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# Assessment of type and usage of thermal water in Mahalat, Markazi province, Iran

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## Abstract

In this study, water samples were collected from 10 thermal and non-thermal springs of Mahalat setting during four periods in 2011. The discharge rates of these springs vary from 2 l/s to 45 l/s and their temperature range from an average minimum of 18°C to maximum 47°C. Spring water is high in $SO_4$-Cl and this is related to gypsum dissolution. Correlation coefficient, principal component analysis, and isotopic data of samples showed there was mixing of young and old water and meteoric water in springs. The quality of water for irrigation was assessed by parameters such as SAR, SSP, RSC, PI, MAR and Kelly's index for major elements ($SO_4^{2-}$, $HCO_3^-$, $Cl^-$, $Ca^{2+}$, $Na^+$, $Mg^{2+}$ and $K^+$). All water quality indices have shown that the water is suitable for irrigation. The metal index of heavy metals (Hg, Zn, Co, As, B, Cu, Mn, Mo and Ni) was compared to the Standard Iranian Guideline values for irrigation and was also used to determine the contamination index. The calculated values have shown that almost all samples are above the threshold of warning and most of the water samples are contaminated.

***Keywords:*** *Mahalat, chemical data, contamination, irrigation, thermal water*

## 1. Introduction

The origin of thermal waters is complex because several parameters effect their composition and final properties, for example, the presence of volcanic activity, movement of water over hot areas, release of rock minerals, presence of carbon dioxide, contact time of water with rocks, as well as the mineral nature of the underlying rocks (Han et al. 2010; Hem 1985; Mimi et al. 1998). In lay terms "thermal water" is defined as water of all types that is usually hot with therapeutic properties. Thermal water has become so because of its long time deep within the earth that has traveled through the geological layers underlying a given site. The ability to use thermal waters is naturally determined by their chemical composition. Springs can be classified into different water types based on compositions of their major ions (Mariner et al. 2003; Minissale et al. 1997). Major ions in spring water include $HCO_3^-$, $Cl^-$, $SO_4^{2-}$, $Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$, which mainly originates from dissolution and mineralization of rocks (Davisson et al. 1994; Minissale et al. 1997). Therefore, water quality of springs is highly associated with their geological conditions and evolution, and hydrochemical composition of spring water can indicate its geological origin (Hair 2009; Tarits et al. 2006).

Furthermore, temperature and pH of springs exhibit high variability, resulting in significant difference in species and quantities of hydrochemical parameters. For instance, bicarbonate ion, which originated from the dissolution of carbonate-rich rocks, controls pH in water and present within the pH range of 4 to10 (Chen and Sung 2009; Gopinath and Resmi). Zhu and Yu (1995) documented that high temperatures in spring water tend to increase dissolution of some of the ions, such as $K^+$, $Na^+$, $Cl^-$ and $SiO_4^{2-}$. Volcanic springs with considerably acidic water quality are rich in sulfate and chloride ions and lack bicarbonate ions.

The study area is situated in the central part of Iran in Markazi province near Mahalat city (Fig 1). Formation of the area is related to the Paleozoic, Mesozoic and Cenozoic eras. Limestone and dolomite with the Permian and Cretaceous age can be widespread in the study area. The geomorphology of the region consists of mountains. The sediments of Eocene in the under-studied region consist of conglomerate, sandstone and marl (Araghi 2009). The most important fault of the region is the Mahalat fault that has an approximately west-east direction and passes through the north of Mahalat city. The length of the fault is about 30 kilometers (Araghi 2009). Climate in the Mahalat is warm and dry, the mean annual temperature is 16°C and the mean precipitation is 350 mm/y. Thermal water in the study area is situated in Mahalat, Iran (Araghi 2009) and has abundant resources of hot and cold springs.

