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Evaluation of drinking water using the water quality index in Middle of Iraq

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ABSTRACT: The aim of the study was to assess the quality of drinking water in Hillah city by analyzing water (river water, tap water, and reverse osmosis water) using the Water Quality Index (WQI) according to Iraqi and international standards. Over the course of six months, from September 2024 to February 2025, 72 water samples were taken, 24 from rivers, 24 from taps, and 24 from RO plants. Using instruments like atomic absorption spectrometry, pH, conductivity, turbidity, hardness, and other tests, the physical and chemical characteristics and heavy metals were assessed. Statistical analysis To identify statistical differences, ANOVA and LSD were employed. The river water's WQI = 230 designation as "Very poor water" (unfit for human consumption) was one of the most noteworthy findings and values. EC = 1226 µS/cm (maximum allowable limit: 750) is the cause of this. Turbidity = 10.4 NTU (limit: 5), TDS = 715 mg/L (limit: 200). TH = 439 mg/L (200 as the limit). Cd = 0.106 mg/L (0.01) is the limit. Limit: 0.02, Ni = 0.092 mg/L. Pb = 0.081 mg/L (0.01 as a limit).). This suggests that there is a health concern (kidney, neurological, and cardiac issues) due to the water's higher than average levels of salts and heavy metals. WQI = 153 indicates that the tap water is "poor water" and needs further treatment. This is because of: EC is 1223 µS/cm. 714 mg/L is the TDS. NTU = 10.175 for turbidity. TH is equal to 440 mg/L. Cd is 0.0862 mg/L. Pb = 0.0538 mg/L. Sedimentation, inadequate initial treatment, and possible contamination from aged infrastructure are all present. WQI = 80 for reverse osmosis (RO) water, indicating "Good Water" status. EC is equal to 62.55 µS/cm. 355 mg/L is the TDS. 1.6 NTU is the turbidity. Pb = 0.03 mg/L, Cd = 0.03 mg/L, and TH = 44.9 mg/L. Generally of fair quality, although comparatively high lead and cadmium contents necessitate cautious further treatment. We come to the conclusion that tap and river water are currently unsafe to drink.RO water is preferable, but it needs improvements regarding heavy metals.The need to develop treatment plants and modernize infrastructure.Strictly implement WHO standards and improve screening and treatment procedures.

Keywords: water qualityindex ,heavy meatal, chemical and phesical properties.

1. INTRODUCTION: The most precious resource that the natural world offers to us is water. It is essential to all human endeavors, including trade, industry, agriculture, energy production, and daily drinking, and it is the most crucial component of our existence for the maintenance of life[1]. However, increasing human activity has made many large rivers' water quality poorer. Water quality is affected by a wide range of human and natural factors. Because they have an impact on the amount and quality of water available, geological, hydrological, and climatic factors are the most significant natural effects. As a result, even in cases when there is an adequate supply of water, its low quality restricts the uses that may be made of it. Although the natural ecosystem is sensitive to the quality of fresh water, significant changes in that quality will usually cause the ecosystem to become disrupted[2]. There is an index that is environmentally justifiable and gives a relative number in relation to the minimal acceptable level for various substances. As a result, the Water Pollution Index (WPI) has been proposed, which is easier to understand, widely utilized for all water-related reasons, and simple to use for water pollution prevention and management, as well as recommendations values for certain chemicals[3]. Although it is a significantly altered version of the original, the Water Quality Index (WQI) is used globally. Some crucial factors, such heavy metals and PHYSICAL AND CHEMICAL PROPERTES, are not considered by WQI. WQI is a technique for condensing vast volumes of data on water quality into easily understood sentences for consistent reporting to the public and management. Additionally, WQI makes it possible to compare several rivers. This index makes it possible to evaluate water quality broadly over a variety of values that affect a stream's capacity to sustain life[4]. Scientists have characterized WQI as one of the most effective tools for informing relevant individuals and policymakers about water quality. It developed as an essential metric for surface water assessment and management. The WQI concept was based on comparing a water quality measure to relevant regulatory criteria and using a variety of water quality parameters to get a single value that represented the overall water quality at a given location[5]. (WQI) was used to examine the water quality of the Tigris River. The results of the index showed that the Tigris River had the lowest water quality, ranging from 37 to 42, as a result of the effect of several urban polluting sources[6]. WQI fell in the third (Fair) and fourth (Marginal) categories at every research station[7]. The study found that the dry season had the lowest water quality values for all three of the river's uses. The decline in Shatt al-Arab water quality has been attributed to a combination of factors, including low annual precipitation, an encroaching salt wedge from the Arabian Gulf, and decreased freshwater discharges from the Tigris and Euphrates[8]. The Al-Gharraf River's water quality was evaluated using CCME-WQI. Due to various pollutants entering the river, untreated domestic sewage discharge, and runoff water from nearby agricultural areas, the index had a low value, suggesting that the river's water quality was poor[9]

2. Materials and Methods

2.1. Materials :- Flawautomic absorption spectrophotometer, tube plastic, sample water. :- PH Meter ,Burette, Sensitive Electronic Balance,Na2-EDTA ,turbidity Measuring Device, Thermometer Measuring Device ,EC/TDS/NaCl meter Type Hanna, ammonia solution.

2.2. Methods work:-experimental research was created to compare the water quality in Hillah city in order to accomplish the study's goal. Water samples were collected from several stations and sites spread out over the city. twenty-four river water samples, twenty-four tap water samples, and twenty-four reverse osmosis water samples were collected. Over the course of six months, the samples were gathered from various sites. After being put insterile plastic containers, they were brought to the lab and examined immediately.

2.3. Sampie collected

Samples were collected over three seasons, two months each: summer (September to October 2024), autumn (November to December 2024), and winter (January to February 2025)

*Water samples were collected at a depth of 35-40 cm below the water surface for chemical, physical, biological, and heavy metal tests using 5-liter polyethylene containers. They were then washed with dilute hydrochloric acid (10%) and rinsed with distilled water.

2.4. heavy meatal using a Flawautomic Absorption Spectrophotometer in measure the heavy meatal such as Cd,Co,Ni,Zn,pd.

2.5. PH: The pH was measured using a device PH meter type Lovibond PH 200 after calibrating it with standard buffer solutions PH (9,7,4) before starting work.

