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Comparative analysis of some hot water Aini Aflaj- in Oman

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Abstract
Sultanate of Oman has more than 4000 Aflaj spread in various regions in Oman (Ghrefat, *et al*., 2011) [9]. The present study investigates the physical and chemical parameters of water for four hot water Aflaj known as Aini Aflaj (Tourism, M., 2013) [16]. Aim was to assess their water quality for drinking and other possible purposes. The four Aflaj are Falaj Ain Al-Hammam Figure (1.1), Falaj Ain Ghala Figure (1.2), Falaj Ain Al-Kasfa Figure (1.3) and Falaj Ain Al-Thwarah Figure (1.4). Water samples were collected from the mouth of the Aflaj. The tests were conducted through four laboratories which are approved by the Ministry of Regional Municipalities and Water Resources Sultanate of Oman (MRM&WR); and instruments, i.e., Inductively Coupled Plasma Mass Spectrometry (ICP-MS) model: Perken Elmer Nexoin 300d, Ion Chromatography system model: Dionexics-2000, Memo Titrator and Dissolved Oxygen DO (analyzer) / Biological Oxygen Demand BOD meter model: Mettler Toledo model: Seven Excellence were used. The results were mainly compared using Gulf Corporation Council Standardization Organization GSO149:2014 [10]. It was noticed that these Aflaj contain slightly high concentration of Total Alkalinity, TDS and EC due to weathering process of limestone and gypsum. According to the GSO149:2014 [10] and Omani standards these waters are having other chemical and physical parameters less than the permissible limits of unbottled drinking water which indicate the quality of water is fairly good enough.

Keywords: Oman, Aini-Aflaj-, Water Quality Standards, Chemical and Physical Parameters Analysis.

1. Introduction
Oman is situated in the south eastern part of Arabian Peninsula, is bordered by the United Arab Emirates from the northwest, Saudi Arabia from west, Gulf of Oman and Arabian Sea from the east and northeast covering 309,500 square km (Tourism, M., 2013) [16]. Oman's climate can be described as arid, the average rainfall between 100 – 200 mm/year. 92% of the total renewable water resources are procured from the groundwater. 87% of these renewable resources consumed for the agriculture (Ghrefat, *et al*., 2011) [9].
More than two thousand years ago, Omanis introduced the oldest irrigation engineering in the region by devising the Falaj system which has remained the main source of irrigation water in the Sultanate (Tourism, M., 2013) [16]. It is a unique system that is rarely found in other countries (MRM&WR, 2013) [14]. This system effectively contributed to prosper the agriculture in Oman. Aflaj system reflects a blended culture of more than 2000 years and is still in vogue up to the present day era (Tourism, M., 2013) [16].
Falaj (singular) is a water channel dug in the ground constructed by human in order to transfer the water from one point to another. It is primarily based on subsurface flow of water from areas higher than the place where such water is to be used (MRM&WR, 2009) [13]. Oman had 4112 Aflaj distributed in all the regions, 3017 Aflaj are live and flowing, around 680 million m3 annually. 410 million m3 are used for mainly irrigation purposes, after it fulfills the domestic needs. It feeds around 17600 hectares of agricultural land which is 33% of the total crops in Oman, mostly used for palm trees (MRM&WR, 2013) [14]. The Aflaj (plural of falaj) are categorized into three types; Falaj Al-Dawoodi, Falaj Al-Ghaili and Falaj Al-Aini (MRM&WR, 2009) [13].
Falaj Al-Aini under the present study, Figure1.1 to Figure 1.4 (self taken pictures by the authors), allow flow of water directly from the hot springs. The importance of these Aflaj depends on the quality of their waters, how much hot, fresh drinking water or saline, alkaline

or mixed with valley water (MRM&WR, 2013) [14]. Selected hot Aflaj are Falaj Ain Al-Hammam in Al-Ansab and Falaj Ain Al-Kasfa in Al-Rustaq. The lengths of these Aflaj within the inside of mountains are in between 100m to 200m. Moreover, these hot Aflaj have therapeutic properties according to the presence of mineral salts. Because of the high concentration of sulphate and other minerals Ain Al-Hammam and Ain Al-Ghala waters are helpful for rheumatism, some skin diseases, respiratory and joints diseases, inflammation of muscle and chronic gout. Al-Aini Aflaj constitutes a proportion of only 28 % of the total number of Aflaj in Oman. In order to safe guard the health and interests of the consumers the study of water quality of these Aflaj is of significant importance, so as to assess their water chemically and physically.

