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Article

Monitoring Quality and Pollution Assessment of Groundwater for Drinking Purposes to Assure Sustainability

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Abstract: A Water demand per capita will rise in the Arab world as a result of climate change and population expansion. One of the most important aims in coping with population increase around the world is to conserve water supplies. As a result, the Kingdom of Saudi Arabia constructed Al Wajeed Water Treatment System to meet the demands of the southern population. This research aims to assess the drinking water quality produced from the AlWajeed Water Treatment System. Monthly water samples were collected (January 2018 to January 2021) from the Al Wajeed Water Treatment Framework (4sites), extending to governorates; Bishah`s distribution system (5sites) and Tathleeth`s distribution system (7sites). Water quality criteria, such as physical, chemical, and microbiological parameters, revealed that the majority of water samples collected from the Al Wajeed Water Framework and its environs are of a good quality matched the national and international standards. Few sites showed water quality criteria, such turbidity, fluoride and total coliform did not comply with national and global standards. The obtained results explained the importance of monitoring and follow-up programs for drinking water criteria. In addition, they can help the authorities and stakeholders in the sustainable development.

Keywords: Drinking water management; drinking water criteria; groundwater; reverse osmosis; sustainable development; water aesthetics

1. Introduction

Water is the source life for all creatures. The basics of human rights are safe drinking water and sanitation because they are essential to maintain dignity and well livelihoods of all individuals. In 2015, 2.1 billion people worldwide could not have safe, readily obtainable water at home, while 4.5 billion failed to get safely managed sanitation. There is a huge gap between and within countries, as well as between the richest and poorest [1].

Human rights confirm the right of every one to have sufficient, safe, palatable water [2-5]. The development of any nation relies mainly on the availability of safe and pure water. Contaminated water can effect economic and social life by causing water-borne diseases such as typhoid fever, dysentery, hepatitis A, vibrio illness, poliomyelitis and *E. coli* diseases, this leads increasing the cost of medical treatment [6,7]. It is critical to

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manage drinking water sources in order to identify potential hazards and reduce or eliminate the risk of contamination.

It is well known that the groundwater is estimated to be the world's primary source of drinking water, with 2.5 billion people relying solely on it to meet their water needs [5, 8, 9]. As a result, it is critical to manage and monitor groundwater, as well as its quantity and quality. Moreover, it is difficult and expensive to treat groundwater when becomes contaminated. A contaminant that has been released into the environment may migrate through an aquifer and into the groundwater based on its physical, chemical, and biological characteristics. Pathogens such as viruses, bacteria, parasites, microscopic protozoa and worms are examples of microbial contaminants [10, 11].

Groundwater is the primary source of potable water supply for roughly half of the world's population. The quality of groundwater used for domestic and irrigation can vary greatly in quality. Land-use/land-cover changes such as deforestation, agricultural areas expansion, urbanization and other human activities directly impact water resources condition [12, 13]. Furthermore, it is necessary to measure other quality parameters, especially nitrate and phosphate because the development of agriculture and subsequent use of chemical fertilizers increase the emission of these pollutants. As a result, it is advised that future research on various groundwater resource quality metrics take into account not just their historical patterns but also potential alterations [14, 15].

The Middle East is now in a water crisis and The United Nation (UN) classified Saudi Arabia and the other countries of the Gulf Cooperation Council (GCC) as water-scarce nations. While 97% of Saudis have access to potable water, Saudi Arabia ranks as one of the most water-scarce countries on the planet. The absolute water scarcity level is 500 cubic meters per capita per year. Saudi Arabia has only 89.5 cubic meters per capita per year. Despite the high levels of water access in the Kingdom, severe over consumption and lack of reliable sources of renewable water have made this issue a top priority. Saudi Arabia constitutes the majority of the Arabian Peninsula and is one of the largest arid countries without permanent rivers or lakes [16]. Water supply and sanitation in Saudi Arabia is characterized by challenges and achievements. One of the main challenges is water scarcity. In order to overcome water scarcity, substantial investments have been undertaken in seawater desalination, water distribution, sewerage and wastewater treatment. Today about 50% of drinking water comes from desalination, 40% from the mining of non-renewable groundwater and only 10% from surface water in the mountainous southwest of the country [17].

The study sought to evaluate the quality of groundwater in southern Saudi Arabia and comparing water quality of Gulf Cooperation Council national norms [18] and [19] guidelines. The results of this study can serve as a starting point for other initiatives that are anticipated to be launched in the Saudi Arabia and/or other countries globally.

2. Materials and Methods

2.1. Al Wajeed Drinking Water Treatment System:

Al Wajeed is a geological system located at the southern region of Saudi Arabia. It was discovered in 1966 in Wadi Al Dawaser governorate. It consists of sandstones inlaid with layers of clay, as it is directly located on a composite stone base, as heading west of Wadi Al Dawaser as it is directly located on a composite stone base. The treatment plant produces fresh water with salt concentration of 520 ppm. Since its discovery, many wells have been drilling with 100-1.100 m in depth producing about 25,000,000 m^3 of fresh water. The water configuration aims to transporting water from Al-Rubaa Al-Khali to Bishah and Tathleeth governorates, was launched in January 7, 2018 by OVELOIA WATER- Solutions & Technologies under the supervision of the Ministry of Environment, Water and Agriculture, its production capacity was 61500 m^3/day. Al Wajeed water framework configuration (Figure 1) consists of the following components:

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2.1.1. The wells area:

The field consists of 28 tube-wells, 1000 m apart from each other in all direction, with 200 mm in diameter and 250 m in depth. The average discharge per well is 110 m^3/hr, pumped with submerged 92 kW, 200 m. pumps installed at a depth of 200 m. All the wells can be operated at the same time when needed.

