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Water Quality Analysis of Underground Reservoirs in Hot and Arid Regions

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ABSTRACT

Drinking water resources are limited, and this issue is one of the most important problems in our modern world. Access to clean and safe drinking water is an essential need for all communities. In hot and arid or semi-arid regions, collecting and storing rainwater in underground reservoirs provides a major resource of potable water, particularly in rural zones. Due to the lack of water resources, providing sufficient drinking water is extremely difficult in these regions. In this paper, the water quality of underground reservoirs in 6 villages among 20 villages around Khusf City, which is located in a hot and arid region in the South Khorasan province of Iran, is analyzed using physical, chemical, and microbial tests. Additionally, an experimental design method is employed to evaluate the quality of water. The physical and chemical tests show that several parameters such as pH, Total Hardness (TH), Chloride, Sulfate, Nitrite, Nitrate, Calcium, Magnesium, Sodium, Potassium, and Manganese are within an acceptable range of World Health Organization (W.H.O.) standards for drinking water; however, some parameters including Turbidity, Electrical Conductivity (EC), Fluoride, Iron, and Total Dissolved Solids (TDS) are outside of the standard acceptable range. In terms of microbial parameters in 100 *ml* of the samples, the percentage of Coliforms reaches 77% in the presumptive stage, and 33% in the confirmed stage, which are higher compared to the standards. Also, Faecal Coliform is observed in 11% of the samples. The obtained results indicate that the physical and chemical quality of water in the reservoirs is to a large extent within the acceptable range, while the microbial parameters are not at an appropriate level.
KEYWORDS: Underground Reservoir, Water Quality, Arid and Semi-arid Regions, Drinking Water

1. INTRODUCTION

Water is the basis and origin of life on Earth. All of the earliest civilizations were established around water resources. In addition, water is a substantial element in civilization's development. Nowadays, accessing water resources is an important factor to achieve sustainable development. In fact, water plays a key role in underpinning all aspects of sustainable development [1]. Water also has a major impact on all social and economic activities and development, healthy ecosystems and human survival itself [1, 2]. In 2015, the population of the world was roughly 7.3 billion people [3], but the world's population will reach over 9 billion people in 2050 [4]; thus, population growth and other factors such as climate change, food and energy security policies, industrial growth, increasing farming, macro-economic processes and urbanization will create critical challenges, such as a growing water shortage for water supply systems [1, 5-9].

About 75% of Earth's surface is covered by water, but the volume of freshwater available in the world represents only a small part of the Earth's total water (approximately 2.5%). Of this amount, less than 1% can be accessed for human needs [10, 11]. The shortage of water in many parts of the world is owing to the excessive harvesting of water resources, because global water demand has increased for various sectors including food, energy, and other human uses. The water shortage can be determined by different methods, such as "per capita availability" and "percentage of water resources used" [12]. Fig. 1 indicates total renewable water resources per capita in 2013. As can be seen in Fig. 1, the areas with the greatest limitation in renewable water resources, as well as water shortage potentials, are in the Middle East, North Africa, sub-Saharan Africa, and Central Asia. According to Fig. 2, these areas are situated mostly in arid or semi-arid regions. The amount of precipitation in arid or semi-arid regions is in the range of 0-300 *mm* and 300-600 *mm*, respectively [13]. As a result, conservation and management of water resources in these regions is a very important issue.

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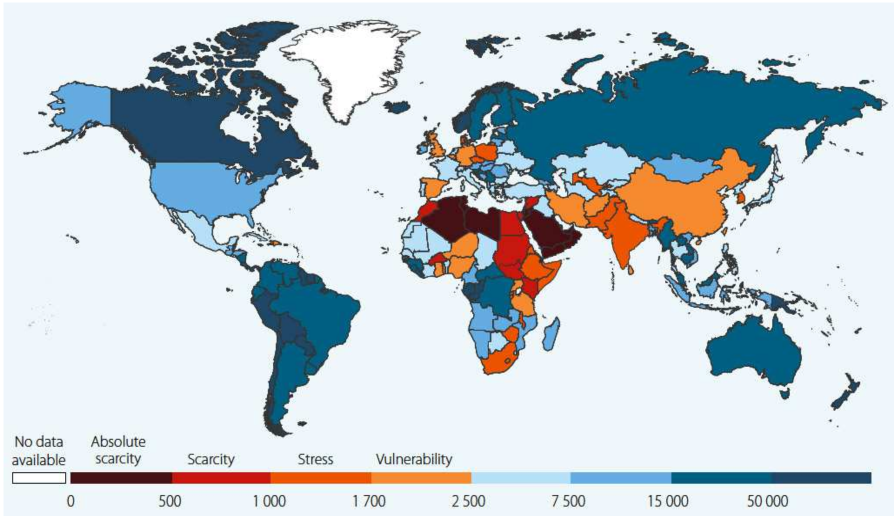

Fig. 1. Total renewable water resources per capita. The numbers are in m^3 [1].
Source: WWAP[1], with data from the FAO AQUASTAT database [1, 14], (collected data for all countries except Andorra and Serbia, external data), and using UN-Water category thresholds.

