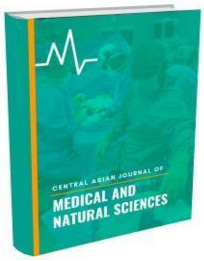

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Article

Evaluation of Drinking Water Quality Index in Kirkuk City, Iraq

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Abstract: This study aimed to evaluate the Drinking Water Quality Index (WQI) in Kirkuk City over the period from October 2023 to April 2024. To achieve this, water samples were systematically collected from seven different locations: the collection basin, pumping basin, Rahimawa area, Al-Mas area, Al-Wasiti neighborhood, Al-Hajjaj neighborhood, and Area 55. The WQI was calculated based on an extensive analysis of several key physical, chemical, and biological properties. The physical properties assessed included turbidity, total dissolved solids (TDS), total suspended solids (TSS), electrical conductivity, and salinity. The chemical properties measured were pH, total alkalinity, total hardness, calcium hardness, magnesium hardness, chloride, total phosphorus, total nitrogen, nitrate, and fluoride. Additionally, biological properties such as total bacterial count, coliform bacteria, and fecal bacteria were evaluated. The results of the study indicated that the Kirkuk water treatment plant is highly effective in altering the characteristics of raw water. This effectiveness was reflected in the excellent values recorded for the Water Quality Index across all sampled sites. The specific WQI values were as follows: site two recorded a WQI of 24.62, site three 25.78, site four 37.53, site six 37.57, site five 39.57, and site seven 42.19. These findings suggest that the water treatment station is highly efficient in producing water that is suitable for daily sanitary purposes, thereby ensuring the safety and quality of drinking water for the residents of Kirkuk City.

Keywords: WQI ,Kirkuk, Salinity, Nitrate, Total bacterial count .

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1. Introduction

Despite being water essential for life, contaminated water deteriorates people's health. Drinking water is primarily obtained from three main sources: surface water, groundwater, and rainwater [1]. It is widely known that water is the most abundant compound on Earth, existing in three different states of matter: liquid, solid, and gas. However, providing safe drinking water is crucial for sustaining life and enhancing human well-being [2].

Water pollution is a major environmental concern that poses economic and health risks to both humans and other living organisms. In many developing countries, there is an urgent issue related to the contamination of drinking water supplies, leading to a significant decline in the surface water quality [3]. The World Health Organization (WHO) has established exposure standards or safe limits for contaminants of all types in drinking water[4] . National and international organizations in various countries have developed additional types of water quality indicators based on their need to assess the water quality level in a specific area of interest. To date, specialists have not proposed a consistent method for evaluating water quality that can be used worldwide to provide drinking water with 100% objectivity and accuracy[5].

Contaminated drinking water has a direct impact on consumer health and the spread of epidemic diseases[6]. According to reports, a significant proportion of the world's population, approximately two billion people, still rely on drinking water supplies contaminated with This indicates contamination with sewage [7].

This study aims to calculate is to calculate the Water Quality Index (WQI) values for the water produced by the Kirkuk Water Treatment Plant to determine its suitability for health and daily use purposes.

In their study on the impact of certain physical and chemical properties of the Lower Zab River on the Tigris River, the results showed that the Lower Zab influences the Tigris River's environment. Additionally, there was a decrease in nutrient values at some stations, which is attributed to environmental conditions. and they showed in other study[9] to assess the quality of water produced from the Hawija district desalination plant - Kirkuk that the plant produces high quality water and is suitable for various human uses, including drinking.[10] In a study assessing some characteristics and environmental pollutants affecting the Tigris River, the study's results showed that some of the studied water properties do not match the specified drinking water standards. This reflects the geological nature of the area, as well as the impact of rainfall and other factors, rendering it unsuitable for most uses.[11] The current study was conducted to assess the water quality of Valley Duhok as a water source for drinking livestock and poultry in the region. The results of the water quality index indicated that the water of Duhok Dam Lake (site N1) was of good quality for drinking livestock and poultry, while the rest of the sites on the valley were in the category of water very poor for drinking animals, with WQI values ranging from (204-286).