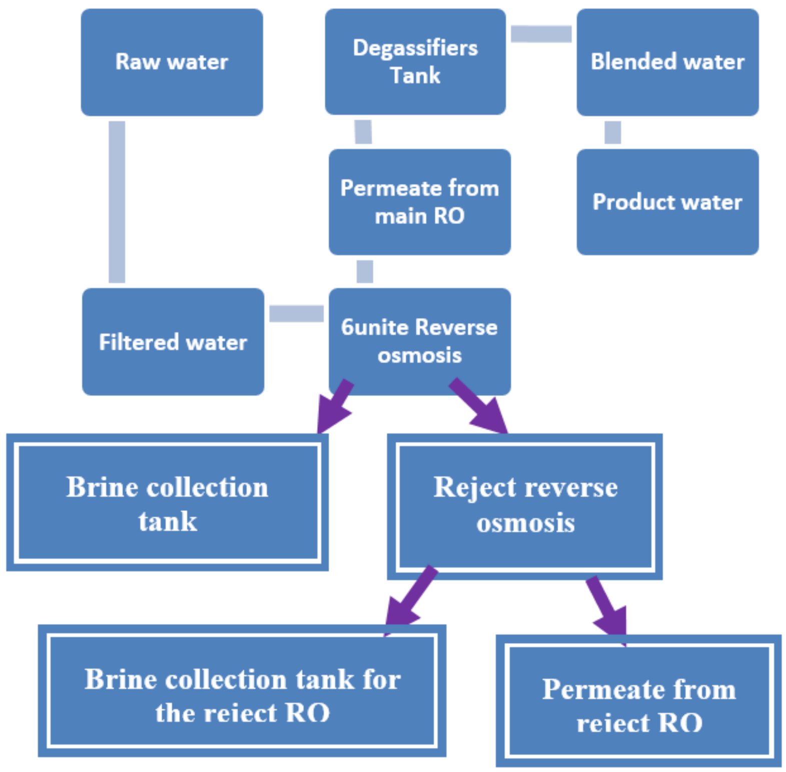

Figure 1. Schematic illustration of Al Wajeed Water Treatment Framework

2.1.2. Raw water tanks:

Raw water is pumped to two concrete tanks with a total capacity of 100,000 m^3. Chlorine gas is fed into the raw water with an initial dose of 5 ppm as a disinfectant and for oxidizing iron oxides into precipitated oxides that can be trapped inside the sand filters.

2.1.3. Raw water pumping station:

The raw water pumping station consists of 4 pumps (3 in service + 1 reserve), with a discharge of 970 m^3/hr. each.

2.1.4. Primary treatment with chemicals (addition of coagulant materials):

- Ferric chloride with a concentration of 5 ppm, is injected at the entrance of the raw water tanks, as coagulant materials to collect suspended particles
- Sodium meta bisulfite is added as 0.1 mg/L to the water to remove the residual chlorine before entering the membranes as chlorine is the oxidizing agent for the membrane material.
- Then acid and anti-scaling agent were added to prevent the scaling of salts inside the membranes.

2.1.5. Sand filters:

Raw water is pumped to the sand filters to get rid of turbidity, impurities and odors by pumping the water through the filter layers of gravel, graded sand and activated carbon. There are 10 sand filters, with a discharge of 291 m^3 /hr each.

2.1.6. Reverse osmosis unit: It consists of:

- Cartridge filters 5µm to remove suspended particles.
- 6unite Reverse osmosis: 6 reverse osmosis unite which produce 400m^3/hr treated water for each unites (so, reject water reached to 70 m^3/hr from each unite). Therefore, the maximum possible amount of treated water produced by the plant is 2535 m^3 /day.
- Final treatment with chemicals: In this process chemicals are added to the treated water to improve the quality of the water through complying with the Gulf water standards.
- Addition of sodium carbonate to elevate the pH value between 7.5- 8.5.

2.1.7. Post chlorination with 2 ppm chlorine gas, to water disinfection inside the storage tanks and inside the distribution system. Calcium salt added to keep ionic balance of water, to ensure that water is safe to drink.

2.1.8. Treated water tanks:

The treated water reaches to two concrete treated water tanks with the total capacity of 100,000 m^3, where it is stored until pumped to the distribution system.

2.1.9. Pumping station:

Four pumps (3 in-service + 1 reserve) are to draw the treated water from the tanks and pump it into the distribution system. The power of each pump is 720 kW with a discharge of 710 m^3/hr and a total head of 245 m.

2.1.10. Booster pumping stations:

Three booster pumping stations, PSA, PSB, and PSC, are located at three different locations to transmit the treated water through the pipe lines of the distribution system. Each of the booster pumping stations consists of a covered 10,000 m^3 concrete tank and six 720 kW pumps (5 in-service in PSA and PSB, and 2-in-service in PSC + 1 reserve), discharging 710 m^3/hr. each, at a head of 245 m. Each station is equipped with three electric generators of 2.5 MVA each.

