International Journal of Scientific Research & Engineering Trends
Volume 12, Issue 4, July-Aug-2026, ISSN (Online): 2395-566X

Hydrochemical Characterization and Sodium Adsorption Ratio (Sar) of Groundwater in the Central Kyzylkum Desert Ecosystem, Uzbekistan

Adilov Sobit Uktamovich,
Chief Researcher, “Central Kyzylkum” State National Nature Park[1]

Gulomov Gofir Komil o‘g‘li,
Senior Researcher, “Central Kyzylkum” State National Nature Park[2]

Umirzoqov Jamshid Mirzayevich,
Researcher, “Central Kyzylkum” State National Nature Park[3]

Umirov Ismoil Eshonqulovich,
Researcher, “Central Kyzylkum” State National Nature Park[4]

Abstract — This study presents a hydrochemical characterization of groundwater from four wells (Chanishbay yakka quduq, Kupet turar joy, Nissan uy oldi, and Beknazar quduq) within the Central Kyzylkum desert ecosystem, Uzbekistan, focusing on major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), a set of regulated trace elements (Cu, Cr, Fe, Cd), and the Sodium Adsorption Ratio (SAR). Samples were collected on 30 April 2026 and analysed by Flame Atomic Absorption Spectrometry (FAAS) at an accredited laboratory (Workshop No. 081, order No. 23764). Results were compared against World Health Organization (WHO) drinking-water guidelines and the United States Salinity Laboratory (USSL) SAR classification. The hydrochemical facies at all sites were sodium-dominant ($Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$), and sodium concentrations exceeded the WHO palatability threshold (200 mg/L) at every site. Calculated SAR values ranged from 4.9 (low hazard, S1) to 55.8 (very high hazard, S4), indicating a substantial sodium/salinity hazard should these waters be used for irrigation. Concentrations of the regulated heavy metals (Cu, Cr, Cd) were below the detection limit at all sites. The findings underline the need for expanded hydrochemical monitoring of groundwater in arid desert ecosystems such as Central Kyzylkum.

Keywords— hydrochemistry, groundwater, Sodium Adsorption Ratio (SAR), salinization, Central Kyzylkum, desert ecosystem, irrigation water quality.

I. INTRODUCTION

Groundwater represents the almost exclusive stable source of drinking water for the population, livestock, and wildlife of desert and semi-desert ecosystems, including the Kyzylkum Desert of Central Asia, since the region lacks a permanent surface-water network [16]. Annual precipitation in the Kyzylkum Desert averages 100–200 mm, surface water sources are practically absent, yet the region holds substantial reserves of fresh and brackish groundwater [17]. Salinization, elevated mineralization, and, in certain cases, anthropogenic contamination can significantly affect groundwater quality, a matter of importance not only for human health but also for the water supply of wild flora and fauna within protected areas and national parks.

Numerous studies worldwide have assessed groundwater quality by comparing concentrations of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and heavy metals (Cu, Cr, Cd, Fe, Pb, and others) against World Health Organization (WHO) guideline values [9–15,20]. In semi-arid regions in particular, reported cation abundance sequences are commonly $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ or $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$, while total dissolved solids (TDS) and electrical conductivity (EC) vary widely depending on local geology and evaporation intensity [9]. Comparable studies have been conducted across a range of climatic settings, including Bangladesh [10], Pakistan [11], Iran [12], Romania (Tisa River Basin protected area) [13], Egypt (Western Desert, Nubian Sandstone Aquifer) [14], and India [15], all of which employed comparative assessment against WHO standards as a common methodological approach.

International Journal of Scientific Research & Engineering Trends
Volume 12, Issue 4, July-Aug-2026, ISSN (Online): 2395-566X

In Uzbekistan, intensive irrigated agriculture and chemical inputs during the Soviet period produced substantial anthropogenic pressure on both surface- and groundwater quality [16]. Recent studies conducted in the Chirchik and Akhangaran river basins have shown that spring water used for drinking generally meets WHO and national standards of the Republic of Uzbekistan, although several trace elements (Zn, Mo, Sb, Pb, Ni, U, As, B) exceeded global average concentrations, underscoring the need for continuous monitoring [17]. For the territory of the Central Kyzylkum National Nature Park and its surrounding settlements, however, such systematic hydrochemical data remain very limited to date.

