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Assessment of Heavy Metal Concentrations and Water Quality Parameters in Hemodialysis Water in Kirkuk, Iraq

Ameen M. Al-Juraisy¹, Sarhan A. Salman², Firas T. Maher³

¹Kirkuk Education Management, Iraqi Ministry of Education. Kirkuk, Iraq

²Department of Food Science, College of Agriculture, Tikrit University, Tikrit, Iraq

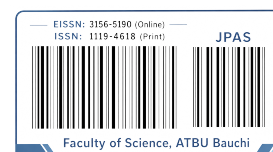
³Department of Chemistry, College of Sciences, Tikrit University. Tikrit, Iraq

Abstract

This study assessed physicochemical parameters and selected trace/heavy metals in water before and after reverse osmosis (RO) treatment at the main dialysis center in Kirkuk, Iraq, and compared results with WHO reference values and applicable AAMI/ANSI/ISO requirements. Water samples were collected from the RO inlet (In) and outlet (Out) at two-week intervals from early April to mid-May 2024 using 0.5-L polyethylene bottles and stored at approximately 8 °C before analysis. pH, total dissolved solids (TDS), electrical conductivity (EC), Na, K, Ca, Mg, and selected trace metals were determined using pH/TDS/EC meters, flame photometry, flame atomic absorption spectrometry, and ICP-OES. pH decreased from 7.60 ± 0.0493 to 6.50 ± 0.0950 . TDS decreased from 688.3 ± 1.528 to 6.00 ± 0.800 mg/L, while EC declined from 1459 ± 2.646 to 13.00 ± 1.00 $\mu\text{S}/\text{cm}$ ($P < 0.0001$). Na remained below its applicable limit. K decreased from 9.439 ± 0.1063 to 4.053 ± 0.02292 mg/L ($P = 0.0002$). Ca and Mg decreased to 39.08 ± 0.02235 and 21.70 ± 0.1865 mg/L, respectively, but remained above applicable limits ($P < 0.0001$). Zn, Pb, and Cd decreased after RO but remained above their respective limits. Cr decreased from 0.0200 ± 0.0006 mg/L ($P = 0.004$) to undetectable levels. Fe decreased from 0.1044 ± 0.0001 to 0.09550 ± 0.0002 mg/L. Al, Be, Ba, As, Ag, Sb, Se, Tl, Co, Ni, Mn, and Cu were undetected. RO substantially improved water quality but failed to achieve chemical compliance for Ca, Mg, Zn, Pb, and Cd, supporting routine monitoring and systematic evaluation of pretreatment, membrane condition, storage, and distribution components.

Keywords

Hemodialysis;
Heavy Metals;
Water Treatment;
Pollution;
RO



INTRODUCTION

Chronic kidney disease (CKD) is a major global health problem, and hemodialysis is a widely used renal replacement therapy. Because water is the major component of dialysate, the chemical and microbiological quality of water used in hemodialysis is critical to patient safety. During a hemodialysis session, patients are exposed indirectly to large volumes of water through the dialysate; therefore,

contaminants that remain after water treatment may become clinically relevant. Reverse osmosis (RO) is a central component of dialysis-water treatment because it reduces dissolved ions and other contaminants before the water is used to prepare dialysis fluids. Treatment performance, however, depends on source-water quality, pretreatment, membrane condition, storage, distribution materials, and maintenance practices [37,38].

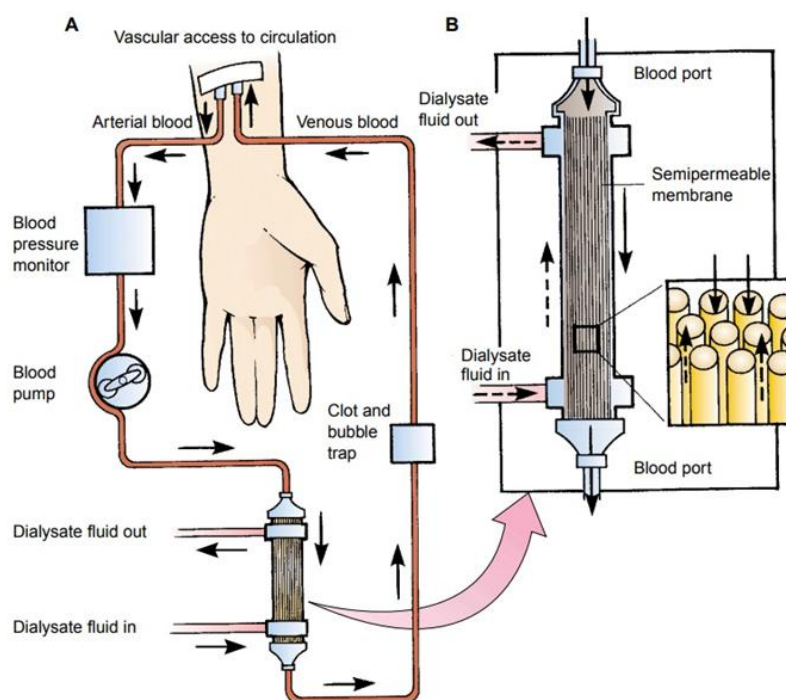


Figure 1. Hemodialysis system.

