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Case study on water quality index for wastewater treatment in Mumbai

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ABSTRACT

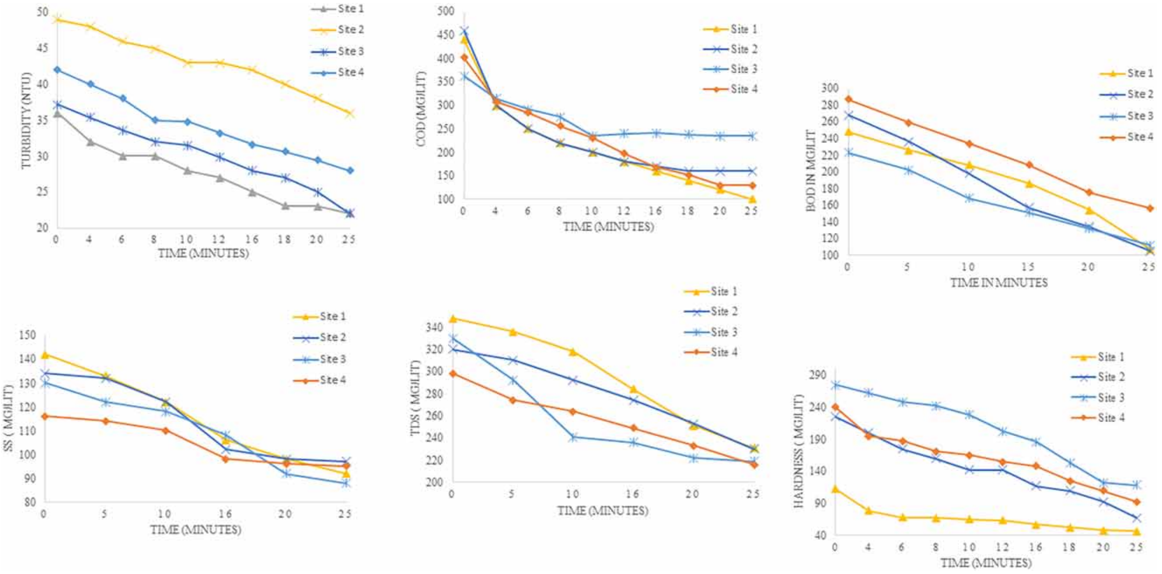
The traditional wastewater treatment process is laborious and demanding in terms of time, energy, and space. With rapid advancements, there's a quest for more efficient techniques that can achieve comparable treatment outcomes while minimizing these demands. This study proposes a solution by employing ozone as an Advanced Oxidation Process (AOP) to expedite the treatment while enhancing the water quality. The Water Quality Index (WQI) offers a consolidated representation of overall water quality by considering multiple quality parameters. Although typically used for assessing surface water quality, this study utilizes WQI to gauge the enhancement in parameters post-treatment. The research investigates the impact of varied ozone doses on raw sewage samples collected from four different sites in Mumbai, focusing on parameters such as dissolved oxygen, turbidity, hardness, chemical oxygen demand (COD), and WQI. The results demonstrate a notable percentage enhancement in WQI, ranging from 30 to 60% across various sites within a short 25-minute timeframe, attributed to the application of ozone.

Key words: AOP, domestic wastewater, municipal wastewater, ozonation, WQI

HIGHLIGHTS

- Conventional wastewater treatment methods are time-consuming and resource-intensive.
- AOP is proposed as a solution to expedite treatment and improve water quality.
- Normally used for surface water assessment, WQI is employed here to measure improvements post-treatment.
- Study examines varied ozone doses on sewage samples from Mumbai, analyzing parameters like DO, turbidity, hardness, COD, and WQI.
- Significant enhancements in WQI (30–60%) within 25 minutes demonstrate ozone's promise in reducing treatment time and space requirements, with simplified installation and maintenance compared to traditional methods.