The aim of this study is to characterize the hydrochemical composition (major cations Ca, Mg, Na, K, and the regulated trace elements Cu, Cr, Fe, Cd) of groundwater from four wells within the Central Kyzylkum desert ecosystem, to calculate the Sodium Adsorption Ratio (SAR), and to compare the results against WHO and USSL reference values, providing a preliminary assessment of regional groundwater quality.

II. MATERIALS AND METHODS

Study area. The study was carried out in the Central Kyzylkum National Nature Park and adjacent territories. The area lies in the central part of the Kyzylkum Desert and is characterized by a sharply continental climate (hot, dry summers and cold winters), low annual precipitation (100–200 mm), and a variety of landscape types, including residual mountain outcrops, sand dunes, and saline flats [18]. Permanent surface watercourses are practically absent, so wells and other groundwater sources constitute the principal water supply for the local population, livestock, and wildlife.

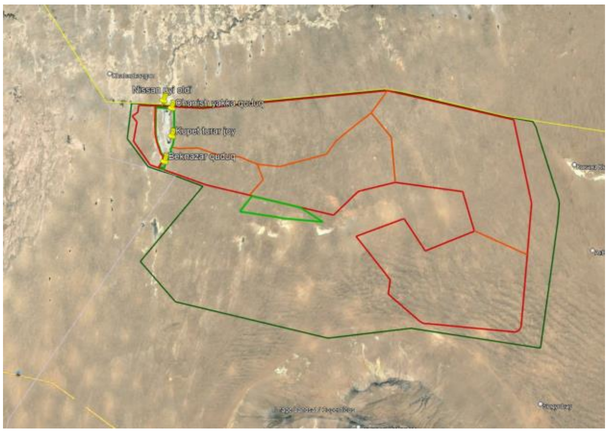

Figure 1. Schematic location of the sampling points within the Central Kyzylkum National Nature Park

Sampling. Water samples were collected on 30 April 2026 at four sites: (1) Chanishbay yakka quduq; (2) Kupet turar joy; (3) Nissan uy oldi; (4) Beknazar quduq. Samples were collected into pre-cleaned polyethylene containers and stored at room temperature in a cool, shaded location until analysis. In accordance with standard practice, polyethylene–polypropylene containers are recommended for cation and trace-element analysis, since glass containers may adsorb or release certain metals [25]. According to the official laboratory report, the samples were received and analysed by Workshop No. 081 under order No. 23764.

This study is based on a single sampling event (30 April 2026) and was not conducted over a seasonal monitoring cycle. The results are therefore representative only of the sampling date and do not capture potential variability associated with other periods of the year (e.g., peak summer evaporation or winter low-temperature conditions). This is addressed below as a key methodological limitation of the study (Section: Study Limitations). The precise geographic coordinates of the sampling points are given in Table 1.

Table 1. Geographic location of the sampling points

No.	Sampling site	Latitude (N)	Longitude (E)
1	Chanishbay yakka quduq	43°29'12.37"N	62°18'21.31"E
2	Kupet turar joy	43°23'32.05"N	62°19'28.23"E
3	Nissan uy oldi	43°18'15.44"N	62°18'27.05"E
4	Beknazar quduq	43°30'33.78"N	62°15'48.49"E

Chemical analysis methods. All parameters (Ca, Cu, Mg, Cr, Fe, Cd, Na, K) were determined by Atomic Absorption Spectrometry (AAS) in flame atomization mode (Flame AAS, FAAS). This is a widely used standard method for the determination of major cations and trace elements in natural and drinking water [10,25]. Samples were filtered prior to analysis in accordance with standard protocol, and instrument calibration was performed using certified standard solutions. Results were compared against the reference values published in the WHO “Guidelines for Drinking-water Quality” (4th edition) and the corresponding chemical-specific background documents [1–8].

Sodium Adsorption Ratio (SAR). To assess the salinity hazard of the water for irrigation and livestock use, the Sodium Adsorption Ratio (SAR) was calculated from the measured Na^+, Ca^{2+}, and Mg^{2+} concentrations. SAR is defined by the following formula (all ion concentrations expressed in meq/L) [21,22]:

International Journal of Scientific Research & Engineering Trends
Volume 12, Issue 4, July-Aug-2026, ISSN (Online): 2395-566X

$$\mathrm{SAR} = \frac{[\mathrm{Na}^+]}{\sqrt{\frac{[\mathrm{Ca}^{2+}]+[\mathrm{Mg}^{2+}]}{2}}}$$

The calculated SAR value was classified according to the classic system developed by the United States Salinity Laboratory (USSL): SAR < 10 — low sodium hazard (S1); 10–18 — medium (S2); 18–26 — high (S3); >26 — very high sodium hazard (S4) [21,22].

