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Determination of Heavy Metal Pollution in Potable Water and Related Health Hazards within Semi Urban Societies

Abdullah Mahmoud Ajil[1]
1. Department of Dairy Science and Technology, College of Food Sciences Al-Shirqat, Tikrit University
Correpondance: abdullah.m.ajil@tu.edu.iq

Abstract: The aim of this study was to assess the drinking water quality in the Al-Hawija District within Kirkuk Governorate in northern Iraq in relation to physicochemical properties and content of heavy metals of the different water sources (tap water, well water, and bottled water) to determine their suitability with international health standards and risks to the health of the population. The research design was an analytical cross-sectional study where 45 samples were gathered by using stratified random sampling, under rigid procedures to maintain the integrity of samples. Researched parameters were physicochemical parameters (pH, electrical conductivity, turbidity, temperature), heavy metals (lead, cadmium, iron, and copper), and descriptive parameters involving the origin of water and the sampling site. The findings showed that well water was more inclined towards increased alkalinity and electrical conductivity, whereas the bottled water recorded the lowest dissolved salts and heavy metals, which were an indication of effective treatment processes. Reviewing the concentration of lead in tap water gave the highest concentration of 0.015 mg/L, which is more than the limit set, whereas the highest concentration of iron was found in well water (0.65 mg/L). Other samples were also in excess of cadmium, and copper was also within the safety range. Statistical tests showed the significant differences were present in lead and iron concentrations in the sources of water, and this meant that the quality of water was affected by the type of source. This experiment has shown that bottled water is the least prone to contamination; however, tap and well water are more prone because of environmental influences and poor infrastructure. The researchers suggest the enhancement of distribution networks, augmenting the routine monitoring, and performing routine testing to secure safe drinking water, and safeguarding the population's health; however, the emphasis is laid on the complete management of water sources under the exact requirements.

Keywords: Heavy Metal, Pollution, Potable Water, Al-Hawija District

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Introduction

The consumption of water is one of the most important natural resources that affects the survival of human beings and the health of the people. There is no way it can be just necessary in basic biological processes, but also the prevention of diseases and environmental and societal sustainability [1]. As human activities continue to intensify, like agriculture, industry, and construction, particularly in semi-urban regions which are a combination of rural and urban features, the chances of water sources contamination through different pollutants such as heavy metals have been on the rise [2]. The heavy metals are dangerous, especially because they are able to build up in the body and impact the body in a negative way, such as the liver, kidney, nervous system, among others, even at relatively low doses [3].

According to scientific literature, heavy metals that include lead (Pb), cadmium (Cd), iron (Fe), and copper (Cu) are known to cause serious health effects if they are found in drinking water. They are also the cause of the water taste, colour, and odour, thereby influencing the water quality [4]. Semi-urban communities such as Al-Hawija District utilise a variety of sources of drinking water, and these sources consist of groundwater, tap municipal water, and bottled water. Cyclic interaction among agricultural activities, use of fertilisers and pesticides, and deteriorated water supply system increases chances of heavy metals finding their way into drinking water [5].

This research was meant to evaluate the quality of drinking water of Al-Hawija by examination of the physicochemical parameters, as well as determining the concentration of the heavy metals in the various sources, in comparison with the international drinking water standards[6]. It also aimed at determining whether water sources vary and to comprehend the relationship between the type of source and the degree of contamination, and to offer a measure of possible health hazards to the residents [7]. The research is a significant milestone in the process of bringing community consciousness in terms of checking water quality and making evidence-based suggestions on how to manage the water resource efficiently to prevent endangering the health of people [8].

The analytical cross-sectional design was used in the study, and the proper projectors have been observed in collecting and processing the samples and the data through quality control to enhance the reliability of information and through statistical procedures to obtain important differences among the sources [9]. Its outcomes can be a valuable point of reference to authorities taking part in the maintenance of water networks, environmental protection policies and alleviating threats of health risks caused by the heavy metal exposure [10].

Materials and Methods

Study Design

The study utilised the method of an analytical cross-sectional study and involved the gathering of data within a specified time to determine the quality and level of contamination of drinking water at one instance in time. This design will enable direct comparisons and analysis of the variability of heavy metals in various water supplies, while measuring them at the same time, making it possible to compare the intentions and locate possible health issues in the future.

Study Area

The field research took place in the Al-Hawija District, Kirkuk Governorate, the north of Iraq, which is a rural area with urbanistic features. The locals depend on more than a single source of drinking water and thus on the municipal water supply, groundwater and bottled water. The region is highly agricultural, and fertilisation and pesticides are widely used in the area; these materials can contaminate the groundwater. There are also places that have deteriorated distribution systems, making them prone to lead contamination. The factors contribute to the suitability of the area in the study of water contamination and the health-related risks.