Fig 1.1: Ain Al-Hammam

Fig 1.2: Ain Al-Ghala

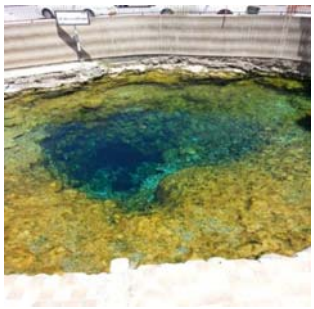

Fig 1.3: Ain Al-Kasfa

Fig 1.4: Ain Al-Thwarah

2. Methodology

Water samples were collected from four Aini Aflaj in special lab bottles 500 ml and 1000 ml plastic bottles and 250 ml glass bottle according to the GSO149:2014 [10]. Three samples were collected from each site at the appropriate distances and results in each sample at any site were found identical. These Aflaj are located in different locations in Oman. Falaj Ain Al-Hammam in Wilayat Bousher, Al-Ansab and Falaj Ain Ghala in Wilayat Bousher, Ghala both are in Muscat Governorate. In addition two other Aflaj chosen are in South Al-Batinah Governorate; Falaj Ain Al-Kasfa in Al-Rustaq and Falaj Ain Al-Thwarah in Nakhl. Physical and chemical tests were conducted on the samples. ICP-MS Figure (2.1), instrument was used to detect trace metal cations in the water (Center, Introduction to ICP-MS, 2013) [7] while the ION Chromatography was used to detect anions (M. Life, 2015) [11]. Memo Titrator Figure (2.2) was used to determine the pH, EC, TDS, total hardness and alkalinity.

Fig 2.1: ICP-MS

Fig 2.2: Memo Titrator

pH was measured using Memo Titrator instrument with electrode along with software LabX 6.0. Before start of taking readings, calibration process was conducted with a buffer solution pH 4, pH 7 and pH 10 (ASTM D1293, 2011) [3].

Memo Titrator was used to measures the EC, calibration was conducted by 1413KCl buffer solution.

To determine the total alkalinity by titration technique in Memo Titrator $0.1NH_2SO_4$ was used (ASTM D1067, 2011) [2].

In case of TDS mathematical equation

"TDS = 0.55 x EC" was applied.

While for total hardness it was calculated from the concentration of Mg and Ca using the following equation:

Total hardness= 4.12 Mg +2.5 Ca.

Bicarbonate, HCO_3, was measured by titration using $0.1NH_2SO_4$ (ASTM D513, 2011) [4].

The water samples for the cations and anions analysis was filtered with 0.45 µm Millipore membranes to separate suspended solids. Cations were analyzed with Nexion 300D

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) Figure (2.1), the testing parameters chosen were potassium K, calcium Ca, Silicon as dioxide SiO_2, strontium Sr, sodium Na, magnesium Mg, vanadium V, cobalt Co, cadmium Cd, molybdenum Mo, lead Pb, copper Cu, chromium Cr, iron Fe, nickel Ni and zinc Zn. The ICP-MS is connected to PC with Nexion software V 1.5, attached to auto sampler. ICP-MS used combines a high-temperature ICP (Inductively Coupled Plasma) source with a mass spectrometer. The ICP source converts the atoms of the elements in the sample to ions. These ions are then separated and detected by the mass spectrometer (Center, 2013) [7].

