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# Assessment of the Quality of Ground Water in Kalar City- Kurdistan Region- Iraq

**Hnar Ali Karim Al-Jaf** [1]
**Nyaz Fadhil Ahmed Jaf** [1]
[1]University of Garmian, Building and Construction Engineering Department

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**About the Authors:**
**Corresponding author:**
Hnar Ali Karim
**E-mail:** hunar.ali@garmian.edu.krd
**Researcher Involved:**
Nyaz Fadhil Ahmed

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**Abstract**

This paper was carried out to test the quality of ground water in Kalar city- Kurdistan Region- Iraq, bacteria, TDS, calcium, magnesium, sodium, potassium and nitrate were tested in order to the quality assessment. The assessment was done for the water quality of 39 wells in kalar city as case of study. It was concluded that TDS levels of these wells were high levels in general and the main reason was due to high levels of calcium and magnesium. Turbidity, pH, sodium, potassium and nitrate values for the samples of water were in standard region. The maximum and non-standard values of TDS, calcium and magnesium were recorded in sample of well no. 27 in values of 545 mg/l, 149 mg/l and 52 mg/l respectively. The research suggested water softener system to cure the hardness of the ground water by decreasing the high levels of TDS, calcium and magnesium to be in safe ranges. It was also proposed the reverse OSMOSIS removes as a second way of ground water treatment. High level of TDS was reduced to standard range from 545 mg/l to 296 mg/l through the water softener system and reduced to 98 mg/l through the reverse OSMOSIS. It found that ground water may contain bacteria such as E. coli and Coliform, and chlorine treatment can be used to avoid bacteria contaminant.

## 1. Introduction

The quality of ground water of the wells is significant for the human life and health. Cotruvo and Bartram (2009) claimed that approximately 17% of the population in world uses drinking water from unprotected sources. The source of ground water is from underground water from the layer that known as aquifer (Jing, Anua, and Mazlan, 2019). Water moving in pores of soil and rocks around well then minerals from soil and rocks dissolve to the water because water is solvent especially for some materials such as calcium $Ca^{2+}$, magnesium $Mg^{2+}$, sodium $Na^{1+}$, potassium $K^{1+}$and nitrate $NO_3$. (WHO, 2017; Azlan, 2012). So, if the kinds of minerals are available in the soil surrounding well then dissolve to the water and end up with hard water (Skipton and Dvorak, 2016).

Total dissolved solids (TDS) in water are some organic and inorganic materials, which include minerals and ions that dissolved in water. When water passes through soil, stones, transferring pipes then the particles are absorbed into the water (KENT Health Care, 2020). National Science Foundation (2019) and Jing, Anua, and Mazlan, (2019) have pointed out that TDS mainly consists of inorganic salts such as calcium, magnesium, sodium, potassium, chlorides, bicarbonates and sulfates. Hardness in water is high of dissolved materials in water especially calcium and magnesium (Christina et al., 2003).

The Environmental Protection Agency in the US reported that the maximum level of TDS is 500 mg/l (EPA, 2003). Furthermore, table 1 shows that the excellent level of TDS is in range of 50-150 (mg/l). High amount of calcium and magnesium in drinking water can cause health problem such as high blood pressure (Hypertension) and kidney stone (Cotruvo and Bartram, 2009,16; Yang and Chiu 1999; WHO, 2009). The TDS amount in water can be reduced by a water purifier (KENT Health Care, 2020). High TDS level in water leads to hard water, so the TDS amount should be reduced by using water softener (National Science Foundation, 2019; Lantagne, 2008).

In addition, WHO (2017) reported that hardness can be treated with a water softener that uses ion exchange process to reduce the hardness minerals. On the other hand, high level of sodium content in water in form of sodium chloride (salt) can be removed through reverse OSMOSIS purification. The acceptable range of sodium content in drinking water should not more than 200 mg/l as maximum (Iraqi Standard of Drinking Water, 2009; WADH, 2016).

Level of pH indicates the acid and alkaline condition of water. The pH level is from 0 to14, the neutral point of pH is 7. The acceptable pH level of drinking water is from the range 7.0 to 8.5 (Blacks, 2014). The pH range in well water is affected by geological conditions at the area and the type of mineral in local soil and rock (DWHH, 2019). Water with a pH less than 7 is acidic (low pH), however, water with a pH greater than 7 states alkalinity (high pH). Soda ash increases the sodium level of water which may affect human health, the sodium content must be checked after adding soda ash into the water to confirm the acceptable range of sodium content (WHO, 2017). TDS should also be taken in consideration during the selection of pH treatment methods, because additional materials may increase the TDS level in water. In contrast, high level of pH is treated by adding acid through chemical feed pump to inject the acid solution into the water (DWHH, 2019).