2.6. Electrical Conductivity (E C) & Total Dissolved Solid (TDS): They were measured using a type of device HANNA H19032 after calibrating it with standard solutions, and the electrical conductivity was expressed in micro siemens/cm, while the total dissolved salts were expressed in g/liter**.**

2.7. Total Hardness: By titrating 50 milliliters of diluted material with EDTA2 Na solution in the presence of a regulator ammonia solution with index (Erichromic black T), total hardness was determined. The results were represented in milligrams per liter or grams per liter .

A×1000 / V ml of sample equals total hardness (mg/l)

Where: the EDTA solution is A

2.8. Turbidity: Turbidity was measured by using the turbidity meter model(Lamotte 2020), after calibration with standard (0,10 ,100) regulated solutions, and the results were expressed in NTU units .

2.9. Water quality index

The water quality index calculation is determined using these equations: Overall

$$\mathbf{WQI}=\frac{\sum wi\times qi}{\sum wi}$$

Where:

Qi = quality rating

$$Qi = (vi \setminus si) \times 100$$

Where:

Vi = observed value

Wi = unit weight

$$Wi = k \setminus si$$

Where: k = constant of proportionality **= 1(1\ ∑ wi)**,Si = standard value

2.10. Statistical Analysis

Analysis of variance (ANOVA) and the least significant difference test (LSD) were used to analyze the results statistically, and the correlation coefficient (r) was adopted to find relationships between physical and chemical properties and heavy metal concentrations (SAS.,2010).

3. Results and discussion

3.1. Electrical conductivity:- The Table (1) shows the electrical conductivity values for different stations during a six-month period from September to February, with the average values and standard deviation for each station, Note that the first four samples (s1, s2, s3, s4) are river water, the other four samples (s5, s6, s7, s8) are tap water, and the last four samples (s9, s10, s11, s12) are RO water. The Tabel (1) show With an average electrical conductivity of 1221 ± 1229 micro/cm, demonstrates that the water of the Euphrates River in Hillah has a high concentration of dissolved salts and metals as a result of surface runoff, industrial and agricultural processes, and maybe sewage pollution. Wintertime sees a minor rise in monthly variability, which is indicative of greater salt concentrations brought on by less water flow. The average values for river water and tap water are very comparable. A considerable amount of dissolved salts and metals are still present despite the first treatment's minor reduction in mineral concentrations. The monthly fluctuations are somewhat smaller than those of river water, indicating some source control. The typical readings for reverse osmosis water range from 37 to 88, which is quite low. This illustrates how effectively salts and contaminants are eliminated by the reverse osmosis process. Month-to-month differences are minimal, suggesting that the treatment process is stable and that there are no seasonal fluctuations in flow. Because of their increased salt content, which can lead to environmental issues such salt buildup in the soil, we conclude that tap and river water are less appropriate for residential or agricultural applications. The efficiency of the treatment technology is demonstrated by the fact that reverse osmosis water is better suited for industrial and medicinal applications. In comparison to reverse osmosis water, the standard deviation shows more variability in tap and river water. These variations show how environmental conditions affect natural resources. Scientific credibility is increased by the reduced standard deviation values in reverse osmosis water, which show uniformity in the results. The LSD values (4.202, 14.617, and 5.867) indicate that there are statistically significant variations between different water sources, especially between river water and water produced by RO systems. Additionally, we see that conductivity fluctuates with the seasons, increasing in the winter as a result of decreased water flow, which concentrates salts in the water which compatibl with results of [11].

Table (1) Electrical conductivity

Station	September	October	November	December	January	February	mean± SD
S1	1034	1156	1265	1292	1369	1263	1229.83±117.7
S2	1053	1131	1255	1279	1390	1247	1225.83±118.2

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S3	1039	1145	1249	1285	1360	1299	1229.50±117.2
S4	1044	1128	1247	1271	1340	1297	1221.17±112.3
S5	1060	1102	1246	1273	1340	1295	1219.33±112.2
S6	1068	1126	1255	1281	1350	1297	1229.50±108.7
S7	1034	1133	1268	1284	1355	1275	1224.83±118.04
S8	1045	1140	1248	1275	1333	1285	1221.00±107.3
S9	27	15	25.77	24.7	23.25	106.9	37.10±34.4
S10	66.5	83	90.8	140.1	85.6	67.4	88.90±26.9
S11	59.5	55	70.2	103.1	81.5	22.5	65.30±27.1
S12	59.1	51	60.2	59.1	69	55.2	58.93±5.99
mean± SD	715.76± 489.3	772.08 ± 532.9	856.66± 587.2	880.58± 590.5	924.70 ± 635.3	875.83 ± 600.7	837.60±77.9
LSD	**4.220**						**5.967**
LSD interaction	**14.617**						

3.2. Total Dissolved Solids (TDS):-Table (2) shows the T.D.C values for different stations during a six-month period from September to February, with the average values and standard deviation for each station, Note that the first four samples (s1, s2, s3, s4) are river water, the other four samples (s5, s6, s7, s8) are tap water, and the last four samples (s9, s10, s11, s12) are RO water . Table (2), The water from the Euphrates River near Hillah (S1-S4) has high TDC values, ranging from 620 to 806 micro/cm, with an average of around 717 ± 64.3 micro/cm. This suggests a high level of dissolved metals and salts, which are caused by surface runoff and pollution from agriculture and industry. Because of the decreased water flow and elevated salt concentration during the winter months of January and February, it gradually increases. The typical readings for tap water (S5-S8) are between 629 and 783 micro/cm, with an average of around 714 ± 63.4 micro/cm. This is an example of primary treatment, which lowers the concentration of salt while retaining a sizable amount of dissolved metals. Tap water has more constancy in monthly readings than river water. The readings for reverse osmosis water (S9-S12) are extremely low, averaging around 236.88 ± 523 micro/cm and ranging from 9 to 1304 micro/cm. Low numbers indicate how well reverse osmosis systems remove contaminants and salts. Significant differences: Significant differences in readings are seen, particularly at station S9, which could point to issues with the treatment process' stability. Reverse osmosis water's standard deviation (SD), which reflects instability at certain locations, varies significantly (236.88 ± 523 micro/cm)... Conversely, there is comparatively less fluctuation in beach and dam water. Least significant difference (LSD): High values highlight the significance of treatment optimization by indicating substantial differences between sources. Elevated TDC levels in tap and river water can cause environmental issues such soil salt buildup, which impacts farming. Reverse osmosis water needs more stability, but its lower values make it appropriate for industrial and medicinal applications which compatibl with results of [12] .

