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Assessment of Algal Proliferation and Control Processes in the Al-Shajarah Water Treatment Facility

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Abstract

This study examined the seasonal variation of raw and treated drinking water quality at the Al-Shajarah Water Treatment Plant (Khartoum, Sudan) across winter, summer, and autumn of 2021, with particular focus on water quality shifts associated with algal bloom dynamics. Key physico-chemical parameters, turbidity, pH, electrical conductivity (EC), alkalinity, nutrients, and iron were measured using standardized laboratory procedures. Seasonal consumption of powdered activated carbon (PAC) and chlorine was evaluated to assess operational responses to raw water fluctuations and algal-related organic loading.

Raw water showed marked seasonal deterioration consistent with intensified algal activity during warmer months. Turbidity increased from **65.1 NTU in winter** to **122 NTU in autumn**, coinciding with elevated particulate and algal biomass. Nitrate concentrations peaked at **15.3 mg/L in summer**, while ammonia reached **0.16 mg/L**, reflecting increased microbial and algal metabolic processes. In contrast, alkalinity (88–93 mg/L as $CaCO_3$) and pH (8.0) remained relatively stable throughout the year.

Treatment processes effectively mitigated these fluctuations. Turbidity was reduced to **8 NTU in summer**, **16 NTU in winter**, and **30 NTU in autumn**, while nitrate concentrations declined to **5.6–12 mg/L**. Ammonia was lowered to **0.021–0.55 mg/L**, depending on season. Treated water

maintained stable pH (7.7–7.8), alkalinity (87–93 mg/L as $CaCO_3$), and iron levels (**0.16–0.21 mg/L**). PAC usage peaked in August (**36 barrels**), aligning with increased turbidity and algal organic matter, whereas chlorine consumption remained relatively constant (**614–640 kg**).

Overall, the findings demonstrate that despite significant seasonal degradation of raw water quality driven largely by algal bloom-associated increases in turbidity and nutrient loading. Al-Shajarah Water Treatment Plant consistently produced water that met acceptable standards. This highlights the importance of continuous monitoring, early detection of bloom conditions, and adaptive chemical dosing to ensure resilient and reliable drinking water treatment in surface-water systems vulnerable to algal proliferation.

Keywords: Algal blooms; drinking water quality; seasonal variation; cyanotoxins; turbidity; water treatment efficiency; coagulation and filtration; adaptive chemical dosing.

Introduction

Algal blooms substantially alter the physicochemical properties of drinking-water sources and can reduce the efficiency of conventional treatment processes. Rapid increases in algal biomass elevate turbidity and suspended particulate matter, increasing the demand on coagulation, flocculation, and filtration. As blooms collapse, decomposition releases dissolved organic carbon (DOC), which enhances the formation of disinfection by-products (DBPs) during chlorination. Elevated nitrogen and phosphorus conditions that favour bloom formation also contribute to shifts in electrical conductivity and alkalinity. Many cyanobacteria release cyanotoxins that persist long after bloom decline, posing risks to public health and complicating treatment operations.

Algal activity further affects treatment performance by promoting filter clogging, increasing headloss, and reducing filter run times, thereby raising operational costs. Taste, odor, and color problems associated with metabolites such as geosmin and MIB often require activated carbon or additional advanced treatment. These cumulative effects underscore the vulnerability of conventional treatment systems and highlight the need for adaptive management to maintain compliance with drinking-water standards.

Fresh water is essential for human wellbeing and economic development, yet only about 2.5% of global water is freshwater, and an even smaller proportion is readily accessible. Poor water quality remains a major health challenge, with millions of cases of water-borne disease recorded annually, largely due to unsafe water and insufficient sanitation (World Health Organization, 2022). Natural waters contain contaminants introduced through erosion, runoff, and leaching, many of which such

as organic matter, phosphates, and nitrates—originate from sewage and agriculture. Polluted environments typically support motile algal groups such as *Chlamydomonas* and *Euglena*, which can contribute to turbidity, clog filters, and occasionally release toxins in treatment systems.