The dialyzer pumps blood from the patient through semipermeable membrane fibers, while dialysate flows on the opposite side of the membrane. Solutes and waste products diffuse across the membrane according to concentration gradients.

Chemical contaminants in dialysis water are of particular concern because the dialysis membrane permits exchange between blood and dialysate. Previous studies in Iraq and other countries have documented chemical and microbiological deviations from dialysis-water quality requirements [10-

12,17,27,39-41]. These findings support the need for site-specific monitoring rather than assuming that treatment performance is uniform among dialysis centers.

Among the contaminants of concern, lead, cadmium, chromium, zinc, and aluminum have recognized toxicological relevance when exposure is repeated. In dialysis facilities, persistent contamination may arise from incomplete treatment, deterioration of treatment components, or materials in contact with the water. Therefore, comparing

water at the RO inlet and outlet can help identify parameters that are not adequately removed and can provide a baseline for subsequent longitudinal monitoring [19,21-25,39].

The objective of this study was to assess physicochemical parameters and selected trace/heavy metals in water before and after the RO treatment system at the main dialysis center in Kirkuk, Iraq, and to compare the measured concentrations with WHO drinking-water reference values and the applicable AAMI/ANSI/ISO requirements for dialysis water. The study provides center-specific baseline data that can support local quality monitoring and future longitudinal assessment of treatment performance.

HYPOTHESIS

We hypothesized that RO treatment would significantly reduce selected physicochemical parameters and trace/heavy-metal concentrations

between the inlet (In) and outlet (Out) sampling points. We further hypothesized that some contaminants, particularly Ca, Mg, Zn, Pb, and Cd, could remain above the applicable dialysis-water limits after treatment if removal was incomplete or if additional contributions occurred within the treatment or distribution system.

MATERIALS AND METHODS

1. Study site:

Al-Amal Dialysis Center is the main dialysis center in Kirkuk, Iraq. The center was opened in December 2022 and serves 63 dialysis patients. It includes a water-treatment plant supplied by the local piped-water network and groundwater from a well located in the center courtyard. The center's water-distribution system is connected to the network used for drinking and other medical purposes. The present study focused on the water-treatment pathway serving the dialysis unit.

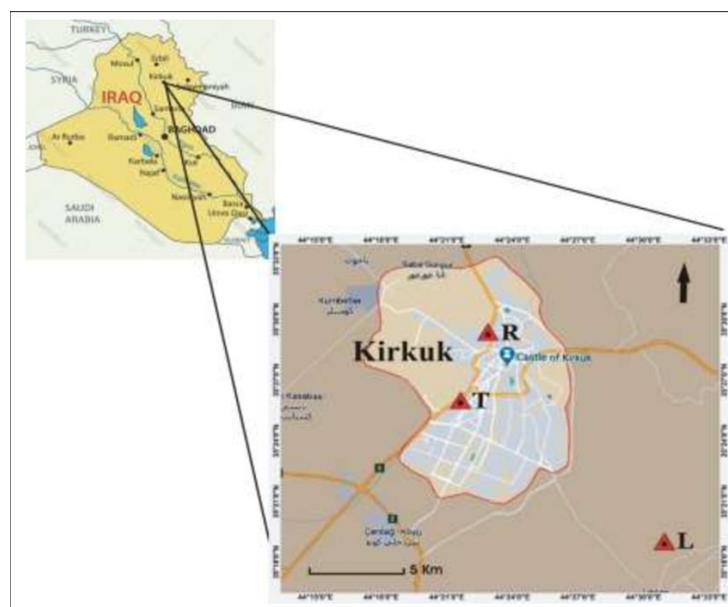


Figure 2. Map of Kirkuk City, Iraq [28].

2. Sampling:

Water samples were collected from the beginning of April to mid-May 2024 at two-week intervals. Before each collection, the sampling ports were rinsed with the water being sampled for five minutes. Samples were collected in 0.5-L polyethylene bottles after the bottles were thoroughly rinsed with the corresponding sample water. Two sampling points were investigated: (In), water leaving the main tank immediately before the RO system; and (Out), water collected after the RO system. The collected samples were stored in polyethylene bottles under refrigerated conditions at approximately 8 °C until the analytical measurements were performed. For pH, TDS, and EC, three consecutive analytical readings were obtained for each sample and averaged. The exact number of independent sampling rounds and the number of analytical replicates used for FAAS and ICP-OES were not explicitly recorded in the available study documentation and are therefore not inferred here.

3. Measurement of pH:

pH was measured using a JENWAY-3310 pH meter after calibration with buffer solutions of known pH. The reported value was based on the mean of three consecutive readings for each sample.

4. Measurement of total dissolved solids TDS:

TDS was measured using a TDS meter after the electrode was rinsed several times with deionized water. The reported value was based on the mean of three consecutive readings for each sample.