III. RESULTS

Table 2 presents the quantitative chemical parameters at the four sampling sites.

Table 2. Chemical analysis results of the water samples (mg/L)

No.	Sampling site	Ca (mg/L)	Cu (mg/L)	Mg (mg/L)	Cr (mg/L)	Fe (mg/L)	Cd (mg/L)	Na (mg/L)
1	Chanishbay yakka quduq	105.25	n.d.	39.0	n.d.	0.26	n.d.	232.5
2	Kupet turar joy	24.45	n.d.	6.0	n.d.	n.d.	n.d.	500.0
3	Nissan uy oldi	34.4	n.d.	8.5	n.d.	n.d.	n.d.	427.5
4	Beknazar quduq	4.96	n.d.	1.65	n.d.	n.d.	n.d.	562.5

Potassium (K) concentrations, mg/L: site 1 — 16.6; site 2 — 4.74; site 3 — 5.0; site 4 — 3.62.

n.d. = not detected (below the instrumental detection limit).
According to the results, the average cation concentration follows the sequence: Na^+ (232.5–562.5 mg/L) > Ca^{2+} (4.96–105.25 mg/L) > Mg^{2+} (1.65–39.0 mg/L) > K^+ (3.62–16.6 mg/L). This sodium-dominant hydrochemical composition has also been reported in studies conducted in other desert and semi-desert regions [9,12], where elevated sodium concentrations are typically attributed to the dissolution of salt- and gypsum-rich geological strata combined with ion concentration under conditions of high evaporation. The distribution of cations across the sampling sites is shown in Figure 2.

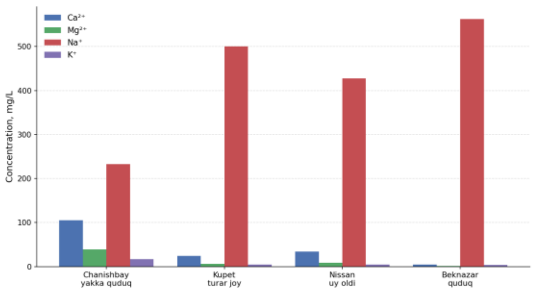

Figure 2. Ca^{2+}, Mg^{2+}, Na^+ and K^+ concentrations (mg/L) at the four sampling sites

Chanishbay yakka quduq (site 1) differs markedly from the other three sites, showing substantially higher Ca (105.25 mg/L) and Mg (39.0 mg/L) concentrations, as well as the only detectable Fe concentration (0.26 mg/L); this may reflect different geological–hydrological conditions or withdrawal from a different aquifer depth relative to the other three wells.

Notably, sodium concentration at this same site (232.5 mg/L) was considerably lower than at the remaining three sites (427.5–562.5 mg/L), indicating an inverse hydrochemical pattern (lower Na relative to elevated Ca–Mg).

Copper (Cu), chromium (Cr), and cadmium (Cd) were below the detection limit in all four samples, indicating the absence of detectable anthropogenic or geogenic contamination by these heavy metals in the surveyed area.

The obtained results were compared against WHO drinking-water quality guideline values (Table 3).

Table 3. Comparison of results with WHO guideline values

Parameter	Range in tested wells (mg/L)	WHO guideline value (mg/L)	Remark
Calcium (Ca)	4.96–105.25	No specific guideline (assessed via total hardness)	Highest value at site 1 (Chanishbay)
Magnesium (Mg)	1.65–39.0	No specific guideline (assessed via total hardness)	Site 1 notably higher than the rest
Sodium (Na)	232.5–562.5	≤ 200 (palatability; no formal health-based guideline)	Exceeded the WHO palatability threshold at all 4 sites [2,7,8]
Potassium (K)	3.62–16.6	No specific guideline established	All values low; no concern
Iron (Fe)	n.d.–0.26	≤ 0.3 (aesthetic guideline)	Detected only at site 1, below the guideline value [5]

Table 3 (continued). Heavy metals vs. WHO guideline values

Parameter	Range in tested wells (mg/L)	WHO guideline value (mg/L)	Remark
Copper (Cu)	not detected	≤ 2.0	Below detection limit at all sites [4]
Chromium (Cr)	not detected	≤ 0.05	Below detection limit at all sites [1,6]
Cadmium (Cd)	not detected	≤ 0.003	Below detection limit at all sites [1,3]

Ca, Mg, and Na concentrations were converted to meq/L, and the SAR value was calculated for each sampling site (Table 4).

