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Assessing the Impact of Zaatari Syrian Refugee Campin Central North Jordan on the Groundwater Quality

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Abstract

Zaatari Refugee Camp is the largest Syrian camp in Jordan with about 80,000 inhabitants. It was established in 2012 following the Syrian conflict. This refugee camp has been a constant source of concern to public authorities and local communities because it was built in the Amman-Zarqa Basin, a major groundwater aquifer system in Jordan, with a large number of wells. Thirty groundwater wells located in this refugee camp and its surrounding area were sampled and investigated for Total dissolved solids, pH, total hardness, Ca^{2+}, Mg^{2+}, HCO_3^-, K^+, Na^+, Cl^-, NO_3^-, SO_4^{2-}, Fe, Mn, Ni, Cu, Pb, Zn, Cd, Cr and E. coli. Groundwater wells were clustered (based on water quality data), statistically analyzed and compared with previous data (before establishing the camp), for better characterization of changes in water quality. The majority of water quality parameters showed values within the permissible limits based on Jordan standards for drinking water, with few exceptions. While weathering of rocks is the primary process governing water chemistry, uncontrolled and intensive pumping, dissolution of aquifer materials and leaching soluble salts following irregular rainfall events are contributing factors to water quality. Interestingly, groundwater samples collected from wells located in the camp and the nearest area showed a relatively better water quality, compared to other wells. This finding challenges the public opinion that groundwater wells in the vicinity of the camp would probably be of low quality. Also, this indicated that groundwater wells in this camp are probably better managed and controlled compared to others. It was also found that most water quality variables exhibited similar patterns, with lower values observed in the pre-2012 data. Although elevated levels of water quality parameters coincided with establishing the camp, no imminent threats of pollution to these groundwater resources have been observed.

Keywords: Zaatari Refugee Camp, groundwater quality, Jordan, Amman Zarqa Basin

1. Introduction

Jordan has experienced a dramatic population growth over the last seven years due to the influx of Syrian refugees. The growing number of population along with the urban expansion and economic development, have put major pressures on Jordan's existing water resources, especially in the northern region (Irbid, Zarqa, Mafraq). Before the Syrian conflict, the per capita share of water in Jordan ranged between 140 and 145 m^3 compared to the international standard of 1000 m^3 (UNHCR, 2018). According to MWI (2013), the rapid increase in the number of Syrian refugees exerted high pressure on public water supply systems, where in certain areas, the number of served persons almost doubled.

With its very limited surface water resources, Jordan relies heavily on groundwater resources to fulfill the growing demand for water (Al-Rawabdeh et al., 2014). In addition to a rapid decline in groundwater levels, excessive withdrawal of the groundwater reserve along with the unregulated expansions of domestic and industrial areas, have exacerbated water quality problems, where groundwater pollution has increasingly become an imminent threat to the water supplies (Al-Taani, 2013; 2014; 2018b). Evidence of water quality deterioration has been frequently reported (Al-Rawabdeh et al., 2013; Al-Taani et al., 2012).

Following the Syrian conflict, about 1.4 million Syrians have been displaced to Jordan (UNHCR, 2018), of which about 80,000 persons are housed in the Zaatari Refugee Camp (ZRC). The ZRC is the largest Syrian refugee camp in Jordan, located in the northeastern region, close to Jordan's northern border with Syria (Al-Harahsheh et al., 2015). The ZRC was built in the Amman-Zarqa Basin (AZB) which is a major source of groundwater in Jordan (Al-Taani et al., 2018a). A large number of new groundwater wells have been drilled

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within ZRC and its surrounding area to meet the growing demands of water for refugees and the host communities. Due to groundwater abstraction, a5-m decrease in water table has been observed in one of the observation wells in ZRC during the period 2000-2012(UNEP/UNDP, 2015). In addition, water samples from wells in close proximity to ZRC showed elevated levels of E. Coli and Total Cell Count with time since 2011(UNEP/UNDP, 2015).

Groundwater aquifers of northeastern Jordan (in AZB), where ZRC was established, are of critical economic and social significance to the region, as they are the primary source of irrigation and drinking water. AZB contains about a quarter of all groundwater wells in Jordan (Margane et al., 2015). Also, this region is part of the recharge areas to groundwater aquifers, where changes in land use and human activities will ultimately affect groundwater quality.