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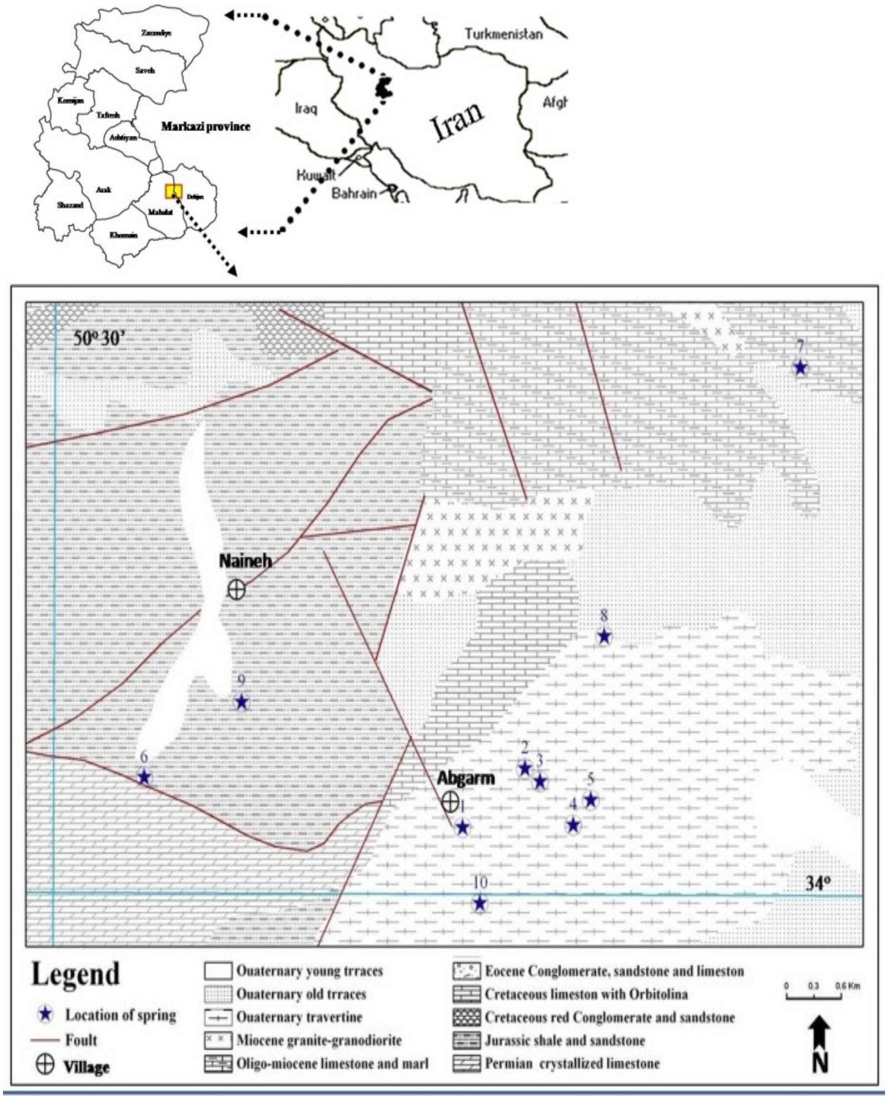

Fig 1. Geological map of Mahalat Abgarm, showing lithology and sample points

Tourism in the spring areas of Mahalat developed over two hundred years. Recently, many villas and hotels are equipped with facilities to use the spring water for bathing and, after cooling down, for irrigation. Hence, the water quality is an important factor for assessing and developing areas (Samsudin et al. 1997). The present study deals with: (1) the characterization of thermal and non-thermal water; (2) the source of thermal and non-thermal water; and (3) classification for irrigation.

## 2. Material and method

In this study, 10 thermal and non-thermal water samples were collected during four periods in 2011. The discharge rates of these springs vary from 2 l/s for thermal Solimani spring to 45 l/s for Shafa spring and their fluid temperatures range between 18$^o$C and 47$^o$C. Water samples were collected by immersing amber glass bottles at the points of hot water emission. All samples were filtered (0.45 micron) and placed in a portable cooler, with ice, immediately after collection to prevent bio alteration. In the laboratory, these water samples were transferred and analyzed within 24 h. Two groups of water samples were collected: One sample for the analysis of cations (metals), which acidified with HNO3); and the other non-acidified one for anions. Temperature, pH and electrical conductivity of waters were measured in the field. Trace elements were determined by inductively coupled plasma mass spectrometry (ICP-MS). Sodium, potassium, calcium, and magnesium were measured by the atomic absorption spectrophotometer. Chloride and sulfate anions were determined by capillary electrophoresis. Bicarbonate was determined by acidimetric titration. Analytical errors are generally <5% for the main components.

Use of poor water quality can create four types of problems, namely toxicity, water infiltration, salinity, and others (Göb et al. 2013). To assess water quality for irrigation, there are several popular criteria: TDS or

EC, sodium adsorption ratio (SAR), chemical concentration of elements like $Na^+$, $Cl^-$, and residual sodium carbonate (RSC) (Michael 1993; Raghunath 1987). For current irrigation water quality assessment, the following parameters were considered (Table 1).