Cyanobacterial harmful algal blooms (CyanoHABs) are of particular concern because they generate potent cyanotoxins and challenge conventional treatment processes (Anantapantula & Wilson, 2023). A recent meta-analysis reported that only certain chemical algaecides, including copper sulfate and hydrogen peroxide, consistently improved water-quality outcomes, whereas many biological or plant-based control strategies showed limited effectiveness in field conditions (Anantapantula & Wilson, 2023). Nevertheless, biotechnological approaches, such as cyanobactericidal bacteria, fungi, microalgae, zooplankton, and cyanophages are emerging as potentially eco-friendly and highly specific alternatives, although issues of scalability and ecological risk remain (Applied Microbiology & Biotechnology, 2024).

From a treatment perspective, conventional coagulation, activated carbon, and oxidation processes can reduce dissolved cyanotoxins but often face constraints related to cost, by-product formation, and operational complexity (Science of the Total Environment, 2024). Advanced processes offer improved performance; for example, a two-stage polymeric ultrafiltration system achieved more than 96% removal of microcystins under optimized conditions, providing a strong barrier against both cells and dissolved toxins (Zhang *et al*., 2023). Source-control strategies such as plant-based coagulants (e.g., *Moringa oleifera*) have also shown promise, though further optimisation is required to enhance floc stability and removal efficiency (Environmental Science and Pollution Research, 2022).

Hybrid disinfection–oxidation technologies are gaining interest. Combining UV light with chlorine has been shown to degrade cyanotoxins more effectively than chlorination alone, while limiting DBP formation. A recent laboratory study demonstrated that this approach can reduce toxin levels below WHO guideline values without creating harmful by-products (Kong *et al*., 2025). Meanwhile, monitoring innovations such as spectral flow cytometry adopted by the US EPA enable real-time assessment of cyanobacterial responses to algaecides like hydrogen peroxide, improving dosing accuracy and reducing chemical overuse (EPA, 2024).

Algal blooms arise from nutrient-enriched, warm, and stable waters, and may visibly alter water colour and surface characteristics. While some blooms are benign, cyanobacterial blooms can release

toxins that remain in the water column for weeks or months, even following physical disruption or algaecide application (Zeng *et al*., 2023; Alhaithloul *et al*., 2024). Climate change is intensifying these risks by altering freshwater dynamics and threatening aquatic food webs. Phytoplankton underpin these ecosystems, and both their depletion and overgrowth can be detrimental.

Given the importance of environmental drivers, we hypothesise that river altitude influences algal diversity likely through variations in oxygen saturation and that these differences impact turbidity and treatment requirements, including coagulant (e.g., polyaluminum chloride, PAC) consumption at the Al-Shajarah Water Treatment Plant.

Study Area

This study was conducted at the Al-Shajarah Water Treatment Plant, located on the White Nile. At this facility, algae significantly challenge water quality, particularly by increasing turbidity and reducing filter run-times.



Figure (1) location map for study area

The Al-Shajarah plant produces approximately 15,000 m³/day of treated water, supplying neighborhoods such as Al-Shajarah, Dabasin, Yathrib, Al-Azouzab, Al-Hamdab, and parts of Abu Adam and Jabra squares. The plant also provides employment for local residents in the surrounding

communities. The problemat the Al-Shajarah Water Treatment Plant can be statement by many challenges such as frequent filter shutdowns (50–100 hours run time), disruption of the turbine system, corrosion of metal structures, potential production of algal toxins and recurrent algal blooms. During treatment, water passes through sand and gravel filters to remove suspended solids and viscous materials. However, the buildup of algal biomass often forces premature filter closure (sometimes in less than 10 hours), because algae not removed by sedimentation clog the filter media. This greatly reduces the filter's operational efficiency and lifetime. Therefore, the presence of algae in drinking water quality is problematic for several reasons like aesthetic issues: taste, odor, and discoloration, increased chlorine demand during disinfection, filter clogging, reducing filtration efficiency, proliferation of organisms within distribution systems, biofilm formation and corrosion of infrastructure and pH changes and sedimentation of organic matter.

The main objective of this study is to evaluate the impacts of algal proliferation on water quality at the Al-Shajarah Water Treatment Plant. Specific sub-objectives include: examining the influence of algae on turbidity, assessing filter media performance and maintenance requirements, and ensuring that treated water consistently meets the quality standards established by the Sudanese Standards and Metrology Organization (SSMO).