2. Materials and Methods

Study Area

Samples were collected from seven sites, two of which were at the Kirkuk Water Treatment Plant (K1). The first site was the raw water storage before treatment, and the second site was the treated water tank prepared for distribution to residential areas, specifically The area, Almas area, Al-Wasiti neighborhood, Al-Hajaj neighborhood, and Area 55. The selection of these five sites distributed across the neighborhoods of Kirkuk aimed to study the impact of distribution networks on the quality of the produced water(figure 1)

Sample Collection

Samples were collected from seven different locations, two within the station and five from residential neighborhoods, during the period from October 2023 to April 2024. A method was used to collect the samples. 1-liter polyethylene bottles, and their water was used for physical and chemical tests. Sterilized glass bottles were used to estimate the Total bacteria count, Total coliforms or E. coli. These samples were transported to the laboratory in a chilled container to preserve them until testing.

Method of Measurement of Physical, Chemical and Biological Factors

The Properties physical (Turbidity, TSS, TDS,EC and Salinity) Properties chemical (pH, Total alkalinity, Total hardness, Ca hardness, Mg hardness, Cl, TN, TP, NO3, F) and Properties biological (Total count bacteria, total coliform, fecal coliform) factors determined according to [12].

Statistical Analysis

Using SPSS version 26, which is compatible with Windows 10, data was statistically analyzed employing a one-way ANOVA (F-test) and Pearson correlation coefficient

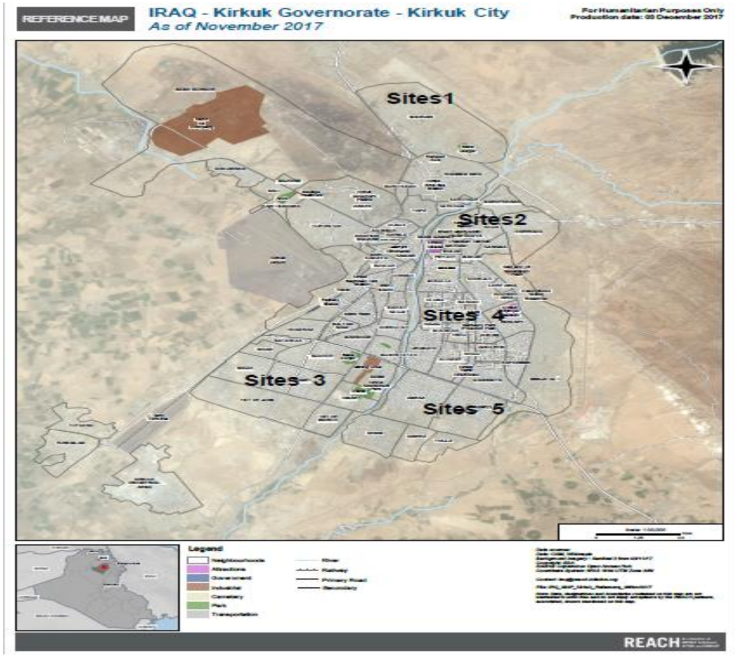

Figure 1. Shown Map of the study area

Water Quality Index

The Weighted Mathematical Model was used to calculate the Water Quality Index (WQI), which involves the following five steps 15][14][13]] [16][17]:

First Step:

In this step, the relative weight (RWi) is calculated using the Equation (1):

$$RWi = \frac{w\ i}{\Sigma_{i=i}^{n} wi}.........(1)$$

Since:

- RWi: Relative weight.
- wi: Weight of the parameter.
- $\Sigma_{i=i}^{n} wi$: Sum of parameter weights

Second Step:

Finding the average of quality rating (qi) values using the Equation (2):

$$qi = \frac{Ci}{Si} \times 100........ \ (2)$$

since:

- Ci: Observed value of the parameter.
- Si: Standard concentration of the parameter according to international classifications.