Table 1. Equations for assessment of water quality **(**All ionic concentrations are in meq/l)

| | |
|---|---|
| **Sodium adsorption ratio (Todd and Mays 1980)** | $SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \times 100$ |
| **Soluble sodium percentage (Todd and Mays 1980)** | $SSP = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$ |
| **Permeability index (Doneen 1962)** | $PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$ |
| **Magnesium adsorption ratio (Raghunath 1987)** | $MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$ |
| **Kelley's ratio (Raghunath 1987)** | $KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$ |
| **Residual sodium carbonate (Todd and Mays 1980)** | $RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$ |
| **Percent of sodium (Todd and Mays 1980)** | $\%Na = \frac{(Na^+ + K^+)100}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)}$ |

## 3. Results and Discussion

### 3.1. Quality of chemical data

The accuracy of chemical data can be checked by computing of the ionic charge balance error, which is explained below in Equ. 1. (Lloyde and Heathcote 1985):

$$\text{Reaction Error} = \frac{\sum_{Cations} - \sum_{Anions}}{\sum_{Cations} + \sum_{Anions}} \times 100 \qquad (1)$$

$\Sigma_{Cations}$: sum of meq/l concentrations of cations and Σ anions: sum of meq/l concentrations of anions. If the reaction error of the chemical data set is greater than 10%, the qualities of analysis are questionable (Lloyde and Heathcote 1985). In this study, reaction errors are given in Table 2. All the reaction errors are under the 5% range. Therefore, the quality of chemical data is acceptable according to the ionic charge balance criteria.

### 3.2. Chemical characteristics

Chemical data of springs were mapped on the Piper diagram (Fig 2). The central diamond-shaped figure shows that most of the spring water samples have high $SO_4$-Cl concentrations (Fig 2**)**. According to the Piper diagram it can be said that springs can be rich with any ion depending on the chemical composition of the land. Spatial lithological changes, ion changes, solubility increases, sulfate reductions and so forth can partially affect the properties of thermal water. It is possible the thermal springs have gypsum dissolution because the pH ranges are high and because some of the non-thermal springs also have high amounts of $SO_4^{2-}$ (samples 1, 2, 3, 4, 6, 8, 9 and 10) (Table 3). Table 3 shows saturation indexes for minerals such as anhydrite, aragonite, calcite, dolomite, gypsum, and halite. Results show near saturations of aragonite, calcite and dolomite and under saturations of anhydrite, halite and gypsum minerals.

All of the thermal springs and non-thermal springs fall into $SO_4$-Ca regions but two springs (samples 5 and 7) of non-thermal springs with relatively high bicarbonate are distant from the above group. For thermal springs, the temperature and pH of discharging water range from 35.8 to 47.3°C and from 6.81 to 7.29, respectively (Table 2). The spring water is rich in $SO_4^{2}$ and$^-$, $Ca^{2+}$ ions, and contains small amounts of $Cl^-$, $Mg^{2+}$, $Na^+$, $K^+$, $HCO_3^-$ ions except for spring 7, which is rich in $HCO_3^-$ and $Ca^{2+}$ ions. All of the springs are close to the hydrothermal source; therefore, are rich in $SO_4^{2-}$ and these springs originated from limestone rock with abundant $Ca^{2+}$ ions. Spring 7 is non-thermal and far from the thermal source; therefore, has abundant $HCO_3^-$. Hosted rocks of all the springs are limestone and have abundant $Ca^{2+}$ ions. Major ion composition can act as a track-record of water-rock interaction during flow (Saç et al. 2014). In the thermal spring of Mahalat Abgarm, water flows through limestone aqu $Ca^{2+}$ and $SO_4^{2-}$ in this water. Non-thermal springs are mainly $SO_4$-Ca and $HCO_3$-Ca type and are similar to the type of the thermal water. This may reflect mixing non-thermal springs and thermal springs (Han et al. 2010).