GRAPHICAL ABSTRACT



INTRODUCTION

Water, a vital environmental component, is experiencing a decline in quality due to both natural processes and human activities (Uddin *et al.* 2021). Over 1.7 billion individuals reside in river basins where water usage surpasses natural replenishment, a concerning trend expected to result in two-thirds of the global population residing in water-stressed nations by 2025 (UN WATER 2017). Anticipated population growth and shifts in the Earth's climate equilibrium are expected to create a demand-supply gap of nearly 50%. World Bank data reveals a drastic reduction in the annual renewable water availability per person, plummeting from 13,000 m^3 in the 1960s to under 6,000 m^3 presently, owing to the escalating need for energy and natural resources (Capocelli *et al.* 2019). Worldwide, groundwater basins are being overused and the quality of water is deteriorating (UN WATER 2017; Panara 2018). Given the ongoing surge in population, industrialization, and urbanization, there is a simultaneous increase in wastewater production. Conventional wastewater treatment methods struggle to handle this escalating volume efficiently, becoming increasingly time and energy intensive, resulting in water pollution when treatments fail and further burdening water bodies. As an essential alternative, reusing treated wastewater can alleviate stress on over-exploited resources (Capocelli *et al.* 2019) Recent trends indicate a partial repurposing of this water for irrigation in urban and peri-urban regions, aiming to conserve water (Rajasulochana & Preethy 2016).

The treatment of domestic wastewater primarily involves the segregation, extraction, and appropriate disposal of contaminants to facilitate the reuse of treated water. Typically, a wastewater treatment system comprises primary, secondary, and tertiary treatment stages. The presence of suspended or floating matter determines the necessity of preliminary treatment. The primary treatment focuses on removing floating and suspended particles, while the secondary treatment is aimed at reducing or eliminating Biological Oxygen Demand (BOD) to permissible levels. Tertiary treatment is crucial for eradicating pathogens from the water. Many Wastewater Treatment Plants (WTPs) worldwide release treated effluents into water bodies. However, conventional treatment methods consume significant energy and require substantial land for disposal. To address these challenges, various techniques and environmentally friendly solutions are being introduced (Bakkaloglu *et al.* 1998).

Since 1990, there has been a remarkable increase in scientific knowledge, contributing to a better understanding of the long-term effects of wastewater discharge. This heightened awareness has shed light on potential health issues arising from the release of toxic and potentially harmful chemicals into the environment (Bolong *et al.* 2009). Attention has shifted towards nitrogen and phosphorus removal, which are primary contributors to eutrophication and algal blooms. For WTPs, considerations of aesthetics and environmental impacts have gained prominence. Consequently, there has been a heightened focus on treatment objectives, regulatory concerns, and stricter laws to exert better control over the quality of discharged effluents.

The primary drawback of traditional wastewater treatment processes lies in the substantial energy consumption, particularly in aeration and sludge circulation. Aeration alone accounts for a significant portion, ranging from 45–75% of the total energy used in a typical activated sludge-based Wastewater Treatment Plant (WTP) (Ozturk *et al.* 2016; Fan *et al.* 2017). Additionally, pumping stations consume about 22% of the energy, and activated sludge aeration alone constitutes 42% of the total energy required by the plant. With the global challenges of water scarcity and economic crises with volatile energy prices, there's a pressing need to adopt sustainable and renewable energy sources to ensure a sustainable economy in the future (Rojas & Zhelev 2012). In this context, wastewater treatment methods should not only aim to conserve critical resources like water and energy (Scott *et al.* 2011; Panepinto *et al.* 2016) but also explore innovative wastewater treatment approaches (Bakkaloglu *et al.* 1998).

In the past, WTPs heavily relied on chlorine for its effectiveness and cost-efficiency in disinfection. Chlorine was proficient in destroying various bacteria, viruses, and protozoa, including pathogens like Salmonella, Shigella, and Vibrio cholera (Blaney 2014). However, studies have demonstrated that chlorine, when reacting with organic matter, produces carcinogenic disinfection by-products such as tri-halomethanes and haloacetic acids (Lee *et al.* 2012) . These by-products have adverse effects on both public health and aquatic life. Water bodies receiving municipal wastewater treated with chlorine have reported fish kills, as chlorine and chlorine-ammonia compounds are toxic to various freshwater fish species (Nasuhoglu *et al.* 2018).