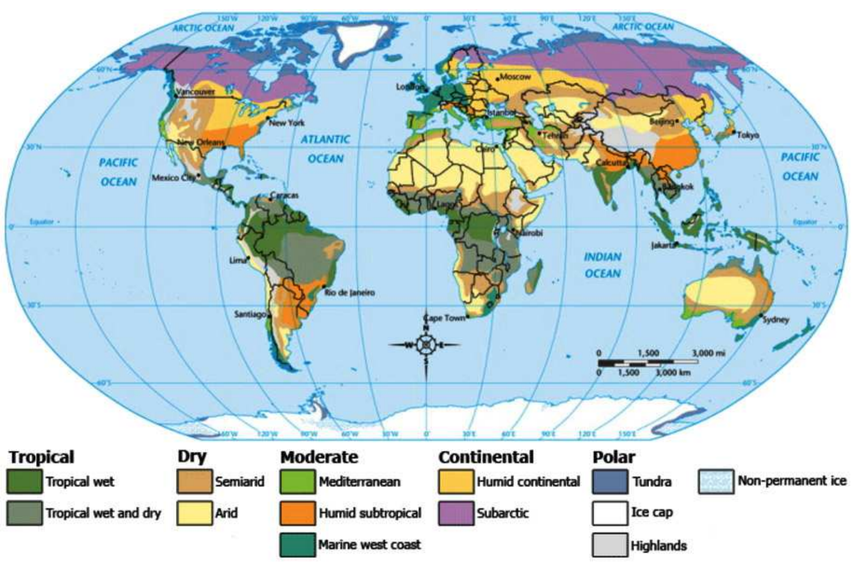

Fig. 2. Climate Atlas of the world [15]

In arid or semi-arid regions, collecting rainwater and storing it in reservoirs is one of the most effective and common strategies to deal with the problem of water shortage. The collected water is used as drinking water, especially in rural zones [16]. Rainwater harvesting systems have a long history, and have been utilized in different areas of the world. For instance, the remains of these systems have been discovered in the Edom mountains of southern Jordan, and date back more than 9000 years [17]. In Iran, different traditional systems for collecting rainwater such as underground reservoirs or cisterns (Fig. 3), "Khoushabs[2]", and "Houtaks[3]" have been used, which date back several millennia [18].

1. World Water Assessment Programme
2 . Dams or open pits to collect rainwater and runoff water
3 . Open water reservoir to collect rainwater and runoff water

Fig. 3. A view of several cisterns in Larestan, Fars Province, Iran

The water quality in underground reservoirs affects human health considerably; therefore, the collected water must be analyzed so that contaminants in drinking water can be removed. Dehghani et al. [16] investigated the quality of water using physical and chemical tests in underground reservoirs for ten villages around Lar City, which is situated in the Fars Province of Iran. The city of Lar is located in a hot and arid climate, and its underground reservoirs are still used there as major sources of drinking water. The results demonstrated that several parameters such as pH, Temperature, Alkalinity, Nitrate, Nitrite, and Turbidity in the water of all reservoirs were at acceptable levels for drinking. However, other parameters (i.e., EC, TH, Chloride, Sulfate, and Fluoride) were not at suitable levels. It should be noted that microbial tests are necessary to determine the drinking water quality in these reservoirs.

Eskandarinejad et al. [19] studied the water quality of underground reservoirs in rural zones around Gonbad-e Kavus City, which is located in the Golestan Province of Iran. The authors analyzed the value of heavy metals such as Chromium and Lead, as well as Faecal Coliforms, in the reservoirs over the course of four months. During this period, 96 samples were collected from 24 reservoirs. To survey microbial parameters, such as total Coliforms, Escherichia coli and Streptococcus faecalis, separated tests and the poor plate were carried out. The results showed that the quantities of Lead and Chromium in 12% and 4% of the samples, respectively, were more than the maximum permissible. In addition, the total Coliforms in 75%, Escherichia coli in 25% and Streptococcus faecalis in 11% of the samples were higher compared to the maximum allowed.

In order to determine the thermal behaviour of water in underground reservoirs, Dehghani et al. [20-28] utilized several different approaches. They selected an underground reservoir in the city of Yazd, which is located in a hot and arid climate in central Iran. The reservoir was filled on one of the coldest days of winter in early January, 2002, and was not used until the first of May. During the discharging period (between May and October), the results illustrated that the water temperature changes in the discharge layer were between 11.5℃ and 13.1℃, whereas the average changes of ambient air temperature were between 23℃ and 38℃. As a result, the water temperature at the outlet of the reservoir was within a suitable temperature range for drinking.

The major purpose of this study is to analyze the water quality of underground reservoirs in 6 villages around Khusf City that are situated in the South Khorasan province of Iran. These villages are unique because they are located in hot and arid regions, and approximately 70% of the population relies on groundwater as drinking water. Previously, no comprehensive evaluation of reservoir water quality had been conducted in this region. To fill the knowledge gap, the physical, chemical, and microbial parameters of water in the reservoirs of the 6 villages were tested. Then, an experimental design method was applied to evaluate the quality of water. Finally, the results were compared with W.H.O. standards for drinking water.

2. METHOD AND MATERIALS

2.1. Investigation Process

In this research, 12 samples of water were taken from different underground reservoirs in the spring and summer of 2010. These reservoirs are located in the various villages of Kouran, Hemmat Abad, Kamar Sabz, Akbarieh, Basiran and Bisheh that surround Khusf City in the South Khorasan province. Fig. 4 shows that South Khorasan is one of the 31 provinces of Iran, which is located in the east of Iran. Khusf City is also situated in a hot and arid region. Note that these villages were selected among 20 villages around Khusf, because they had a higher population and fewer water resources compared to other villages.

The samples were subjected to physical, chemical and microbial tests. The physical and chemical parameters were: Turbidity, pH, EC, Temperature, TH, Calcium Hardness, Temporary Alkalinity, Total Alkalinity, Chloride, Sulfate, Carbonate, Bicarbonate, Nitrite, Nitrate, Fluoride, Calcium, Magnesium, Sodium, Potassium, Iron, Manganese, and TDS. To evaluate the microbial parameters, Coliform (in the presumptive stage and in the confirmed stage), Faecal Coliform, and Heterotrophic Plate Counts (HPC) were studied. After collecting the samples, they were transferred to the laboratory of the Birjand Water and Wastewater Company to be quantified. Then, physical, chemical and microbial analyses were conducted on the collected data.