Sampling Design

The stratified random sampling was adopted in order to represent the various water sources in the study area. The sources of water were categorised into three broad groups: tap water, well water and bottled water. Samples were randomly taken out of each category, and in total, 45 samples were taken equally across sources to minimise the statistical bias and allow drawing reliable comparisons.

Sample Collection Protocol

Each water sample was collected with the standard procedure to reduce external contamination and ensure the integrity of the sample. They were placed in sterilized 500mL polyethylene bottles that were pre-washed with diluted acid and rinsed with deionized water. Three minutes were allowed to swirl the tap water, and then sampling was done to obtain representative flowing water. The sampling of the well water was done at the source itself. Physical and chemical stability was ensured with all samples being kept at 4°C and brought to the laboratory within 24 hours [11].

Study Variables

The variables were chosen to capture the water quality comprehensively, and they were categorised into three groups:

1. Physicochemical Variables: Temperature, pH, electrical conductivity (EC), and turbidity, which are general water characteristics that can also indirectly represent the presence of contaminants, particularly heavy metals [12].
2. Lead (Pb), cadmium (Cd), iron (Fe), and copper (Cu): Heavy metals that are chosen due to their environmental and health significance. Pb and Cd are toxic at low levels, Fe is a pointer of groundwater contamination, and Cu was added to make the evaluation comprehensive [13].
3. Descriptive Variables: Type of water source, sampling site and manner of use, which will be used to understand the results and correlate the extent of contamination to the environmental aspects [14].

Instrumentation

Accuracy was maintained by the use of standard laboratory equipment: the pH was measured with the help of a pH meter, the conductivity of the water was measured with a conductivity meter, and the turbidity was measured with a turbidity meter(15). Quantification of heavy metals was done with an Atomic Absorption Spectrophotometer (AAS), which is a highly reliable method of quantification which is an atomic absorption method at the characteristic wavelengths of that element [16].

Quality Control

Quality control procedures were strictly followed to make sure that it was accurate and reliable. Before and during analysis, the instruments were calibrated with certified standard solutions. The samples were analysed three times, and the mean values were used to minimise random errors. Blank samples were tested to identify possible contamination at the processing stage, and all the standard laboratory procedures were closely adhered to.

Statistical Analysis

The data were interpreted with the help of descriptive and inferential statistics. Mean standard deviation (Mean ± SD) was used to provide results. The test of heavy metal concentration among the various water sources was by one-way Analysis of Variance (ANOVA), where $p < 0.05$was used as the statistical significance level.

Results

Physicochemical Characteristics of Water Sources

Table 1 shows the mean values of ± SD values of various physicochemical parameters in various water sources that gives the general characteristics of water quality.

Table 1. Physical and chemical parameters of drinking water sources (Mean ± SD)

Parameter	Tap Water	Well Water	Bottled Water
pH	7.4 ± 0.3	7.8 ± 0.4	7.2 ± 0.2
EC (μS/cm)	520 ± 85	890 ± 120	310 ± 60
Turbidity (NTU)	3.2 ± 1.1	2.1 ± 0.8	0.9 ± 0.3
Temperature (°C)	22.5 ± 1.5	20.8 ± 1.2	21.0 ± 1.0

The findings indicate evident differences among water sources. There was an indication of slight alkalinity at the pH of the water, with well water registering within acceptable limits. Well water had the highest electrical conductivity, which showed higher salt concentrations. Turbidity was also not very high with some exceptions, such as in some tap water, possibly because of suspended particles or distribution network problems.