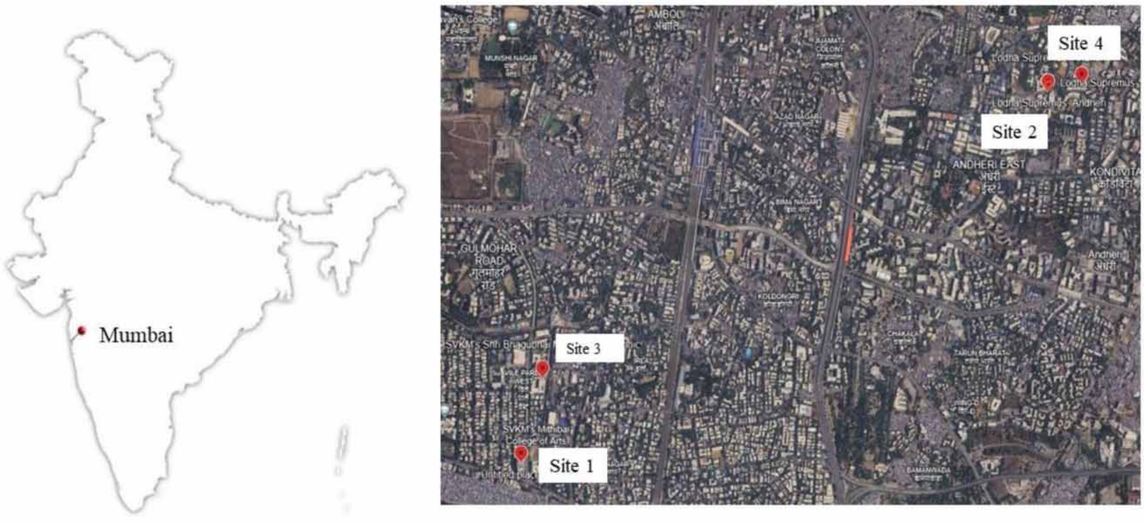
Due to the shortcomings of chlorinated effluents, alternative disinfection methods have been explored. Ozone and Ultra-Violet (UV) treatment have emerged as viable alternatives, drawing from their successful application in drinking water treatment. Ozone, which decomposes to hydroxyl radicals, is highly effective in transforming antibiotics in real systems, presenting a promising solution to the antibiotics issue (Friedrich *et al.* 2009). When ozone decomposes in water, it forms hydroxyl ions, potent oxidizing agents that contribute to efficient disinfection.

MATERIALS AND METHODS

The investigation into ozonation comprises three primary phases: sample collection, ozone generation, and sample analysis.

Sample collection

Grab samples of untreated domestic wastewater, pre-screened for impurities, were obtained from four distinct sites for testing purposes. The locations of all four sites are shown in Figure 1. These effluent samples were collected over specific intervals: from August to November 2019 for site 1, December 2019 to March 2020 for site 2, April 2022 to September 2022 for site 3, and November 2022 to January 2023 for site 4. Each sample was promptly tested within 20 minutes of collection. The characteristics of raw sewage during the respective testing periods for each site are detailed in Table 1. Additionally, Table 2 presents the ratio of Biochemical Oxygen Demand (BOD) to Chemical Oxygen Demand (COD) for all the sites. Wastewater is deemed readily biodegradable if this ratio falls within the range of 0.4 to 0.8 (Metcalf & Eddy 2003).



LHS: Map of India showing Mumbai

RHS: Location of the four sites in Mumbai

Figure 1 | Location of the testing sites.

Table 1 | Characteristics of the raw screened sewage

Parameter	Value range Site 1	Value range Site 2	Value range Site 3	Value range Site 4
DO (mg/lit)	0.5–1.5	0.5–1	0–1	0.5–1
COD (mg/lit)	380–440	440–480	330–400	380–420
Turbidity in NTU	28–38	43–52	35–42	36–48
Hardness (mg/lit)	100–125	220–250	260–300	280–300
Chlorides (mg/lit)	105–145	65–75	100–120	85–105
BOD (mg/lit)	248	268	223	287
Suspended solids (mg/lit)	142	127	134	116
Total dissolved solids (mg/lit)	348	325	326	298