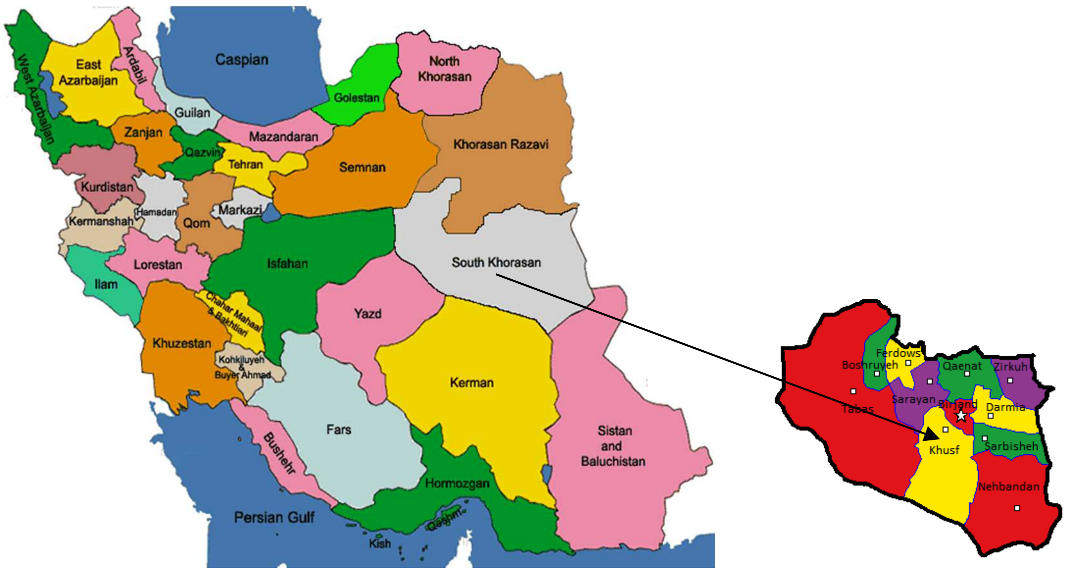

Fig. 4. Maps of Iran and South Khorasan

2.2. Sampling Method and Equipment

The samples were taken from the underground reservoirs according to the procedure outlined in the standard methods of water and wastewater examinations [29]. To determine pH, TDS, and EC, a digital meter was used. To measure the Hardness, Ethylene-Diamine-Tetraacetic Acid (EDTA) titration was applied. To obtain the temperature, a digital thermometer with desirable accuracy was employed. To measure several chemical parameters such as Chloride, Sulfate, Fluoride, Calcium, Magnesium, Sodium and Potassium, an Ion Chromatography (Dionex ICS-5000) was used. Alkalinity was determined by titration with Sulfuric Acid, and Turbidity was specified by Nephelometry. To determine the parameters of Nitrite, Nitrate, Iron and Manganese, a Spectrophotometer was employed [30]. The microbial tests were carried out using a multiple tube fermentation technique and differential tests [29]. Note that to retrieve the water, the temperature and pH measurements were performed on location. In addition, the samples were collected in special test tubes and secured in a bag.

2.3. Experimental Design Method

In order to evaluate the water quality of the underground reservoirs, a general factorial design of experiments was employed. The two categorical factors considered were: (a) the location of the reservoirs and (b) the season of sampling. Six levels for location were used, and the time factor, which has two levels, was introduced by spring and summer. Experiments were conducted in a randomized order to evaluate and analyze the impact of the different variables on some physical and chemical responses. Additionally, factorial designs were used to explore the effects of variables and the interactions between them; in other words, how the impact of one factor differs with the level of another factor in responses. Minimizing the number of runs and cost are included in the advantage of the factorial experiment designs. In this investigation, 12 different runs were conducted in a single replication to estimate the effect of independent factors on the water quality of the reservoirs. The experimental results can be analyzed using the Design-Expert software [31].

3. RESULTS AND DISCUSSION

In this research, physical, chemical, and microbial parameters are measured in the water quality analysis of the underground reservoirs under study in the spring and summer of 2010. Table 1 shows the average values of physical and chemical parameters. The average amounts of microbial parameters are illustrated in Table 2.

In the following sections, the results of the physical, chemical, and microbial tests are analyzed individually and then compared with W.H.O. standards of drinking water. In addition, a design of experiment method is employed to determine the quality of drinking water in the underground reservoirs.

3.1. Physical and Chemical Analysis

The obtained results of the physical and chemical tests, which are shown in Table 1, are discussed as follows:

- *Turbidity*: The parameter of turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates; it has no health effects. The variations of turbidity in the samples were between 1.05 and 84.6 *NTU*, and so the average value of turbidity was 18.85 *NTU*. Based on W.H.O. standards, the maximum allowed is 25 *NTU* [32]. As a result, the value of turbidity in some reservoirs exceeded the acceptable range of W.H.O. standards. It should be noted that due to heavy rainfall, the turbidity in the first sampling was at a high level; however, the turbidity of water in the reservoirs dropped after a lapse of time. This is because rainfall in hot and arid regions firstly leads to runoff on the ground surface and thus absorbs more solutes, suspended solids and colloids so that the water turbidity increases. Later on, once most substances in water bodies are settled, the turbidity of water in the reservoirs will be reduced. The longer the sedimentation time, the more the turbidity will be decreased [33].