5. Measurement of electrical conductivity EC:

Electrical conductivity (EC) was measured using an EC meter, model BC3020. The reported value was based on the mean of three consecutive readings for each sample.

6. Measurement of sodium, potassium and calcium concentrations:

Sodium (Na), potassium (K), and calcium (Ca) were analyzed using a flame photometer, model CL 26D (India). Calibration curves were prepared before analysis.

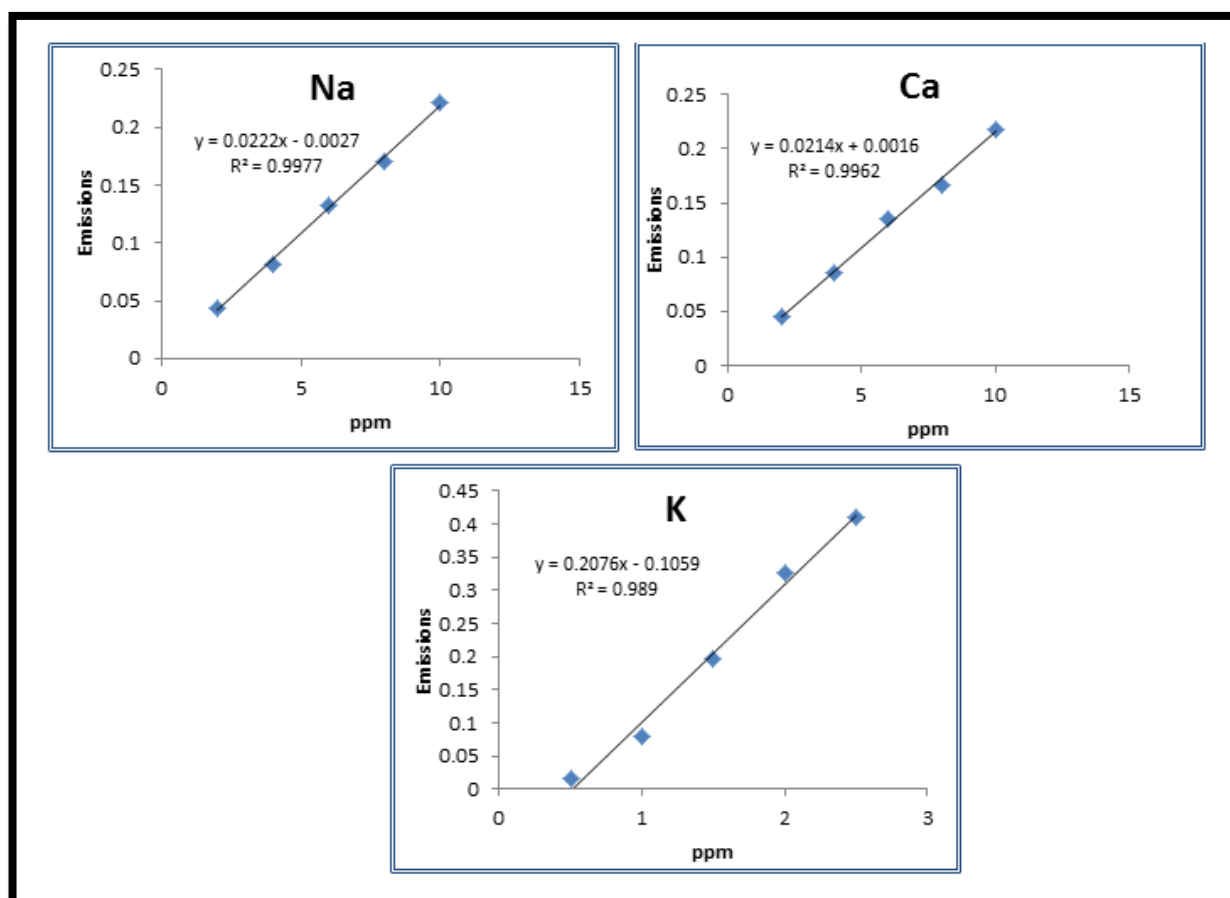


Figure 3. Calibration curves for sodium, potassium, and calcium.

7. Measurement of heavy metal concentrations:

The concentrations of Fe, Cr, Co, Ni, Zn, Cu, Pb, Cd, and Mn were determined by flame atomic absorption spectrometry (FAAS) using a SHIMADZU AA-6200 (Japan). Ag, Al, As, Ba, Be, Sb, Se, Th, and Mg were determined using ICP-OES (Varian 730-ES).

Calibration curves were prepared for the measured analytes before analysis. The type of RO membrane, operating pressure, and water flow rate were not documented in the available study records and therefore are not reported.