2.1.11. Reservoir of Ashayab Tathleeth station:

The treated water is received at the reservoir and station of Ashayab Tathleeth through a 65.23 km long line that is branched to feed the ground reservoir. A control valve is equipped on the branched line to feed the reservoir with a maximum of 500 m^3/hr. of water for transmission line safety.

2.1.12. Bishah reservoir:

The treated water arrives from the pumping booster station PSC to Bishah 50,000 m^3 reservoir, which is a covered concrete tank divided in two halves, where the reservoir stores the water and distributes it through two150 mm. branched pipelines to feed some facilities located in Bishah and Ashayab. Treated water is fed by gravity through K9-type ductile lines of diameters varying from 300 to 700 mm, with different lengths depending on the location of transmission.

2.2. Sampling

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Water samples were collected at monthly basis (January 2018 to January 2021) from the distribution network of the Al Wajeed Water Treatment Framework (sample sites of 6002PS, 600Stage line, 8002PS and 2nd Stage Line) and extending to Bishah (sample sites of King Fahd Station, Wadi Hergab, Bishah-Net Tank, South Bihah Tank and Bishah Running 400km) and Tathleeth (sample sites of Elsharf Tank, Elmaared Tank, Ashyab King Fahd Dam, Bis-02, Bis-01, 800Stage Line and 800End-Line) governorates. Samples were collected in 1L sterile plastic bottles and transferred to the Lab for analysis according to [20].

2.3. Analytical Measurements

Water temperature was measured on the site using mercury thermometer, pH was measured using digital pH meter (Model Metrohm, pH Lab 827). All measurments of water quality criteria (turbidity, total dissolved solids, total alkalinity, total hardness, calcium, magnesium hardness, chloride, sulphate, fluoride, ammonia, nitrite, nitrate, iron and manganese) were conducted according to [20].

Also, water samples were digested according to the method described in [20]. Trace elements (Al, Cr, As, Se, Zn, Cd, Ba, Pb, Be, B, Co, Mo, Cu, V, Li and Ni) were measured by Atomic absorption spectrophotometric method. To prevent contamination, all tools associated with trace metal sampling and analyses were thoroughly acid cleaned before use. Glassware and Teflon vessels were treated in a solution 10% v/v nitric acid for 24 hrs. and then washed with distilled and deionized water [20].

Total Coliforms and *E. coli* to emphasis the microbiological quality of water samples were measured by most probable number (MPN) method (APHA 2017).

All the chemicals as well as the standard solutions needed to measure heavy metals were purchased from Sigma Aldrich Merck group, USA.

2.4. Radioactive Materials Measurements

Water samples from the main 28wells were collected to radioactive atoms measurements. All measurements were performed in the Laboratory of the Ministry of Environment, Water and Agriculture, KSA. The activity concentrations of 226Ra, 228Ra, Ur234 and Ur238 in the water wells' samples were measured using Liquid scintillation counting. The water samples were collected in 1 liter polyethylene container. Acidification to pH 2, by adding HCl or HNO_3, was performed to prevent microorganism growth [20, 21].

2.5. Statistical Data Analysis

The data was presented in tables as arithmetic means, and the standard deviation (SD) was computed [22]. All statistical visualizations were performed by GraphPad Prism 8.3.0 (GraphPad, USA). Meanwhile, the statistical analyses were conducted using correlation analysis GGally package in R 4.1.1 [23] and ggplot2 package for the boxplot figures. The obtained correlation charts display the distribution of each variable; the bivariate scatter plots (bottom of the diagonal); and the correlation values and significance level stars (top of diagonal) [24].

3. Results

3.1. Physicochemical criteria

According to the human rights framework, water required for various human uses must be safe and free of microorganisms, radiological hazards and chemicals that cause a threat to a person's health [2]. In addition, excessive withdrawal of well water and

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changes in land use can affect groundwater quality and quantity with particularly rapid changes taking place worldwide from forestry to agricultural land use, as well as industrialization, urbanization and landfill [25].

Water quality monitoring and evaluation are critical for ensuring the efficient operation of Water Treatment Plants (WTPs) and promoting health, and contributing to a more sustainable urban water cycle [26]. Twenty quality parameters are applied to samples collected from the pumping station before being pumped to the distribution network, as well as from the Tathleeth and Bishah networks.

The quality standards for drinking water have been specified by the World Health Organization and Gulf Cooperation Council national norms [18, 19]. The behavior of major ions (Ca, Mg, Na, K, HCO_3, SO_4, Cl) and important physico-chemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and total hardness (TH) and the suitability of groundwater in the study area are discussed. Results in details revealed that aesthetic parameters (pH, color, turbidity and TDS) of all samples are almost in the permissible level of [18, 19] (Tables 1, 2, 3 & 4).