Table 1. The average values of physical and chemical parameters

Parameter	Number of Samples	Average	Max. observed	Max. allowed (W.H.O.)
Turbidity (*NTU*)	12	18.85	84.6	25
pH	12	7.97	8.38	8.5
EC (*μmohs/cm*)	12	642.67	1224	1500
Temperature (*ºC*)	12	23.27	29.7	-
TH (*mg/l as* $CaCO_3$)	12	154.80	351.92	500
Calcium Hardness (*mg/l as* $CaCO_3$)	12	135.86	290.73	-
Temporary Alkalinity (*mg/l as* $CaCO_3$)	12	3.46	13.39	-
Total Alkalinity (*mg/l as* $CaCO_3$)	12	84.28	144.16	-
Chloride (*mg/l*)	12	75.03	174.05	600
Sulfate (*mg/l*)	12	125.73	305.74	500
Carbonate (*mg/l*)	12	4.15	16.07	-
Bicarbonate (*mg/l*)	12	94.34	163.07	-
Nitrite (*mg/l as* NO_2^-)	12	0.024	0.083	3
Nitrate (*mg/l as* NO_3^-)	12	3.11	13.05	50
Nitrite plus Nitrate *(mg/l)*	12	0.0699	0.261	1
Fluoride (*mg/l*)	12	0.113	0.45	1.5
Calcium (*mg/l*)	12	54.34	116.29	200
Magnesium (*mg/l*)	12	4.59	14.87	150
Sodium (*mg/l*)	12	71.45	129.82	200
Potassium (*mg/l*)	12	3.81	7.94	-
Iron (*mg/l*)	12	0.145	0.45	0.3
Manganese (*mg/l*)	12	0.144	0.317	0.5
TDS (*mg/l*)	12	386.39	791.76	500

Table 2. The average values of microbial parameters

	Number of Samples	Average	Max. observed	Max. allowed
Coliform in presumptive stage (*CFU/100 mL*)	9	2.38	15	0
Coliform in confirmed stage (*CFU/100 mL*)	9	0.40	7.3	0
Faecal Coliform (*CFU/100 mL*)	9	0.11	3	0
HPC (*CFU/100 mL*)	9	5.77	83	500

- *pH*: The pH level describes the amount of alkalinity or acidity of water, and is one of the important parameters in drinking water treatment. The variations of pH in the reservoirs were from 7.74 to 8.38 so that the average value was 7.97; these values were in the acceptable range of W.H.O. standards, namely, between 6.5 and 8.5 [32].
- *EC*: The parameter of EC is an indication of the concentration of TDS and major ions in a given water body. The EC of the samples was between 242 and 1224 *μmohs/cm*. According to W.H.O. standards (1000-1500 *μmohs/cm*) [32], the value of EC in several reservoirs was lower compared to the standards. In addition, the high value of EC in some reservoirs was due to the high amount of TDS in the water. The relationship between the parameters of TDS and EC is shown in the following formula [34, 35]:

$$TDS = (0.55 \text{ to } 0.7)\, EC \tag{1}$$

- *TH*: The parameter of TH is one of the main properties of drinking water, and is specified as the sum of Calcium and Magnesium hardness. The amounts of TH were in the range of 72.72-351.92 *mg/l as* $CaCO_3$; therefore, these values were suitable since the maximum acceptable range was 500 *mg/l as* $CaCO_3$. Note that the degree of TH based on "local conditions" and "the taste of water" is a variable factor for different societies [36].
- *Calcium Hardness*: The values of Calcium hardness were in the range of 62.68-290.73 *mg/l as* $CaCO_3$ so that the average value was 135.86 *mg/l as* $CaCO_3$.
- *Total Alkalinity*: The alkalinity is defined as the quantitative ability to react with (neutralize) a known quantity of standard acid. Also, total alkalinity is a measure of the amount of alkaline substances in the water. The amounts of total alkalinity were in the range of 34.45-144.16 *mg/l as* $CaCO_3$. It should be noted that the value of temporary alkalinity in some samples was zero; this means that the total alkalinity was equivalent to the Bicarbonate alkalinity.
- *Chloride*: The values of Chloride were in the range of 15.35-174.05 *mg/l*. These values were within the acceptable range of W.H.O. standards. For drinking water, the recommended maximum is 250 *mg/l* [32].
- *Sulfate*: The amount of Sulfate was between 25.1 and 305.74 *mg/l*, and so the average amount was 125.73 *mg/l*. Almost all of these amounts were suitable since the acceptable range of the W.H.O standard for drinking water is from 250 to 500 *mg/l* [32].
- *Carbonate and Bicarbonate*: The values of Carbonate and Bicarbonate in the samples were from 0 to 16.07 *mg/l* and from 42.03 to 163.07 *mg/l*, respectively. Note that the ions of Carbonate and Bicarbonate are the main factors in alkalinity.
- *Nitrite*: The amounts of Nitrite were between 0 and 0.083 *mg/l as* NO_2^-, and so the average amount was 0.024 *mg/l as* NO_2^-. These amounts were acceptable, since the maximum allowable value is 3 *mg/l as* NO_2^-.
- *Nitrate*: The values of Nitrate were from 0.97 to 13.05 *mg/l as* NO_3^-, and so the average value was 3.113 *mg/l as* NO_3^-. These values were acceptable because the maximum allowable value is 50 *mg/l as* NO_3^-. The amount of Nitrate concentration in the samples was variable, and the high Nitrate concentration in most reservoirs was owing to the use of chemical fertilizers on agricultural land around the reservoirs.
- *Nitrite plus Nitrate*: For evaluation of drinking water, Nitrite and Nitrate concentration should be considered together; consequently, the sum of the ratio of the concentration of each to its respective guideline value should not exceed one [36]. The variations of Nitrite plus Nitrate were between 0.024 and 0.261 *mg/l*. These values were within an acceptable range of W.H.O. standards.
- *Fluoride*: The values of Fluoride in the reservoirs were between 0.03 and 0.45 *mg/l*. These values were under the maximum allowable value of the W.H.O. standards; however, for most reservoirs, the value of Fluoride was suboptimal.
- *Calcium*: The amounts of Calcium in the samples were between 25.07 and 116.29 *mg/l*. According to W.H.O. standards, the maximum allowed is equal to 200 *mg/l* [32], so the values of Calcium were acceptable. The parameter of Calcium is one of the major components of water hardness, and water with more than 100 *mg/l* of Calcium is categorized as medium-hard or hard. One of the reservoirs was in the medium-hard category because the amount of Calcium in this reservoir was 116.29 *mg/l*.
- *Magnesium*: The values of Magnesium were from 0.82-14.87 *mg/l*, and so the average value was 4.59 *mg/l*. Based on W.H.O. standards for drinking water, a maximum acceptable level is 50 *mg/l*, and a maximum allowable level is 150 mg/l [32, 36]; thus, the values of Magnesium were suitable in the samples.
- *Sodium*: The obtained measurements for this parameter were in the range of 22.25-129.82 *mg/l*; hence, these values were within an acceptable range of W.H.O. standards.
- *Potassium*: The amounts of Potassium in the samples were between 2.06 and 7.94 *mg/l*, and so the average amount was 3.81 *mg/l*. According to European standards for drinking water, a maximum allowable level is 12 *mg/l* [36]. As a result, the amounts of Potassium in the reservoirs were acceptable.
- *Iron*: The values of Iron in the reservoirs were between 0.01 and 0.45 *mg/l*, and so the average value was 0.145 *mg/l*. 16% of the samples were higher compared to the maximum allowed.