ION Chromatography System 2000, Figure (2.3) was used for the anions (fluoride F, chloride Cl, nitrate NO_3, sulphate SO_4, Br). It measures the concentrations of ionic species by separating them based on their interaction with a resin. Ionic species separate differently depending on species type and size. Sample solutions pass through a pressurized chromatographic column where ions are absorbed by column constituents (ASTM E1151, 2011) [6]. As an ion extraction liquid, known as fluent, runs through the column, the absorbed ions begin separating from the column. The retention time of different species determines the ionic concentrations in the sample (M. Life, 2015) [11].

Fig 2.3: ION Chromatography System

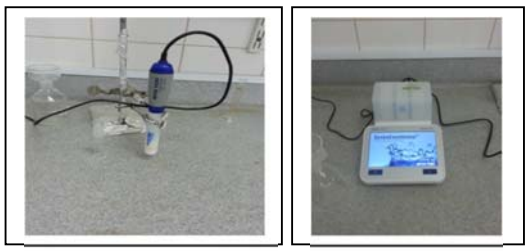

Fig 2.4: DO/BOD

Biochemical oxygen demand (BOD) test was also conducted as per (ASTM D5210, 2007) [5] and measured by DO/BOD meter Figure (2.4) along with dilution techniques using four reagents.

The reagents were:
(1) Phosphate buffer: Dissolved 8.5 g KH_2P0_4 + 21.75 g K_2HP0_4 + 33.4 g $Na_2HP0_4 \bullet 7H_20$ + 1.7 g NH_4Cl in approx. 500 ml reagent water, Diluted to 1 Liter.
2) Magnesium sulfate solution: Dissolved 22.5 g $MgSO_4 \bullet 7H_20$ in reagent water, Dilute to 1 Liter.
3) Calcium chloride solution: Dissolved 27.5 g $CaCl_2$ in reagent water, Diluted to 1 Liter.
4) Ferric Chloride solution: Dissolve 0.25 g $FeCl_3 \bullet 6H_20$ in reagent water, Diluted to 1Liter.

3. Results and analysis

Results of testing the four Aflaj waters are shown in Table 3.1 and Table 3.2.

Table 3.1: Chemical parameter (Ammar, T.H., 2015) [1]

Parameter	Falaj Ain Al-Hammam	Falaj Ain Ghala	Falaj Ain El-Kasfah	Falaj Ain Al Thwarah	Maximum level GSO149:2014 [10]	Unit
Temperature	65	45	45	41	Not offensive / Acceptable	^{0}C
Potassium	4.40	3.25	4.38	2.53	10	mg/l
Calcium	122.30	94.55	75.61	57.31	200	mg/l
TDS	890.73	630.96	567.97	415.36	1000	mg/l
pH	7.54	7.14	7.62	7.45	8	
Silicon as SiO_2	49.20	31.22	30.84	23.31	60	mg/l
Bicarbonate	235.92	192.05	229.57	227.57	350	mg/l
Total hardness	445.25	389.67	296.23	254.19	500	mg/l
Nitrite N	0.20	0.46	1.28	1.62	11.29	mg/l
Fluoride	0.96	0.78	1.11	0.74	1.5	mg/l
Strontium Sr	2.33	1.67	1.80	1.10	4 for life time use (EPA)	mg/l
Sodium	138.40	98.27	100.40	59.59	400	mg/l
Magnesium	33.48	36.79	25.73	26.62	150	mg/l
BOD	0.20	0.20	0.20	0.20	5	mg/l
Total alkalinity	193.37	157.42	188.17	186.53	120 (EPA)	mg/l
Chloride	175.56	109.00	125.18	64.17	600	mg/l
Sulphate	237.43	152.94	78.57	56.24	250	mg/l
Nitrate as NO_3	0.87	2.03	5.66	7.19	50	mg/l
Conductivity	1100.98	1384.11	747.99	992.87	0 - 800 good drinking water 800-2500 can be consumed by humans, >2500 not suitable for human consumption (US EPA)	µS/cm

Table 3.2: Trace Metal parameter (Ammar, T.H., 2015) [1]