Table 4. Sodium Adsorption Ratio (SAR) and irrigation-water hazard class

No.	Sampling site	Na (meq/L)	Ca (meq/L)	Mg (meq/L)	SAR
1	Chanishbay yakka quduq	10.11	5.26	3.21	4.9 — S1 (low)
2	Kupet turar joy	21.74	1.22	0.49	23.5 — S3 (high)
3	Nissan uy oldi	18.59	1.72	0.70	16.9 — S2 (medium)
4	Beknazar quduq	24.46	0.25	0.14	55.8 — S4 (very high)

The results show that only Chanishbay yakka quduq (site 1) falls within the low sodium hazard class (S1), where the comparatively higher Ca and Mg concentrations offset the adverse effect of sodium. The remaining three sites (2, 3, 4) correspond to medium, high, and very high sodium hazard classes, respectively [21,22]. These findings indicate considerable spatial variability in groundwater composition across the study area and highlight the importance of regular hydrochemical monitoring of well water quality — a matter of particular relevance for the long-term observation of wells that serve as principal water sources for wildlife within the national park.

IV. DISCUSSION

The most notable aspect of the results is that sodium concentrations at all four sites exceeded the WHO palatability threshold of 200 mg/L by a factor of 1.2–2.8 [2,7,8]. It should be emphasized that WHO documents do not establish a formal health-based guideline for sodium, since the relationship between sodium intake from drinking water and elevated blood pressure has not been fully established; the existing threshold is based solely on taste acceptability [7,8]. Nevertheless, recent research suggests that this threshold is not sufficiently strict relative to current medical evidence, and that considerably lower thresholds (20–60 mg/L) are recommended for population groups predisposed to cardiovascular disease [8]. From this perspective, if the tested wells are used as a permanent drinking-water source, this finding merits particular attention, especially for individuals predisposed to cardiovascular conditions.

Elevated sodium and overall mineralization in groundwater is a widespread phenomenon in desert and semi-desert regions, generally explained by: (a) transfer of salts from the soil–rock layer into groundwater under conditions of low precipitation and high evaporation; (b) dissolution of salt- and gypsum-rich geological strata (gypsum, halite); and (c) infiltration of drainage water generated by long-term irrigated agriculture into groundwater aquifers [16,17]. In naturally saline desert areas such as Kyzylkum, the first two factors are likely predominant, although confirming this would require additional hydrogeological and isotopic investigation.

The finding that heavy metals (Cu, Cr, Cd) were below the detection limit in all samples is encouraging, indicating no current heavy-metal contamination from industrial or agricultural sources in the area. This result is partly consistent with studies conducted in other protected areas (e.g., the Tisa River Basin protected area, Romania), where the principal heavy metals were likewise below permissible limits, although localized contamination by certain other elements (Al, Mn) was recorded [13]. Iron (Fe) was detected at only one site (0.26 mg/L), a value below the WHO aesthetic guideline of 0.3 mg/L and posing no health risk [5].

The calculated SAR values, particularly at Beknazar quduq (SAR = 55.8) and Kupet turar joy (SAR = 23.5), indicate a relatively high proportion of sodium ions at these sites. These indices characterize the hydrochemical properties of the well water and suggest that groundwater composition in the study area has been shaped by natural geochemical processes [21,22]. The wells examined in this study are used primarily to provide artificial watering points for wildlife of the Central Kyzylkum National Nature Park, including the goitered gazelle (Gazella subgutturosa), the kulan (Equus hemionus), and other wild species. Consequently, water-quality assessment in this context should focus primarily on regular monitoring of ecological suitability for wildlife. Future studies incorporating total dissolved solids (TDS), electrical conductivity (EC), and other hydrochemical parameters would allow a more reliable characterization of well-water quality.