MATERIALS AND METHODS

Study Area and Research Focus

This study was conducted to investigate the impacts and removal efficiency of algae in the Al-Shajarah Water Treatment Plant, Khartoum State, Sudan. The plant receives surface water from the White Nile and supplies treated tap water to surrounding communities. Sampling and analysis were carried out under the supervision of the Central Laboratory of the Khartoum State Water Authority.

Sampling Design

Water sampling was performed during three distinct seasons of 2021, winter, summer, and autumn to capture potential temporal variations in algal presence and water quality parameters. A total of 18 water samples were collected across these seasons. For each sampling event**:** Raw water samples (n = 9): collected before treatment at the plant inlet**.** Treated tap water samples (n = 9): collected after treatment at the distribution outlet.

All samples were collected in pre-cleaned 1-L plastic containers, following standard sampling protocols to avoid contamination. Immediately after collection, samples were labeled, stored in coolers, and transported to the Central Laboratory for analysis. Water samples were collected in triplicate (n = 3) from each designated site to ensure statistical reliability. At each sampling point,

three independent grab samples were taken in pre-cleaned polyethylene bottles following SSMO sampling guidelines. Field measurements (pH, EC, DO, temperature) were also recorded in triplicate to minimize measurement uncertainty.

Laboratory Analysis

Alkalinity Determination Method

Determination of alkalinity, iron and Nutrient concentrations for drinking water samples was conducted at the Central Laboratory of the Khartoum State Water Authority using standardized and quality-controlled procedures. Alkalinity was determined using a potentiometric titration procedure following Standard Methods for the Examination of Water and Wastewater (Method 2320 B) and in accordance with national drinking-water laboratory guidelines. The procedure quantifies the acid-neutralizing capacity of water, expressed as milligrams per litre (mg/L) of $CaCO_3$.

Iron in drinking water is commonly determined using 1,10-phenanthroline method by UV–Visible Spectrophotometer**,** calibrated, set at 510 nm, which measures both ferrous (Fe^{2+}) and, after reduction, ferric (Fe^{3+}) iron. In this method, Fe^{2+} forms an orange-red complex with 1,10-phenanthroline that absorbs light at 510 nm. Any ferric iron present in the sample is reduced to ferrous iron prior to complex formation. The color intensity is proportional to the total iron concentration.

Field Measurements

Turbidity

Measured using a nephelometric turbidity meter (e.g., Hach 2100N or equivalent) in accordance with SSMO turbidity testing methods. Results were recorded in nephelometric turbidity units (NTU). Each sample was measured three times to verify consistency.

pH

Determined with a bench-top digital pH meter (e.g., Hach HQ411d or equivalent). The probe was calibrated daily using standard pH 4.00, 7.00, and 10.00 buffer solutions.

Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

Measured using **a** conductivity/TDS meter (e.g., Jenway 4510 or equivalent). The instrument was calibrated using 84 µS/cm and 1413 µS/cm conductivity standards.

Dissolved Oxygen (DO)

Measured using **a** portable DO meter (e.g., YSI Pro20 or equivalent), calibrated using water-saturated air according to manufacturer instructions.

Temperature

Water temperature was measured in the field using a calibrated digital thermometer. Prior to measurement, the instrument was inspected to ensure proper functioning and was rinsed with sample water to equilibrate the sensor. The probe was then immersed directly into the water source at a depth of approximately 10–20 cm, avoiding contact with container walls, the riverbank, or areas of stagnant flow to prevent thermal bias. The sensor was allowed to stabilize for 30–60 seconds or until the reading became constant. Temperature was recorded to the nearest 0.1 °C. All measurements were taken *in situ* to avoid thermal alteration during sample transport, and the instrument calibration was verified daily using standard reference conditions or an ice-water bath (0 °C) as recommended by manufacturer guidelines.

Odour of drinking water samples were evaluated *in situ* using standard sensory methods. Samples were collected in clean, odor-free containers and immediately covered to minimize loss of volatile compounds. For odour assessment, containers were gently swirled to release any volatile compounds, and the headspace was inhaled carefully to detect unusual or objectionable odours. An odour was recorded qualitatively using a 0–5 scale (0 = none, 5 = extremely objectionable) for intensity, and multiple samples were assessed to ensure reproducibility. Observations were performed under controlled field conditions to minimize interference from environmental factors and personal scents.