Nitrate is the common of chemical materials in water of wells, water contamination of greater than 50 mg/l as $NO_3$ would not be used for the drinking, even in food preparing especially for children (Iraqi Standard of Drinking Water, 2009; McCasland et al., 2020; Rogan and Brady 2009). It causes long term effect like gastric cancer and endogenous due to exposure amount of nitrate (Rogan and Brady 2009). McCasland et al., (2020) and WHO (2011) figured out that nitrate is common in well water in rural areas and excess levels of nitrate can cause methemoglobinemia, or "blue baby" disease. High level of nitrate in water would be reduced through reverse OSMOSIS removes, which is the considerable method. In addition, potassium level normally in drinking water are low and does not cause health concern, potassium chloride uses as water softener to increase its level (WHO, 2009; Kyncl, 2002).

Turbidity is an indicator of water clarity, it looks like cloudy or opaque and would affect the colour of the water. Water becomes turbid due to suspension of some materials into the water such as sand, silt, clay and fine dissolved materials (organic and inorganic). Kotlarz, et al. (2009) pointed out that there are some methods for treating turbid water such as sand filtration, cloth filtration and settling. WHO (2017) stated that the turbidity of drinking water must not be more than 5 nephelometric turbidity unit (NTU).

In this research the assessment is done for water quality of some wells in kalar city from Kurdistan Region of Iraq as case of study. In Kalar city approximately 60% of population uses water from the source of wells (Directorate of Water and Sewerage of Kalar, 2020). So the test of water quality of the

wells in Kalar should be in consideration more seriously.
The main aim of this study is to test the ions and minerals contaminant of samples of water from wells in order to check the wells for the purpose of using them as a source of drinking and household purposes and propose the ways of improvement for the ground water quality.

**Materials and Method**

The study included the physical, chemical and bacteriological evaluation for the well water quality. It focused on some materials that contaminate in water of wells such as calcium $Ca^{2+}$, magnesium $Mg^{2+}$, sodium $Na^{1+}$, potassium $K^{1+}$ and nitrate $NO_3$. In addition, the pH levels of the wells were determined to know about the acidity and alkalinity of the water. TDS level assessment was used to indicate the hardness level of well water.
Regarding the physical consideration, the turbidity of water for the wells was tested. The samples were collected from the wells directly without treatment. One form of sample testing was used for all wells, and the samples were collected and tested in the same day at the morning between 9 to 12 AM.
The samples were tested in the laboratory of directorate of water and sewerage of Kalar. Figure 1 shows the locations of the total number of wells in Kalar city. The samples were collected from 39 wells in Kalar city- Kurdistan Region-Iraq, such as wells number (4, 5, 9, 10, 12, 15, 16, 17, 23, 25, 26, 27, 28, 29, 31, 32, 34, 35, 36, 42, 43, 45, 50, 52, 53, 55, 56, 57, 62, 63, 65, 66, 68, 71, 76, 78, 79, 85, 91). The depth of the wells is between 80 to 100 *m* below the ground level and the static water table in Kalar city is between 15 to 25 *m* below the ground level in general as showed in table 2 (Directorate of Water and Sewerage of Kalar, 2020).
Sample of Well no. 27 was passed into the reverse OSMOSIS and water softener system as a treatment and to check the reliability of these two methods in quality of water. Then the samples were collected after treatments for the both methods and tested again for the same previous tests. Regarding the bacteriology assessment, water samples were collected from 7 wells such as wells number 5, 10, 16, 27, 53, 55 and 63, in order to explore the bacteria contaminants such as Escherichia coli (E. coli) and Coliform.