In the setting of a national nature park, the quality of well water is important not only for the local population but also for the wildlife inhabiting the park — including ungulates, rodents, and birds — which frequently rely on these same natural and artificial water sources. The long-term availability of highly saline water sources may lead animals to selectively favor certain species (e.g., salt-tolerant species) for drinking, although confirming this hypothesis would require dedicated ecological–physiological research.

Study Limitations. This study is preliminary in nature, and several methodological limitations should be considered when interpreting and generalizing the results:

- Absence of seasonal monitoring. Water samples were collected on a single date — 30 April 2026. Consequently, hydrochemical variability associated with the intensive summer evaporation period or low winter temperatures is not captured in this study, and the results are representative only of the sampling date.
- Small sample size. The number of sampling points (n = 4) is insufficient for statistical inference, for reliably assessing inter-site differences, or for broad regional generalization.
- Limited set of parameters. Only major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and a small subset of regulated trace elements (Cu, Cr, Fe, Cd) were measured. pH, electrical conductivity (EC), total dissolved solids (TDS), and the major anions (HCO_3^{-}, SO_4^{2-}, Cl^{-}) were not measured in this study, yet they are needed to more fully characterize water type (e.g., via a Piper diagram) and the salinization mechanism [9,12,15].
- Geographic coverage. The four wells represent only a portion of the Central Kyzylkum National Nature Park; extrapolation of the results to the entire park territory should therefore be made with caution.

Recommendations for Future Research. To address the limitations outlined above, the following measures are recommended for future studies in the Central Kyzylkum National Nature Park:

- Establish a seasonal monitoring program spanning at least one year, with quarterly sampling (spring, summer, autumn, winter), in accordance with ISO 5667-3 and APHA (2017) standards;
- Expand the sampling network by incorporating additional wells and sources across the various geomorphological zones of the park (sand dunes, saline depressions, gypsum plateaus), thereby increasing the number of sampling points;
- Measure pH, electrical conductivity (EC), and total dissolved solids (TDS) directly in situ at the wellhead, and determine the major anions in the laboratory (HCO_3^{-}, CO_3^{2-} by titrimetry; SO_4^{2-}, Cl^{-} by ion chromatography);
- Use the expanded cation–anion dataset to construct a Piper diagram and apply integrated assessment approaches such as a Water Quality Index (WQI) to more precisely characterize water type and the salinization mechanism;
- Ensure an adequate sample size (at least n = 10–12) to enable calculation of the electroneutrality balance error for

quality control of each sample and to permit appropriate statistical analysis.

V. CONCLUSION

Analysis of the chemical composition of water from four wells surrounding the Central Kyzylkum State National Nature Park led to the following conclusions:

- In all samples examined, the heavy metals copper, chromium, and cadmium were below the detection limit, indicating that, in this respect, water quality fully meets WHO requirements;
- At all four sites, sodium concentration (232.5–562.5 mg/L) exceeded the WHO-recommended palatability threshold of 200 mg/L, which is presumed to be related to the natural salinization of groundwater in the region;
- Chanishbay yakka quduq exhibited a hydrochemical composition distinct from the other three sites (higher Ca, Mg, and Fe, and comparatively lower Na), suggesting recharge from a different aquifer;
- According to the calculated SAR values, only site 1 falls within the low sodium hazard class (S1), whereas the remaining three sampling sites fall within the medium-to-very-high sodium hazard classes (S2–S4). These results demonstrate considerable spatial variability in the hydrochemical properties of well water and highlight the importance of ongoing monitoring of water sources used to provide artificial watering points for wildlife in the Central Kyzylkum National Nature Park;
- The results obtained are preliminary in nature; a complete assessment of regional groundwater quality will require an increased number of sampling points, the inclusion of additional physicochemical parameters (pH, EC, TDS, major anions), and the establishment of seasonal monitoring.

Acknowledgements
The authors thank the staff of the analytical laboratory that carried out the water-sample analyses (Head of Workshop No. 081, D.R. Yarkulova; chemist R.I. Khakimova; laboratory assistants S.A. Haqberdiyeva and E.Z. Hamitova) for the data provided.