Table 1 Standard levels of physiochemical water quality criteria according to WHO and GCC 149

Parameters	Unit	WHO	GCC
pH		6.5–8.5	6.5–8.5
Color		15	15
Turbidity	NTU	5	5
Total Dissolved Solids (TDS)	mg/L	1000	1000
Total alkalinity ($CaCO_3$)	mg/L		
Total hardness ($CaCO_3$)	mg/L	500	500
Chloride	mg/L	250	250
Sulphate	mg/L	250	250
Ammonia	mg/L	1.5	1.5
Nitrite	mg/L	3	3
Nitrate	mg/L	50	50
Fluoride	mg/L	1.5	1.5
Iron	mg/L	0.3	0.3
Al	mg/L	0.200	0.200
Cr	mg/L	0.050	0.050
As	mg/L	0.010	0.010
Se	mg/L	0.010	0.010
Zn	mg/L	3.00	3.00
Cd	mg/L	0.003	0.003
Ba	mg/L	0.700	0.700
Pb	mg/L	0.010	0.010
B	mg/L	0.500	0.500
Mo	mg/L	0.070	0.070
Cu	mg/L	2.000	2.000
Ni	mg/L	0.070	0.070
Total coliform	MPN/100ml	-ve	-ve
E. coli	MPN/100ml	-ve	-ve

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Table 2. Water quality assessment traits for the main distribution pumping station branches

Parameter	Unit	600 2PS	600 Stage Line	800 2PS	2nd Stage Line	SD
pH		6.75	6.70	6.95	6.80	0.611
Color		10.5	10.0	8.5	6.5	2.62
Turbidity	NTU	0.55	0.70	0.80	0.75	1.265
TDS	mg/L	437	435	439.5	445	215.1
Total alkalinity ($CaCO_3$)	mg/L	77	74	86	58	45.3
Total hardness ($CaCO_3$)	mg/L	216	225	226	219	81.3
Calcium hardness ($CaCO_3$)	mg/L	179	188	187	186	59.9
Magnesium hardness ($CaCO_3$)	mg/L	37	37	39	33	23.7
Calcium	mg/L	71.6	75.2	74.8	74.2	23.97
Magnesium	mg/L	8.8	8.9	9.4	7.9	5.69
Chloride	mg/L	87	83	82	95	49.2
Sulphate	mg/L	94	93	86	114	44.3
Ammonia	mg/L	0.04	0.01	0.01	0.23	0.071
Nitrite	mg/L	0.16	0.03	0.02	0.03	0.037
Nitrate	mg/L	4.0	3.0	6.5	3.5	2.56
Fluoride	mg/L	0.42	0.27	0.29	0.27	0.104
Iron	mg/L	0.14	0.09	0.13	0.10	0.047
Residual chlorine	mg/L	0.10	0.10	0.60	0.03	0.032
Total coliform	MPN/100ml	-ve	-ve	-ve	-ve	
E. coli	MPN/100ml	-ve	-ve	-ve	-ve	

Means are average of 36 collected samples for each parameter per location. SD = Standard Deviation.

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Table 3. Water quality assessment traits for Bishah distribution network extension

Parameter, SD	**Unit**	**King Fahd station Bisha**	**Wadi Hergab**	**Bisha-Net Tank**	**South Bisha Tank**	**Bisha Running (400 km)**	SD
pH		7.0	7.9	7.0	7.6	8.5	0.615
Color	Co-Pt unit	4	5	3	4	4	2.43
Turbidity	NTU	0.6	15.3	0.9	0.5	2.7	1.143
TDS	mg/L	535	140	543	368	774	211.1
Total alkalinity ($CaCO_3$)	mg/L	124	64	122	138	178	43.3
Total hardness ($CaCO_3$)	mg/L	218	102	219	224	206	79.2
Calcium hardness ($CaCO_3$)	mg/L	164	88	168	156	167	56.6
Magnesium hardness ($CaCO_3$)	mg/L	54	14	51	61	39	20.5
Calcium	mg/L	65.6	35.2	67.2	62.3	66.8	23.57
Magnesium	mg/L	13.0	3.4	12.3	14.7	9.4	5.43
Chloride	mg/L	102	15	104	77	157	49.1
Sulphate	mg/L	90	22	92	67	115	41.2
Ammonia	mg/L	0.01	0.20	0.01	0.01	0.03	0.59
Nitrite	mg/L	0.02	0.01	0.02	0.01	0.05	0.029
Nitrate	mg/L	0.33	0.80	4.00	0.98	7.00	2.76
Fluoride	mg/L	3.00	0.13	0.36	0.31	0.38	0.107
Iron	mg/L	0.07	0.17	0.06	0.04	0.05	0.043
Residual chlorine	mg/L	0.24	0.05	0.95	0.57	0.20	0.034
Total coliform	MPN/ 100ml	-ve	-ve	-ve	-ve	-ve	
E. coli	MPN/ 100ml	-ve	-ve	-ve	-ve	-ve	

Means are average of 36 collected samples for each parameter per location. SD = Standard Deviation.