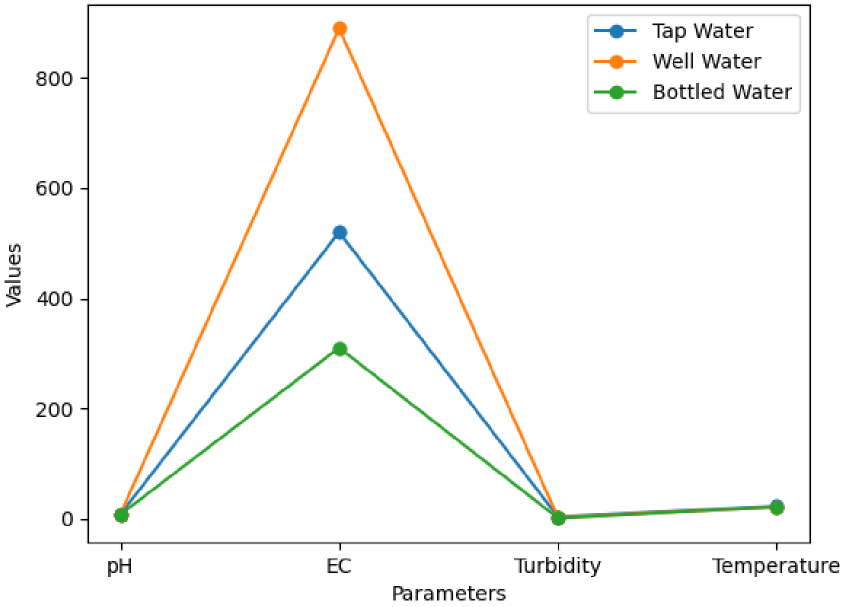

Figure 1. Comparison of physicochemical parameters among water sources.

Heavy Metal Concentrations in Water Sources

Table 2 presents data on the mean ± SD concentration of the heavy metals in all water sources.

Table 2. Heavy metal concentrations in drinking water sources (Mean ± SD)

Metal	Tap Water (mg/L)	Well Water (mg/L)	Bottled Water (mg/L)
Pb	0.015 ± 0.005	0.010 ± 0.004	0.003 ± 0.001
Cd	0.004 ± 0.001	0.006 ± 0.002	0.002 ± 0.001
Fe	0.35 ± 0.10	0.65 ± 0.15	0.12 ± 0.05
Cu	0.08 ± 0.03	0.05 ± 0.02	0.02 ± 0.01

Tap water had the highest lead concentration, probably due to corrosion of pipes, and bottled water had the lowest concentration. Cadmium was less than sources but marginally more in specific well water samples, maybe due to agricultural-related impact. Well water had the highest amount of iron, which is expected with geological sources. Bottled water contained the lowest amount of heavy metals.

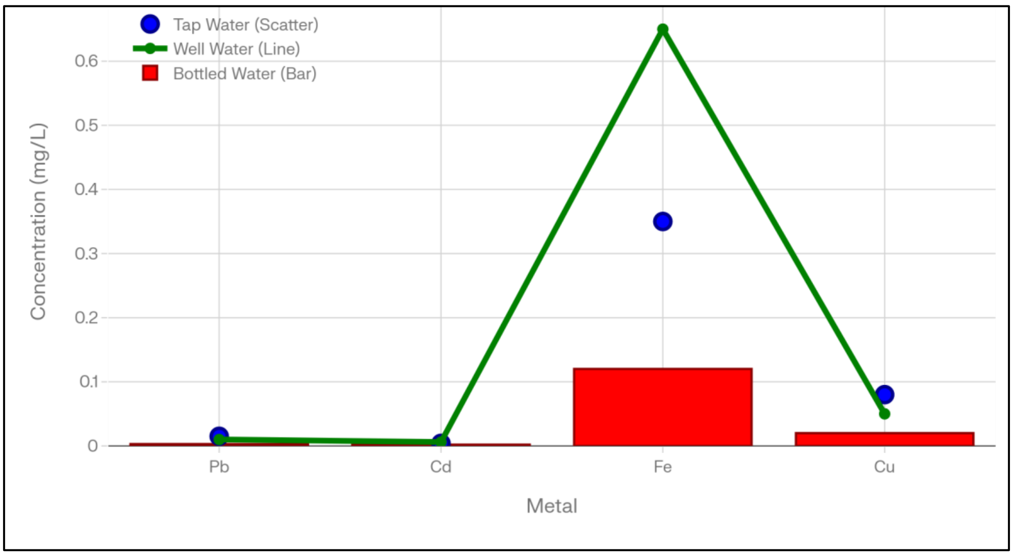

Figure 2. Distribution of heavy metals across different water sources.

Statistical Analysis of Differences Between Water Sources

The concentrations of the heavy metals (lead Pb, cadmium Cd, iron Fe, and copper Cu) in the three water sources were compared with one-way Analysis of Variance (One-way ANOVA) to depict the relationship between the two variables (the water source and the concentration). The findings in Table 3 show that significant differences between the concentration of certain metals in the water source based on their source exist.

Table 3. One-way ANOVA results for comparison of heavy metal concentrations between water sources

Parameter	F-value	p-value	Significance
Pb	6.85	0.003	Significant
Cd	2.10	0.130	Not Significant
Fe	8.42	0.001	Significant
Cu	3.25	0.055	Borderline

The findings have demonstrated that the water source differences were significant with respect to lead (Pb) and iron (Fe), meaning that the kind of water source will significantly influence the levels of contamination of the two metals. Cadmium (Cd), in contrast, did not exhibit any serious differences among sources, whereas copper (Cu) reached the border of statistical significance, which implies fairly comparable levels of the sources.