Table(2) Total Dissolved Solids

Station	September	October	November	December	January	February	mean± SD
S1	620	660	734	749	794	745	717±64.3
S2	631.8	645	736	742	806	735	715.97±65.8
S3	623.4	654	724	746	788	766	716.90±64.9
S4	626.4	644	723	737	777	765	712.07±62.5
S5	636	629	722	738	775	764	710.67±63.4
S6	640.8	643	737	743	783	765	718.63±61.6
S7	620.4	647	735	745	786	752	714.23±65.2
S8	627	651	734	740	773	758	713.83±60
S9	16.3	9	15	14	1304	63	236.88±523
S10	40	47	52	81	50	40	51.67±15.2
S11	36	22	41	60	47.3	13	36.55±17.04
S12	35.5	20	35	34	40	33	32.92±6.77

mean± SD	429.5± 293.6	439.3± 306.3	499±342.2	510.8± 342.6	643.6± 389.6	516.6± 354.2	506.44±76.2
LSD	**28.05**						**39.67**
LSD interaction	**97.18**						

3.3. Turbidity:- The Table (3) shows the turbidity values for different stations during a six-month period from September to February, with the average values and standard deviation for each station, Note that the first four samples (s1, s2, s3, s4) are river water, the other four samples (s5, s6, s7, s8) are tap water, and the last four samples (s9, s10, s11, s12) are RO water. Table (4) shows the pH values for different stations during a six-month period from September to February, with the average values and standard deviation for each station, Note that the first four samples (s1, s2, s3, s4) are river water, the other four samples (s5, s6, s7, s8) are tap water, and the last four samples (s9, s10, s11, s12) are RO water. Table (3)The turbidity investigation of the Euphrates River water sources in Hillah (S1 to S4) reveals notable fluctuation throughout months, according to the data displayed in the table. In contrast to cooler months like February, higher turbidity levels were recorded during the fall months of September and October. Turbidity at station S2, for instance, peaked in September at 25.8, then dropped sharply to 1.38 in February. Increased runoff and sediment transfer from nearby regions may be the cause of the high turbidity in the fall, but decreased water flow and less human activities may be the cause of the wintertime decline. The results of the tap water turbidity study (S5 to S8) were wildly inconsistent. Significant variations between stations were shown by the data. Station S5, for instance, had extremely high turbidity in September (31), but it dramatically dropped in October (0.83), suggesting a possible flaw or uneven treatment effectiveness. Additionally, we discovered that stations like S6 and S8 had high turbidity in some months (22.7 for S6 in November), which could be a sign of the treatment system's continued inefficiency . Analysis of reverse osmosis water's turbidity (S9 to S12): comparatively low levels of turbidity. Turbidity in reverse osmosis (RO) facilities was generally relatively low during this time. The efficacy of the purification technologies in these facilities was demonstrated by the fact that the highest value, 5.73, was recorded in S9 during September, while the remaining values were significantly lower. When compared to other sources, we see relative stability; this kind of treatment shows more control and stability in lowering turbidity. . As a result, we compare river water to tap water and reverse osmosis, finding that river water is more variable and turbid due to both natural and man-made variables. Reverse osmosis water, on the other hand, is more effective at lowering turbidity, which increases its stability. Seasons, sources, and the effectiveness of the employed treatment systems all had an impact on turbidity, underscoring the necessity of better process monitoring and treatment technology selection. Small statistically significant changes are shown by low LSD values (0.120), which suggests that variations across stations or months may be statistically significant. Significant variability is demonstrated by certain stations' high standard deviations (e.g., S6: 12.06) which compatibl with results of [12] .

Table (3) Turbidity

Station	September	October	November	December	January	February	Mean± SD
S1	3.65	3.56	8.59	5.52	4.63	0.15	4.35±2.76
S2	25.8	11.2	21	8.74	8.93	1.38	12.84±8.95
S3	14.5	21.6	14.3	6.98	11.2	1.86	11.74±6.81
S4	9.17	19.5	18.8	14.2	10.53	1.49	12.28±6.74
S5	31	0.83	1.86	1.13	2.19	3.35	6.73±11.9
S6	30.7	11.2	22.7	0.55	4.2	3.55	12.15±12.06
S7	5.46	16.6	29.5	4.23	5.87	2.42	10.68±10.4
S8	24.3	11	19.1	4.67	4.49	3.27	11.14±8.77
S9	1.17	5.73	0.61	1.03	2.72	0.45	1.95±2.01
S10	1.68	0	0.82	0.07	5.1	0.4	1.35±1.93
S11	0.15	1.44	3.41	2.17	2.7	0.43	1.72±1.28
S12	4.05	0.7	1.78	1.02	2.43	0.08	1.68±1.42
mean± SD	12.63±12.06	8.61±7.70	11.87±10.2	4.19±4.2	5.41± 3.15	1.56± 1.31	7.38±4.40
LSD	**0.120**						**0.170**
LSD interaction	**0.418**						

3.4. PH:-Table (4) shows the pH values for different stations during a six-month period from September to February, with the average values and standard deviation for each station, Note that the first four samples (s1, s2, s3, s4) are river water, the other four samples (s5, s6, s7, s8) are tap water, and the last four samples (s9, s10, s11, s12) are RO water. Table(4) shows the pH results for samples of river water (S1 to S4). Throughout the measurement sites, the average pH values vary from 6.86±1.19 to 7.37±0.28. Seasonal fluctuations or environmental factors like industrial pollution or agricultural silt runoff may be the cause of this value variance. A low score, as 4.45 in November at Station S1, implies seasonal changes and environmental factors, whilst values near 7 are regarded as very acceptable and imply a neutral character. Stable treatment efforts at these stations are indicated by the very close values for tap water (S5 to S8), which range from 7.27±0.27 to 7.33±0.22. Although this stability shows how well the pH management system works, it might be enhanced to better meet global requirements. Results for reverse osmosis water (S9 to S12) The highest average pH in this group, reaching 7.46±0.38, is found at station S10. These values demonstrate the effectiveness of reverse osmosis (RO) technology in achieving pH balance, although they are very close to the normal range. The slightly higher values indicate that the RO system may be removing some acidic ions, making the water more balanced. Monthly variations show fluctuations in pH values between months (e.g., 4.45 in November and 8 in December for different stations), indicating the importance of monitoring seasonal conditions such as low rainfall and high temperatures. International standards suggest values between 6.5 and 8.5 as a safe limit. Therefore, most samples fall within this range, with the exception of a few anomalies such as 4.45 in November. RO systems demonstrate a relative superiority over river and tap water in achieving pH stability, highlighting the importance of this technology in improving water quality . As a result, except from a few outliers like 4.45 in November, the majority of samples fall inside this range. When it comes to attaining pH stability, RO systems outperform tap and river water, underscoring the significance of this technology in enhancing water quality) which compatibl with results of [13].