Nutrient Analysis

Nutrient concentrations were quantified using standardized spectrophotometric procedures. Nitrate (NO_3^-) was measured using the UV spectrophotometric cadmium reduction method in accordance with SSMO/Standard Methods 4500-NO_3**.** Nitrite (NO_2^-) was determined by the colorimetric diazotization method following SSMO/4500-NO_2**.** Ammonia (NH_3/NH_4^+) was analysed using the Nesslerisation method**,** which forms a yellow–brown complex detectable spectrophotometrically. Orthophosphate (PO_4^{3-}) was measured using the molybdenum blue method with a UV–Vis spectrophotometer (e.g., Shimadzu UV-1800). All analyses adhered to quality-assured laboratory procedures, and calibration curves were prepared for each nutrient using certified standard solutions.

Data Processing and Statistical Analysis

Data obtained from laboratory measurements were compiled, organized, and analyzed using **Microsoft Excel** spreadsheets. Descriptive statistics, tables, and graphical plots were generated to

evaluate seasonal variations, compare raw and treated water quality, and assess the treatment plant's effectiveness in reducing algal-related parameters.

RESULTS AND DISCUSSION

Seasonal Variation of Physicochemical Parameters in Raw Water

The physicochemical properties of raw water collected from the Al-Shajarah Water Treatment Plant exhibited pronounced seasonal variability **(Table 1).** Turbidity values increased from 42.3 NTU in January to 140 NTU in September, indicating higher suspended solids and sediment loads during late summer and autumn. Such seasonal turbidity peaks have been attributed to rainfall, runoff, and soil erosion in surface water catchments (Adewale, Bello, & Olayemi, 2020). Nitrate concentrations were lowest in winter (1.0– 1.4 mg/L) and peaked during summer (15.0– 15.9 mg/L), likely reflecting agricultural runoff and enhanced microbial activity during warmer months (Zhang, Chen, & Liu, 2021). Temperature ranged from 23.0°C in winter to 29.5°C in March, consistent with climatic trends in the region. pH remained slightly alkaline (7.9–8.2), while EC values ranged from 208 to 262 µmhos/cm, indicating relatively stable ionic composition. Alkalinity (86–98 mg/L as $CaCO_3$), ammonia (0.05– 0.18 mg/L), and nitrite (0.020–0.080 mg/L) were within acceptable ranges. Iron and phosphate concentrations were generally low, reflecting minimal industrial contamination. Overall, these findings demonstrate that raw water quality is subject to significant seasonal influence, particularly regarding turbidity and nutrient concentrations, which is consistent with previous studies (Abdel-Rahman, El-Sheikh, & Ali, 2020; Kumar, Singh, & Sharma, 2021).

Table 1. Seasonal Variation of Physico-Chemical Parameters in Raw Water at Al-Shajarah Water Treatment Plant (Winter, Summer, and Autumn 2021)

Parameter	Winter			Summer			Autumn		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Turbidity (NTU)	42.3	60.0	93.5	108	100	99	112	114	140
Color	Turbid	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Turbid
Temperature (°C)	23.0	24.0	29.5	27.0	27.5	28.0	27.0	28.0	27.5
EC (µmhos/cm)	208	210	262	262	262	260	214	208	214
Odor	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Parameter	Winter			Summer			Autumn		
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
pH	8.0	8.0	8.2	8.0	7.9	8.0	8.0	8.0	8.0
Alkalinity (mg/L as $CaCO_3$)	92	90	98	90	90	90	92	86	86
Ammonia (mg/L)	0.08	0.05	0.10	0.16	0.18	0.15	0.10	0.08	0.08
Nitrite (mg/L)	0.023	0.028	0.020	0.080	0.080	0.020	0.028	0.030	0.028
Nitrate (mg/L)	1.4	1.0	1.0	15.9	15.0	15.0	15.0	5.6	5.6
Iron (mg/L)	0.10	0.20	0.27	0.20	0.20	0.18	0.05	0.03	0.03
Phosphate (mg/L)	0.20	0.19	0.20	0.18	0.16	0.18	0.15	0.18	0.18