- *Manganese*: The obtained measurements for this parameter were in the range of 0.016-0.317 *mg/l*; therefore, these amounts were within an acceptable range of the standards.
- *TDS*: The parameter of TDS refers mainly to inorganic substances dissolved in water. The principal constituents of TDS are Chloride, Sulfates, Calcium, Magnesium and Bicarbonates. The values of TDS in the reservoirs were between 139.51 and 791.76 *mg/l*. The palatability of drinking water with a TDS level less than 500 *mg/l* is commonly considered to be desirable; hence, several reservoirs were outside the acceptable range of the standards.

The physical and chemical tests showed that some parameters such as pH, TH, Chloride, Sulfate, Nitrite, Nitrate, Calcium, Magnesium, Sodium, Potassium, and Manganese were within an acceptable range of W.H.O. standards for drinking water; however, several parameters, including Turbidity, EC, Fluoride, Iron and TDS were outside an acceptable range of the standard. The physical and chemical parameters can be controlled in the underground reservoirs by using several different methods.

3.2. Microbial Analysis

In order to analyze the microbial quality of water in the reservoirs under study, Coliform in the presumptive stage and in the confirmed stage, Faecal Coliform and HPC were investigated (Table 2). The results showed that the percentages of observed Coliform in the presumptive stage and in the confirmed stage were 77% and 33% in the samples, respectively. Furthermore, Faecal Coliform existed in 11% of the samples. This percentage of Faecal Coliform was observed in the first sampling due to heavy rainfall, which caused the microbial contaminants to enter the reservoirs. It should be noted that the maximum number of observed Faecal Coliform was 3, and it existed in only one of the samples.

There were several reasons for the presence of microbial contaminants in the reservoirs: (a) contamination of the water inlet in the reservoirs because of different pollutants on the ground surface, since rainwater flowing on the ground surface of the surrounding cisterns enters the reservoirs; (b) entrance of any contaminants through ventilation windows in the reservoirs; these windows are made on the roof or the body of the reservoir to ventilate the air and keep the water cool; (c) leakage or entry of runoff from agricultural land, or contamination from human or animal wastes in the reservoirs; and (d) lack of timely dredging, cleaning and chlorinating of reservoirs.

3.3. Experimental Design Analysis

Location and time were determined as categorical factors to study their effects on the physical and chemical water quality of the reservoirs. In this investigation, the statistical design of the experiment methodology is proposed to illustrate the influence of independent variables on responses. The general factorial design, including two factors and a single replication, was carried out under controlled conditions to show the significant factors. As mentioned, the factor of location has six levels, including the villages under study, and the time factor has two levels, which are spring and summer. The matching of two factors and their different levels produced 12 different experiments (Table 3).

Table 3. The independent factors and their levels for the experimental design and obtained results of physical and chemical parameters

Parameter \ Villages	Kouran	Hemmat Abad	Kamar Sabz	Akbarieh	Basiran	Bisheh
Turbidity (*NTU*)	84.6	12.5	11.5	2.4	18.8	6.05
	37.1	43.5	1.93	1.38	5.42	1.05
pH	7.88	8.02	8.08	8.08	8.38	8.19
	7.89	7.86	7.75	7.78	7.98	7.74
EC (*μmohs/cm*)	242	734	997	1128	334	545
	274	392	612	426	804	1224
Temperature (*℃*)	17.1	17.1	17	16.8	17	17.2
	29.3	29.7	29.5	29.7	29.7	29.2
TH (*mg/l as $CaCO_3$*)	72.72	77.65	271.72	325.30	70.89	149.34
	76.70	75.17	185.84	118.45	81.99	351.92
Calcium Hardness (*mg/l as $CaCO_3$*)	62.68	74.28	226.70	271.93	63.15	143.13
	69.13	65.13	176.63	110.30	76.60	290.73
Temporary Alkalinity (*mg/l as $CaCO_3$*)	0.00	4.24	3.18	5.30	0.00	0.00
	5.67	3.09	0.00	0.00	6.70	13.39
Total Alkalinity (*mg/l as $CaCO_3$*)	74.20	65.72	124.55	144.16	46.64	34.45
	84.46	80.85	70.04	64.89	77.25	144.16
Chloride (*mg/l*)	15.35	155.61	101.47	112.92	35.32	33.24
	16.38	36.95	45.24	36.61	174.05	137.25
Sulfate (*mg/l*)	25.1	45.87	229.24	271.62	62.05	175.12