Table (4) PH

Station	September	October	November	December	January	February	Mean± SD
S1	7.56	7.19	4.45	7.45	7.5	7	6.86±1.19
S2	7.6	7.24	7.15	7.75	7.01	7.08	7.31±0.30
S3	7.6	7.28	7.4	7.78	7.07	7.06	7.37±0.28
S4	7.61	7.21	7.31	7.77	7.05	7.02	7.33±0.30
S5	7.52	7.43	7.37	7.25	7.2	7.03	7.30±0.17
S6	7.51	7.31	7.05	7.59	7.15	7.01	7.27±0.27
S7	7.53	7.3	7.35	7.61	7.16	7.03	7.33±0.21

S8	7.55	7.27	7.3	7.65	7.15	7.08	7.33±0.22
S9	7.21	7.15	7.4	7.92	7.7	7.15	7.42±0.32
S10	7.23	7.2	7.78	8	7.55	7.01	7.46±0.38
S11	7.22	7.19	7.05	7.69	7.5	7.01	7.28±0.26
S12	7.22	7.19	7.17	7.97	7.64	7.02	7.37±0.36
mean± SD	7.45±0.17	7.25±0.07	7.07±0.84	7.70±0.21	7.31±0.25	7.04±0.04	7.30±0.24
LSD	**0.032**						**0.045**
LSD interaction	**0.112**						

3.5. Total Hardness (TH) :-Table (5) shows the values for Total Hardness different stations during a six-month period from September to February, with the average values and standard deviation for each station, Note that the first four samples (s1, s2, s3, s4) are river water, the other four samples (s5, s6, s7, s8) are tap water, and the last four samples (s9, s10, s11, s12) are RO water. Table (5) demonstrates how water samples' overall hardness differs depending on the source. According to the data, the overall hardness of the river samples (S1–S4) was much higher than international requirements, frequently surpassing 400 mg/L. This suggests that minerals like calcium and magnesium are present in large concentrations. As in S1 and S2, there was a discernible variation from month to month, which might be due to environmental or seasonal variations. The findings of tap water (S5-S8) samples revealed a total hardness that was comparable to those of the Euphrates River samples in Hillah. This might suggest that the tap water supply in Hillah depends on Euphrates River water that has undergone minimal treatment The effectiveness of reverse osmosis technology in eliminating heavy metals was confirmed by the extremely low total hardness readings (less than 100 mg/L) for all samples of reverse osmosis water (S9–S12). There were noticeable monthly differences in total hardness (TH) across the various sources. The impact of environmental factors like temperature and water flow is shown in monthly numbers. December and January had higher readings, which might have been brought on by decreased water flow or higher metal concentrations from evaporation Mean and Standard Deviation: A general trend in the concentration of total hardness is reflected in the mean for each source. For instance, S1 has a greater mean (453.5 mg/L) than the other sources, indicating a high metal content. Significant changes in the standard deviation, particularly in river water (e.g., S2 at 104 mg/L), indicate that the quality of the water varies from month to month. Reverse osmosis water tests reveal a considerable difference between treated and untreated water, although Shatt al-Hillah and tap water samples show identical values. The World Health Organization (WHO) states that in order to prevent health hazards, drinking water should have a total hardness of less than 300 mg/LTap water and samples from the Euphrates River in Hillah significantly surpass this threshold, rendering the water unfit for human consumption which compatibl with [14]

Total Hardness table(5)

Station	September	October	November	December	January	February	Mean±SD
S1	400	368	484	501	520	448	453.5±59.3
S2	280	340	432	495	569	440	426.0±104
S3	435	353	422	497	472	488	444.5±53.6
S4	354	350	420	482	560	448	435.7±80.1
S5	339	340	480	485	472	388	417.3±69.9
S6	325	360	489	492	489	488	440.5±76.2
S7	467	364	490	493	500	520	472.3±55.7
S8	361	366	430	489	481	448	429.2±55.2
S9	8	12	19	21	32	98	31.7±33.5
S10	32	50	57	66	72	81	59.7±17.3
S11	25	41	46	54	60	31	42.8±13.3
S12	20	40	43	41	52	78	45.7±19
mean± SD	253.83± 178.5	248.67 ± 157.7	317.67± 205.9	343± 220	356.58 ± 225.7	329.67± 193.5	308.2±46
LSD	**0.461**						**0.652**

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LSD interaction	**1.598**

3.6. cadmium

Table (6) shows the concentration of cadmium in water samples from different sources over a period of six months. The first four groups are Shatt water (1, 2, 3, 4), the second four groups are tap water (5, 6, 7, 8), and the last four groups are RO water (9, 10, 11, 12) as shown in the diagram (1-2).Over a six-month period (September2024 to February 2025), the table show the concentration of cadmium in water samples from various sources, including three groups: river water (S1-S4), tap water (S5-S8), and reverse osmosis (RO) desalination plant water (S9-S1). Cadmium concentrations in river water samples (S1–S4) varied significantly from month to month, with comparatively high values in November and December, especially in sample S3, which had a November reading of 0.309 micro/L. October and January had notable drops in cadmium content, with certain values being close to zero (S3 in January was 0.0006 micro/L), indicating the possible existence of mitigating factors such high water levels or natural precipitation. This group's total average concentration was around 0.105±0.09 micro/L, showing considerable fluctuation that might be attributed to environmental variables such surface runoff and human activity close to water sources as well as seasonal variations.In comparison to river water, tap water (S5–S8) exhibited intermediate concentration levels, with values ranging from 0.001 to 0.250 micro/L. The highest concentration was reported in S7 in December (0.250 mg/L). During October and January, when values were nearly zero, there was a discernible drop in the content of cadmium, suggesting that treatment procedures had a part in lowering the element's concentration at certain times. When compared to surface water, the total average for tap water was 0.091±0.06 micro/L, which indicates a partial effectiveness in lowering the cadmium content, although it is still greater than several international quality criteria.Reverse osmosis water (S9–S12) had the lowest cadmium amounts of any group, as predicted, with levels often falling below 0.132 micro/L. Certain samples (such S10 and S11 in the initial months) had nearly negligible amounts, which increased the efficiency of RO technology in eliminating heavy metals. In comparison to tap and river water, the total mean was 0.043±0.05 micro/L, demonstrating the effectiveness of reverse osmosis technology in enhancing water quality and dramatically lowering cadmium levels.Statistical Differences Observations of notable variances across months and sources are supported by the LSD value (0.00052), which shows substantial differences between time periods and stations. According to the monthly average, January had the lowest concentration (0.021±0.04 micro/L) and February the highest (0.128±0.01 micro/L). Low temperatures and other seasonal climate factors may have an impact on the element's solubility and environmental movement. The World Health Organization (WHO) states that 0.003 micro/L of cadmium is the most amount that may be present in drinking water. Accordingly, all values found in untreated water (river and tap water) are higher than what is considered acceptable, highlighting the necessity of further treatment technologies and improvement measures to guarantee public health and safety which compatibl with[15].