Parameter	Falaj Ain Al-Hammam	Falaj Ain Ghala	Falaj Ain El-Kasfah	Falaj Ain AlThowarah	Maximum level by GSO:2014 [10]	Unit
Vanadium	0.0015	-	0.0011	0.0014	0.006	mg/l
Cobalt	0.0001	0.000002	0.000005	<0.001	≤0.001	mg/l
Cadmium	<0.001	<0.001	0.000014	0.00002	0.003	mg/l
Molybdenum	0.008	0.006	0.005	0.002	0.07	mg/l
Lead	0.00005	<0.001	0.0009	0.000008	0.01	mg/l
Copper	0.001	0.001	0.001	0.001	2	mg/l
Chromium	0.0004	0.00102	0.0007	0.0012	0.05	mg/l
Iron	0.020	0.008	0.008	0.003	1	mg/l
Nickel	0.0042	0.0007	0.0002	0.00015	0.02	mg/l
Zinc	<0.001	<0.001	<0.001	<0.001	3	mg/l

All trace metals were present far below maximum permissible range.

High temperatures combined with permissible presence of minerals, Sulphate, Magnesium, Sodium and Potassium, Fluorides, Strontium and Bicarbonates in water are capable of therapeutic usage (Sasaki, K. *et al*., 2013) [15]. As due to hot water the skin has effect of relaxing to the effect that skin pores are dilated and soluble minerals are absorbed to have the required therapeutic effects (Moerman, A., *et.al*, 2014) [12]. Therefore the waters of those hot water Aflaj has been of medical use since ages without any adverse side effects on human beings (Ghrefat, *et al*., 2011) [9].

pH values of the four Aflaj are above seven which indicates the alkalinity of the waters but within safe range. The difference in pH values in water are because of the variation of EC and HCO_3 (Ghrefat, 2011) [9].

Total alkalinity variation according to the concentration of $CaCO_3$ in all waters is above permissible range and thus safety issue in regard to the usage as drinking water arises (WHO, 2008) [17] but these limits can easily be rectified if waters are needed to be used for drinking purpose. Not much cost could be involved, generally, particularly in comparison to desalination.

Total Alkalinity in all four sites is more than, United states Environmental Protection Agency (EPA) limits recommended as the maximum limits. These limits for Total Alkalinity are not listed by GSO149:2014 [10].

Variation of the TDS concentration levels is owing to the presence of non-organic solids dissolved in the water.

Total hardness variation depends on the minerals dissolved in water, from the data obtained, All Aflaj waters would be considered as hard water according to the GSO149:2014 [10].

From Table 3.1 all values of Bicarbonate ions (HCO_3), and its variations in values refers to the chemical weathering of dolomite rocks and limestone due to the high concentration of Calcium and Manganese (WHO, 2008) [17].

Potassium originates by dissolving due to weathering processes (Shan, W., *et al*., 2011), values obtained from Falaj Ain Al-Hammam and Falaj Ain Al-Kasfa are approximately similar 4.40 mg/l and 4.38 mg/l respectively. They are available in good range as it is useful to human body and is permissible upto 8mg/l by WHO.

Calcium dissolved from rocks like limestone, gypsum and marble, Falaj Ain Al-Hammam has the highest Calcium value 122.30 mg/l recorded while as 200 mg/l is the maximum level allowed according to the GSO149:2014 [10]. So all are in good range

In case of Nitrite as N sources originate from human activities, agricultural and industry. Trace amount of Nitrate detected in four aflaj, Falaj Ain Al-Hammam recorded 0.20 mg/l which the lowest record, Level of Nitrate in Falaj Ain Al-Thwarah detected the highest value 1.62 mg/l however allowable maximum level of Nitrate is 11.29 mg/l (GSO149:2014) [10].

Nitrate NO_3 arises from soil, animal wastes and fertilizer absorbed. The concentration of Nitrate in Falaj Ain Al-Hammam in Wilayat Bousher, Al-Ansab is the lowest value recorded with 0.87 mg/l, Falaj Ain Al-Thwarah recorded the highest NO_3 value 7.19 mg/l. The values of Nitrates should be below 50mg/l and could be associated to geographic location of the falaj and the ambient soil composition.