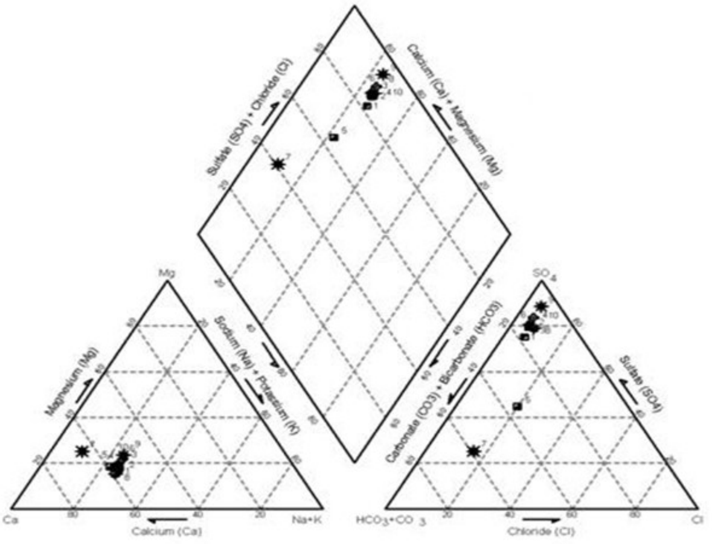

Fig 2. Piper diagram of thermal and non-thermal water

Table 2. Chemical data for thermal and non-thermal waters in the study area

| No. | Name | Tem. | pH | EC | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $SO_4^{2-}$ | $Cl^-$ | $HCO_3^-$ | RE | $\delta^{18}O$ | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **Shafa** | 47.3 | 6.81 | 1674 | 5.84 | 0.08 | 6.1 | 4.78 | 11.72 | 1.43 | 3.75 | -0.29 | -9.40 | -66.5 |
| 2 | **Dombeh** | 46 | 6.92 | 1681 | 5.90 | 0.08 | 6.4 | 4.50 | 12.4 | 1.39 | 3.17 | -0.23 | -9.47 | -68.4 |
| 3 | **Solimani** | 46 | 6.86 | 1683 | 5.49 | 0.09 | 6.6 | 4.78 | 11.91 | 1.41 | 3.56 | 0.23 | -9.29 | -66.6 |
| 4 | **Soda** | 45.1 | 6.83 | 1685 | 5.50 | 0.09 | 7.34 | 4.02 | 11.85 | 1.40 | 3.65 | 0.14 | -9.25 | -63.9 |
| 5 | **Naineh** | 19.9 | 8.16 | 653 | 2 | 0.05 | 2.90 | 1.75 | 2 | 1.61 | 2.60 | 3.79 | -9.11 | -64.3 |
| 6 | **Abgarm** | 35.8 | 7.29 | 1692 | 5.60 | 0.10 | 6.81 | 4.47 | 12.4 | 1.39 | 3.21 | -0.05 | -9.42 | -64.4 |
| 7 | **Ziaratghah** | 18.4 | 7.96 | 339 | 0.42 | 0.04 | 1.60 | 1.29 | 0.62 | 0.60 | 2.23 | -1.47 | -8.97 | -56.8 |
| 8 | **Siagohar** | 18.2 | 7.34 | 1631 | 6.34 | 0.09 | 6.80 | 3.16 | 11.36 | 1.82 | 3.27 | -0.18 | -8.80 | -63.3 |
| 9 | **Talkheh** | 25 | 8.12 | 2470 | 8 | 0.11 | 8.75 | 7.99 | 20.42 | 2.14 | 2.27 | 0.04 | -7.20 | -54.4 |
| 10 | **Biname** | 19.8 | 8.13 | 2170 | 7.22 | 0.10 | 7.96 | 6.50 | 16.48 | 1.79 | 3.52 | -0.02 | -8.52 | -61.3 |

Tem. $^0$C; EC: µmho/cm; Cations and Anions: meq/l; RE: Reaction Error; Isotope Oxygen and Hydrogen Deuterium respectively, δO and D: $^o/_o$

### 3.3. Statistical analysis

Before drawing conclusions on the probable origin, chemical data was examined on the basis of linear correlation in terms of the significant positive correlation coefficient, $r>0.70$, at $p<0.05$. Strong positive correlations were observed for EC, $Cl^-$, $SO_4^{2-}$, $Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$ (Table 4), indicating the existence of a common source of these data in the thermal and non-thermal water (Hair 2009). Principal component analysis was selected as a useful tool to better understand the relationships among the variables and to reveal groups that are mutually correlated within a data. This procedure reduces overall dimensionality of the linearly correlated data by using a smaller number of new independent variables called principal components. Therefore, the purpose of principal components is to discover a system of organized observations where a number of variables share properties in common (Everitt et al. 1993; Kaasalainen and Stefánsson 2012). This helps define source of variables, such as chemical concentrations and their interpretation in terms of possible sources (Jobson 2012).

Principal component analysis was carried out and reduced the data set to two factors. The total variance explained by these two components accounts for 91.86% of the variability of the data (Table 5). Factor 1 is clearly distinct from the others, mainly by their higher EC, $Cl^-$, $SO_4^{2-}$, $Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$. The sequence $Ca^{2+} > Mg^{2+}$ is similar to the general sequence for groundwater composition outlined by Chebotarev (Chebotarev 1955). When $Ca^{2+} > Mg^{2+}$, it means that young/surface water is present. A young fraction in a confined aquifer suggests possible modern recharge continuity with surface/shallow waters, or mixing of young and old water. The factor 2 contains the water samples that are distinguished due to their negative pH and positive $HCO_3^-$. This factor belongs to the spring (sample 7), that is distant from other springs.

### 3.4. Isotopic analysis

Isotopic data are presented in Table 2. Values of D are in the range -68.4‰ to -54.4‰. Values of $\delta^{18}O$ are in the range -9.47‰ to -7.20‰. All samples fall under the meteoric water line (MWL) indicating no significant evaporation during recharge and lack of higher temperature water-rock interaction (Fig 3). The samples from Mahalat Abgarm seem to be a mixture of an old groundwater component with negative isotopic values and a component of isotopically enriched modern groundwater. Therefore, thermal waters in the study area have meteoric origin, and hence we can use these waters for irrigation.