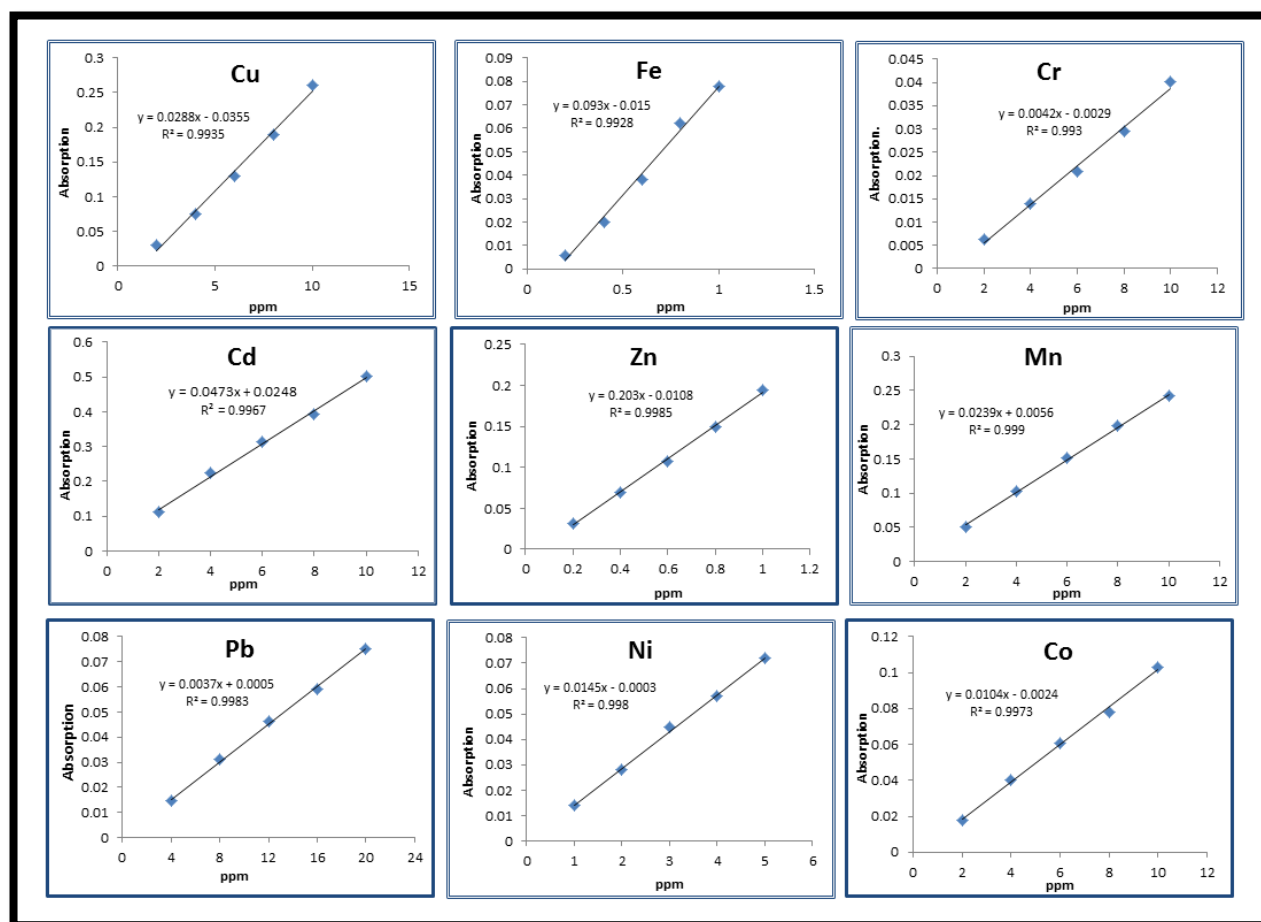


Figure 4. Calibration curves for the analyzed heavy metals.

8. statistical analysis:

Statistical analysis was performed using GraphPad Prism 9. Results are presented as mean $\pm$ standard deviation (SD). Comparisons between paired In and Out observations were performed using a paired two-sample t-test, with statistical significance defined as $P \leq 0.05$. The measured values were also compared with the applicable WHO drinking-water reference values and AAMI/ANSI/ISO dialysis-water limits. The three consecutive readings reported for pH, TDS, and EC represent analytical repeat measurements for each collected sample and should not be interpreted as independent field samples.

Results and Discussion

Results

The RO system markedly reduced several physicochemical parameters and electrolytes. pH decreased from 7.60 ± 0.0493 at the inlet to 6.50 ± 0.0950 at the outlet, remaining within the stated 6.5–8.5 reference range. TDS decreased from 688.3 ± 1.528 to 6.00 ± 0.800 mg/L, corresponding to an approximate 99.1% reduction. EC decreased from 1459 ± 2.646 to 13.00 ± 1.00 $\mu\text{S}/\text{cm}$ ($P < 0.0001$), an approximate 99.1% reduction. Na remained below the AAMI/ANSI/ISO maximum level at both points. K decreased from 9.439 ± 0.1063 mg/L at the inlet,

above the 8.0 mg/L limit, to 4.053 ± 0.02292 mg/L after RO ($P = 0.0002$), below the limit. Ca decreased from 85.59 ± 0.1722 to 39.08 ± 0.02235 mg/L and Mg from 38.34 ± 0.01413 to 21.70 ± 0.1865 mg/L; both remained above their respective 2.0 and 4.0 mg/L dialysis-water limits ($P < 0.0001$ for each comparison).