**Results and Discussion**

Table 3 illustrates the results of the tests which have done for the 39 wells water in order to show the level of calcium $Ca^{2+}$, magnesium $Mg^{2+}$, sodium $Na^{1+}$, potassium $K^{1+}$, nitrate $NO_3$, TDS, pH, and turbidity.
The turbidity results show that these wells do not need physical treatment because their turbidities are zero. The maximum level of pH is 7.6 for the wells numbers 27, 29 and 35 and the minimum is 6.9 for the well number 9. So, the levels of pH are accepted because all levels are in range of 6.5 to 8.5.
Maximum level of TDS is recorded from the well no. 27 which is 545 (mg/l) and the second largest value is from well no. 35 by amount of 514 (mg/l). These values illustrate that the well water contains high amount of dissolves materials. It can be said that the water of these wells needs treatment because the maximum range of TDS in drinking water must not exceed 500 (mg/l) as shown in table 4 (WHO, 2011; Iraqi Standard of Drinking Water, 2009). KENT Health Care (2020) reported that TDS level of water between 50-150 (mg/l) is excellent for drinking, 150-250 (mg/l) is good, 250-300 (mg/l) is fair and 300-500 (mg/l) is poor. Based on the results from table 3, the majority of TDS level is between 300-400 (mg/l) which is in poor range.
While only the TDS of one well (well no. 25) is in excellent range 50-150 (mg/l) which is 142 mg/l. Furthermore, TDS levels of wells no 31 and 71 are in good range 150-250 (mg/l) which are 215 and 192 (mg/l) respectively.
The maximum level of calcium $Ca^{2+}$ and magnesium $Mg^{2+}$are recorded from the same well (no. 27) that recorded the top level of TDS. Well

no. 27 contains 149 (mg/l) of calcium and 52 (mg/l) of magnesium, these values are passes the maximum accepted ranges as shown in table 4. So, the water of well must be treated to be possible for drinking purpose. In addition, the second largest levels of calcium and magnesium are recorded from the well no. 35 which are 110 and 36 (mg/l) respectively. Also, well no. 35 has a high level of TDS. These results confirm that the majority of TDS consists from calcium and magnesium.

Total Hardness (TH) can be figured out in order to check the hardness of the ground water, through the following equation:

$$TH = [Ca^{2+}] \times 2.5 + [Mg^{2+}] \times 4.08$$

The well no. 27 as a critical well is examined with the above equation to check the hardness. It is found out that the total hardness of water sample of well no. 27 is 584.66 (mg/l), while the standard level of total hardness should not exceed 500 (mg/l) (Iraqi Standard of Drinking Water, 2009). Thus, water of well no. 27 is hard and not possible for the drinking purpose.

$$TH = [149] \times 2.5 + [52] \times 4.08 = 584.66 \text{ (mg/l)}$$

The results emphasize that the sodium $Na^{1+}$ is of the main mineral content in well water. The peak level of sodium is 30.9 (mg/l) in well no. 63 and the lowest level is 22.8 (mg/l) in well no. 4. Table 4 shows that the acceptable range of sodium ion should be between 30-180 (mg/l) which is adapted from some reliable sources. So, the sodium levels of all wells water are in safe range and possible for the drinking and other household purposes.

The level of potassium $K^{1+}$ is 4.2 (mg/l) in well no. 5 and 1.5 (mg/l) in well no. 25. Moreover, the peak level of nitrate $NO_3$ is 6.31 (mg/l) in well no. 27 and the lowest level is 0.98 (mg/l) in well no. 31. Thus, these outcomes approve that potassium and nitrate contaminants are in possible range (0-10 mg/l) as shown in table 4.

Figure 2 illustrates the differences in concentration of some elements such as TDS, calcium, magnesium, sodium, potassium and nitrate for the 5 critical wells among the 39 wells, which are well no. 5, 25, 27, 35 and TDS levels of the wells water are high and must be treated to improve their qualities in order to avoid their negative effects on human health. The main reason of high level of TDS is due to high level of calcium and magnesium in water.

This research proposed water softener system as a method of treatment to change the hard water to soft water. It is known that the water softener system is reducing calcium and magnesium and increasing sodium in water by ion exchange. Thus, the water softener system is quite fit to solve the problem of hard water in these wells because the levels of calcium and magnesium are high and the level of sodium is normal. The maximum level of sodium is 30.9 (mg/l) in well no. 63, while the maximum accepted level of sodium in water is 200 (mg/l) (Iraqi Standard of Drinking Water, 2009; WADH, 2016).

This is confirmed that, we will not face problem of high level of sodium content when water softener system is increasing sodium level, but the level of sodium must be detected after the treatment to make sure that sodium is not exceed the standard level.

Potassium $K^{1+}$, nitrate $NO_3$, turbidity and pH in the wells water are in standard ranges and they do not need treatment. Occasionally, these elements in these wells water would be improved in their qualities by mixing water of wells in treatment station to balance their ion contents.

The research proposed the reverse OSMOSIS treatment as a second method of treatment for treating the water of these wells. It can be said that the reverse OSMOSIS purification for the whole water of the wells is not easy before distribution to residential.

So, the water that need for drinking purpose can be treated by reverse OSMOSIS removes and the rest of well water that uses for other purposes does not need treatment.