With ever-increasing water demands, the management and protection of these groundwater resources are significant to maintain adequate water supply for the host communities and refugee camp. This study intends to determine and assess the groundwater quality conditions in wells located in ZRC and the surrounding areas. The ZRC has been a constant source of concern to public authorities and local communities because it was built in the Amman-Zarqa Basin, a major groundwater aquifer system in Jordan. This study also compares water quality data before ZRC was established to the results confirmed by the current study. This assessment is likely to unveil the natural and anthropogenic sources governing the aquifer water quality, including the potential impact of ZRC on these water reserves. This aids decision-makers and public authorities manage existing water supplies for sustainable use through the implementation of preventive measures and strategies for wellfield management.

2. Study Area

The ZRC is the largest Syrian refugee camp in Jordan with an area of about 5.5 km^2. It was opened in 2012, following the Syrian conflict and is currently hosting about 80,000 people. It is located in the northeastern region, close to Jordan's northern border with Syria (figure 1). The ZRC was built in AZB which is a major source of groundwater in Jordan (Al-Taani et al., 2018a). In response to the rapid increase in water demands, a large number of groundwater wells were dug within ZRC and its surrounding area. In 2016, three water wells were established within the ZRC border with a total daily capacity of 3800 m^3 (UNHCR, 2018). Also, a wastewater treatment plant with a total capacity of 3600 m^3/d was constructed. In addition, a piped water supply distribution system is currently under construction along with a piped sewerage network, linking the collection system to the wastewater treatment plant to meet the needs of the camp's population (UNHCR, 2018).

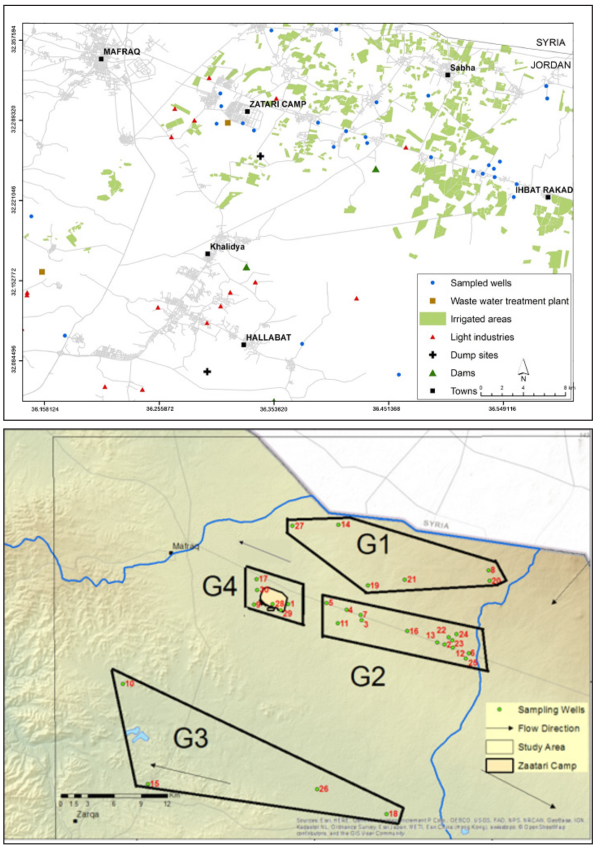

Figure 1. Location map of water sampling wells (upper) and their clusters (lower).

The AZB represents a transitional area between Jordan highlands in the west and the desert in the east. It is subdivided into two main catchments; Wadi Dhuliel sub-basin representing the arid conditions and flat land (where ZRC is located), and the Zarqa River sub-basin which represents the most populated mountainous area. The total catchment area is about 3918 km^2 (RSS, 2005), with 89% located in Jordan and 11% inside the Syrian territory.

The AZB is part of the Mediterranean climate, with an arid climate in the southeastern, eastern, and northeastern regions and rainy humid conditions in the west. Humidity and precipitation decrease rapidly towards the eastern deserts (USAID and WAJ, 1989), with an average annual precipitation of 300 mm (commonly occur as flash floods).