Physicochemical Parameters of Tap Water

Treated water showed substantial improvements in all major quality indicators (**Table 2**). Turbidity was reduced to 8– 28 NTU, confirming effective sediment removal through coagulation, flocculation, and filtration. Nitrate concentrations were lowered from a raw water peak of 15 mg/L to 5.6– 14 mg/L, indicating effective nitrification and denitrification processes. Ammonia exhibited a summer peak (0.55– 0.56 mg/L), potentially due to residual ammonium after chloramination, as reported by Li, Wang, and Zhao (2022). pH (7.7–7.8) and alkalinity (86– 96 mg/L as $CaCO_3$) remained stable, which is important for maintaining water buffering capacity and treatment efficacy. Iron levels decreased from 0.27 mg/L in raw water to a maximum of 0.20 mg/L in tap water, highlighting the efficiency of coagulation and filtration steps. These results align with prior research demonstrating that conventional treatment processes can significantly mitigate seasonal fluctuations in raw water quality (Zhang *et al*., 2021).

Table 2. Physical and Chemical Parameters of Tap Water Across Seasons

Parameter	Winter			Summer			Autumn		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Turbidity (NTU)	23	15	10	8	8	10	14	28	28
Colour	Turbid	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Turbid
Temperature (°C)	23.4	23.0	29.4	29.5	28.0	27.0	27.5	27.0	27.0
EC (µmhos/cm)	206	250	271	270	270	270	210	210	210
Odour	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
pH	7.7	7.8	7.7	7.7	7.8	7.8	7.8	7.8	7.8
Alkalinity (mg/L as $CaCO_3$)	90	94	96	94	96	90	90	86	86
Ammonia (mg/L)	0.05	0.08	0.50	0.55	0.55	0.56	0.00	0.00	0.00
Nitrite (mg/L)	0.04	0.03	0.02	0.02	0.02	0.02	0.025	0.026	0.02
Nitrate (mg/L)	4.0	10.0	14.0	13.0	13.0	10.0	5.6	5.6	5.6
Iron (mg/L)	0.08	0.20	0.20	0.23	0.24	0.20	0.20	0.20	0.20
Phosphate (mg/L)	0.26	0.20	0.14	0.14	0.20	0.20	0.20	0.20	0.26

Seasonal Averages of Raw Water Quality

The seasonal average analysis (**Table 3**) reinforces the observed trends. Turbidity was highest in autumn (122 NTU) and lowest in winter (65.1 NTU). Nitrate concentrations peaked in summer (15.3 mg/L), likely due to surface runoff and elevated microbial activity. Iron and phosphate levels remained low, while pH and alkalinity were consistent across seasons. These findings confirm that the source water is subject to seasonal impacts that require continuous monitoring and adaptive treatment strategies (Adewale *et al*., 2020; Abdel-Rahman *et al.*, 2020).

Table 3. Average Readings of Raw Water Across Seasons

Parameter	Winter	Summer	Autumn
Turbidity (NTU)	65.1	102	122
Colour	Nil	Nil	Nil
Temperature (°C)	25.0	27.0	27.4
EC (µmhos/cm)	226	261	212
Odour	Nil	Nil	Nil
pH	8.0	8.0	8.0
Alkalinity (mg/L as $CaCO_3$)	93.3	90.0	88.0
Ammonia (mg/L)	0.07	0.16	0.06
Nitrite (mg/L)	0.02	0.06	0.02
Nitrate (mg/L)	1.0	15.3	8.7
Iron (mg/L)	0.19	0.20	0.03
Phosphate (mg/L)	0.20	0.16	0.17

Seasonal Averages of Tap Water Quality

Average tap water measurements (**Table 4**) demonstrated effective treatment across all seasons. Turbidity ranged from 8 NTU in summer to 30 NTU in autumn. Nitrate and ammonia concentrations were substantially reduced compared to raw water, indicating efficient nitrogen compound removal. pH and alkalinity were maintained within optimal ranges, and iron concentrations were effectively controlled. The relatively stable quality of tap water across seasons indicates the robustness of the Al-Shajarah Water Treatment Plant in maintaining safe and potable water standards, consistent with the findings of Li *et al*. (2022) and Zhang *et a*l. (2021).