The data in table 5 approves that reverse OSMOSIS removes and water softener system are both reliable methods to improve the quality of well water. As stated water of well no. 27 is not possible for the drinking purpose due to high levels of TDS, calcium and magnesium that exceeded the acceptable ranges. So, the water of this well is passed into the reverse OSMOSIS removes and water softener system for the treatment. Then the level of TDS is reduced from 545 to 296 (mg/l) through the water softener system and reduced to 98 (mg/l) through the reverse OSMOSIS. Furthermore, the rest of the ions and minerals are also amended within the both treatment methods (table 5).

Figure 3 shows the differences in concentration of main elements such as TDS, calcium, magnesium and sodium for the water sample of well no.27 before and after the treatments by two methods, which are Water softener system and reverse OSMOSIS.

Table 6 shows the bacteria investigation such as Escherichia coli (E. coli) and Coliform for the water samples of 7 wells. Water samples from well no. 10 and 27 are free from bacteria, however well no. 5 and 53 contain both E. coli and Coliform. The results confirm that ground water may contain bacteria such as E. coli and Coliform. Bacteria contaminant in ground water can be avoided through adding chlorine. The chlorine should be added to the water through the injection to the distribution pipe of well water. Moreover, chlorine treatment can be carried out in treatment station.

This research suggests to collect the well water in some treatment stations, in order to pass the water into water softener system and reverse OSMOSIS, then collect in reservoir tank and distribute to people. Moreover, treatment station is also benefit to mix the water of some wells to balance their ions and minerals content. There are some wells that have moderate levels of TDS, so the water of these wells can be mixed with the water of those wells that have high level of TDS to reduce their TDS levels into acceptable range. In addition, treatment station is significant for the chlorine treatment, which allows chlorine to mix properly with water to avoid bacteria contaminant before distribution to the beneficial.

**Conclusion**

In this research the assessment is conducted for 39 wells in Kalar city as case of study. Maximum level of TDS is recorded from the sample of well no. 27 which is 545 (mg/l) and the minimum value of TDS is recorded in well no. 25 in amount of 142 mg/l. The maximum level of calcium $Ca^{2+}$and magnesium $Mg^{2+}$are recorded from the water sample of same well (no. 27), in values 149 (mg/l) of calcium and 52 (mg/l) of magnesium. Moreover, total hardness of this well sample is 584.66 (mg/l) which is unacceptable, thus it is found that the ground water is hard.

It concludes that the ground water contains high level of TDS and the main reason of this is due to high levels of calcium and magnesium in ground water. The turbidities of the assessed wells water are zero because they are fee from sand, silt and clay suspensions, thus these wells are not admired physical treatments. The results approve that the sodium, potassium, nitrate and pH levels of all wells water are in accepted range. The study is also concluded that the levels of calcium and magnesium must be decreased. It is suggested water softener system to cure the hardness of the ground water which is reducing the high levels of calcium and magnesium to be in safe ranges.

It is also proposed the reverse OSMOSIS water purification as a second way of the ground water treatment. Both treatment methods are tested practically to checked their capability in treatment of ground water. Unsafe level of TDS in water sample of well no. 27 is minimized to standard range from 545 mg/l to 296 mg/l through the water softener system and reduced to 98 mg/l through the reverse OSMOSIS. The research is also concluded that ground water may contain bacteria such as E. coli and coliform. Water samples of wells 5 and 63 are both presented E. coli and coliform in amount of more than 16 count/100 ml. The study suggests to collect the well water in treatment stations, in order to pass the water into water softener system and reverse OSMOSIS for the treatment, before distribution to people. Moreover, treatment station is also benefit to mix the water of some wells to balance their ions and minerals content, it is also useful to add chlorine and mix with water properly to avoid bacteria contaminants.

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# تقييم جودة المياه الجوفية في مدينة كلار– إقليم كردستان العراق