Table (6) concentration cadmium in water

Station	September	October	November	December	January	February	mean± SD
S1	0.151	0.014	0.191	0.1373	0.1397	0.1190	0.125±0.06
S2	0.147	0.001	0.206	0.1961	0.0147	0.1338	0.116±0.08
S3	0.001	0.001	0.309	0.1618	0.0006	0.1568	0.105±0.09
S4	0.044	0.0012	0.132	0.1422	0.0098	0.1387	0.078±0.06
S5	0.176	0.001	0.176	0.1176	0.0015	0.1269	0.099±0.08
S6	0.088	0.0011	0.001	0.1397	0.0001	0.1308	0.060±0.04
S7	0.143	0.014	0.015	0.2500	0.0029	0.1263	0.091±0.06
S8	0.161	0.015	0.044	0.1618	0.0637	0.1266	0.095±0.06
S9	0.132	0.0017	0.002	0.0147	0.0002	0.1084	0.043±0.05
S10	0.001	0.029	0.001	0.0551	0.0110	0.1275	0.037±0.04
S11	0.001	0.0012	0.001	0.0015	0.0034	0.1205	0.021±0.05
S12	0.102	0.0013	0.015	0.0539	0.0048	0.1211	0.049±0.05
mean± SD	0.095±0.06	0.006±0.009	0.091±0.106	0.119±0.07	0.021± 0.04	0.128± 0.01	0.077± 0.033
LSD	**0.00052**						**0.0074**
LSD interaction	**0.0018**						

3.7. cobalt

Table (7) shows the concentration of cobalt in water samples from different sources over a period of six months. The first four groups are Shatt water (1, 2, 3, 4), the second four groups are tap water (5, 6, 7, 8), and the last four groups are RO water (9, 10, 11, 12) as shown in the diagram(7).

Cobalt concentrations in river water (S1–S4) varied; the greatest concentration was found in September, especially in S2 (0.009 micro /L), and levels fell precipitously over the next few months. Between October and February, values were nearly negligible (0.0001 micro /L), which may have been caused by seasonal hydrodynamic impacts in river water as well as natural processes like sedimentation or adsorption onto sediments. This group's total mean was 0.00118±0.002 micro /L, which suggests a slow drop brought on by chemical interactions and environmental variables.Compared to river water, tapping water (S5–S8) had lower amounts, ranging from 0.001-0.005 micro /L in September to nearly nil levels thereafter.The data demonstrates a steady decrease in the months that follow, demonstrating how well treatment procedures remove cobalt. The global average for tap water was 0.00054±0.001 mg/L, which illustrates how filtering and chemical treatment procedures may lower this element's content. The lowest cobalt content was found in RO Water (S9–S12), with some samples showing 0.005 mg/L in September but dropping to 0.0001 micro /L in the months that followed.With the lowest overall mean of 0.00052±0.0008 micro /L when compared to other sources, the statistics show how successful reverse osmosis (RO) technology is in removing cobalt. Significant variations across samples are shown by LSD analysis (0.00044 micro /L), which supports the idea that treatment procedures and environmental variables can alter cobalt content.The impact of seasonal variations on the element's movement throughout the water system is demonstrated by the fact that September had the highest average concentration, averaging 0.00391±0.002 micro /L, while the other months were constant at 0.0001 micro /L. The maximum amount of cobalt that can be present in drinking water is not specified by World Health Organization (WHO) guidelines, however it is advised to be less than 0.001 micro /L in order to guard against long-term harmful effects. As a result, throughout September, river and tap water values above permissible limits, requiring more advanced treatment methods to guarantee public health and safety which compatibl with [16].

Table(7)concentration cobult in water

Station	September	October	November	December	January	February	mean± SD
S1	0.006	0.0001	0.0001	0.0001	0.0001	0.0001	0.00108±0.002
S2	0.009	0.0001	0.0001	0.0001	0.0001	0.0001	0.00158±0.001
S3	0.007	0.0001	0.0001	0.0001	0.0001	0.0001	0.0012±0.003
S4	0.005	0.0001	0.0001	0.0001	0.0001	0.0001	0.000916±0.002

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S5	0.001	0.0001	0.0001	0.0001	0.0001	0.0001	0.00025±0.0003
S6	0.002	0.0001	0.0001	0.0001	0.0001	0.0001	0.00041±0.0007
S7	0.005	0.0001	0.0001	0.0001	0.0001	0.0001	0.00091±0.002
S8	0.003	0.0001	0.0001	0.0001	0.0001	0.0001	0.00058±0.001
S9	0.005	0.0001	0.0001	0.0001	0.0001	0.0001	0.0009±0.002
S10	0.001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002±0.0003
S11	0.002	0.0001	0.0001	0.0001	0.0001	0.0001	0.000416±0.0007
S12	0.001	0.0001	0.0001	0.0001	0.0001	0.0001	0.00025±0.0003
mean± SD	0.00391 ± 0.002	0.0001 ± 0.0002	0.0001± 0	0.0001± 0	0.0001 ±0	0.0001 ±0	0.0007±0.005
LSD	**0.00044**						**0.0068**
LSD interaction	**0.0014**						