	25.86	55.47	170.8	90.21	51.67	305.74
Carbonate (*mg/l*)	0.00	5.09	3.82	6.36	0.00	0.00
	6.8	3.71	0.00	0.00	8.03	16.07
Bicarbonate (*mg/l*)	90.52	69.81	144.02	163.07	56.9	42.03
	89.01	91.33	85.45	79.17	77.78	142.98
Nitrite (*mg/l as* NO_2^-)	0	0	0.001	0.01	0	0.018
	0.07	0.083	0.014	0.014	0.018	0.063
Nitrate (*mg/l as* NO_3^-)	2.59	13.05	2.02	1.1	2.36	1.53
	2.44	1.5	0.98	0.97	7.46	1.34
Nitrite plus Nitrate (*mg/l*)	0.051	0.261	0.040	0.025	0.047	0.036
	0.072	0.057	0.024	0.024	0.155	0.047
Fluoride (*mg/l*)	0.13	0.45	0.08	0.06	0.1	0.19
	0.09	0.07	0.04	0.03	0.06	0.06

Regarding the temperature parameter, experimental data were studied using the Pareto analysis of variance in order to survey the statistical significance of the model term. In Table 4 (an ANOVA table) the high model F-value, (13682.95) and its low p-value ($p < 0.05$) show that the model is significant. Also, the table verifies that the time factor has a considerable effect on temperature because its p-value is less than α-level. Thus, the model is adequate if ANOVA assumptions are valid. Fig. 5 shows that the points are not well distributed along the inclined line; therefore, transformation is needed.

Table 4. Analysis of variance table before transformation for temperature

Source	F-value	P-value
Model	13682.95	< 0.0001
Time	13682.95	< 0.0001

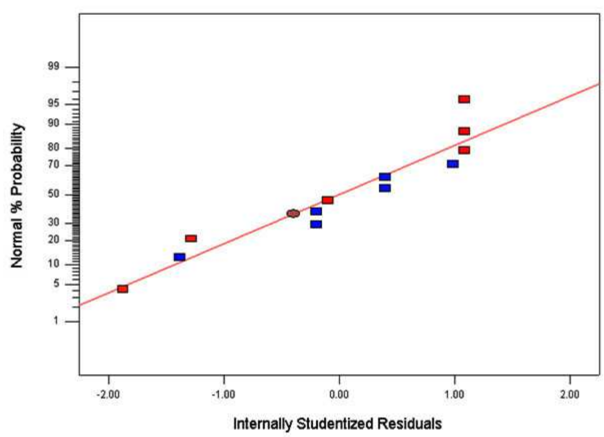

Fig. 5. Normal plot of residuals for temperature

After transformation, it can be seen from Table 5 that the model is significant, so residual plots should be investigated. Fig. 6 (a) illustrates that the points are scattered around the inclined line, which is still acceptable. In addition, Fig. 6 (b) shows that no point is beyond the borders and that there is no defined shape; hence, constant variance of the groups is valid. Finally, Fig. 6 (c) shows that there is no pattern; thus, the independence of the observation assumption is confirmed.

According to Fig. 7, the time factor has a substantial impact on temperature. It is clear that by increasing ambient air temperature, the temperature of water in the reservoirs is increased. It should be noted that temperature is one of the most important water quality parameters. Temperature directly or indirectly affects several physical parameters of water, such as taste, turbidity, colour and odour. Additionally, it has a considerable influence on the rate of dissolved oxygen in water; by reducing temperature, the rate of dissolved oxygen will increase (Fig. 8). Furthermore, according to W.H.O. standards, the maximum allowed temperature of drinking water is within the range of 26.3-32.3*℃* [32]. As a result, all values of temperature in the reservoirs were under the maximum allowable value of the standards.

For the parameter of pH as response, residuals plots were surveyed after checking an ANOVA table. The results demonstrated that ANOVA assumptions were not valid; therefore, transformation was employed. According to Table 6, the model is significant at $p < 0.05$. Moreover, time is a significant factor based on p-value.