**هنر علي كريم الجاف[1]**
**نياز فاضل احمد جاف[1]**
[1] جامعة كرميان، قسم هندسة البناء والإنشاءات

## المستخلص

أجريت في هذه الدراسة قياس تراكيز مكونات المياه الجوفية في مدينة كلار – إقليم كردستان العراق – تم قياس البكتيريا وتراكيز المواد الصلبة الذائبة والكالسيوم $Ca^{2+}$ والمغنيسيوم $Mg^{2+}$ , والصوديوم $Na^{1+}$ والبوتاسيوم $K^{1+}$ والنترات $NO_3$ من أجل تقييم نوعية مياه الشرب التي يكون مصدرها من مياه الابار. تم إجراء التقييم لنوعية المياه في 39 بئراً في مدينة كلار كدراسة حالة. وخلص البحث إلى أن مستويات TDS من هذه الآبار كانت عالية بشكل عام والسبب الرئيسي يرجع إلى ارتفاع مستويات الكالسيوم والمغنيسيوم. كانت قيم التعكر ، الرقم الهيدروجيني ، الصوديوم ، البوتاسيوم والنترات لعينات الماء في المنطقة القياسية. تم تسجيل القيم القصوى وغير القياسية لـــ TDS والكالسيوم والمغنيسيوم في عينة البئر. 27 في قيم 545 مجم / لتر و 149 مجم / لتر و 52 مجم/لتر على التوالي. اقترح البحث نظام تنقية ومعالجة الماء لحل مشاكل عسرة المياه الجوفية عن طريق خفض المستويات العالية من المواد الصلبة الذائبة والكالسيوم والمغنيسيوم لتكون في نطاقات آمنة. كما تم اقتراح إضافة نظام التناضح العكسي كطريقة ثانية لمعالجة المياه الجوفية. تم تخفيض المستوى العالي من المواد الصلبة الذائبة إلى نطاق قياسي من 545 مجم / لتر إلى 296 مجم / لتر من خلال نظام تنقية الماء وخفضه إلى 98 مجم / لتر من خلال التناضح العكسي. وجد أن المياه الجوفية قد تحتوي على البكتيريا مثل البكتريا الإشريكية القولونية والكوليفورم ، ويمكن استخدام المعالجة بالكلور لتجنب التلوث البكتيري.

**الكلمات المفتاحية :** جودة مياه الآبار، معالجة المياه ، إجمالي المواد المذابة (TDS) ، الكالسيوم ، المغنيسيوم.

**Table 1: The TDS range in the water.**

| TDS Level in parts per million (ppm) | Palatability Quotient |
|---|---|
| Between 50-150 | Excellent for drinking |
| 150-250 | Good |
| 250-300 | Fair |
| 300-500 | Poor |
| Above 1200 | Unacceptable |

*Adapted from: KENT Health Care (2020)*

**Table 2: Depth of wells and static level of water below the ground level.**

| Well number | Depth of well below ground level (m) | Water table (static level of water) below ground level (m) | Well number | Depth of well below ground level (m) | Water table (static level of water) below ground level (m) |
|---|---|---|---|---|---|
| 25 | 95 | 21 | 78 | 98 | 20 |
| 76 | 90 | 18 | 65 | 85 | 19 |
| 4 | 85 | 20 | 66 | 90 | 22 |
| 26 | 88 | 22 | 43 | 90 | 20 |
| 29 | 85 | 20 | 53 | 85 | 20 |
| 35 | 85 | 19 | 50 | 80 | 20 |
| 9 | 90 | 21 | 16 | 85 | 19 |
| 52 | 85 | 18 | 17 | 90 | 21 |
| 10 | 80 | 19 | 55 | 90 | 20 |
| 68 | 83 | 20 | 56 | 85 | 22 |
| 28 | 80 | 20 | 57 | 87 | 18 |
| 63 | 80 | 16 | 36 | 90 | 22 |
| 23 | 80 | 16 | 31 | 100 | 23 |
| 45 | 90 | 21 | 42 | 80 | 19 |
| 62 | 85 | 20 | 12 | 80 | 20 |
| 27 | 97 | 21 | 32 | 82 | 20 |
| 34 | 87 | 20 | 15 | 85 | 20 |
| 5 | 95 | 19 | 85 | 80 | 15 |
| 79 | 90 | 19 | 91 | 100 | 22 |
| 71 | 83 | 16 | | | |