3.8. zinc

Table (8) shows the concentration of zinc in water samples from different sources over a period of six months. The first four groups are Shatt water (1, 2, 3, 4), the second four groups are tap water (5, 6, 7, 8), and the last four groups are RO water (9, 10, 11, 12) as shown in the diagram (8)**.** The show River water (S1-S4): Zinc contents vary over the months, with certain samples showing a relative rise between October and February. Seasonal fluctuations in water levels, runoff, and the impact of contaminants from industrial and human activity might all be to blame for these variances. In most months, zinc levels in tap water (S5–S8) were extremely low; nevertheless, for certain stations, there was a discernible rise in February. This rise is associated with variations in the quality of distribution or treatment systems as well as the consequences of pipe corrosion. The lowest zinc amounts are often seen in RO water (S9–S12), which is in line with how well reverse osmosis systems remove contaminants and heavy metals. Significant monthly fluctuation in zinc contents is shown by the data in Table (8), where the mean and standard deviation show how variable each water source is. The statistically significant variation in concentrations between months and sources is shown by the LSD (Least Significant Difference) defined in the table. Given that seasonal variations, environmental factors, and human activity all have an impact on zinc concentrations, we see a significant influence of the water source component across time. The table is far lower than the maximum permissible zinc concentration in drinking water, which is regulated by the World Health Organization (WHO) at 3 micro /L. This shows that every sample is within the acceptable ranges which compatibl with [17]

Table(8) concentration zinc in water

Station	September	October	November	December	January	February	mean± SD
S1	0.004	0.0243	0.001	0.0001	0.0001	0.035354	0.0108±0.01
S2	0.001	0.0012	0.001	0.0001	0.0001	0.440025	0.0739±0.17
S3	0.003	0.0012	0.001	0.0001	0.0001	0.125	0.0217±0.05
S4	0.002	0.027	0.001	0.0001	0.0001	0.149937	0.0300±0.05
S5	0.001	0.001	0.001	0.0001	0.0001	0.05524	0.0097±0.02
S6	0.004	0.0018	0.0011	0.0001	0.0001	0.048927	0.0093±0.01
S7	0.007	0.0014	0.001	0.0001	0.0001	0.08428	0.0156±0.03
S8	0.003	0.0014	0.001	0.0001	0.0001	0.085859	0.0152±0.03
S9	0.003	0.0016	0.001	0.0001	0.0001	0.049558	0.0092±0.01
S10	0.002	0.0011	0.001	0.0001	0.0001	0.044508	0.0081±0.01
S11	0.008	0.0021	0.001	0.0001	0.0001	0.043876	0.0092±0.01
S12	0.001	0.001	0.001	0.0001	0.0001	0.020518	0.0040±0.008
mean± SD	0.0033± 0.002	0.0054 ±	0.0010± 0.0001	0.0001± 0	0.0001 ±	0.0986± 0.01	0.0181±0.03

		0.009			**0**		
LSD	**0.00046**						**0.0064**
LSD interaction	**0.0015**						

Table(8) concentration zinc in water

3.9. nickal

Table (9) more shows the concentration of nikal in water samples from different sources over a period of six months. The first four groups are Shatt water (1, 2, 3, 4), the second four groups are tap water (5, 6, 7, 8), and the last four groups are RO water (9, 10, 11, 12) as shown in the diagram(9). River water (S1-S4): We can see distinct variations in nickel content in the initial samples, with some readings being comparatively high in particular months. This is brought on by metal deposits, pollution from nearby industrial and agricultural operations, and seasonal variations in water flow. Nickel levels in tap water (S5–S8) are comparatively lower than in river water, however they are still influenced by treatment quality and environmental variables. Higher nickel contents in tap water during specific months are caused by aging water pipes or chemical reactions inside the network. Reduced nickel levels in RO water (S9–S12) show how well the reverse osmosis method removes heavy metals. The quality of the filters utilized or variations in the primary water sources prior to treatment are the causes of minor variations between samples. The maximum permissible content of nickel in drinking water is determined by the World Health Organization (WHO) as 0.07 mg/L. The water is deemed safe if the readings fall within this range, however any exceedance necessitates research to guarantee water quality which compatibl with [18]

Tabel (9) concentration Nickal in water

Station	September	October	November	December	January	February	mean± SD
S1	0.008	0.0016	0.0017	0.0001	0.0001	0.02723	0.0065±0.01
S2	0.001	0.0016	0.0016	0.0001	0.0001	0.030047	0.0057±0.026
S3	0.001	0.0016	0.0016	0.0001	0.0001	0.065728	0.0117±0.05
S4	0.001	0.0016	0.0016	0.0001	0.0001	0.073239	0.0129±0.01
S5	0.003	0.0017	0.0016	0.0001	0.0001	0.023474	0.0050±0.011

S6	0.011	0.0016	0.0016	0.0001	0.0001	0.031925	0.0077±0.01
S7	0.009	0.0017	0.0016	0.0001	0.0001	0.026291	0.0065±0.02
S8	0.001	0.0016	0.0017	0.0001	0.0001	0.029108	0.0056±0.008
S9	0.003	0.0016	0.0016	0.0001	0.0001	0.022535	0.0048±0.009
S10	0.002	0.0016	0.0016	0.0001	0.0001	0.003756	0.0015±0.001
S11	0.003	0.0016	0.0016	0.0001	0.0001	0.021596	0.0047±0.008
S12	0.001	0.0016	0.0018	0.0001	0.0001	0.000939	0.0009±0.0007
mean± SD	0.0037± 0.003	0.0016 ± 0.0001	0.0016± 0.0001	0.0001± 0	0.0001 ± 0	0.0297± 0.02	0.0037± 0.06
LSD	**0.00038**						**0.0062**
LSD interaction	**0.0012**						

3.10. lead

Table (10) shows the concentration of lead in water samples from different sources over a period of six months. The first four groups are Shatt water (1, 2, 3, 4), the second four groups are tap water (5, 6, 7, 8), and the last four groups are RO water (9, 10, 11, 12) as shown in the diagram(10). The show River water (S1-S4): The data show that the lead content varies clearly from month to month, with notable spikes in some times. Seasonal impacts like decreased water flow in some months, which raises the concentrations of heavy metals, or higher runoff, which may convey pollutants from agricultural and industrial sources, might be the cause of these fluctuations. Tap water (S5–S8): Data indicate some variation in lead amounts, despite treatment systems' efforts to eliminate heavy metals. This is connected to variations in the quality of water treatment at facilities and corrosion of water transmission lines. RO water (S9-S12): Since reverse osmosis (RO) systems filter pollutants more effectively than other sources, the lower lead content results show how effective RO systems are in eliminating heavy metals. To guarantee health safety, the numbers in the table should be compared to the maximum allowable lead concentration in drinking water, which is defined by the World Health Organization (WHO) at 0.01 micro /L.The findings suggest that seasonal and environmental

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variables are significant contributors to the fluctuations in lead levels in water which compatibl with [19][20][21].