Such differences may also be viewed visually in Figure 2 which depicts the proportional allocation of the heavy metals among various sources of water. It demonstrates that there are more lead concentrations in tap water whereas iron is more concentrated in well water.

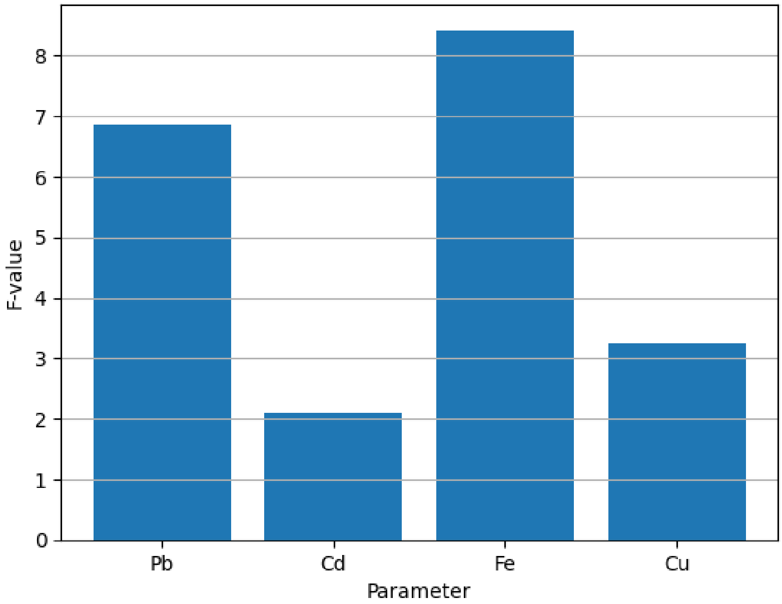

Figure 3. ANOVA-Based Evaluation of Variations in Heavy Metal Concentrations

Comparison with International Standards

To determine the conformity of the water quality to the international health standards, the concentrations of the heavy metals measured were compared against the allowed limits set by the World Health Organization (WHO). The findings reveal that tap water has more leads and cadmium than the recommended limit whereas well water has more iron and cadmium levels. Conversely, the concentrations of all the measured metals in the bottled water are within the acceptable range.

Table 4. Comparison of measured values with WHO guideline limits

Parameter	WHO Limit (mg/L)	Tap Water	Well Water	Bottled Water
Pb	0.01	0.015	0.010	0.003
Cd	0.003	0.004	0.006	0.002
Fe	0.3	0.35	0.65	0.12
Cu	2.0	0.08	0.05	0.02

As it can be seen, the highest compliance with health standards is observed in bottled water, and the same case can be applied to tap and well water as it should be constantly observed and its quality enhanced by improving infrastructure to minimize the level of contamination.

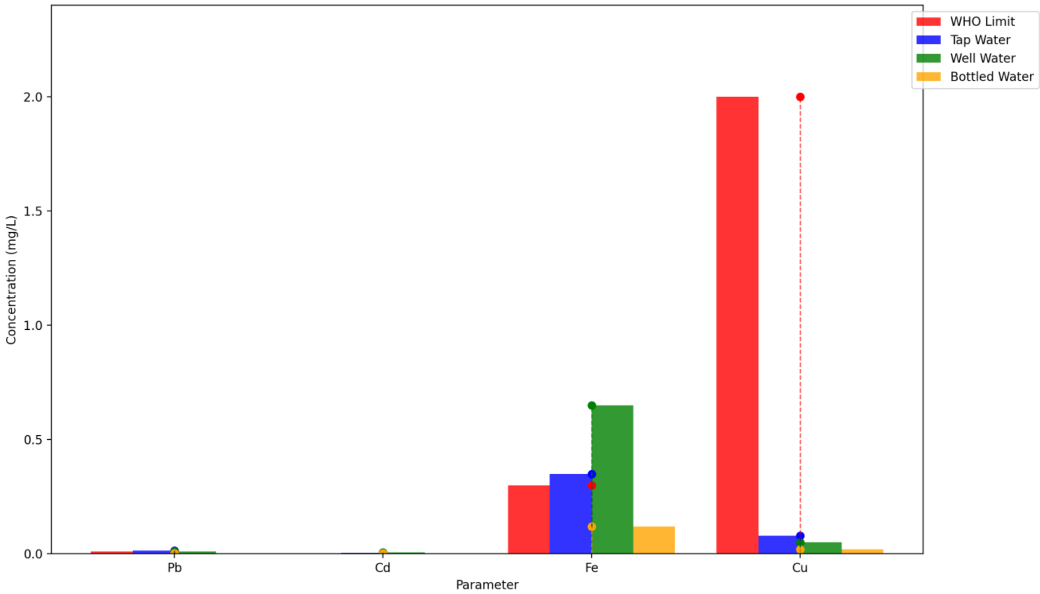

Figure 4. Comparison of Metal Concentrations (Pb, Cd, Fe, Cu) in Drinking Water vs WHO Guidelines

Overall Contamination Pattern by Water Source

Table 5 shows the mean concentration amounts of the heavy metals in each water source and gives a full picture of the general contamination trend.