Table 2 | BOD: COD ratios for sites

Sample details	BOD (mg/lit)	COD (mg/lit)	Ratio
Site 1	248	440	0.564
Site 2	268	460	0.582
Site 3	223	342	0.652
Site 4	287	402	0.714

Ozone generation

Ozone, being highly unstable, necessitates on-site generation at the point of application. In this study, ozone was produced using an oxygen concentrator (Ventox oxycon-1) and an ozone generator. This setup utilized ambient air at room temperature and pressure, converting it into ozone through electric sparks. The ozone content of the gas was determined by iodometric titration and was 30 mg/lit.

Testing of samples

Assessment of pH, Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Turbidity, and Hardness was conducted using Aquasol brand test kits manufactured by Rakiro Biotech Systems. These test kits comply with the testing standards outlined by the American Public Health Association (APHA) and are certified by NSF/ANSI 60. These kits were used for site 1 and 2. Subsequently, Biochemical Oxygen Demand (BOD), chlorides, Suspended Solids (SS), and Total Dissolved Solids (TDS) were included in the parameter list, and their analysis was carried out using APHA methods. The testing for these diverse parameters was conducted using APHA methods, initially employing Rakiro test kits for some tests on site 1 and 2, later for sites 3 and 4 APHA methods were used. The industrial-grade reagents and chemicals used for the testing were sourced from Loba chemie Pvt.Ltd, Mumbai, India.

RESULTS AND DISCUSSION

The reduction in parameter values is presented in Figure 2.

Effect of ozonation on turbidity

The reduction in turbidity varies from 2 to 44% in a time span of 25 min. as seen in Figure 2(a). This decrease does not seem to be large enough to warrant this method as a means of reduction in turbidity as the economics of providing ozonation for such long duration would lead to higher cost whereas this cost does not give sufficient reduction in turbidity.

Effect of ozonation on COD

The percentage reduction in COD is seen to be around 4% for 2 min of ozonation to 77% for 25 min of ozonation. Figure 2(b) shows the percentage reduction in the values of COD for various durations of ozonation. For all the