Table3. Calculated Saturation index (SI) for thermal and non-thermal spring waters in the study area

| | Shafa | Dombeh | Solimani | Soda | Abgarm | Naineh | Ziaratghah | Siagohar | Talkheh | Biname |
|---|---|---|---|---|---|---|---|---|---|---|
| **Anhydrite** | -0.71 | -0.71 | -0.71 | -0.72 | -0.75 | -0.69 | -0.92 | -0.58 | -1.74 | -0.55 |
| **Aragonite** | -0.12 | -0.17 | -0.13 | -0.06 | -0.14 | 0.45 | 0.10 | 0.39 | 0.61 | 0.35 |
| **Calcite** | 0.01 | 0.04 | 0.01 | 0.07 | 0.01 | 0.60 | 0.24 | 0.54 | 0.75 | 0.50 |
| **Dolomite** | -0.20 | -0.33 | -0.31 | -0.34 | -0.25 | 0.79 | 0.18 | 0.63 | 1.49 | 0.68 |
| **Gypsum** | -0.62 | -0.62 | -0.60 | -0.62 | -0.62 | -0.46 | -0.69 | -0.34 | -1.51 | -0.36 |
| **Halite** | -6.88 | -6.85 | -6.82 | -6.87 | -6.88 | -6.73 | -6.40 | -6.53 | -6.81 | -6.23 |

Table 4. Correlation Coefficient matrix for selected chemical parameters in water samples

| | pH | EC | $HCO_3^-$ | $Cl^-$ | $SO_4^{2-}$ | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ | $Na^+$ |
|---|---|---|---|---|---|---|---|---|---|
| **pH** | 1 | | | | | | | | |
| **EC** | -0.17 | 1 | | | | | | | |
| **$HCO_3^-$** | -0.73 | 0.39 | 1 | | | | | | |
| **$Cl^-$** | 0.21 | 0.75 | 0.10 | 1 | | | | | |
| **$SO_4^{2-}$** | -0.13 | 1.00 | 0.32 | 0.73 | 1 | | | | |
| **$Ca^{2+}$** | -0.25 | 0.98 | 0.47 | 0.73 | 0.97 | 1 | | | |
| **$Mg^{2+}$** | 0.02 | 0.94 | 0.19 | 0.69 | 0.96 | 0.88 | 1 | | |
| **$K^+$** | -0.21 | 0.96 | 0.42 | 0.71 | 0.96 | 0.98 | 0.66 | 1 | |
| **$Na^+$** | -0.23 | 0.99 | 0.45 | 0.78 | 0.97 | 0.98 | 0.69 | 0.95 | 1 |

Table 5. Varimax normalized rotated principal component loading of selected data in water samples

| Chemical data | Factor 1 | Factor 2 |
|---|---|---|
| **pH** | 0.02 | -0.94 |
| **EC** | 0.97 | 0.18 |
| **$HCO_3^-$** | 0.24 | 0.88 |
| **$Cl^-$** | 0.84 | -0.20 |
| **$SO_4^{2-}$** | 0.97 | 0.14 |
| **$Ca^{2+}$** | 0.95 | 0.27 |
| **$Mg^{2+}$** | 0.94 | -0.01 |
| **$K^+$** | 0.94 | 0.23 |
| **$Na^+$** | 0.95 | 0.25 |
| **Eigenvalue** | 6.53 | 1.72 |
| **Total variance %** | 72.64 | 19.21 |
| **Cumulative %** | 72.64 | 91.86 |