Third Step:

Calculating the values of the subindex (SLi) using the Equation (3):

$$SLi = Wi \times qi........ \ (3)$$

Fourth Step:

Finding the Water Quality Index (WQI) values using the Equation (4):

$$WQI = \Sigma SLi........ \ (4)$$

And then the types of water are classified in comparison with Table (1).

Fifth step:

For the purpose of calculating the impact of each criterion on the WQI value and then judging it, involves calculating the Effective Weight Percentage (Ewi) for each parameter. It is calculated by dividing the sub-index score (Sli) by the WQI value, as in the Equation (5) .

$$Ewi=\frac{SLi}{WQI}\times 100........ \quad (5)$$

since:

- Ewi :Effective Weight Percentage for each criterion.
- SLi :Sub-index score for each criterion.

After obtaining the Water Quality Index value, the water quality is classified based on the following table 1

Table 1. Classification of water quality by WQI values [15]

WQI Range	Water Quality
< 50	Excellent
100-50	Good
200-100	Poor
300-200	Very Poor
> 300	Unsuitable

3. Results and Discussion

The weighted mathematical model was used to assess the drinking water quality at the Asala Water Station in Kirkuk, which was referred to by some researchers [13] [14] [15] [16][17]:

The selected factors for evaluating the drinking water quality at the stations are shown in Table 2, indicating the water quality index values for the selected areas. It was found that the water quality at the first site was poor, with a high value of 181.9912. However, the values for the second, third, fourth, fifth, sixth, and seventh sites indicated excellent water quality, with values of 24.62, 25.78, 37.53, 37.57, 39.57, and 42.19, respectively. This indicates that the station operates with high efficiency, meeting the Iraqi Standard Specifications [18]

Table 2. Of Drinking Water Quality Parameter Values at Selected Sites

Sites	Water Quality Index (WQI) Value	Qualitative function
1	181.9912	Poor
2	24.62808	Excellent
3	25.78739	Excellent
4	37.53697	Excellent
5	39.57927	Excellent
6	37.57106	Excellent
7	42.1955	Excellent

Table 3. Shows The Studied Factors

factors	sites1	sites2	sites3	sites4	sites5	sites6	sites7
Tur N.T.U	(0.01-0.35) b0.09167	(0.02-0) a0.005	(0.04-0) a 0.00667	(0-0.04) a 0.01167	(0-0.02) a 0.005	(0-0.02) a 0.005	(0-0.03) a 0.01286
TSS PPm	(1.38-0.3) a 0.58667	(1.24-0.22) a 0.64	(1.04-0.4) a 0.58333	(0.2-1.2) a 0.57333	(0.3-1) a 0.54667	(0.3-1) a 0.61	(0.18-0.94) a 0.53714
TDS PPm	(0.18-0.02) a 0.13333	0)(0.12- a 0.07333	(0.2-0.02) a 0.09333	(0-0.18) a 0.05	(0-0.18) a 0.13666	(0-0.14) a 0.09	(0.2-0.16) a 0.15142
EC MS/cm	(552-276) a423	(565-297) a 430.166	(589-288) a 434.5	(276-561) a 428	(286-656) a 441.333	(276-599) a 425.166	(295-594) a 456.428