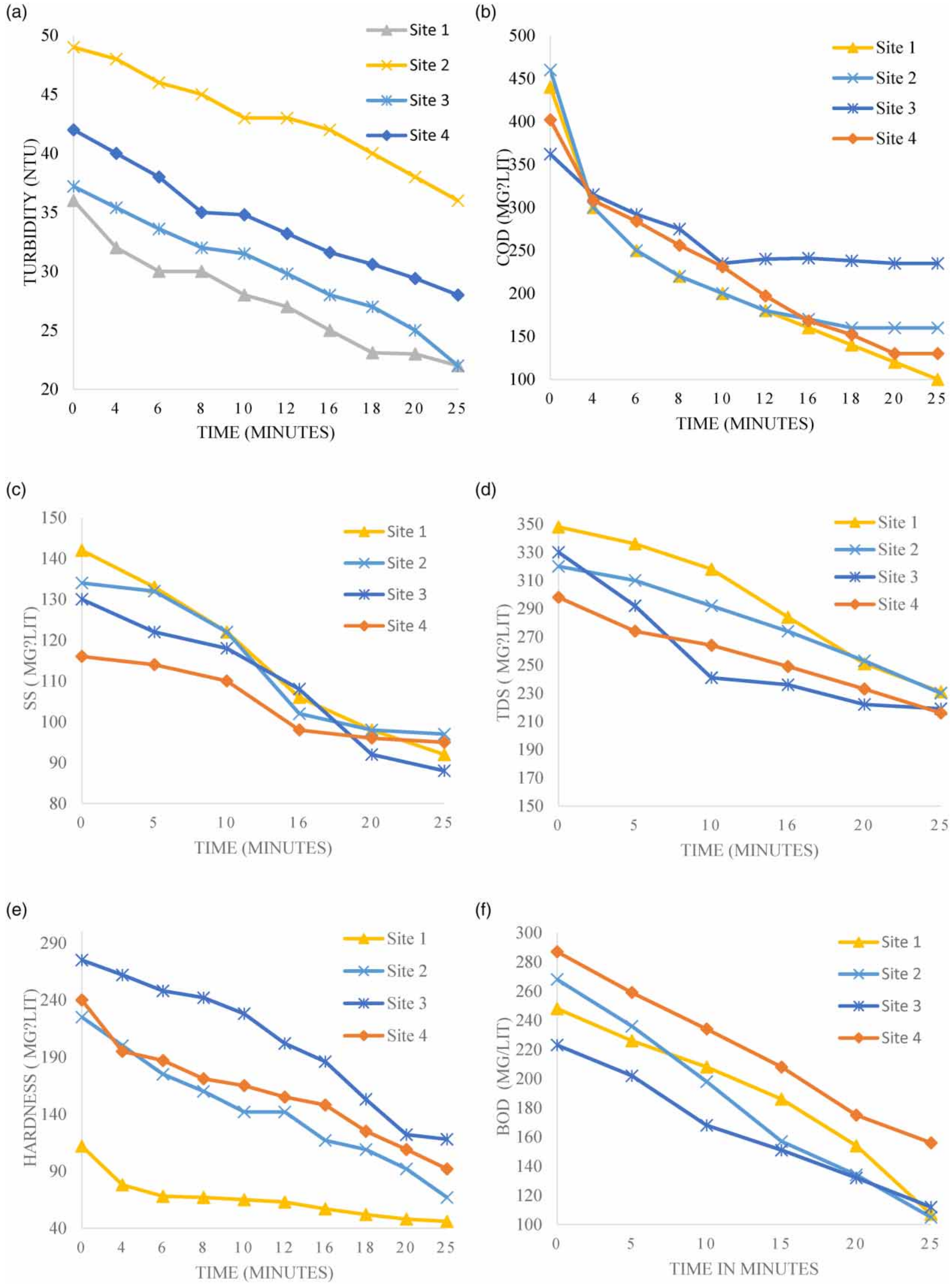


Figure 2 | Reduction in various parameters due to ozonation. (a) Effect on turbidity, (b) Effect on COD, (c) Effect on SS, (d) Effect on TDS, (e) Effect on hardness and (f) Effect on BOD.

sites, the values were found to be within the permissible range within a span of 15 minutes. This could lead to large savings in terms of time required for the treatment.

Effect of ozonation on SS and TDS

The reduction in SS and TDS is seen in Figure 2(c) and 2(d). The permissible limit for suspended solids in wastewater is 30 mg/lit. As this level is not attained by use of ozone alone, use of filtration process like sand filters is required in further stages.

Effect of ozonation on hardness

The percentage reduction in hardness varies from 10–75 in a time span of 2 to 25 min. as seen in Figure 2(e). The maximum permissible limit of total hardness is 300 ppm, which is greater than the values seen in these sites. Hence, treatment for this parameter is not required. A larger percent of reduction is seen in the initial 5–6 minutes so even for sites where the hardness values are greater than permissible values; reduction can be expected in a very short duration leading to savings in time of treatment.

Effect of ozonation on BOD

A reduction in Biochemical Oxygen Demand (BOD) was observed, as depicted in Figure 2(f). While the desired BOD levels were not achieved within the 25-minute duration, a noticeable decrease in BOD values was evident. Although not a direct replacement for conventional treatment, ozonation could prove valuable in expediting treatment times, leading to cost savings.

Water quality index (WQI)

The Water Quality Index (WQI) serves as a tool to gauge the overall quality of surface waters by integrating various parameters into a single value ranging from 0 to 100. Four prominent methods are commonly used for WQI calculation, as outlined below (Chidiac *et al.* 2023):