Tabel (10)concentration lead in water

Station	September	October	November	December	January	February	Mean±SD
S1	0.0031	0.001	0.001	0.0007	0.0075	0.4444	0.0762±0.18
S2	0.0024	0.001	0.014	0.0210	0.0046	0.3777	0.0701±0.15
S3	0.0049	0.001	0.0021	0.0006	0.0019	0.4888	0.0832±0.19
S4	0.0012	0.001	0.003	0.0062	0.0023	0.5555	0.0948±0.22
S5	0.0012	0.003	0.001	0.0012	0.0083	0.4333	0.0746±0.17
S6	0.0012	0.001	0.001	0.0087	0.0035	0.2555	0.0451±0.10
S7	0.0043	0.004	0.001	0.0012	0.0053	0.2666	0.0470±0.10
S8	0.0043	0.0012	0.001	0.0148	0.0044	0.2666	0.0487±0.11
S9	0.0062	0.001	0.0012	0.0125	0.0008	0.1777	0.0332±0.07
S10	0.0013	0.0013	0.012	0.0123	0.0035	0.15	0.0300±0.05
S11	0.0018	0.001	0.0043	0.0009	0.0037	0.1833	0.0325±0.07
S12	0.0031	0.001	0.011	0.0050	0.0031	0.2222	0.0409±0.08
mean± SD	0.0029± 0.001	0.0015 ± 0.0009	0.0044± 0.004	0.0071± 0.006	0.0041 ± 0.002	0.3185± 0.13	0.0563± 0.02
LSD	**0.00044**						**0.0068**

LSD interaction	0.0014

3.11. Water Quality Index (WQI)

Iraqi and international environmental standards were adopted during the study to evaluate the quality of river water, tap water, and reverse osmosis water, and to determine their suitability for , drinking purposes. The Iraqi guideline was applied to 72 samples collected from four river water sites, four tap water stations, and four reverse osmosis stations over a six-month period: summer (September to October 2024), autumn (November to December 2024), and winter (January to February 2025). Laboratory tests were conducted according to internationally accepted methods (APHA, AWWA, and WCPE) and according to the following equations . The water quality index is calculated using the following equations:

Tabel11: Water quality classification (WQI) WHO

N0	WQI value	Water Quality Classification
1	< 50	Excellent water
2	50.1-100	Good water
3	100.1 – 200	Poor water
4	200.1 – 300	Very poor water
5	> 300.1	Unfit for drinking

Table (12)According to the World Health Organization's guidelines, the river's total Water Quality Index (WQI) rating looks to have surpassed 230, designating it as "very poor water." This indicates that without the right care, it is unsuitable for consumption. The pH of this water is within the permissible range, so it has no direct adverse effects, but it could interact with other substances, which is why it does not fulfill drinking requirements. An increase in dissolved chemicals in the water is indicated by the high (EC) value of 1226 microsiemens/cm, which is more than the suggested limit of 750 microsiemens/cm. When compared to the permitted limit of 200, the T.D.S. value was 715, suggesting organic contamination that might be caused by the breakdown of biological materials or industrial waste. Elevated TDS and E.C. levels can cause digestive issues and salt buildup, which impairs kidney function and raises the risk of kidney stones. This impacts the water's quality and flavor and adds to its increased hardness. High turbidity: It rises to 10.4, which is twice the allowable limit (5), which could impact the water's clarity and signal the presence of insoluble particles that could harbor bacteria and parasites, which raises the risk of intestinal infections and other gastrointestinal disorders. High T.H., which can cause deposits in pipes and render the water unfit for human consumption, can reach 439 compared to the WHO maximum of 200. The effects of high total hardness (T.H.) on health. The buildup of calcium and magnesium in the body due to a high hardness value raises the risk of cardiovascular issues. Also, surpassing the concentration of particular heavy metals such as (Cd) by a rate of 0.106, which is greater than the allowed limit (0.1), may cause major health concerns. In addition to being linked to bone and renal issues, it is also regarded as a chronic carcinogen. Because of its toxic effects, nickel (Ni) is a health issue at 0.092 compared to the safe level of 0.02. It may have an impact on the immune system in addition to causing skin damage and respiratory discomfort. Lead (Pd): The danger of lead poisoning is increased since the concentration was recorded at a high level (0.081) compared to the recommended limit of 0.01. causes neurological issues, including delayed mental development and cognitive impairment, particularly in children. It also causes high blood pressure and renal illness in adults which compatibl with[22].

Tabel 12: river water quality index

parameter	C_i	S_i	W_i	Q_i	$Wi*Q_i$
PH	**7.21**	**7.5**	**0.133**	**96.133**	**12.78**
E.C	**1226**	**750**	**0.0013**	**163.46**	**0.212**
T.D.C	**715**	**200**	**0.005**	**357.5**	**1.787**
Turibidity	**10.4**	**4**	**0.25**	**260**	**65**
T.H	**439**	**200**	**0.005**	**219.5**	**1.0975**
Cd	**0.106**	**0.01**	**100**	**1060**	**106000**
Co	**0.001**	**0.001**	**1000**	**100**	**100000**
Zn	**0.0341**	**3**	**0.333**	**1.136**	**0.37**
Ni	**0.0092**	**0.02**	**50**	**21**	**1050**
Pd	**0.081**	**0.01**	**100**	**810**	**81000**
			1250		**288131**
Over all WQI = 230 (Very poor water)					