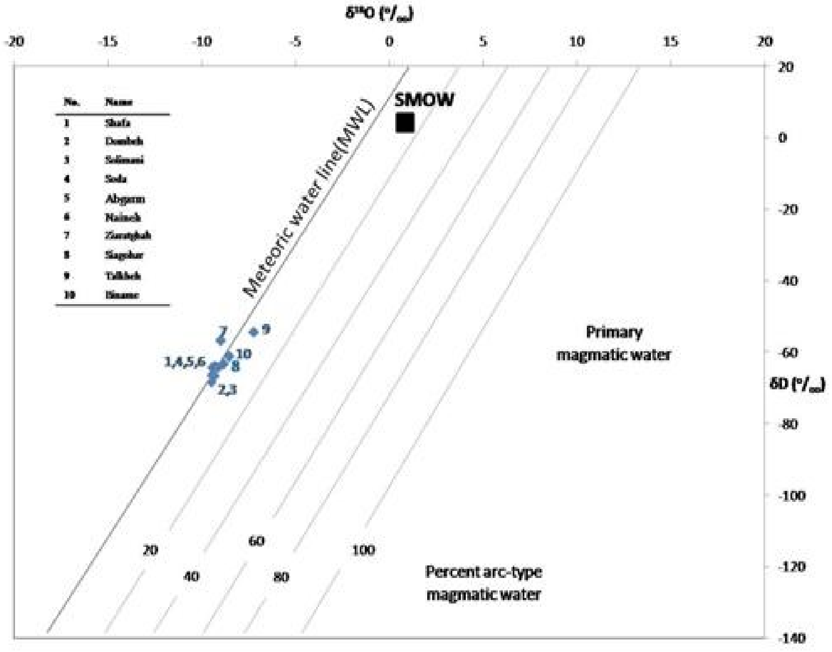

Fig 3. δ18O vs. D plot in thermal and non-thermal water in the study area (Han et al. 2010)

## 3.5. Usage of thermal water

The development and maintenance of successful irrigation projects involve not only the supplying of irrigation water to the land, but also the control of salt and alkali in the soil. The characteristics of water for irrigation, which are important in determining its quality, are: (1) total concentration of soluble salts; (2) relative proportion of sodium to other principal cations (magnesium, calcium, and potassium); (3) concentration of other elements that may be toxic to plants; and (4) the bicarbonate concentration, under some conditions, related to the concentration of calcium and magnesium. Important parameters with respect to the use in irrigation are represented in Table 1. The total concentration of soluble salts in irrigation water can be adequately expressed in terms of electrical conductivity for purposes of diagnosis and classification. In general, water having conductivity below750 mhos/cm is satisfactory for irrigation. Water has a range 750 to 2250 µmhos/cm in the study area. In our study, (EC) varied in the range from 339 µmhos/cm to 2470 µmhos/cm. About 10% of the water samples have EC higher than 2250 µmho/cm (samples 9) and continuous application of such water may lead to formation of saline soils. The relative proportion of sodium to other cations in irrigation water usually has been expressed as the percentage of sodium among the principal cations called as the percent sodium. Percent of sodium varied from 13.73 to 39.23. Based on percent of sodium (Wilcox 1955), it was observed that all of the samples, with %Na value >60, to be good to excellent for irrigation (Fig 4). Based on Wilcox diagram, 20% of samples were in the range of doubtful to unsuitable class (samples 9 and 10), 60% in the class of good to permissible (samples 1, 2, 3, 4, 6 and 8 ) and samples 5 and 7 were in class of excellent to good (Fig 4).

The sodium adsorption ratio (SAR), used to express the relative activity of sodium ions in exchange reactions with soil, is a measure of suitability of water for irrigation with respect to the salinity (sodium) hazard. The SAR of water samples ranged from 0.35 to 2.84. The water having SAR < 10 is good for irrigation. It was observed that all samples studied were good for irrigation. Sodium adsorption was stimulated when $Na^+$ proportion increased as compared to $Ca^{2+}$ and $Mg^{2+}$ resulting in soil dispersion (Rhoades et al. 1992). The SAR was also expressed as Sodium Hazard. In SAR the $Ca^{2+}$ and $Mg^{2+}$ ions are important since they tend to counter the effects of sodium. Continues use of water having high SAR leads to the breakdown of the physical structure of the soil particles. Sodium would be absorb and become attached to the soil particles. The soil then becomes hard and compact when dry and increasingly impervious to water penetration. The degree to which irrigation water tends to enter in the cations exchange reaction in soil can be indicated by the sodium absorption ratio. Sodium replacing adsorbed calcium and magnesium is a hazard as it causes damage to the soil structure (Nishanthiny et al. 2010). In water having a high concentration of bicarbonate, there is a tendency for calcium and magnesium to precipitate since the water in soil becomes more concentrated as a result of evaporation. The calcium and magnesium are precipitated as carbonates, and any residual carbonate or bicarbonate is left in the solution as residual sodium carbonate (RSC) or bicarbonate hazard. RSC remained negative for most of the water samples, thus showing that the water was good for use in irrigation. When the excess carbonate concentration becomes too high, the carbonates combine with calcium and magnesium to form a solid material that settles out of the water (Dhembare 2012). The RSC value < 1.25 is safe for irrigation, a value between 1.25 and 2.5 is of marginal quality and a value > 2.5 is unsuitable for irrigation. In this study, the RSC value was in the range of minimum-14.47 to maximum of -0.66. However, water is suitable for irrigation.