1. National Sanitation Foundation Water Quality Index (NSFWQI): This method incorporates nine parameters (temperature, dissolved oxygen, biochemical oxygen demand, acidity, nitrate, total phosphorus, total soluble solids, faecal coliform, and turbidity) to calculate the WQI. It offers a range of 0 to 100, where 100 signifies optimal water quality and zero indicates water unfit for use, necessitating further treatment (Samadi *et al.* 2015). However, it does not consider water use capacities and neglects various types of water consumption during evaluation.
2. Canadian Council of Ministers of Environment Water Quality Index (CCMEWQI): This method mandates a minimum of four parameters to be sampled at least four times but doesn't specify which parameters should be used. It is characterized by its simplicity, utilizing eight parameters, and employs diagrams or analytical relationships to determine sub-indices (Lumb *et al.* 2006).
3. Oregon Water Quality Index (OWQI): Primarily used for evaluating water quality for activities like swimming and fishing, this method categorizes water based on its intended usage (e.g., drinking, industrial). Given that the focus of this study is on wastewater reuse for purposes like irrigation, this method was not adopted.
4. Weighted Arithmetic Water Quality Index (WAWQI): Utilized to calculate the treated water quality index based on its purity level, this method involves three key steps. It encompasses the calculation of quality rating or sub-index, unit weight based on inversely proportional recommended standard values, and the aggregation of quality rating and unit weight to determine the overall WQI.

WQI is generally used for quantifying the quality of surface waters where a large number of parameters are brought down to a single numeric value which makes comparison easier. In this study, WQI was used to quantify the reduction in parameters due to ozone treatment. WQI was calculated for all four sites using the weighted average method. The results obtained are summarized in Table 3 below.

Table 3 | WAWQI values for all four sites

	Raw wastewater	Treated wastewater	Percentage reduction
Site 1	627.03	266.18	57.45
Site 2	570.55	272.38	52.25
Site 3	768.08	524.19	31.75
Site 4	711.8	388.97	45.35

CONCLUSION

Decrease in COD ranges from 4% within 2 min ozonation to 77% within 25 minutes of ozonation which is quite promising. A permissible limit of 250 mg/lit is attained within a span of 15 minutes. The BOD values show a reduction of 45 to 60% in 25 minutes. Reduction in turbidity is in the range of 40% in a span of 25 minutes which is not impressive in itself. Decrease in suspended solids is also not sufficient to suggest the use of ozonation as a stand-alone secondary treatment. Addition of a filtration stage will be helpful in reduction of both turbidity and suspended solids. Reduction in various parameters prove that ozone is a promising addition to the treatment process. But as the reduction in other parameters is rapid, it can lead to savings in time and in space. Ozonation presents a promising avenue to significantly reduce the overall treatment time and space requirements – a critical aspect in metropolitan cities. It also offers simplified installation, operation, and maintenance in comparison to traditional methods aligning with Sustainable Development Goal 6, which aims to enhance water quality and promote wastewater recycling. The Water Quality Index (WQI) values show a reduction from 31.75 to 57.45% due to ozonation. Testing of various parameters using higher doses of ozone may be considered as a scope for further studies but is beyond the scope of this study.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Bakkaloglu, I., Butter, T. J., Evison, L. M., Holland, F. S. & Hancock, I. C. 1998 Screening of various types biomass for removal and recovery of heavy metals (Zn, Cu, Ni) by biosorption, sedimentation and desorption. *Water Science and Technology* **38**(6), 269–277. https://doi.org/10.2166/wst.1998.0261.

Blaney, L. 2014 Ozone Treatment of Antibiotics in Water. In: *Water Reclamation and Sustainability*. Elsevier, pp. 265–316. https://doi.org/10.1016/B978-0-12-411645-0.00012-2.

Bolong, N., Ismail, A. F., Salim, M. R. & Matsuura, T. 2009 A review of the effects of emerging contaminants in wastewater and options for their removal. *Desalination* **239**(1–3), 229–246. https://doi.org/10.1016/j.desal.2008.03.020.

Capocelli, M., Prisciandaro, M., Piemonte, V. & Barba, D. 2019 A technical-economical approach to promote the water treatment & reuse processes. *Journal of Cleaner Production* **207**, 85–96. https://doi.org/10.1016/j.jclepro.2018.09.135.

Chidiac, S., El Najjar, P., Ouaini, N., El Rayess, Y. & El Azzi, D. 2023 A comprehensive review of water quality indices (WQIs): History, models, attempts and perspectives. *Reviews in Environmental Science and Bio/Technology* **22**(2), 349–395. https://doi.org/10.1007/s11157-023-09650-7.

