbi: methodology; validation and study design; and supervision of the study. Mahsa Salimi: material preparation; data collection; experiments; and formal analysis. Ali Assadi: design and formal analysis; writing the first draft of the paper. All authors reviewed and approved the final manuscript.

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Conflicts of Interest

The authors declare that they have no competing interests.

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Ethical considerations

This study received approval from the Ethics Committee of Zanjan University of Medical Science. (Code: IR.ZUMS.BLC.1401.025).

Using artificial intelligence

The website, editmyenglish.com, was used to edit the English text.

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