For trace/heavy metals, Cr was 0.0200 ± 0.0006 mg/L at the inlet, exceeding the 0.014 mg/L limit, and was not detected after RO at the reported analytical level ($P = 0.004$). Zn decreased from

0.5806 ± 0.0003 to 0.2016 ± 0.0002 mg/L, Pb from 0.0181 ± 0.0002 to 0.01494 ± 0.0002 mg/L, and Cd from 0.02477 ± 0.0002 to 0.01767 ± 0.00015 mg/L; despite these reductions, all three remained above their respective AAMI/ANSI/ISO maximum levels after RO. Fe was detected at 0.1044 ± 0.0001 mg/L before RO and 0.09550 ± 0.0002 mg/L after RO; no applicable maximum level for Fe was reported in the standard used in this study. Al, Be, Ba, As, Ag, Sb, Se, Tl, Co, Ni, Mn, and Cu were not detected at the reported analytical level. The complete results are presented in Tables 1-3.

Table 1. Physicochemical parameters compared with the reference values used in the study

P-value	Reference value	Mean $\pm$ SD	Sample	Unit	Variable
NS	6.5-8.5	7.6 ± 0.0493	In	-	pH
NS	6.5-8.5	6.5 ± 0.0950	out	—	
NS	6.5-8.5	688.3 ± 1.528	In	mg/L	TDS
NS	1500	6.000 ± 0.800	out	—	
<0.0001*	1500	1459 ± 2.646	In	$\mu\text{S}/\text{cm}$	EC
NS	1200	13.00 ± 1.00	out	—	

Table 2. Electrolyte concentrations compared with the maximum allowable levels of ANSI/AAMI/ISO 23500-3:2024

Variable	Unit	Sample	Mean $\pm$ SD	Maximum level (mg/L)	P-value
Na	mg/L	In	67.11 ± 0.5237	70	NS
		Out	23.24 ± 0.2166		NS
K	mg/L	In	9.439 ± 0.1063	8.0	0.0002*
		Out	4.053 ± 0.02292		NS
Ca	mg/L	In	85.59 ± 0.1722	2.0	<0.0001*
		Out	39.08 ± 0.02235		<0.0001*
Mg	mg/L	In	38.34 ± 0.01413	4.0	<0.0001*
		Out	21.70 ± 0.1865		<0.0001*

* $P \leq 0.05$; NS = not significant. Values are presented as mean $\pm$ SD.

Table 3. Trace/heavy-metal concentrations compared with the maximum allowable levels of ANSI/AAMI/ISO 23500-3:2024

Variable	Sample	Mean $\pm$ SD	Maximum level (mg/L)	P-value
Al	In	0.0000 $\pm$ 0.0000	0.01	NS
	Out	0.0000 $\pm$ 0.0000		NS
Be	In	0.0000 $\pm$ 0.0000	0.0004	NS
	Out	0.0000 $\pm$ 0.0000		NS
Ba	In	0.0000 $\pm$ 0.0000	0.1	NS
	Out	0.0000 $\pm$ 0.0000		NS
As	In	0.0000 $\pm$ 0.0000	0.005	NS
	Out	0.0000 $\pm$ 0.0000		NS
Ag	In	0.0000 $\pm$ 0.0000	0.005	NS
	Out	0.0000 $\pm$ 0.0000		NS
Sb	In	0.0000 $\pm$ 0.0000	0.006	NS
	Out	0.0000 $\pm$ 0.0000		NS
Se	In	0.0000 $\pm$ 0.0000	0.09	NS
	Out	0.0000 $\pm$ 0.0000		NS
Tl	In	0.0000 $\pm$ 0.0000	0.002	NS
	Out	0.0000 $\pm$ 0.0000		NS
Co	In	0.0000 $\pm$ 0.0000	-	NS
	Out	0.0000 $\pm$ 0.0000		NS
Fe	In	0.1044 $\pm$ 0.0001	-	NS
	Out	0.09550 $\pm$ 0.0002		NS
Cr	In	0.0200 $\pm$ 0.0006	0.014	0.0040*
	Out	0.0000 $\pm$ 0.0000		NS
Ni	In	0.0000 $\pm$ 0.0000	-	NS
	Out	0.0000 $\pm$ 0.0000		NS
Zn	In	0.5806 $\pm$ 0.0003	0.1	<0.0001*
	Out	0.2016 $\pm$ 0.0002		<0.0001*
Pb	In	0.0181 $\pm$ 0.0002	0.005	<0.0001*
	Out	0.01494 $\pm$ 0.0002		<0.0001*
Mn	In	0.0000 $\pm$ 0.0000	-	NS
	Out	0.0000 $\pm$ 0.0000		NS
Cd	In	0.02477 $\pm$ 0.0002	0.001	<0.0001*
	Out	0.01767 $\pm$ 0.00015		<0.0001*
Cu	In	0.0000 $\pm$ 0.0000	0.1	NS
	Out	0.0000 $\pm$ 0.0000		NS

* $P \leq 0.05$; NS = not significant. Values are presented as mean $\pm$ SD. "—" indicates that no maximum level for that element is specified in the cited dialysis-water standard.