*Adapted from: Directorate of Water and Sewerage of Kalar (2020).*

**Table 3: The results of the tests which have done for the 39 wells in Kalar city.**

| No | Well number | Date of test | Turbidity (NTU) | pH | TDS (mg/l) | Calcium (mg/l) | Magnesium (mg/l) | Sodium (mg/l) | Potassium (mg/l) | Nitrate (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 25 | 27-Oct-19 | 0 | 7.3 | 142 | 60 | 26.2 | 26.5 | 1.5 | 2.11 |
| 2 | 76 | 28-Oct-19 | 0 | 7.2 | 329 | 64 | 24.2 | 23.6 | 2.4 | 3.32 |
| 3 | 4 | 28-Oct-19 | 0 | 7.1 | 350 | 60 | 19.4 | 22.8 | 1.9 | 1.68 |
| 4 | 26 | 28-Oct-19 | 0 | 7.3 | 276 | 54 | 30.3 | 27.2 | 3.2 | 1.85 |
| 5 | 29 | 29-Oct-19 | 0 | 7.6 | 301 | 48 | 23.7 | 25.8 | 1.9 | 3.19 |
| 6 | 35 | 29-Oct-19 | 0 | 7.6 | 514 | 110 | 36 | 26.7 | 1.6 | 3.18 |
| 7 | 9 | 30-Oct-19 | 0 | 6.9 | 477 | 54 | 22.3 | 29.4 | 2.4 | 2.11 |
| 8 | 52 | 31-Oct-19 | 0 | 7 | 347 | 60 | 22.5 | 27.7 | 2.8 | 1.68 |
| 9 | 10 | 31-Oct-19 | 0 | 7.2 | 254 | 64 | 35 | 23.8 | 3.1 | 1.82 |
| 10 | 68 | 4-Nov-19 | 0 | 7.3 | 291 | 72 | 51 | 28.6 | 2.7 | 2.35 |
| 11 | 28 | 6-Nov-19 | 0 | 7.2 | 380 | 108 | 23 | 26.1 | 2.8 | 1.88 |
| 12 | 63 | 6-Nov-19 | 0 | 7.5 | 293 | 86 | 27 | 30.9 | 2.1 | 2.53 |
| 13 | 23 | 11-Nov-19 | 0 | 7 | 304 | 88 | 19 | 28.6 | 1.9 | 4.13 |
| 14 | 45 | 13-Nov-19 | 0 | 7.1 | 377 | 128 | 33 | 24.9 | 1.6 | 4.18 |
| 15 | 62 | 13-Nov-19 | 0 | 7 | 264 | 73 | 22 | 27.3 | 1.8 | 5.26 |
| 16 | 27 | 13-Nov-19 | 0 | 7.6 | 545 | 149 | 52 | 25.9 | 2.8 | 6.31 |
| 17 | 34 | 18-Nov-19 | 0 | 7.3 | 298 | 84 | 26 | 27.8 | 1.9 | 1.54 |
| 18 | 5 | 18-Nov-19 | 0 | 7 | 368 | 100 | 39 | 27.5 | 4.2 | 2.49 |
| 19 | 79 | 20-Nov-19 | 0 | 7.2 | 302 | 81 | 16 | 26.6 | 3.1 | 3.28 |
| 20 | 71 | 20-Nov-19 | 0 | 7.3 | 192 | 52 | 21 | 27.4 | 3.9 | 1.6 |
| 21 | 78 | 25-Nov-19 | 0 | 7.4 | 280 | 72 | 22 | 28.4 | 3.5 | 2.97 |
| 22 | 65 | 25-Nov-19 | 0 | 7.3 | 398 | 98.4 | 30.6 | 26.5 | 2.8 | 3.79 |
| 23 | 66 | 27-Nov-19 | 0 | 7.2 | 302 | 81.6 | 16 | 28 | 2.2 | 4.16 |
| 24 | 43 | 27-Nov-19 | 0 | 7.2 | 358 | 96 | 9.73 | 28.5 | 2.8 | 1.46 |
| 25 | 53 | 4-Dec-19 | 0 | 7.1 | 368 | 100 | 32 | 28.9 | 2.3 | 2.76 |
| 26 | 50 | 4-Dec-19 | 0 | 7.3 | 298 | 84 | 26 | 25.9 | 2.9 | 3.41 |
| 27 | 16 | 4-Dec-19 | 0 | 7.3 | 261 | 120 | 9.7 | 28.3 | 3.6 | 1.97 |
| 28 | 17 | 9-Dec-19 | 0 | 7.4 | 307 | 104 | 14.5 | 29.2 | 3.2 | 2.86 |
| 29 | 55 | 9-Dec-19 | 0 | 7.4 | 266 | 107 | 24.3 | 26.7 | 2.8 | 1.54 |
| 30 | 56 | 9-Dec-19 | 0 | 7.1 | 288 | 104 | 7.29 | 24.9 | 2.9 | 3.18 |
| 31 | 57 | 11-Dec-19 | 0 | 7.2 | 307 | 96 | 14.6 | 27.8 | 3.7 | 3.44 |
| 32 | 36 | 11-Dec-19 | 0 | 7.2 | 239 | 120 | 14.6 | 25.6 | 1.9 | 3.01 |
| 33 | 31 | 11-Dec-19 | 0 | 7.3 | 215 | 108 | 24.3 | 26.1 | 3.7 | 0.98 |
| 34 | 42 | 16-Dec-19 | 0 | 7.2 | 285 | 108 | 21.9 | 26.4 | 4.2 | 1.27 |
| 35 | 12 | 16-Dec-19 | 0 | 7.2 | 307 | 80.1 | 20.3 | 26.8 | 3.1 | 1.39 |
| 36 | 32 | 18-Dec-19 | 0 | 7.3 | 327 | 56 | 24.3 | 30.4 | 3.5 | 3.13 |
| 37 | 15 | 18-Dec-19 | 0 | 7.2 | 339 | 104 | 19.4 | 27.5 | 2.2 | 1.84 |
| 38 | 85 | 19-Dec-19 | 0 | 7.3 | 327 | 72 | 14.6 | 27.4 | 3.3 | 2.33 |
| 39 | 91 | 19-Dec-19 | 0 | 7.3 | 352 | 112 | 14.6 | 27.9 | 3.8 | 2.57 |