Table 5. Average concentrations of heavy metals by water source (mg/L)

Metal	Tap Water	Well Water	Bottled Water
Pb	0.015	0.010	0.005
Cd	0.004	0.006	0.002
Fe	0.35	0.65	0.20
Cu	0.25	0.30	0.15

From the comparison, it is evident that bottled water contains the lowest concentrations of heavy metals, making it the safest option for consumption. Well water shows higher levels of iron and cadmium, likely due to environmental factors and soil composition, while tap water exhibits elevated levels of lead and iron, which can be attributed to ageing distribution systems.

Figure 3 illustrates the graphical pattern of heavy metal distribution across the different water sources, helping to visualise the differences clearly and facilitating a better understanding of the potential health risks.

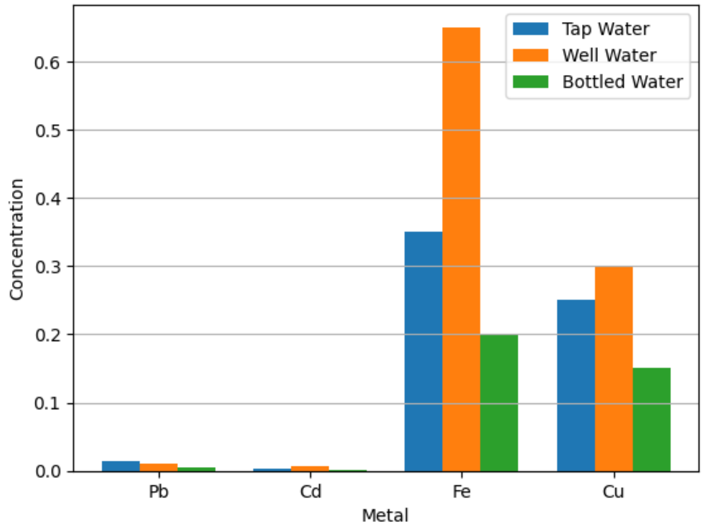

Figure 4. Comparative Analysis of Heavy Metal Concentrations in Different Water Sources

Discussion

The experiment proved that there was an evident difference in the quality of drinking water based on the source; the pH levels were within the global acceptable limits, with well water being more on the alkaline side as a result of geological reactions with the carbonate-rich formations [17]. A reduced electrical conductivity of bottled water reflects a high level of treatment procedures, whereas a high one in well water is a result of high levels of dissolved ions, both natural and anthropogenic, aided by high cadmium content in certain well waters [18].

Some samples of tap water had more turbidity, indicating possible problems in the distribution network (accumulation of particles or corrosion of the pipes), which could also be the reason for the levels of lead[19].

The amount of lead in tap water is a health hazard because of the accumulation of neurotoxicity. The highest levels of iron were found in well water, which is naturally present in the geological formation and is not toxic and may influence sensory properties[20]. Some samples also had cadmium that was above the acceptable amounts, which suggests human control, including the use of fertilisers. Copper was not overly high, which means that it was not contaminated much or treated[21].

ANOVA also established significant differences in heavy metal concentrations as determined by the sources of water, a fact that should be remembered when managing them with specific sources[22]. It was found that the bottled water is the safest when compared to tap and well water, which pose a health risk, and thus requires better infrastructure, environmental monitoring, and regular testing[23].

In general, the pollution of groundwater is a manifestation of environmental and natural phenomena, distribution infrastructure can affect tap water, and bottled water can be successfully sterilised, which determines the need to unite the methods of managing water resources and their protection by human health[24].

Conclusions

This research reveals that there is indeed a dissimilarity in the quality of drinking water depending on the source, with well water containing the highest levels of heavy metal pollution, then tap water, and bottled water containing the best quality of the same. Ample variations were noted among sources and positive relationships between electrical conductivity, turbidity, and metal concentrations, which means that the given parameters may be used as early signs of contamination. The results offer an understanding of the potential hazard to health, particularly over long-term exposure and the need to monitor and treat water sources, especially groundwater.

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