Discussion

Dialysis-water quality is a critical component of hemodialysis safety because patients may be exposed repeatedly to water through the dialysate. ANSI/AAMI/ISO 23500-3:2024 specifies minimum chemical and microbiological quality requirements and emphasizes ongoing monitoring of dialysis-water purity [37]. The present study provides center-specific baseline data from the main dialysis center in Kirkuk and identifies parameters that remained elevated after RO treatment.

pH: The pH of the inlet and outlet water was 7.60 ± 0.0493 and 6.50 ± 0.0950 , respectively, and both values were within the stated 6.5–8.5 reference range. The decrease after RO is compatible with changes in dissolved ionic constituents during membrane treatment; however, pH alone is not sufficient to assess dialysis-water quality and should be interpreted together with the chemical results [31].

Total dissolved solids (TDS): TDS decreased from 688.3 ± 1.528 mg/L before RO to 6.00 ± 0.800 mg/L after RO, an approximate 99.1% reduction. This result indicates effective reduction of dissolved material by the treatment system. TDS is reported here as a process-performance indicator rather than as a health-based WHO compliance parameter.

Electrical conductivity (EC): EC decreased from 1459 ± 2.646 μ S/cm at the inlet to 13.00 ± 1.00 μ S/cm at the outlet ($P < 0.0001$), an approximate 99.1% reduction. Because EC reflects the presence of dissolved ionic constituents, the marked reduction supports substantial removal of ionic material by the RO system and demonstrates the value of EC as a routine process-monitoring parameter [38,40].

Electrolytes: Na remained below the applicable maximum level at both sampling points. K decreased from 9.439 ± 0.1063 mg/L at the inlet to 4.053 ± 0.02292 mg/L after RO, crossing from above to below the 8.0 mg/L limit. In contrast, Ca and Mg remained markedly above their respective limits after treatment, despite reductions of

approximately 54.3% and 43.4%, respectively. This incomplete removal may be associated with pretreatment performance, membrane condition, scaling, or contributions from the treatment/distribution system. However, because intermediate treatment stages and distribution materials were not sampled, the present study cannot establish the specific source of the residual Ca and Mg [34].

Heavy metals: Zn, Pb, and Cd were reduced after RO but remained above their applicable maximum levels. The approximate reductions were 65.3% for Zn, 17.5% for Pb, and 28.7% for Cd. Cr was detected above its stated limit at the inlet and was not detected after RO at the reported analytical level. Fe showed only a small reduction, from 0.1044 ± 0.0001 to 0.09550 ± 0.0002 mg/L. The persistence of Zn, Pb, and Cd may reflect incomplete rejection, source-water loading, or contributions from materials in contact with the water; these mechanisms cannot be distinguished from the present two-point design. Previous dialysis-water studies have likewise emphasized the importance of treatment performance and materials in contact with the water [1,39,40]. Importantly, this study did not measure patient blood concentrations or clinical outcomes; therefore, it does not establish a direct causal relationship between the measured water contaminants and patient health outcomes.

The findings support continued monitoring of both RO inlet and outlet water, together with inspection of pretreatment, membrane condition, storage tanks, pipelines, connectors, and disinfection practices. Where persistent non-compliance is confirmed, a second RO stage or another polishing step may be considered as an engineering option, but the effectiveness of such interventions was not evaluated in this study. Chemical monitoring should also be complemented by microbiological and endotoxin testing because chemical measurements alone cannot establish microbiological safety [37,40,41].

CONCLUSION

The RO system substantially reduced several physicochemical parameters and measured trace elements, but the treated water remained above the applicable ANSI/AAMI/ISO limits for Ca, Mg, Zn, Pb, and Cd. K decreased from above the applicable limit at the inlet to below the limit after RO. Cr exceeded its stated limit at the inlet but was not detected after RO at the reported analytical level, while Fe remained detectable at both sampling points. The findings indicate incomplete chemical compliance after RO and support routine monitoring, preventive maintenance, and systematic evaluation of pretreatment, membrane performance, storage, and distribution components. Because the study did not test corrective interventions, recommendations for a second RO stage or additional polishing should be regarded as options for engineering evaluation rather than demonstrated solutions. Future studies should use a clearly defined number of independent sampling rounds, include different seasons, document RO operating parameters, and incorporate microbiological and endotoxin testing.