**Table 4: The minimum and maximum levels of chemical water elements that show the possibility of water for drinking purpose.**

| Water contaminant | Minimum level | Maximum level |
|---|---|---|
| TDS (mg/l) | 50 | 500 |
| Calcium (mg/l) | 40 | 120 |
| Magnesium (mg/l) | 10 | 50 |
| Sodium (mg/l) | 30 | 200 |
| Potassium (mg/l) | 0 | 10 |
| Nitrate (mg/l) | 0 | 50 |
| pH | 6.5 | 8.5 |
| Turbidity (NTU) | 0 | 5 |

*Adapted from: (WHO, 2011; McCasland, 2020; KENT Health Care, 2020; EPA, 2003; Iraqi Standard of Drinking Water, 2009)*

**Table 5: The results of the tests that conducted for the well no. 27, water softener system and Reverse OSMOSIS removes.**

| Water sample | pH | TDS (mg/l) | Calcium (mg/l) | Magnesium (mg/l) | Sodium (mg/l) | Potassium (mg/l) | Nitrate (mg/l) |
|---|---|---|---|---|---|---|---|
| Well no. 27 | 7.6 | 545 | 149 | 52 | 25.9 | 2.8 | 6.31 |
| Water softener system | 7.4 | 296 | 83 | 31 | 58 | 2.4 | 6.15 |
| Reverse OSMOSIS removes | 7.2 | 98 | 32 | 8 | 2.3 | 0.3 | 2.9 |

**Table 6: The results of the bacteriological test.**

| Bacteria | Unit | Well no. 5 | Well no. 10 | Well no. 16 | Well no. 27 | Well no. 53 | Well no. 55 | Well no. 63 |
|---|---|---|---|---|---|---|---|---|
| Escherichia coli (E. coli) | Count/ 100 ml | >16 | 0 | 0 | 0 | >16 | 0 | >16 |
| Coliform | Count/ 100 ml | >16 | 0 | >16 | 0 | 0 | >16 | >16 |

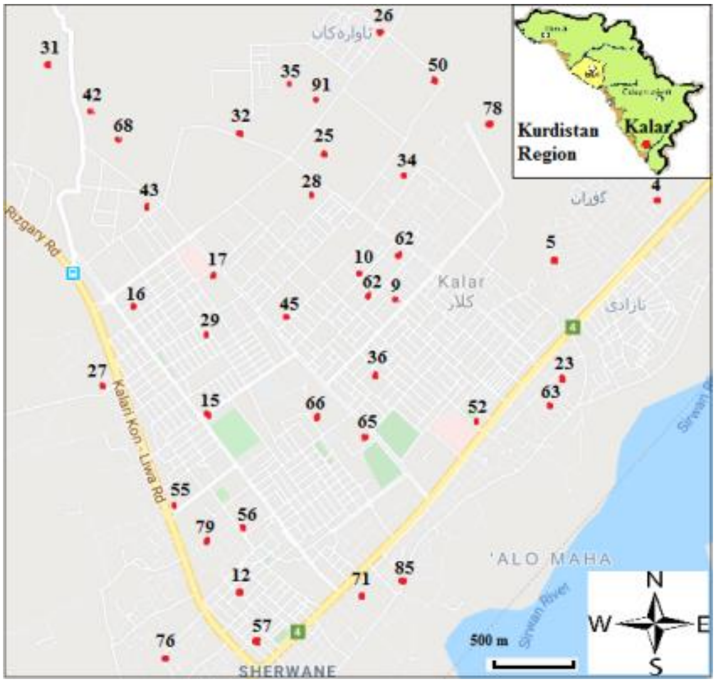


**Figure 1: Location of wells in Kalar city of Kurdistan Region- Iraq**

(Adapted from Directorate of Water and Sewerage of Kalar, 2020).