REFERENCES

1. World Health Organization. Guidelines for Drinking-water Quality, 4th edition. Geneva: WHO, 2011.
2. World Health Organization. Sodium in Drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality (WHO/SDE/WSH/03.04/15). Geneva: WHO, 2003.
3. World Health Organization. Cadmium in Drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality. Geneva: WHO, 2011.
4. World Health Organization. Copper in Drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality (WHO/SDE/WSH/03.04/88). Geneva: WHO, 2004.
5. World Health Organization. Iron in Drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality (WHO/SDE/WSH/03.04/08). Geneva: WHO, 2003.
6. World Health Organization. Chromium in Drinking-water: Background document for development of WHO Guidelines for Drinking-water Quality (WHO/SDE/WSH/03.04/04). Geneva: WHO, 2003.
7. World Health Organization. Acceptability aspects: Taste, odour and appearance. In: Guidelines for Drinking-water Quality. Geneva: WHO Press (NCBI Bookshelf), 2017.
8. Dupraz, W. et al. Global Drinking Water Standards Lack Clear Health-Based Limits for Sodium. Nutrients, 2025, 17(13), 2190. https://doi.org/10.3390/nu17132190
9. Ahada, C.P.S., Suthar, S. Use of Heavy Metal Content and Modified Water Quality Index to Assess Groundwater Quality in a Semiarid Area. Water, 2020, 12(4), 1115. https://doi.org/10.3390/w12041115
10. Islam, M.A. et al. Assessment of health risk of heavy metals and water quality indices for irrigation and drinking suitability of waters: a case study of Jamalpur Sadar area, Bangladesh. Groundwater for Sustainable Development, 2020.
11. Ahmad, W. et al. Risk Analysis of Heavy Metals and Groundwater Quality Indices in Residential Areas: A Case Study in the Rajanpur District, Pakistan. Water, 2022, 14(21), 3551. https://doi.org/10.3390/w14213551
12. Barzegar, R. et al. Quality modeling of drinking groundwater using GIS in rural communities, northwest of Iran. International Journal of Environmental Health Engineering, 2013.
13. Roba, N.T. et al. Quality and Health Risk Assessment of Groundwaters in the Protected Area of Tisa River Basin. International Journal of Environmental Research and Public Health, 2022, 19(22).
14. Basheer, A.O. et al. Hydro-geochemical assessment of the Nubian sandstone aquifer system for sustainable use in the western desert, Egypt. Discover Geoscience, 2025.
15. Kumar, M. et al. GIS-based evaluation of groundwater geochemistry and statistical determination of the fate of contaminants in shallow aquifers from different functional

areas of Agra city, India: levels and spatial distributions. Environmental Monitoring and Assessment, 2022.
16. Groundwater resources of Uzbekistan: An environmental and operational overview. Central Asian Waters Research Report, ResearchGate, 2012.
17. Rasulov, A. et al. Water quality and dissolved load in the Chirchik and Akhangaran river basins (Uzbekistan, Central Asia). Applied Geochemistry / PMC, 2024.
18. Asian Development Bank. Western Uzbekistan Water Supply System Development, Report and Recommendation of the President (RRP UZB 50259). Manila: ADB, 2019.
19. Kyzylkum State Nature Reserve: geographic and ecological characterization. Centralasia Adventures / Peopletravel reference materials, 2021–2024.
20. Adeyemi, A.O. et al. Evaluation of surface water quality indices and ecological risk assessment for heavy metals in scrap yard neighbourhood. SN Applied Sciences / PMC, 2016.
21. Richards, L.A. (Ed.) Diagnosis and Improvement of Saline and Alkali Soils. USDA Agriculture Handbook No. 60. Washington, DC: United States Department of Agriculture, 1954.
22. Ayers, R.S., Westcot, D.W. Water Quality for Agriculture. FAO Irrigation and Drainage Paper No. 29, Rev. 1. Rome: Food and Agriculture Organization of the United Nations, 1985.
23. Australian and New Zealand Environment and Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ). Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Chapter 4.3: Livestock Drinking Water Quality. Canberra, 2000.
24. Ebrahimi, M. et al. Effects of Salinity Levels of Drinking Water on Water Intake and Loss, Feed Utilization, Body Weight, Thermoregulatory Traits, and Blood Constituents in Growing and Mature Blackhead Ogaden Sheep and Somali Goats. Animals, 2024.
25. APHA, AWWA, WEF. Standard Methods for the Examination of Water and Wastewater, 23rd edition, Section 3030 (Sample Preservation and Storage) and Section 3111 (Metals by Flame Atomic Absorption Spectrometry). Washington, DC: American Public Health Association, 2017.