REFERENCES

- [1] E. F. Carney, "The impact of chronic kidney disease on global health," *Nat. Rev. Nephrol.*, vol. 16, no. 5, pp. 251-252, 2020.
- [2] A. K. Bello, I. G. Okpechi, M. A. Osman, Y. Cho, H. Htay, V. Jha, et al., "Epidemiology of haemodialysis outcomes," *Nat. Rev. Nephrol.*, vol. 18, no. 6, pp. 378-395, 2022.
- [3] M. Abbaszadeh, M. Mosaferi, P. Firouzi, M. A. Abedpour, and S. Sheykholeslami, "Evaluation of physicochemical and microbial quality control of hemodialysis machines water in hospitals," *Depict. Health*, vol. 12, pp. 12-23, 2021.
- [4] S. Gentile, F. Strollo, E. Satta, T. Della-Corte, C. Romano, G. Guarino, et al., "Insulin-induced lipodystrophy in hemodialyzed patients: A new challenge for nephrologists?" *Diabetes Metab. Syndr. Clin. Res. Rev.*, vol. 13, no. 6, pp. 3081-3084, 2019.
- [5] R. Pérez García, "The essential role of water treatment system (WTS) in the quality of water for hemodialysis," *Nefrol. (Engl. Ed.)*, vol. 28, no. 5, pp. 475-478, 2008.
- [6] A. A. Alfarisi, H. Gawili, A. O. AlFerjany, S. B. AlTalhi, A. A. Gandrah, and N. M. Bushaala, "Water treatment for hemodialysis in Benghazi Medical Center (BMC)," *Asian J. Med. Health*, vol. 19, no. 1, pp. 48-62, 2021.
- [7] L. Qizalbash, S. Cleghorn, and L. McAlister, "Kidney diseases," in *Clin. Paediatr. Diet.*, 2020, pp. 238-286.
- [8] M. Abualhasan, A. Basim, S. Sofan, and M. Al-Atrash, "Quality of water used in Palestinian hemodialysis centers," *Public Health*, vol. 165, pp. 136-141, 2018.
- [9] M. Totaro, B. Casini, P. Valentini, M. Miccoli, S. Giorgi, A. Porretta, et al., "Evaluation and control of microbial and chemical contamination in dialysis water plants of Italian nephrology wards," *J. Hosp. Infect.*, vol. 97, no. 2, pp. 169-174, 2017.
- [10] D. C. H. Harris, S. J. Davies, F. O. Finkelstein, V. Jha, A. K. Bello, M. Brown, et al., "Strategic plan for integrated care of patients with kidney failure," *Kidney Int.*, vol. 98, no. 5, pp. S117-S134, 2020.
- [11] Y. Raad Humudat and S. K. Al-Naseri, "Evaluation of dialysis water quality at hospitals in Baghdad, Iraq," *J. Health Pollut.*, vol. 10, no. 28, p. 201211, 2020.
- [12] Y. R. Humudat, S. K. Al-Naseri, and Y. F. Al-Fatlawy, "Assessment of microbial contamination levels of water in hemodialysis centers in Baghdad, Iraq," *Water Environ. Res.*, vol. 92, no. 9, pp. 1325-1333, 2020.
- [13] M. N. Suzuki, B. M. Fregonesi, C. S. Machado, G. S. Zagui, L. Kusumota, A. K. Suzuki, et al., "Hemodialysis water parameters as predisposing factors for anemia in patients in dialytic treatment: Application of mixed regression models," *Biol. Trace Elem. Res.*, vol. 190, pp. 30-37, 2019.