Salin PPm	(0.02-0.01) a0.015	(0.03-0.01) a 0.02	(0.03-0.01) a 0.02	(0.01-0.03) a 0.02	(0.01-0.03) a 0.02	(0.01-0.03) a0.02	(0.01-0.03) a0.02
PH	(7.7-6.4) a 7.0666	(7.5-6.5) a 7.0833	(7.6-6.9) a 7.3166	(6.5-7.6) a 7.1833	(6.1-7.7) a 7.0166	(6.5-7.6) a 7.0833	(6.5-7.7) a 7.2428
Talk PPm	(136-112) a 125.333	(132-104) a 117.666	(132-112) a 122.333	(106-128) a 117	(108-132) a 119	(108-132) a 118.333	(108-132) a 120.571
TH PPm	(180-135) a 151.666	(190-120) a 148.333	(190-130) a 153.333	(120-180) a 147.5	(120-200) a 151.666	(120-180) a 145	(130-190) a 157.142
CaH PPm	(125-105) a 110	(135-85) a 107.5	(135-85) a 109.166	(85-135) a 107.5	(85-135) a 105.833	(85-135) a 105	(85-135) a 110.714
MgH PPm	(55-30) a 41.666	(55-30) a 40.833	(55-30) a 44.166	(30-45) a 40	(30-65) a 45.833	(30-45) a 40	(30-55) a 46.428
Cl PPm	(11.36-5.68) a 8.0466	(14.2-5.68) a 9.7033	(14.2-5.68) a 9.7033	(5.68-14.2) 9.7033a	(5.68-14.2) 9.7033a	(5.68-14.2) 9.7033a	(5.68-14.2) 9.7033a
TP PPm	(0.02-0) a 0.0033	(0.01-0) a 0.0033	(0.02-0) a 0.005	(0-0.01) a 0.005	(0-0.01) a 0.0066	(0-0.02) a 0.01	(0-0.02) a 0.0042
TN %	(0.2-0) a 0.0666	(0.2-0) a 0.0666	(0.2-0) a 0.0666	(0-02) a 0.1	(0-0.2) a 0.1	(0-0.2) a 0.1	(0-0.2) a 0.085
NO3 PPm	(5.5-4.7) e 5.05	(4.6-3.9) d 4.116	(3.8-2.8) c 3.4166	(2.5-3.4) b 3.033	(2.5-3) ab2.883	(2.4-3) ab 2.733	(2.3-2.9) a 2.528
F PPm	(0.8-0.5) b0.616	(0.45-0.2) b0.475	(0.45-0.2) a0.325	(0.1-0.38) a0.263	(0.1-0.25) a0.242	(0.1-0.3) a 0.2	(0.1-0.29) a 0.195
TPC cell/100 ml	(250-175) b 229.166	(0-0) a 0	(85-0) a 9.666	(0-185) a 36.666	(0-198) a 47	(0.118) a 39	(0-193) a 64.428
MPN	(25-25) a 25	(0-0) a 0	(0-0) a 0	(0-16) a 2.666	(0-16) a 2.666	(0-16) a 2.666	(0-16) a 2.585
MPN E.coli	(22-18) a 20	(0-0) a 0	(0-0) a 0	(0-16) a 2.666	(0-9.2) a 1.5333	(0.51) a 0.85	(0-9.2) a 1.314