Falaj Ain Al-Kasfa recorded the highest value 1.11 mg/l of Fluoride and the lowest value obtain from Falaj Ain Al-Thwarah with 0.74 mg/l. Falaj Ain Al-Hammam and Falaj Ain Ghala fluoride value are 0.96 and 0.78 mg/l respectively. Fluoride maximum level should not exceed 1.5 mg/l (WHO, 2008) [17].

Falaj Ain Al-Hammam has the highest Sodium value recoded 138.40 mg/l and Falaj Ain Al-Thwarah recoded the lowest value 59.59 mg/l. Others have in between values. Maximum level of Sodium allowed 400 mg/l according to the standard GSO149:2014 [10].

Magnesium arises from minerals and some particular rocks e.g. limestone and gypsum. The highest value recorded in Falaj Ain Ghala 36.79 mg/l while the lowest value detected in Falaj Ain Al-Kasfa 25.73 mg/l. To prevent harmful effects to human body concentration of Mg should not go beyond 150 mg/l according to the GSO149:2014 [10].

From Table3.1 the highest Silicon value recoded was in Falaj Ain Al-Hammam 23.39 mg/l and the lowest value detected 11.08 mg/l. Silicon in water arises from rocks weathering process.

Chloride can be found in salt water as well as fresh water, it arises from weathering process beside the soil. The minimum value of Chloride found 64.17 mg/l in Falaj Ain Al-Thwarah in Nakhal and the maximum value recorded was in Falaj Ain Al-Hammam with 175.56 mg/l. The presence of Chloride should not exceed 600 mg/l according to the GSO149:2014 [10].

Sulphate arises from the mineral salts in soil and weathering of rocks in water. Highest value recorded was 237.43 mg/l in Falaj Ain Al-Hammam. The maximum level of Sulphate allowed by the MRM&WR according to the GSO149:2014 [10] is 250 mg/l, hence safe but towards higher side and for therapeutic purpose.

BOD (Biochemical Oxygen Demand) measures the amount of oxygen absorbed by the water sample, by aerobic bacteria. In the four samples the BOD equal to 0.20 mg/l which indicate very good water quality with not much organic waste existing in it. Normally the BOD range for treated effluent is suggested to be of 80ppm, but elsewhere it is recommended as 5ppm for surface drinking waters (EPA).

4. Conclusion

In four Aflaj, water qualities have been tested, taking at one time three samples, over each site some appropriate distance apart. Test results were found same for all three samples at any site as shown in Table 3.1 and Table 3.2. From those chemical and physical parameters it is clear that these waters could be considered as good for drinking, therapeutic, domestic and agricultural uses after little treatment processes as per use. For Irrigation processes these waters could be used directly. People drinking these waters, for long term may be affected due to slightly high rate of TDS and hardness of the water. These two factors show affect more in the pipes and fitting in short term by sediments of minerals and scaling. These waters rise from deep cracks of rocks rich in minerals. Noticeably, the highest level of EC and TDS is recorded in Muscat Governorate; it leads to form salinity according to the weathering processes of limestone and gypsum beside other elements. Trace metal tests showed a trace amount of metal for all Aflaj which didn't exceed the permissible limit.

In majority, the Aflaj in South Al-Batinah Governorate has less parameter than in Muscat Governorate. Currently people are using these waters for drinking, washing, swimming and irritation without any hesitation toward the water. In addition to that, these waters are used for treatments for rheumatism according to the high presence of minerals. Moreover these Aflaj attract tourist to enjoy the picturesque nature of the area.

The falaj is considered as a private property for the residents of the area and group of families are responsible for water distribution in portions and for different days of the week.

Considering that all parameters are within safe limits according to GSO-149, no doubt people used to drink these waters for ages before getting used to other bottled waters. And surely it can be considered to reuse such waters for domestic purposes after proper minimal treatment processes and disinfection saving much expenditure in processes like desalination. And these waters can too be bottled for drinking purposes at less expenditure thus will be cheaper.

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