The table(13)World Health Organization classifies tap water as low quality when its Water Quality Index (WQI) is 153. This grade means that without further treatment, the water is not suitable for human consumption. This is because of: High Concentration of Total Dissolved Matter (TDS): A high concentration of dissolved salts and minerals is indicated by high TDS readings (714), which can alter flavor and raise the risk of salt buildup in pipes and other home equipment. Long-term use of high TDS might cause gastrointestinal problems. high Electrical Conductivity (EC): Unwanted salts such sulfates and chlorides are present when the EC value is 1223, which denotes a high concentration of dissolved ions. Turbidity: A turbidity score of 10.175 indicates the presence of suspended particles that could include organic matter or microbiological pollutants, as it is greater than the allowable limit. This raises the possibility of contracting infectious illnesses such gastrointestinal infections and diarrhea.Concentrations of heavy metals: Lead (Pd), nickel (Ni), and cadmium (Cd) at below-optimal levels can be harmful to human health. Serious health issues include renal disease, neurological damage, and developmental difficulties in children might result from them. Total hardness (TH): Water with a TH rating of 440 is considered hard, which might cause issues when using it for domestic tasks like cooking and washing. In addition to causing skin issues, hard water reduces the cleaning power of soap and detergents.The contamination of the water source is one of the main causes of pollution.If the source is a lake or river, industrial and agricultural runoff may have polluted it, leading to elevated levels of heavy metals and total dissolved solids (TDS). Human or animal feces can cause microbial contamination, which raises turbidity and degrades water quality and treatment quality in water treatment facilities. Turbidity rises as a result of ineffective filtering systems or coagulation and sedimentation methods that leave a large portion of suspended particles in the water. Electrical conductivity may rise and the equilibrium of dissolved compounds may be impacted if agents like alum and chlorine are added without careful monitoring. Infrastructure related to water transmission may also have a big influence. Total hardness (TDS) may rise as a result of chemical deposition and water mixing with organic or mineral impurities caused by outdated pipes and distribution networks. Unwanted contaminants may be added via leaks or contamination during distribution, lowering the final water quality that customers get. Climate and environmental factors: High temperatures can intensify the chemical reaction of dissolved salts, which can impact water's electrical conductivity. Increased evaporation rates and decreased water flow during seasonal changes can result in higher pollutant concentrations, which raise the TDS level. To lower the concentration of dissolved substances and heavy metals, treatment processes like filtration and ion exchange must be improved. - Use turbidity removal techniques like sedimentation to ensure the removal of suspended particles. - Regularly monitor water quality in accordance with WHO standards to ensure the safety of water consumption which compatibl with[23] .

Tabel 13: tap.water quality index

parameter	C_i	S_i	W_i	Q	W_i*Q_i
PH	7.31	7.5	0.133	97.4	12.95
E.C	1223	750	0.0013	163	0.21
T.D.C	714	200	0.005	357	1.785
Turibidity	10.175	4	0.25	254	63.5
T.H	440	200	0.005	220	1.1
Cd	0.0862	0.01	100	862	86200
Co	0.0005	0.001	1000	50	50000
Zn	0.0124	3	0.333	0.41	0.136

Ni	0.0062	0.02	50	31	155
Pd	0.0538	0.01	100	538	53800
			1250		191629
Over all WQI = 153 (poor water)					

Table(14) Reverse Osmosis Water's Water Quality Index is 80. Although the water is rated as "good" by the Water Quality Index methodology, more treatment is necessary to lower the levels of lead and cadmium in order to fully comply with WHO requirements.This figure, which is within the permissible range for pH 7.3, shows chemical stability and no problems with acidity or alkalinity.E.C. 62.55 µS/cm: After reverse osmosis treatment, low electrical conductivity is a positive indicator of water quality since it shows that dissolved salts have been effectively removed. 355 mg/L of total dissolved solids (TDS) This number shows how well the RO system works to lower the dissolved solids concentration and render the water fit for daily usage and drinking. Turbidity 1.6 NTU: Low turbidity improves the water's appearance and health quality by indicating cleanliness and the absence of suspended particles at dangerously high levels.44.9 mg/L of total hardness (TH)Reduced calcium and magnesium concentrations result from reverse osmosis water's decreased overall hardness, which helps avoid limescale accumulation in pipes and home appliances. Cadmium (Cd) is 0.03 mg/L above the allowable limit for heavy metals (Cd, Co, Zn, Ni, and Pd), suggesting possible pollution. Cadmium is very dangerous even at low doses. Cobalt (Co): 0.0004 mg/L is under the allowable level, indicating that cobalt poses no health risks. Amount of zinc (Zn): 0.007 mg/L. There is no health concern because the quantities of zinc are very low .Ni concentration: 0.002 mg/L. The concentration of nickel is perfectly safe and does not suggest any issues .Three times the allowable limit of lead (Pd), 0.03 mg/L, is dangerous for your health, especially if you're exposed to lead-contaminated water on a regular basis . Although the Water Quality Index rates the reverse osmosis water in this research as satisfactory, further treatment for some heavy metals is necessary to guarantee total safety. Treatment for cadmium and lead is crucial; employ specialist filters, such as ion exchange systems or activated carbon adsorption, to get rid of these substances which compatibl with [24].

Tabel 14: RO.water quality index

parameter	C_i	S_i	W_i	Q_i	$Wi*Q_i$
PH	7.3	7.5	0.133	97.3	12.94
E.C	62.55	750	0.0013	8.34	0.01
T.D.C	355	200	0.005	177.5	0.887
Turibidity	1.6	4	0.25	40	10
T.H	44.9	200	0.005	22.45	0.11

Cd	**0.03**	**0.01**	**100**	**300**	**30000**
Co	**0.0004**	**0.001**	**1000**	**40**	**40000**
Zn	**0.007**	**3**	**0.333**	**0.23**	**0.07**
Ni	**0.002**	**0.02**	**50**	**10**	**500**
Pd	**0.03**	**0.01**	**100**	**300**	**30000**
			1250		**100524**
Over all WQI = 80 (good water)					

4. Conclusions:

1. River water quality: According to the Water Quality Index (WQI) results, river water was deemed to be of "very poor quality" (WQI value 230), which means that it is unsafe to consume without the necessary treatment.
2. Tap water: Because of high levels of turbidity, total hardness, and some heavy metals like lead, it was deemed to be of "poor quality" (WQI = 153) and needs better treatment procedures.
3. Desalinated water from reverse osmosis (RO): This type of water had the best quality, earning a "good" grade (WQI = 80), but it still included lead and cadmium traces, necessitating further treatment to meet international health regulations.

4. High overall hardness and electrical conductivity: These signify a high concentration of dissolved minerals and salts, which can have negative effects on the environment and human health, including higher risk of renal issues and salt buildup in the soil.
5. Exceeding WHO guidelines for some heavy metals, such lead and cadmium, poses a risk to public health and can result in issues like renal illness and neurological system damage.

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