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Table 4. Water quality assessment traits for Tathleeth distribution network extension

Parameter	Unit	Elsharf Tank	Elmaared Tank	Ashyab King Fahd Dam	Bis-02	Bis-01	800 Stage Line	800 End-line	SD
pH		6.95	7.05	8.11	7.80	8.00	6.60	6.95	0.511
Color	Co/Pt unite	5.0	3.5	7.0	4.0	9.0	11.0	9.5	2.43
Turbidity	NTU	0.9	0.7	1.0	0.4	1.3	0.8	0.6	1.16
TDS	mg/L	152	154	469	951	502	440	433	212
Total alkalinity ($CaCO_3$)	mg/L	50	51	155	174	143	70	88	42.3
Total hardness ($CaCO_3$)	mg/L	88	76	272	417	214	218	225	80.2
Calcium hardness ($CaCO_3$)	mg/L	75	68	228	309	163	182	182	57.6
Magnesium hardness ($CaCO_3$)	mg/L	13	8	44	108	51	36	43	21.5
Calcium	mg/L	30.0	27.2	91.2	123.6	65.2	72.8	72.8	22.6
Magnesium	mg/L	3.0	1.9	10.6	26.0	12.2	8.6	10.2	5.28
Chloride	mg/L	23	23	124	203	102	88	81	47.1
Sulphate	mg/L	28	27	132	197	87	86	85	43.2
Ammonia	mg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06
Nitrite	mg/L	0.02	0.02	0.01	0.03	0.02	0.01	0.03	0.04
Nitrate	mg/L	3.0	4.5	0.8	1.0	10.0	4.0	4.0	2.64
Fluoride	mg/L	0.12	0.25	0.26	0.50	0.29	0.44	0.33	0.10
Iron	mg/L	0.12	0.11	0.02	0.02	0.03	0.10	0.11	0.05
Residual chlorine	mg/L	0.02	0.01	0.04	0.01	0.05	0.24	0.10	0.03
Total coliform	MPN/ 100ml	-ve	-ve	-ve	-ve	-ve	-ve	+ve	
E. coli	MPN/ 100ml	-ve	-ve	-ve	-ve	-ve	-ve	-ve	

Means are average of 36 collected samples for each parameter per location. SD = Standard Deviation.

In addition, correlation matrix between those aesthetic parameters and water criteria of ammonia, nitrite and nitrate revealed good correlation in different sampling sites (Figure 2).

Figure 2. Correlation matrix between the target monitored parameters (pH, color, turbidity, TDS, ammonia, nitrite and nitrate) and different sampling sites (main pumping station, Bishah network and Tathleeth network) $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$

Furthermore in this framework, pH measurements showed that the water tends to be as natural and slightly alkaline where it was in the range of 6.6- 8.5 in all water samples (Tables 2, 3 & 4). A research study suggests that, there is no direct effect of the pH of drinking water on human health, but it has some indirect impacts on public health by causing changes in other water quality metrics such as metal solubility and pathogen viability. Whereas, turbidity revealed some fluctuation in its reading within different site branches but still in the permissible level of global standards (within the range 0.4-2.7 NTU) except for the site of Wadi Hergab water samples, it was out of the standard level since it revealed reading of 15.3 NTU (Table 3) which may be indicate that there was a source of pollution may affect the turbidity criteria. Figure (2) revealed high significant correlation ($p \leq 0.996$) between ammonia and turbidity in Bisha sites. The level of turbidity in drinking water is significant for aesthetic reasons as well as treatment plant performance, as excessive turbidity can shield harmful germs from disinfectant actions, making water filtration more difficult and expensive [27-29].

Also, color readings display a pronounced fluctuation between different sits of different network extension (3.0-10.5 Co-Pt unit) but still complied with the standards (Tables 2, 3 & 4). Also, color reading showed no significant correlation with other parameters (Figure 2).

According to previous study, the presence of bicarbonate indicates the kind of rock in the area, implying that rock weathering and leaching are the key mechanisms affecting groundwater chemistry [30,31]. Alkalinity, in the form of $CaCO_3$, is not considered pollution. It is a total measure of the substances in water that have acid neutralizing ability. The bicarbonate alkalinities of Al Wajeed water samples revealed a pronounced fluctuation between different sites and it was in the range of 50-178 mg/L $CaCO_3$. Moreover, it revealed a good correlation with indicator of pollution (NH_3, NO_2 and NO_3) [32].

Salt content of water samples (Total dissolved solids, total hardness, chloride and sulphate) are within the standards level to human and household uses. The obtained results demonstrated the range of TDS, total hardness, chloride and sulphate were 140-951 mg/L, 76-417, 15-203 and 22-197 mg/L respectively, which indicated that the water samples were classified as hard water (Tables 2, 3 & 4).

Soft (0–75 mg/L $CaCO_3$), moderately hard (75–150 mg/L $CaCO_3$), hard (150–300 mg/L $CaCO_3$), and very hard water (>300 mg/L $CaCO_3$) were determined by Khan *et al.* (2013). Although water hardness has unknown negative consequences on the environment, it does cause issues for daily human use [31, 33].

Chloride and sulphate presented a statistically significant correlation (Figure 3) with calcium, magnesium, ammonia, nitrite and nitrate traits ($p \leq 0.979$, 0.970 and 0.988).

Chloride determinations may serve to indicate the intrusion of waters of different composition or to trace and measure rates and volumes of water mass movements.

Pollution indicator parameters (ammonia, nitrite, and nitrate) measurements, on the other hand, showed that all readings were within permissible levels (Tables 1, 2, 3 & 4). Additionally, ammonia showed good correlation with iron concentration (Figure 4) in different sampling sites.

While pollution with nitrate linked to leakage from manufacturing and municipal effluents, the main sources are treated distillery and fertilizers used for crop irrigation [34]. Furthermore, the greater NH_4^+ value in several groundwater samples is primarily attributable to natural decomposition [32].