The results of the study shown in Table 3. The reason for the high turbidity values at the first site may be due to rainfall, which increases the turbidity ratio in the waters of the Zab River. Turbidity is caused by mud, organic, and inorganic materials, particularly high in rivers, due to soil washed into the river by rainwater. The lowest values of turbidity were recorded for various sites and months. Turbidity is expressed as an optical property for scattering light through a water sample [19]. Analysis of variance (ANOVA) and Duncan's multiple range test showed significant differences (at the level of $P \leq 0.05$) between the mean turbidity values relative to the sampling sites, with the mean of the first site being the highest among the site means. The reason for the increase in the TSS in water is attributed to rainy seasons, resulting in an increase in water levels during winter and snowmelt, leading to non-settling of suspended solids. Additionally, rainfall during rainy seasons leads to soil erosion, sedimentation, as well as the presence of plant and animal debris and organic matter [20]. There were no significant correlations recorded between the values of total dissolved substances and the other study factors. Additionally, the total dissolved substances values did not show significant differences between the mean values of the sites and the dates of sample collection. Although water containing a high proportion of dissolved solids can affect its taste, it is not harmful to humans. Readings exceeding 500 ppm may contain toxic particles and heavy metals, while water with readings exceeding 1000 ppm is considered unsafe for human use [21]. The reason for the are very low in the study sites It may depend on the geological nature of the area as well as the efficiency of treatment plants. Analysis of variance (ANOVA) and Duncan's test did not show significant differences between the mean values of the sampling sites. Electrical conductivity is a numerical expression of the negative and positive ions present in the water. It depends on two factors: the first is the concentration and equivalence of the ionized substances dissolved in the water, and the second is the temperature of the water during measurement, as temperature directly affects the movement and direction of different ions [22]. The increase in electrical conductivity values may be due to the increase in suspended materials in the water column. No significant differences were recorded between the means of the sampling sites (at the significance level of $P \leq 0.05$). The decrease in salinity values may be due to washing processes caused by rainwater from the nearby elevated lands. When the river water level rises, the salinity concentration decreases [23]. Analysis of variance (ANOVA) and Duncan's test did not show significant differences between the mean salinity values relative to the sampling sites. pH measurement is important in drinking water treatment because it affects the efficiency of treatment processes such as chlorination, hardness removal, and corrosion control. pH is considered a good indicator of the acidic and alkaline balance in water, with surface water being moderate compared to groundwater, which tends to have higher pH values. pH values are within the standard specifications for Iraqi drinking water [18]. Analysis of variance (ANOVA) and Duncan's test did not show significant differences between the mean pH values relative to the means of the sampling sites. There is no increase in the T. Alkalinity value, it is all within the permissible limits in total alkalinity values is attributed to various reactions present in the water containing CO2 gas. When these waters pass through the earth's layers, it leads to the conversion of insoluble calcium carbonates into soluble bicarbonates. The reason for its decrease may be due to the consumption of carbon dioxide in the process of photosynthesis by aquatic plants as a source of organic and it may be due to the geological nature of the study area [24]. No significant differences were recorded between the mean total alkalinity values relative to the means of the sampling sites. Hardness is primarily attributed to the presence of magnesium and calcium ions, along with other elements at concentrations higher than usual due to pollution. Hard water is not harmful to health, but its drawbacks include its inability to form a lather when used with soap. No significant differences in total hardness values were recorded between the means of the sampling sites. Calcium carbonate is one of the compounds that cause water hardness when present in water. The most important sources of calcium are gypsum and calcite [25].The significant decrease in calcium hardness values in November may be due to the rainfall during that month, which likely resulted in soil washing and the flow of torrents towards the Zab River. Additionally, the local treatments at the Kirkuk water treatment plant affected the reduction in calcium hardness values by adding materials that precipitated suspended and dissolved substances. A significant correlation between these factors was documented. No significant differences were recorded between the mean values of calcium hardness relative to the sampling sites. Magnesium represents the ions that turn water into hardness [26].In some locations, an increase in magnesium hardness values is observed across different sampling sites, which may be due to increased dissolution of deposits in the transport pipes. Analysis of variance (ANOVA) and Duncan's test did not show significant differences between the sampling sites, which could be attributed to the variations in the characteristics and properties of the waters of the Zab River due to increased rainfall and soil erosion washing into the river channel. The decrease in chloride ion