Table 4. Average Readings of Tap Water Across Seasons

Parameter	**Winter**	**Summer**	**Autumn**
Turbidity (NTU)	16	8	30
Colour	Nil	Nil	Nil
Temperature (°C)	25.0	28.0	27.0
EC (µmhos/cm)	242	270	210
Odour	Nil	Nil	Nil
pH	7.7	7.8	7.8
Alkalinity (mg/L as $CaCO_3$)	93.3	92.0	87.0
Ammonia (mg/L)	0.21	0.55	0.021
Nitrite (mg/L)	0.03	0.02	0.024
Nitrate (mg/L)	9.3	12.0	5.6
Iron (mg/L)	0.16	0.21	0.20
Phosphate (mg/L)	0.26	0.16	0.20

1) Seasonal Consumption of PAC and Chlorine

The average consumption of powdered activated carbon (PAC) and chlorine (**Table 5**) reflected seasonal variations in raw water quality. PAC consumption peaked in August (36 barrels), corresponding to periods of higher turbidity and organic load. Chlorine usage remained relatively stable (614–640 kg), reflecting standard disinfection requirements. Raw water intake was highest in August (73 m^3), suggesting increased water demand and higher inflows. These data highlight the necessity for adaptive chemical dosing to ensure optimal water treatment efficiency, corroborating previous reports on seasonal adjustments in chemical usage for surface water treatment (Rahman, Hasan, & Ahmed, 2020).

Table 5. Average Consumption of PAC and Chlorine Across Seasons

Parameter	March	August	December
PAC Consumption (barrel)	31	36	33
Chlorine Consumption (kg)	614	620	640
Raw Water (m^3)	29	73	30
Tap Water (m^3)	11	13	14

Raw and Produced Water Volumes

The average monthly raw and produced water volumes are presented in **Table 6**. Raw water volumes were consistent (498,500–507,600 m^3), whereas produced water volumes decreased slightly from March (435,800 m^3) to December (408,600 m^3). This variation may result from increased treatment losses or operational constraints during periods of high raw water turbidity. The ratio of raw to produced water indicates high treatment efficiency (>85%), consistent with conventional water treatment performance metrics (WHO, 2022).

Table 6. Average Raw and Produced Water Volumes Across Selected Months

Parameter	March (m^3)	August (m^3)	December (m^3)
Raw Water	503,750	498,500	507,600
Produced Water	435,800	427,400	408,600

Collectively, the data from Tables 1–6 demonstrate that the Al-Shajarah Water Treatment Plant effectively mitigates seasonal variations in raw water quality, producing tap water that consistently meets WHO standards. Raw water quality fluctuates seasonally, especially in turbidity and nitrate concentrations, while treated water remains stable across all parameters. Chemical consumption patterns reflect operational adaptation to seasonal changes, ensuring optimal treatment. These findings underscore the importance of continuous monitoring, adaptive chemical dosing, and robust treatment processes to maintain water safety and quality (Kumar *et al*., 2021; Li *et al*., 2022; Zhang *et al*., 2021).

CONCLUSION

This study systematically assessed the physicochemical characteristics of raw and tap water at the Al-Shajarah Water Treatment Plant across winter, summer, and autumn. Raw water quality exhibited significant seasonal variability, with turbidity and nitrate concentrations peaking during summer and autumn, likely due to rainfall-induced runoff, agricultural activities, and increased microbial activity. Other parameters, including pH, alkalinity, iron, and phosphate, remained relatively stable, indicating minimal industrial contamination and generally favorable water chemistry. The treatment processes effectively mitigated these seasonal fluctuations, producing tap water with consistently low turbidity, controlled nitrogen compounds, and stable pH and alkalinity. Chemical dosing, including powdered activated carbon (PAC) and chlorine, was adjusted in response to seasonal variations in raw water quality, ensuring efficient sediment removal and disinfection. High raw-to-produced water ratios (>85%) further reflect the plant's operational efficiency and treatment performance. Overall, the Al-Shajarah Water Treatment Plant demonstrated robust capability in maintaining potable water quality that meets WHO standards, consistent with previous studies on surface water treatment and seasonal water quality management (Adewale *et al*., 2020; Li *et al*., 2022; Zhang *et al*., 2021).

To enhance water quality management and operational efficiency, it is recommended to implement integrated strategies combining real-time monitoring, adaptive treatment, and source protection. Continuous monitoring of key parameters such as turbidity, nitrate, and ammonia would enable early detection of seasonal peaks and facilitate optimized chemical dosing, improving treatment efficiency while minimizing reagent consumption. Adaptive chemical management protocols, guided by ongoing water quality data, can further ensure consistent contaminant removal and maintain compliance with potable water standards. In parallel, strengthening watershed management to reduce nutrient runoff, soil erosion, and sediment load, particularly during high-risk seasons will safeguard raw water quality.