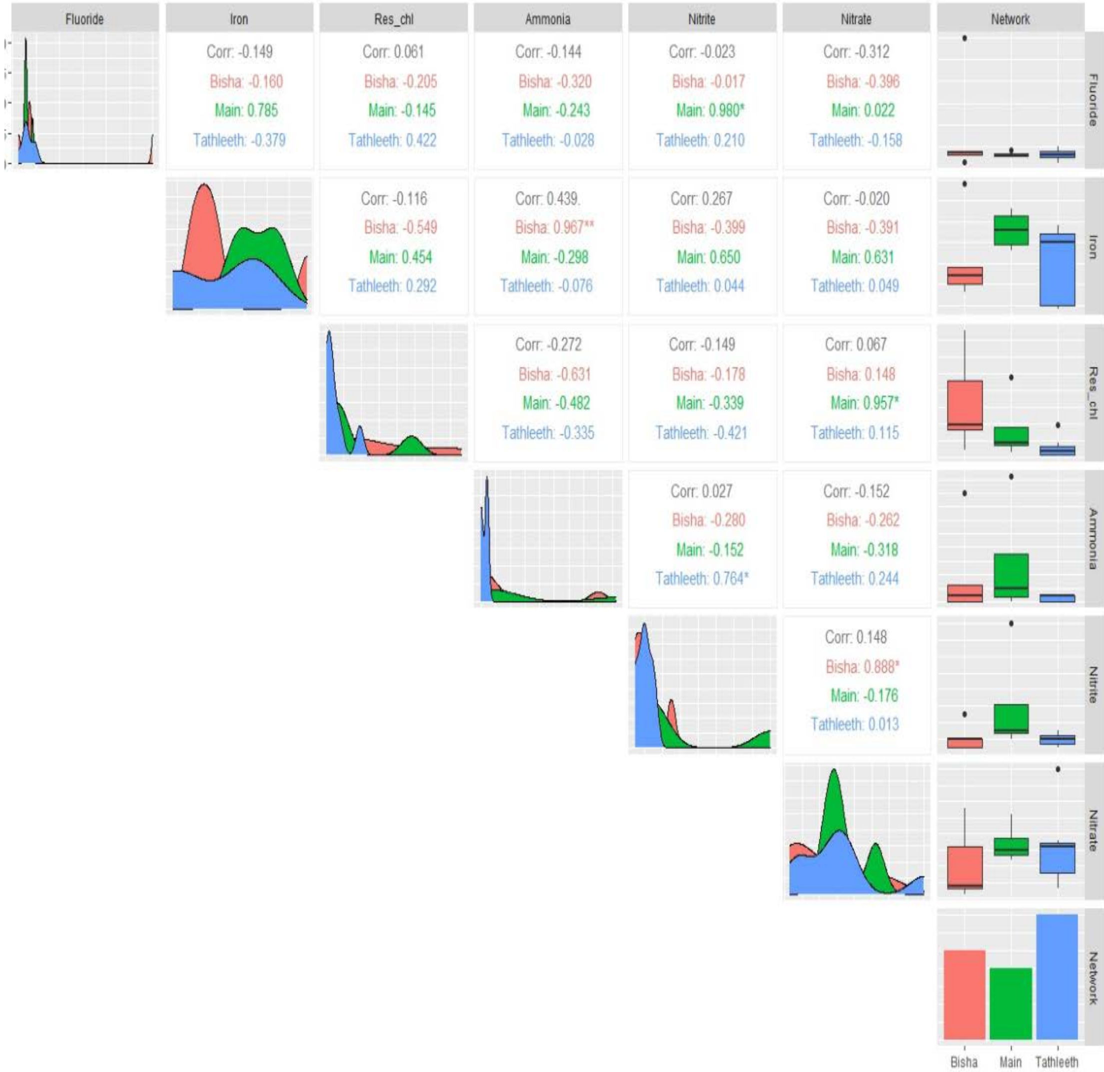

Figure 3 Correlation matrix between the target monitored parameters (calcium, magnesium chloride, sulphate, ammonia, nitrite and nitrate) and different sampling sites (main pumping station, Bishah network and Tathleeth network) $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$