The minimum SSP value observed is 12.53, while maximum value was recorded at 38.68 (sample 8). The SSP values for all samples are under the permissible level 60% for irrigation. Ideally, water intended for agricultural use should have a lower concentration of sodium ions and higher amount of calcium and magnesium ions (Rahman et al. 2012). The average PI (Permeability Index) value varies from 0.34 to 0.57. The highest PI was found in sample 7 and the lowest in sample 9. PI was satisfied in the study area. To be considered satisfactory, irrigation water should have PI <1 according to Donen's chart (Raghunath 1987). MAR (magnesium adsorption ratio) causes a harmful effect when it exceeds a value of 50 (Gupta and Gupta 1987). In the present study area, the average MAR ranged from 31.72 in sample 8 to 47.72 in sample 9. However, in terms of MAR, all of the samples are acceptable for irrigation (Table 6). Klatt et al. (2013) suggested that KR (Kelley's ratio) for irrigation water should not exceed 1.0. All of the thermal and non-thermal waters of the study area have Kr less than 1.0 and that means that a good balance of $Na^+$, $Ca^{2+}$ and $Mg^{2+}$ is present in the all of the study areas.

## 3.6. Metal (MI) index

The MI index was preliminarily defined by Tamasi and Cini (Sen et al. 2014). This index can be expressed by the following Equ. 2:

$$\mathrm{MI} = \frac{\sum C_i}{MAC_i} \qquad (2)$$

Where MI is the metal index, *C* is the concentration of each element in the solution, MAC is the maximum allowed concentration for each element, and the subscript *i* is the *i*th sample. The higher concentration of a metal compared to its respective MAC value the worse the quality of the water is. If, the concentration of an element is higher than the respective MAC value (i.e., MI >1), according to this index the water cannot be used. Therefore, the value of 1.0 for MI is a threshold warning, even in the case where $C_i$ is less than $MAC_i$ for all the elements. For the calculation of the MI index, the heavy metals Hg, Zn, Co, As, B, Cu, Mn, Mo and Ni were considered. The standard Iran guideline values for irrigation [31] were also used for MAC in the index (Hg:0.01; Zn:2; Co:0.05; As:0.1; B:1; Cu:0.2; Mn:0.2; Mo:0.01 and Ni:0.2 mg/l). The calculated values of MI are shown in Fig 5.

As can be seen from Fig 5 the calculated values of MI for all samples (except for samples 6, 7, 10) are above the threshold of warning. It means that based on this index, most of the water samples are contaminated. Therefore, the MI that is most abundant in thermal water is more important than the non-thermal water. The concentrations of all elements are less than their corresponding MAC, in particular, Hg, Zn, Co, Cu and Ni (Fig 6).

Table 6.Various criteria used to evaluate thermal and non-thermal water samples for irrigation

| No. | Name | SAR | RSC | %Na | PI | MAR | KR | SSP |
|---|---|---|---|---|---|---|---|---|
| **1** | **Shafa** | 2.50 | -7.13 | 35.23 | 0.46 | 43.93 | 0.54 | 34.76 |
| **2** | **Dombeh** | 2.53 | -7.73 | 35.42 | 0.45 | 41.28 | 0.54 | 34.95 |
| **3** | **Solimani** | 2.30 | -7.82 | 32.90 | 0.43 | 42.00 | 0.48 | 32.37 |
| **4** | **Soda** | 2.31 | -7.71 | 32.97 | 0.43 | 35.38 | 0.48 | 32.44 |
| **5** | **Naineh** | 1.31 | -2.05 | 30.59 | 0.39 | 37.63 | 0.43 | 29.85 |
| **6** | **Abgarm** | 2.36 | -8.07 | 33.56 | 0.41 | 39.62 | 0.49 | 32.97 |
| **7** | **Ziaratghah** | 0.35 | -0.66 | 13.73 | 0.57 | 44.63 | 0.14 | 12.53 |
| **8** | **Siagohar** | 2.84 | -6.69 | 39.23 | 0.49 | 31.72 | 0.63 | 38.68 |
| **9** | **Talkheh** | 2.77 | -14.47 | 32.63 | 0.34 | 47.72 | 0.47 | 32.19 |
| **10** | **Biname** | 2.69 | -10.94 | 33.61 | 0.42 | 44.95 | 0.49 | 33.14 |