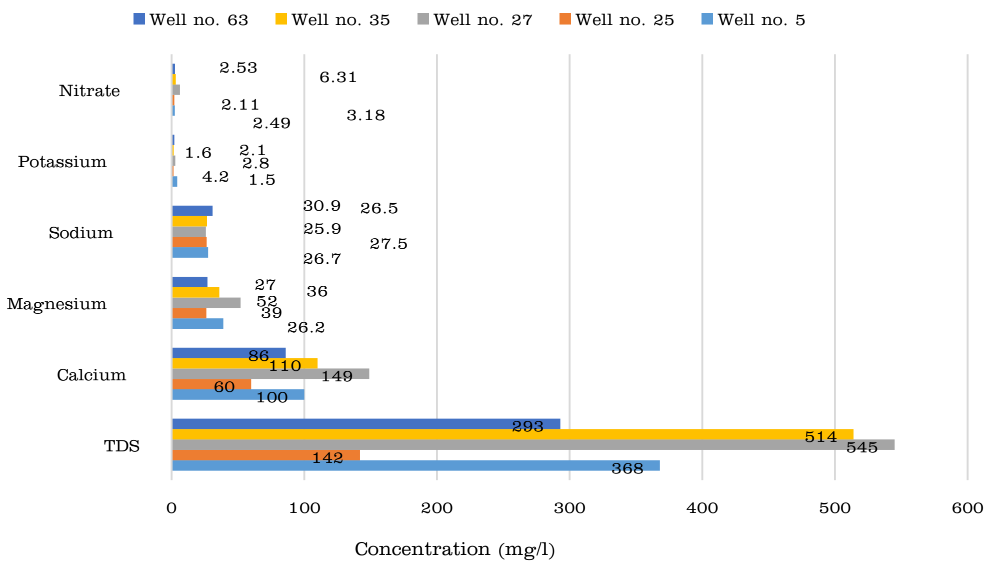


**Figure 2: Concentration of water elements for the 5 critical wells (Wells no. 5, 25, 27, 35 and 63).**

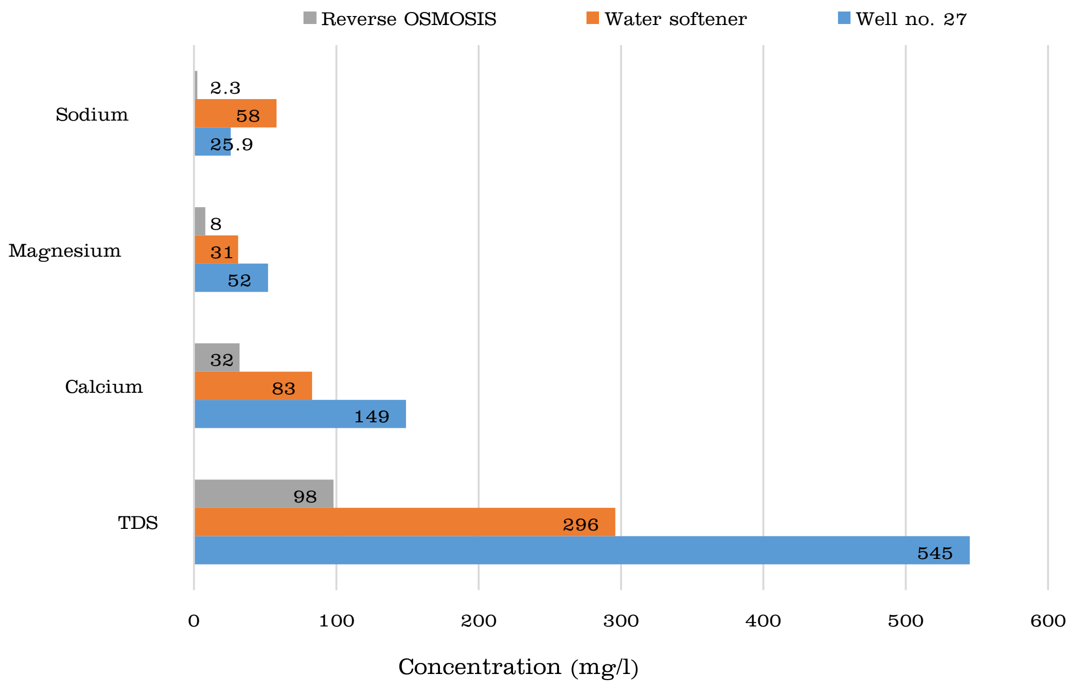


**Figure 3: Differences in concentration of TDS, calcium, magnesium and sodium in water sample of well no. 27 before and after treatments.**