values for some months may be due to its combination with cations or its biological consumption. Chloride is one of the anions that affects the salinity values in water due to its association with cations, most notably sodium [27].The mean chloride values did not show significant differences between the sampling sites. The variation in phosphorus concentrations at the study sites is due to phosphorus increasing as it combines with ions, especially calcium. Decomposers and rainfall play an active role in its increase in water, as total phosphorus is washed away from agricultural lands that use phosphorus as chemical fertilizers adjacent to river waters [28].The reason for its decrease is due to dilution factors in water as well as climate changes occurring in recent years, including the amount of rainfall and the rise and fall of water levels [29]. The mean total phosphorus values did not show significant differences between the means of the sampling sites. Nitrogen is one of the important elements for determining the suitability of water for health uses, and its source in water is in many sources and ways [30].The different values may be the result of treatment processes and low dissolved oxygen values in pipes transporting water suitable for sanitary use. Analysis of variance (ANOVA) and Duncan's test did not show significant differences between the mean values of total nitrogen relative to the sampling sites. Nitrate is one of the ions that exist in nature, either from an organic or inorganic source, and any increase in the values of nitrate in water beyond the permissible limit becomes a toxic ion for living organisms. Some doctors and physiologists agree on the effect of the nitrate ion on humans and animals, as it is toxic and causes several diseases, including Methemoglobinemia, a disease of blue eyes in children, as well as cancerous tumors, including the urinary system and stomach tumors [31].The reason for the decrease in nitrate values is due to its consumption by organisms and phytoplankton [32]. Analysis of variance (ANOVA) and Duncan's test recorded significant differences ($P \leq 0.05$) between the mean nitrate values relative to the sampling sites, where the mean of the first site was highest among the means of the sampling sites. The Earth's crust is the main source of fluoride ion, especially igneous rocks, metamorphic rocks, granite, and calcium phosphate rocks. Fluoride is important in the formation of tooth enamel, but a low level of fluoride in water increases the possibility of tooth decay, and a high level of fluoride in water above the required levels leads to tooth decay and osteoporosis. [33].The apparent decrease in fluoride values may be due mostly to the nature of the Lower Zab River Basin and its mostly natural composition. Analysis of variance (ANOVA) and Duncan's test recorded significant differences ($P \leq 0.05$) between the mean fluoride values relative to the sampling sites, where the mean of the first site was highest among the means of the sampling sites. Bacteria are considered important indicators for assessing water pollution levels .The increase in bacteria count during rainy months is attributed to the increase in turbidity, as reduced sunlight leads to faster water flow, resulting in a significant increase in bacteria counts. The presence of bacteria may be due to the age of distribution network pipes, which could be old. Analysis of variance (ANOVA) and Duncan's test recorded significant differences ($P \leq 0.05$) between the mean values of total bacterial count relative to the sampling sites, where the mean of the first site was the highest among the means of the sampling sites. The presence of coliform bacteria in water is a clear indication of fecal contamination. Through it, fecal pollution in water is detected. There are no significant differences between them relative to the sampling sites. Generally, the decrease in the number of colonic bacteria at the station is a good indicator of the low number of colonic bacteria in wastewater. This is due to good sterilization at the station and the high concentration of chlorine in the water supply pipes from the wastewater project, which works to purify the water supply pipes from bacteria. This is an indicator of tight connections in water supply networks and the absence of leaks in the lines that may cause biological contaminants to enter the transmission lines. There are no significant differences between them relative to the sampling sites.

Dissolved oxygen and biochemical oxygen demand values are measured in open aquatic habitats, not closed ones. Since most of the sampling sites are in closed areas like water transport pipes, measuring these values is not important. Dissolved oxygen values decrease with the addition of chlorine to treated water in treatment plants. The potable water did not contain high levels of enteric and coliform bacteria at all sites except the first site, the Zab River, indicating the efficiency of the Kirkuk water treatment plant under study.

4. Conclusion

The values of the studied physical, chemical, and biological factors of the water produced by the Kirkuk Unified Water Project are within the Iraqi drinking water standards. The results demonstrated the station's ability to filter water well from pollutants, thereby facilitating the purification and filtration process, making the water comply with the Iraqi drinking water standards. The values of WQI indicate the collected samples from six sites in Kirkuk city after treatment have excellent environmental characters which documented the high tap water quality. The total bacteria count values in the first site (raw water) increased significantly, as infinite values were recorded due to human activities and their arrival inside the station.

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