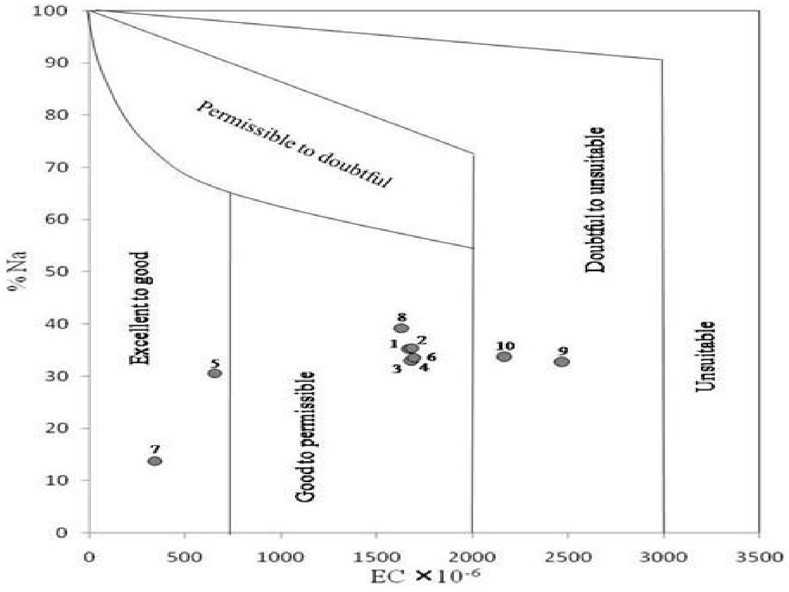

Fig 4. Wilcox diagram for the irrigation classification of the water

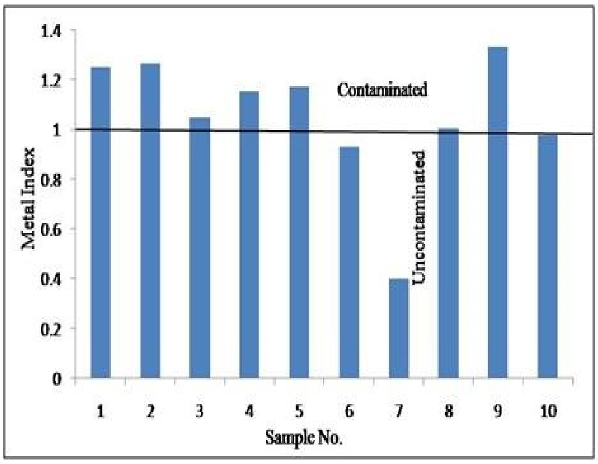

Fig 5. Calculated MI for water samples in the study area

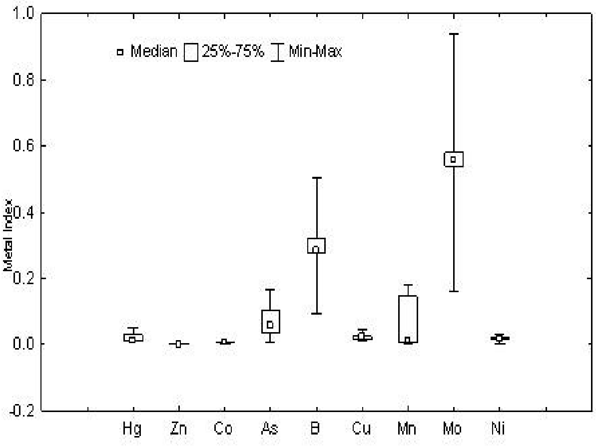

Fig 6. Box-Whisker diagram of MI for each of the elements

## 4. Conclusions

From the range of temperatures (18.2°C to 47.3°C) of the 10 samples investigated, it can be inferred that the origin of Mahalat thermal waters is meteoric. The samples ranged from slightly acidic to moderately alkaline. The major anions ($SO_4^{2-}$, $HCO_3^-$ and $Cl^-$) and major cations ($Ca^{2+}$, $Na^+$, $Mg^{2+}$ and $K^+$) in the thermal and non-thermal waters were variable. This may be attributable to the variability of the lithological composition in the sampling area.

Piper diagram permitted classification of the 10 thermal and non-thermal waters as follows: $SO_4$-Ca and $HCO_3$-Ca. Statistical analysis of the chemical data yielded positive correlation values of $Cl^-$, $SO_4^{2-}$, $Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$ that enabled good interpretation of the same origin for the thermal and non-thermal waters. The isotopic data has shown that all water samples from Mahalat Abgarm seem to be a mixture of an old groundwater with new groundwater. The quality of water was assessed by testing parameters such as sodium [$Na^+$], calcium [$Ca^{2+}$], magnesium [$Mg^{2+}$], alkalinity [$HCO_3^-$], and chlorine [$Cl^-$]. The quality indices were evaluated as the sodium absorption ration, soluble sodium percentage, residual sodium carbonate, Kelly's index and so on. All of the water quality indices have shown that all of the water samples are suitable for irrigation. Metal index of heavy metals Hg, Zn, Co, As, B, Cu, Mn, Mo and Ni were considered. The standard Iran guideline values for irrigation were also used for MAC in the index. The calculated values of MI have shown that almost all the samples are above the threshold of warning. It means that based on this index, most of the water samples are contaminated.

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