Furthermore, given the impact of algal blooms on turbidity, nutrient dynamics, taste, odor, and treatment performance, it is recommended to include systematic algal monitoring in the plant's operational framework. Regular assessment of algal abundance, species composition, and cyanotoxin potential using microscopic, fluorometric, or molecular techniques will provide early warning of bloom events and allow timely adjustments in coagulation, filtration, and disinfection strategies. Integration of advanced treatment technologies, such as membrane filtration or advanced oxidation, may be considered to address residual contaminants during periods of peak pollution. Finally, long-

term multi-year monitoring will support predictive modeling, enabling proactive operational planning and ensuring the reliability, sustainability, and safety of the drinking water supply.

REFERENCES

Abdel-Rahman, M.A., El-Sheikh, A.A. & Ali, A.M., 2020. *Seasonal variations in surface water quality and treatment efficiency in water treatment plants*. Journal of Environmental Management**,** 262, p.110321.

Abouzied, A.H. & Hassan, H.A.S., 2022. *The effect of sedimentation by chemical coagulants and the rapid sand filters on algal removal at drinking water treatment plants in Egypt*. Bulletin of the National Research Centre, 46(1), p.70.

Adewale, O., Bello, O. & Olayemi, A., 2020. *Influence of seasonal changes on physicochemical characteristics of surface water*. Environmental Monitoring and Assessment, 192(4), p.246.

Alhaithloul, H.A.S., Mohamed, Z.A., Saber, A.A. *et al*., 2024. *Performance evaluation of Moringa oleifera seeds aqueous extract for removing Microcystis aeruginosa and microcystins from municipal treated water***.** Frontiers in Bioengineering and Biotechnology, 11, p.1329431.

Anantapantula, S.S. & Wilson, A.E., 2023. *Most treatments to control freshwater algal blooms are not effective: Meta-analysis of field experiments*. Water Research, 243, p.120342.

Applied Microbiology & Biotechnology, 2024. *Biotechnological approaches for suppressing Microcystis blooms: insights and challenges***.** Applied Microbiology and Biotechnology, 108, article 466.

Environmental Science and Pollution Research, 2022. *A review of plant-based coagulants for turbidity and cyanobacteria bloom removal*. Environmental Science & Pollution Research, 29, pp.42601–42615.

Kong, M., Dionysiou, D. & colleagues, 2025. *Guarding drinking water safety against harmful algal blooms: Could UV/Cl_2 treatment be the answer?* Environmental Science & Technology**.**

Kumar, P., Singh, R. & Sharma, V., 2021. *Seasonal impact on drinking water quality and treatment in conventional plants*. Water Science and Technology: Water Supply, 21(1), pp.150–164.

Li, X., Wang, Y. & Zhao, H., 2022. *Assessment of treated drinking water quality and seasonal variability*. Environmental Technology & Innovation, 28, p.102726.

Rahman, M.S., Hasan, M. & Ahmed, M., 2020. *Seasonal adjustment of chemical dosing in water treatment plants*. Water Supply, 20(6), pp.2242–2253.

Science of the Total Environment, 2024. *Physico-chemical treatments for the removal of cyanotoxins from drinking water: Current challenges and future trends*. Science of the Total Environment, 917, p.170078.

Wang, M., Zhang, B., Cao, X., Li, F., Song, X. & Yu, Z., 2023. *Influence of algal organic matter on algal removal efficiency by flocculation of modified clay*. Journal of Marine Science and Engineering, 11(3), p.613.

World Health Organization (WHO), 2022. *Guidelines for drinking-water quality*. 4th ed., incorporating the first addendum. Geneva: WHO.

Zeng, G., Zhang, R., Liang, D. *et al*., 2023. *Comparison of the advantages and disadvantages of algae removal technology and its development status*. Water, 15(6), p.1104.

Zhang, F., Xiong, J., Zhang, C., Wu, X. & Tian, Y., 2023. *Removal of algae and algal toxins from a drinking water source using a two-stage polymeric ultrafiltration membrane process*. Polymers, 15(23), p.4495.

Zhang, L., Chen, X. & Liu, J., 2021. *Effect of seasonal variability on water quality parameters in surface water sources*. Science of the Total Environment, 779, p.146454.