Table 5. Analysis of variance table after transformation for temperature

Source	F-value	P-value
Model	14884.51	< 0.0001
Time	14884.51	< 0.0001

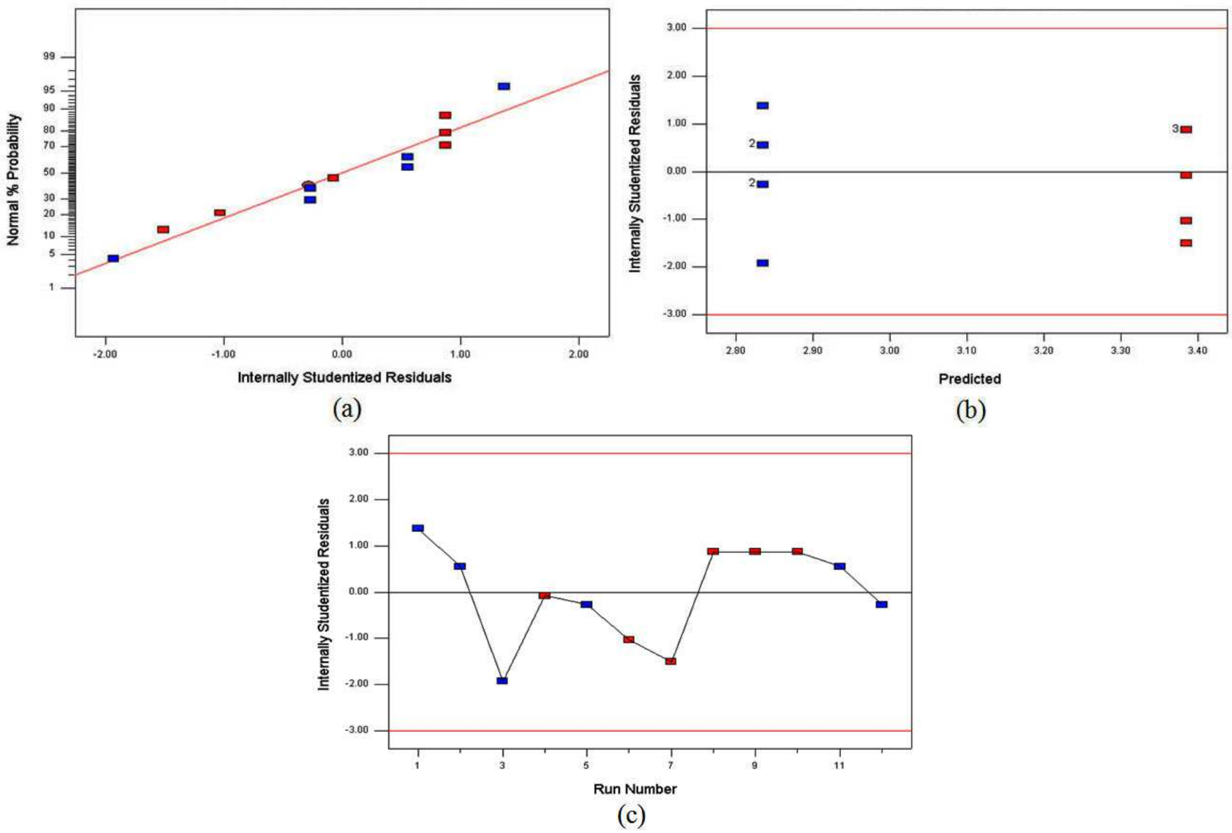

Fig. 6. Residuals plots for temperature, (a) normal plot of residuals, (b) residuals vs. predicted, and (c) residuals vs. run

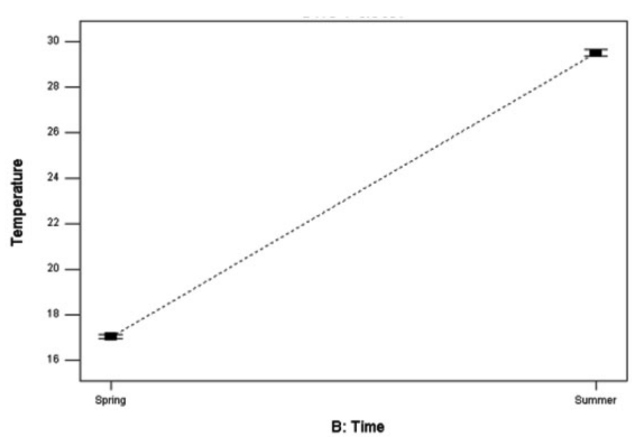

Fig. 7. One factor plot for temperature

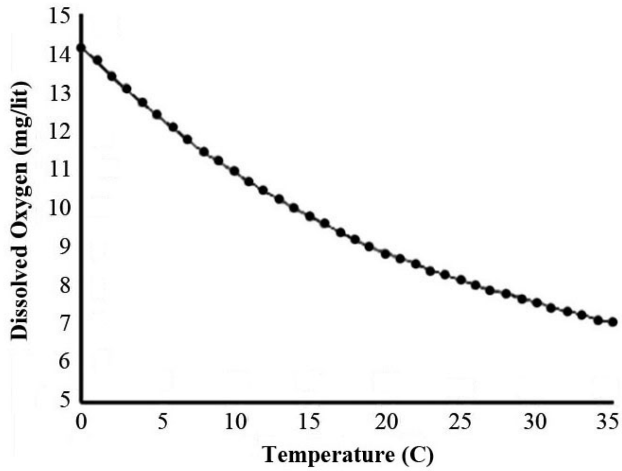

Fig. 8. Oxygen solubility in water at various temperatures [37]

Table 6. Analysis of variance table after transformation for pH

Source	F-value	P-value
Model	12.12	0.0059
Time	12.12	0.0059

The time factor has a considerable influence on the parameter of pH (Fig. 9); when the time factor moves from spring to summer, decreasing the pH of water as a response is shown in Fig. 9. By raising the temperature, the rates of chemical reaction in water are increased; thus, the degree of water solubility and acidity are increased. Hence, the amount of pH in summer has decreased.

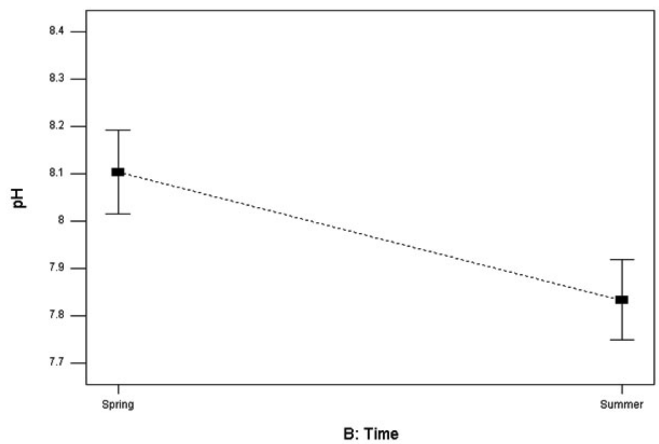

Fig. 9. One factor plot for pH

The parameter of Nitrite has had an effect on the time factor according to an ANOVA table. Nevertheless, residual plots indicated that ANOVA assumptions did not exist. After transformation, the ANOVA table showed that the model is significant and time is the most important factor, since their p-values are less than 0.05 (Table 7). Residual plots verify ANOVA assumptions, which are observed in Fig. 10; thus, adequacy of the model has been proved. Fig. 11 shows that the parameter of Nitrite has been affected by the time factor. As can be seen from Fig. 11, the value of Nitrite increased significantly in summer because the degree of water solubility increased.