- [14] E. G. Hilinski, A. A. B. Almodovar, F. P. de L. e Silva, T. J. A. de Pinto, and A. Bugno, "Is dialysis water a safe component for hemodialysis treatment in São Paulo State, Brazil?" *Braz. J. Pharm. Sci.*, vol. 56, p. e17835, 2020.
- [15] O. O. Okunola and J. O. Olaitan, "Bacterial contamination of hemodialysis water in three randomly selected centers in South Western Nigeria," *Niger. J. Clin. Pract.*, vol. 19, no. 4, pp. 491-495, 2016.
- [16] I. Vorbeck-Meister, R. Sommer, F. Vorbeck, and W. H. Hörl, "Quality of water used for haemodialysis: Bacteriological and chemical parameters," *Nephrol. Dial. Transplant.*, vol. 14, no. 3, pp. 666-675, 1999.
- [17] P. R. de Jesus, J. A. B. Ferreira, J. dos S. do Carmo, S. R. G. Albertino, S. A. Vicentini, L. M. G. dos Santos, et al., "Monitoring the quality of the water used in mobile dialysis services in intensive care units in the city of Rio de Janeiro," *Braz. J. Nephrol.*, vol. 44, no. 1, pp. 32-41, 2021.
- [18] J. Dolar-Szczasny, J. Flieger, B. Kowalska, D. Majerek, M. Tatarczak-Michalewska, I. Zakrocka, et al., "Hemodialysis effect on the composition of the eye fluid of cataract patients," *J. Clin. Med.*, vol. 10, no. 23, p. 5485, 2021.
- [19] A. Fevrier-Paul, A. K. Soyibo, S. Mitchell, and M. Voutchkov, "Role of toxic elements in chronic kidney disease," *J. Health Pollut.*, vol. 8, no. 20, p. 181202, 2018.
- [20] R. A. Ward, "Dialysis water as a determinant of the adequacy of dialysis," in *Seminars in Nephrology*. Elsevier, 2005, pp. 102-111.
- [21] M. Pirsaeheb, S. Naderi, B. Lorestani, T. Khosrawi, and K. Sharafi, "Efficiency of reverse osmosis system in the removal of lead, cadmium, chromium and zinc in feed water of dialysis instruments in Kermanshah hospitals," *J. Maz. Univ. Med. Sci.*, vol. 24, no. 118, pp. 151-157, 2014.
- [22] R. B. de Oliveira, F. C. Barreto, L. A. Nunes, and M. R. Custódio, "Aluminum intoxication in chronic kidney disease," *Braz. J. Nephrol.*, vol. 43, pp. 660-664, 2021.
- [23] P. C. D'haese and M. E. De Broe, "Adequacy of dialysis: Trace elements in dialysis fluids," *Nephrol. Dial. Transplant.*, vol. 11, suppl. 2, pp. 92-97, 1996.
- [24] K. I. Greenberg and M. J. Choi, "Hemodialysis emergencies: Core curriculum 2021," *Am. J. Kidney Dis.*, vol. 77, no. 5, pp. 796-809, 2021.
- [25] A. D. Coulliette and M. J. Arduino, "Hemodialysis and water quality," *Semin. Dial.*, vol. 26, no. 4, pp. 427-438, 2013.
- [26] N. A. Hoenich and R. Levin, "Renal Research Institute symposium: The implications of water quality in hemodialysis," *Semin. Dial.*, vol. 16, no. 6, pp. 492-497, 2003.
- [27] B. Naderi, H. M. Attar, and F. Mohammadi, "Evaluation of some chemical parameters of hemodialysis water: A case study in Iran," *Environ. Health Insights*, vol. 16, p. 11786302221132752, 2022.
- [28] K. Khwedim, M. T. Ahmed, and M. A. Najemalden, "Survey of some heavy metals and radioactivity in the dust in a selected area in Kirkuk Governorate—Northern Iraq," *Iraqi J. Sci.*, pp. 3817-3824, 2022.
- [29] R. Nystrand, "Microbiology of water and fluids for hemodialysis," *J. Chin. Med. Assoc.*, vol. 71, no. 5, pp. 223-229, 2008.
- [30] S. K. Al-Naseri, Z. M. Mahdi, and M. F. Hashim, "Quality of water in hemodialysis centers in Baghdad, Iraq," *Hemodial. Int.*, vol. 17, no. 4, pp. 517-522, 2013.
- [31] S. J. Duranceau, "Modeling the permeate transient response to perturbations from steady state in a nanofiltration process," *Desalin. Water Treat.*, vol. 1, nos. 1-3, pp. 7-16, 2009.
- [32] E. Pantea, T. Romocea, and C. Ghergheleş, "Dialysis water treated by reverse osmosis," 2011.

- [33] T. Burns, S. Tranter, and V. Raghunath, "In-centre night dialysis program: A single-centre experience," *Ren. Soc. Australas. J.*, vol. 13, no. 2, pp. 58-64, 2017.
- [34] L. Malaeb and G. M. Ayoub, "Reverse osmosis technology for water treatment: State of the art review," *Desalination*, vol. 267, no. 1, pp. 1-8, 2011.
- [35] S. Satarug, D. A. Vesey, and G. C. Gobe, "Current health risk assessment practice for dietary cadmium: Data from different countries," *Food Chem. Toxicol.*, vol. 106, pp. 430-445, 2017.
- [36] J. Koropatnick and M. E. I. Leibbrandt, "Effects of metals on gene expression," in *Toxicology of Metals: Biochemical Aspects*, 1995, pp. 93-120.
- [37] Association for the Advancement of Medical Instrumentation (AAMI). ANSI/AAMI/ISO 23500-3:2024, Preparation and quality management of fluids for haemodialysis and related therapies—Part 3: Water for haemodialysis and related therapies. Arlington, VA: AAMI; 2024.
- [38] Centers for Disease Control and Prevention (CDC). Water Use in Dialysis. Dialysis Safety; March 26, 2024.
- [39] Raimundo R, Preciado L, Belchior R, Almeida CMM. Water quality and adverse health effects on the hemodialysis patients: An overview. *Ther Apher Dial.* 2023;27(6):1053-1063. doi:10.1111/1744-9987.14032.
- [40] Vavrinchik J, DeStefano J, Sweeney K, Payton J. Observations from the Field Concerning Water and Dialysate for Hemodialysis. *Nephrol Nurs J.* 2023;50(3):209-238.
- [41] Suravaram S, Gopikonda SS, Siddiqui IA, Kanugula H, Gorakanti D, Vaddanapu L. Enhancing infection control in dialysis at a resource limited public healthcare institute: A cross-sectional study on microbiological quality assessment of dialysis water and dialysate. *Indian J Med Microbiol.* 2024;52:100734. doi:10.1016/j.ijmmb.2024.100734.