Fan, H., Qi, L., Liu, G., Zhang, Y., Fan, Q. & Wang, H. 2017 Aeration optimization through operation at low dissolved oxygen concentrations: Evaluation of oxygen mass transfer dynamics in different activated sludge systems. *Journal of Environmental Sciences (China)* **55**, 224–235. https://doi.org/10.1016/j.jes.2016.08.008.

Friedrich, E., Pillay, S. & Buckley, C. A. 2009 *Water SA (on-Line) 73 Environmental Life Cycle Assessments for Water Treatment Processes-A South African Case Study of an Urban Water Cycle*. Available from: http://www.wrc.org.za.

Lee, C. O., Howe, K. J. & Thomson, B. M. 2012 Ozone and biofiltration as an alternative to reverse osmosis for removing PPCPs and micropollutants from treated wastewater. *Water Research* **46**(4), 1005–1014. https://doi.org/10.1016/j.watres.2011.11.069.

Lumb, A., Halliwell, D. & Sharma, T. 2006 Application of CCME water quality index to monitor water quality: A case of the Mackenzie River Basin, Canada. *Environmental Monitoring and Assessment* **113**(1–3), 411–429. https://doi.org/10.1007/s10661-005-9092-6.

Metcalf, E. T. & Eddy, H. 2003 *Wastewater Engineering, Treatment, Disposal, Reuse*. McGraw Hill, New York.

Nasuhoglu, D., Isazadeh, S., Westlund, P., Neamatallah, S. & Yargeau, V. 2018 Chemical, microbial and toxicological assessment of wastewater treatment plant effluents during disinfection by ozonation. *Chemical Engineering Journal* **346**, 466–476. https://doi.org/10.1016/j.cej.2018.04.037.

Ozturk, M. C., Martin Serrat, F. & Teymour, F. 2016 Optimization of aeration profiles in the activated sludge process. *Chemical Engineering Science* **139**, 1–14. https://doi.org/10.1016/j.ces.2015.09.007.

Panara, A. M. 2018 Water Reuse : Potential for Expanding the Nation's Water Supply through Reuse of Municipal Wastewater. In *IEEE Global Humanitarian Technology Conference*.

Panepinto, D., Fiore, S., Zappone, M., Genon, G. & Meucci, L. 2016 Evaluation of the energy efficiency of a large wastewater treatment plant in Italy. *Applied Energy* **161**, 404–411. https://doi.org/10.1016/j.apenergy.2015.10.027.

Rajasulochana, P. & Preethy, V. 2016 Comparison on efficiency of various techniques in treatment of waste and sewage water – A comprehensive review. *Resource-Efficient Technologies* **2**(4), 175–184. https://doi.org/10.1016/j.reffit.2016.09.004.

Rojas, J. & Zhelev, T. 2012 Energy efficiency optimisation of wastewater treatment: Study of ATAD. *Computers and Chemical Engineering* **38**, 52–63. https://doi.org/10.1016/j.compchemeng.2011.11.016.

Samadi, M. T., Sadeghi, S., Rahmani, A. & Saghi, M. H. 2015 Survey of water quality in Moradbeik river basis on WQI index by GIS. *Environmental Health Engineering and Management Journal* **2**(1), 7–11. Available from: https://core.ac.uk/download/pdf/33488133.pdf.

Scott, C. A., Pierce, S. A., Pasqualetti, M. J., Jones, A. L., Montz, B. E. & Hoover, J. H. 2011 Policy and institutional dimensions of the water–energy nexus. *Energy Policy* **39**(10), 6622–6630. https://doi.org/10.1016/j.enpol.2011.08.013.

Uddin, M. G., Nash, S. & Olbert, A. I. 2021 A review of water quality index models and their use for assessing surface water quality. *Ecological Indicators* **122**, 107218. https://doi.org/10.1016/j.ecolind.2020.107218.

UN WATER 2017 *UN-Water: Analytical Brief Wastewater Management*. Available from: https://www.unwater.org/sites/default/files/app/uploads/2017/05/UN-Water_Analytical_Brief_Wastewater_Management.pdf.

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