Table 7. Analysis of variance table after transformation for Nitrite

Source	F-value	P-value
Model	13.95	0.0039
Time	13.95	0.0039

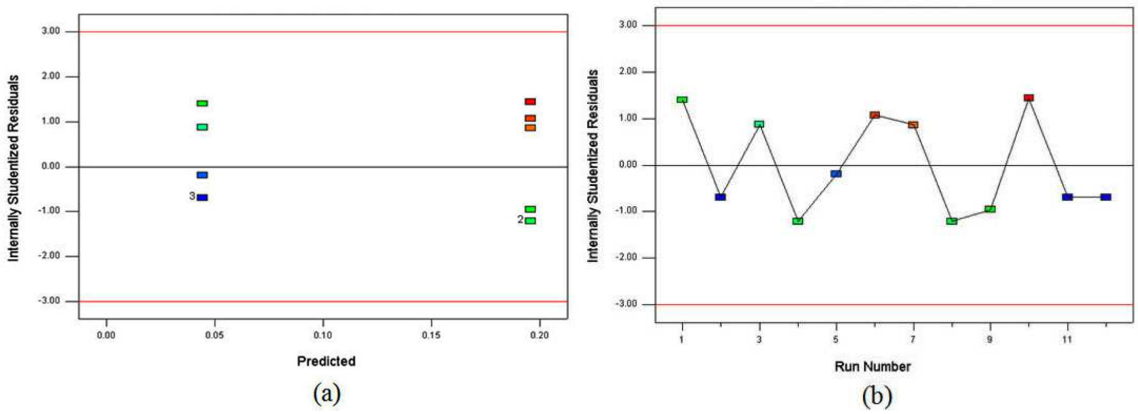

Fig. 10. Residuals plots for Nitrite, (a) residuals vs. predicted and (b) residuals vs. run

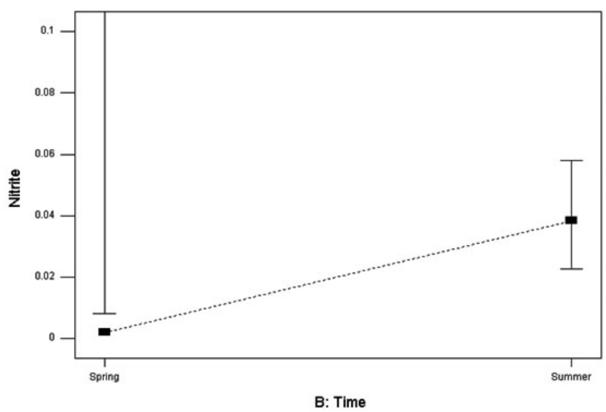

Fig. 11. One factor plot for Nitrite

4. Conclusion

Water as the foundation of life has the most influence on people's well-being, food and energy security, environmental sustainability, and sustainable development. Therefore, water sanitation is an imperative issue in public health and health management. Access to clean drinking water and proper sanitation, particularly in villages situated in arid and semi-arid regions, is a very important factor for survival. Therefore, the physical, chemical and microbial qualities of drinking water can play a significant role in human health in these regions, because unsafe water can lead to various diseases. Another notable issue is that with the increasing global water demand for different sectors, such as agriculture and energy, water shortage is a challenging problem for the world today. To manage and solve this problem, several strategies have been proposed:

(1) The careful management of water resources;
(2) Changing consumption patterns;
(3) Conservation of water resources and effective utilization of these resources;
(4) Collecting surface water, such as rainwater, and storing the water in covered reservoirs (Fig. 12).

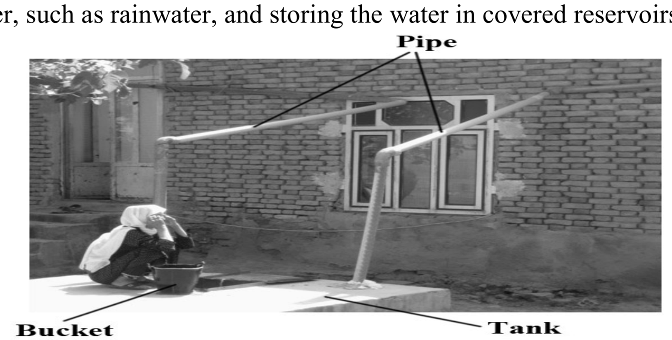

Fig. 12. A view of a system collecting rainwater and storing it in an underground reservoir, which is located in a village around Gonbad-e Kavus City, Golestan province, Iran [16, 38].

This paper analyzes the water quality of underground reservoirs in 6 villages around Khusf City, which were chosen among 20 villages owing to higher population and fewer water resources. For this purpose, the physical, chemical, and microbial parameters of water in the reservoirs are examined. In addition, an experimental design method is used to evaluate the quality of water. It is noteworthy that Khusf City is located in a hot and arid region in the South Khorasan province of Iran. The results show that some physical and chemical parameters such as pH, TH, Chloride, Sulfate, Nitrite, Nitrate, Calcium, Magnesium, Sodium, Potassium and Manganese are within an acceptable range of W.H.O. standards for drinking water. However, other parameters, including Turbidity, EC, Fluoride, Iron and TDS are outside an acceptable range of the standard. In terms of microbial parameters in 100 *ml* of the samples, the percentage of Coliforms reaches 77% in the presumptive stage and 33% in the confirmed stage, which is higher than the standard. Moreover, there is Faecal Coliform in 11% of the samples. According to the obtained results, the physical and chemical qualities of water in the reservoirs are to a great extent within the acceptable range, whereas the microbial parameters are not within a suitable level. As a result, monitoring and controlling the physical, chemical, and microbial parameters of water in the reservoirs are essential in rural zones.

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