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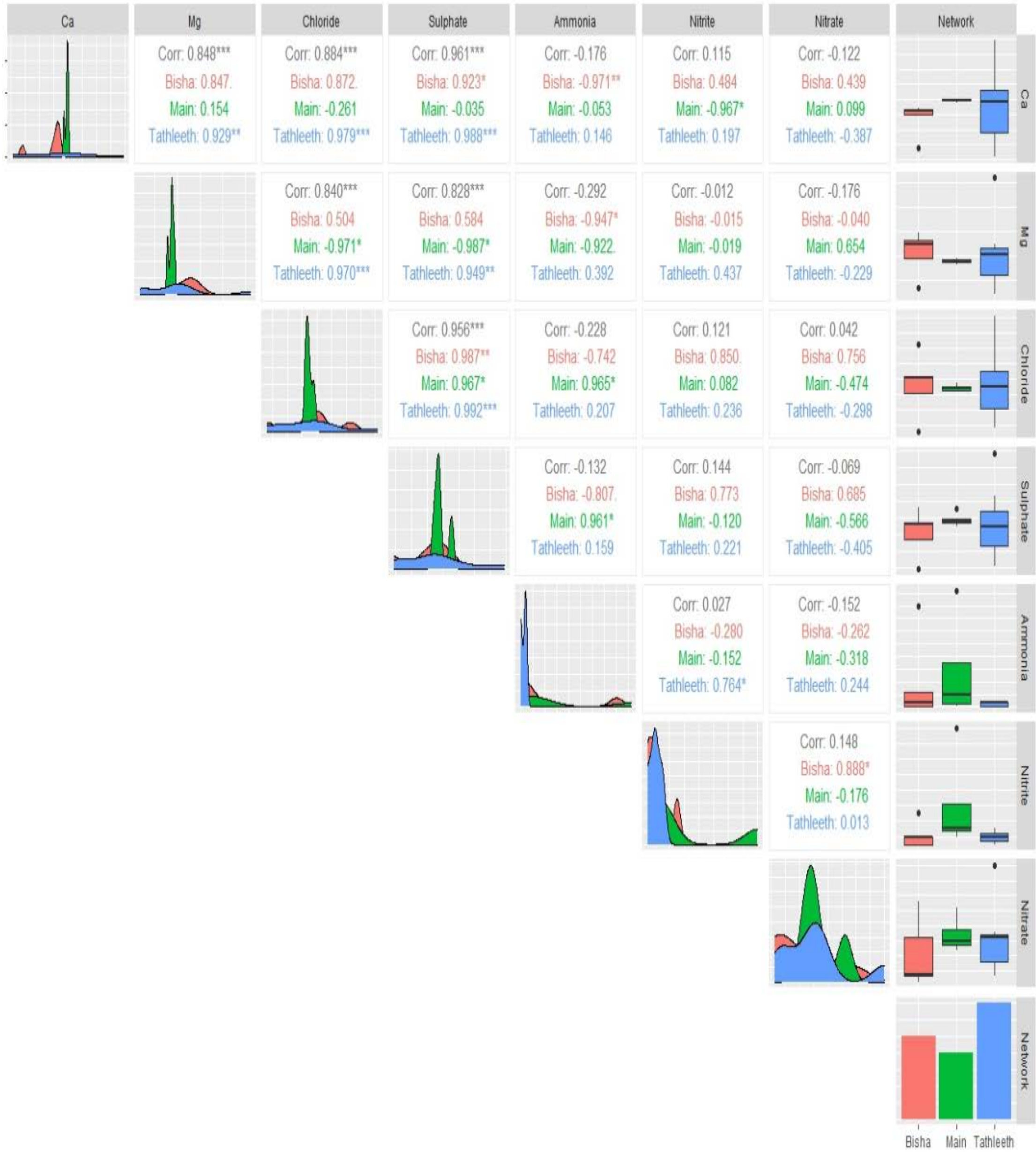

Figure 4 Correlation matrix between the target monitored parameters (fluoride, iron, Res. chlorine, ammonia, nitrite and nitrate) and different sampling sites (main pumping station, Bishah network and Tathleeth network) $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$.

Fluoride and iron levels in water have a negative impact on human health and have an impact on how water is used in the home. The WHO [19] recommends that both elements have acceptable concentrations of 1.5 and 0.3 mg/L, respectively that do not influence human activities. According to WHO and GCC [18, 19], almost all samples collected from Al Wajeed drinking water framework and its network extension have fluoride and iron contents that were within permitted limits with the exception of samples taken from King Fahd Station Bishah, which have fluoride concentrations that above the allowed limit (Table 1 & 3).

A study on fluoride occurrence and distribution in a Loess area of China was carried out to determine the geochemical and anthropogenic factors that influence F–concentration in groundwater [33]. The optimal drinking water concentration of fluoide for dental health is generally between 0.5 and 1.5 mg/L and depend upon the

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volume of drinking water consumed as well as intake and exposure from other sources [28].

3.2. Microbiological quality

It is normal for bacteria to be present in the environment. Total coliform and *E. coli* contamination-related diseases suggest that human and/or animal faeces may be present in the water source [35]. From this point of view, results of the majority of Al Wajeed water samples tested negative for total coliform. However, only one site samples tested positive total coliform (site of 800 end line- Tathleeth Distribution system) which indicate the probability of leakage from a source of pollution. Furthermore, *E. coli* show negative result in all samples collected from AlWajid Drinking water samples and its branches which indicated the effectiveness of chlorine dose used as a disinfectant. Coliform bacteria were found in drinking water sources, possibly as a result of septic tank leakage or discharge, as well as lack of disposal facilities for sewage and solid wastes which were the greatest dangers to water resources. Total Coliform and Fecal Coliform are indicators for pathogenic organisms. According to USEPA [36], every water sample that has coliform must be analyzed for either fecal coliforms or *E. coli*. Many authors have reported waterborne disease outbreaks in water meeting the coliform regulations [37]. So total coliforms of water samples are beyond the permissible limit and were not suitable for drinking purpose without pretreatment. This contamination can be occurred from the poor sanitation and leakage around the tube-wells where the contaminants can enter through the leakage and can mix up with water lifting pathway [38].

Chlorine and its derivatives, such as chloramine or chlorine oxide, are the most frequent strong oxidants employed in disinfection. Chlorine is effective against cyst-forming bacteria and protozoa e.g., *Giardia lamblia* [39]. The water samples in this study were disinfected with chlorine as a chemical disinfectant, and residual chlorine readings indicated the presence of residual chlorine in the distribution network (Tables 2, 3 and 4), as recommended by WHO [19]. Correlation matrix of residual chlorine and water criteria showed negative correlation (Figure 4) in different sampling sites.

3.3. Heavy metals measurements

The site-specific tendency could be a reflection of groundwater susceptibility that is depending on the interaction of ecological and anthropogenic factors at different locations. This notion is supported by studies that show varied levels of groundwater contamination sensitivity based on a variety of parameters such as precipitation infitration, protective cover depletion, and complicated land use activities [40-42].

Organ toxicity is commonly a result of metal exposures, relying on the dosage and time of contact [42, 43]. Whereas, as previously stated, the consuming rate may be a determinant factor in the degree of dangers in consumer populations [44-45].

Figure (5) show the Boxplot of heavy metals concentrations (maximum, minimum and mean value) in water samples collected from Al Wajeed drinking water configuration and its distribution network extension. Since some heavy metals do not have direct health effects but have unpleasant taste or color [46], the study results demonstrate that the heavy metals measurements in water samples meet the recommended acceptable limits established by [18, 19].

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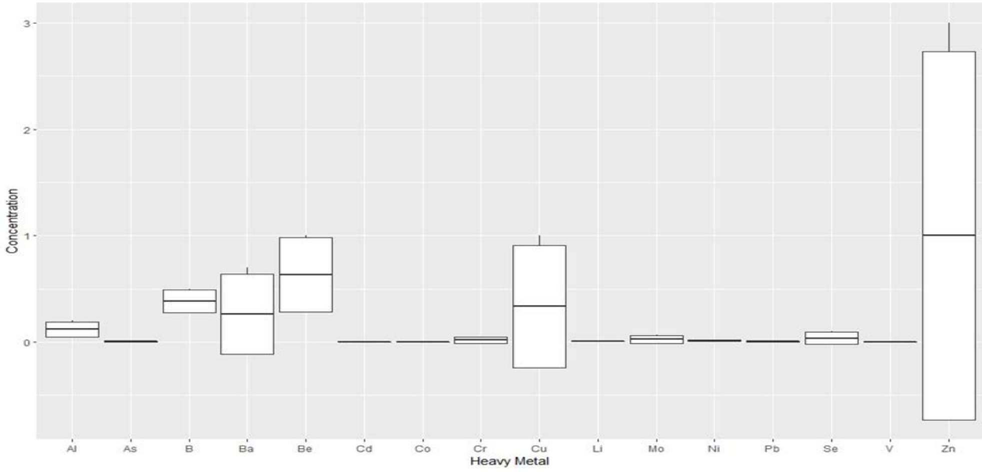

Figure 4. Boxplot of heavy metals concentration of samples collected from studied sites. Means are average of collected random samples sites for each parameter. Min. = Minimum; Max. = Maximum.

3.4. Radioactive atoms concentration

234U and 238U detected in the drinking water samples in Greece ranges from 0.91 to 17.27 mBql^{-1} and from 2.13 to 22.01 mBql^{-1}, respectively [47]. There was a correspondence between the 234U activity concentration values and those of 238U. This observation is related to leaching of uranium isotopes with a high rate to the underground water flowing through the faults and fissures between the grains of reservoir rocks. Consumption of ground waters for human activities would result in increased radiation doses and their utilization for irrigation purposes would not imply an extreme radiation exposure to population, in cases of high uranium concentration [48-50].

However, by studying radioactivity of the 28 water wells which feed Al Wajeed water system, results showed that samples did not exhibit uranium and radium content above limits suggested by WHO [19] for radium and uranium concentration in waters (Table 2).

Table 5 Radioactive atoms' levels in the 28wells water of Al Wajeed System.

Item	Mean+SD	WHO (2011)	GCC (2014)
Radium - 226 (piC/L)	11.1± 1.80		
Radium - 228 (piC/L)	12.3± 0.81		
Uranium - 234 (mBq/L)	74.6± 3.91		
Uranium - 238 (mBq/L)	53.6± 3.02		
Total uranium (ppb)	4.3± 0.24	300	300

Means are average of triplicate samples per each well. SD = Standard deviation.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

5. Conclusion

Improving water resource management and providing everyone with access to safe, affordable drinking water and sanitation is critical for eradicating poverty, building peaceful and prosperous societies, and ensuring long-term development. As a result, the Kingdom of Saudi Arabia established the Al Wajeed Water Treatment Plant to meet the needs of the southern region's population. The majority of the samples met national and international standards. Turbidity showed some fluctuation in its readings within different site branches but remained within the permissible level of global standards (it varies in the range 0.4-2.7 NTU) with the exception of Wadi Hergab water samples, which were above the standard level (~15.3 NTU). This result emphasizes the need to follow up the water quality to find source of pollution.

In addition, the majority of Al Wajeed water samples were found to be free of total coliform. However, only one site sample tested positive for total coliform (800End line-Tathleeth Distribution system), indicating that the chlorine dose was insufficient in some locations and a monitoring program should program implemented to protect the drinking water.

So, the research article suggests that AlWajeed Water Treatment Framework and its branches be regularly observed to make sure that their quality and hygienic practises are in line with local, national, and international requirements. Different scenarios could be developed for the future with focus on conservation principles and land use.

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Data Availability Statement

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

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