According to Bender (1974), the main geological formations outcropped in the study area can be summarized as follows:

Wadi Es-Sir Limestone Formation (WSL) (Turonian) crops out extensively in the northern, central and southern parts of the study area. The massive crystalline limestone is karstic and weathered in the top 20 m of the formation, below which is a general increase in the marl chalky limestone and thin marl beds occur.

Wadi umm Ghudran Formation (WG) (Coniacian - Santonin) lies uncomfortably above Wadi Es-Sir Limestone Formation. It consists of massive chalk white in addition to chalky limestone and some marls, the depositional environment is the mid to inner shelf (Smadi, 2000).

Amman Silicified Limestone Formation (ASL) and Al-Hisa Phosphorite Limestone Formation (AHP) (Santonian-Campanian). These formations are considered as one unit in the study area which consists of alternating micritic limestone with chert varying in thickness and alternating between phosphatic chert and phosphatic limestone. The depositional environment is marine shelf (Smadi, 2000).

The Basalt Plateau (Oligocene-Pleistocene) is composed of basalt, and crops out in the northeastern part of the basin. They are represented by Abed Olivine Basalt (AOB) and Fahda Vesicular Basalt (FA) Formations. Thin layers of clay and gravel of limestone and chert pebbles occur between the successive Scoriaceous basalt and volcanic plugs basalt flows.

The Younger Alluvium Formation (Alluvium mudflat “Amf”, Alluvial “Al”, Sand “S”, and Pleistocene Gravel “Plg”), of a Quaternary age, consists of thin deposits overlying the basalt in the cemented outwash and the old river terraces. River- and superficial- gravels and silts are widespread. Figure 2a shows a geological map of the study area.

Figure 2b shows a simplified hydro-geological units map in the study area. The major groundwater aquifer in AZB is B2/A7 and Basalt systems aquifers. In many parts of the study area, water levels have declined to alarming levels, where farmers have drilled further deep to the next aquifers (A4, A1/2 and often Kurnub aquifers) to obtain enough water for irrigation (Margane et al., 2015 and MWI, 2013). With high salinity levels encountered in the Kurnub, irrigation water has to be desalinated, where the brine has been discharged into adjacent valleys. This has exacerbated the salinity problem in the B2/A7 aquifer as well (Margane et al., 2015 and MWI, 2013). Between 1995 and 2015, a decline in water levels of about 60 m was estimated, with an annual drop rate of 5 m in recent years (Margane et al., 2015 and MWI, 2013), coinciding with increasing water demands following the Syrian refugee influx. This has changed the groundwater quality and flow regime, where agricultural runoff from intensive agricultural lands, ended up in B2/A7 aquifer (Margane et al., 2015). Irrigation effluents (of Wadi Dhuleil-Hallabat and Badia areas) now flow towards the Yarmouk River, with a subsequent increase in salinity levels in this region (Mafraq) (Margane et al., 2015).

The basalt aquifer extends from the northern border of Jordan southwards to Al-Azraq and Wadi Dhuleil areas. The aquifer occupies a surface area of 1,100 km^2 in northeastern Jordan (Shahin, 2007). In some localities, large quantities of groundwater can be withdrawn, since it is characterized by a large thickness. The aquifer discharge increases the base flow in the basin of the Upper Yarmouk River, Wadi Dhuleil-Wadi Zarqa and Zarqa River. The transmissivity of Basalt aquifer system ranges from almost zero to 11300m^{3}d^{-1}, and the specific capacity of wells ranging from 0.07 to 3352m^{3}h^{-1}m^{-1} (Shahin, 2007). The quality of water is classified as good with total of dissolved solids (TDS) ranging from 500 to 1000 ppm (Shahin, 2007). Muwaqqar Chalk Formation B3 (Paleocene) is composed of chalky to marly limestone and cherts that have been deposited in a shallow marine environment. Because of its composition, it acts as an aquitard that separates the upper aquifer systems (Basalt, B4/B5) from the underlying aquifer system (A7/B2) (MWI and BGR, 2019).Figure 2c shows a NW - SE Hydro-geological cross- section to understand the hydro-geological set-up in the study area.

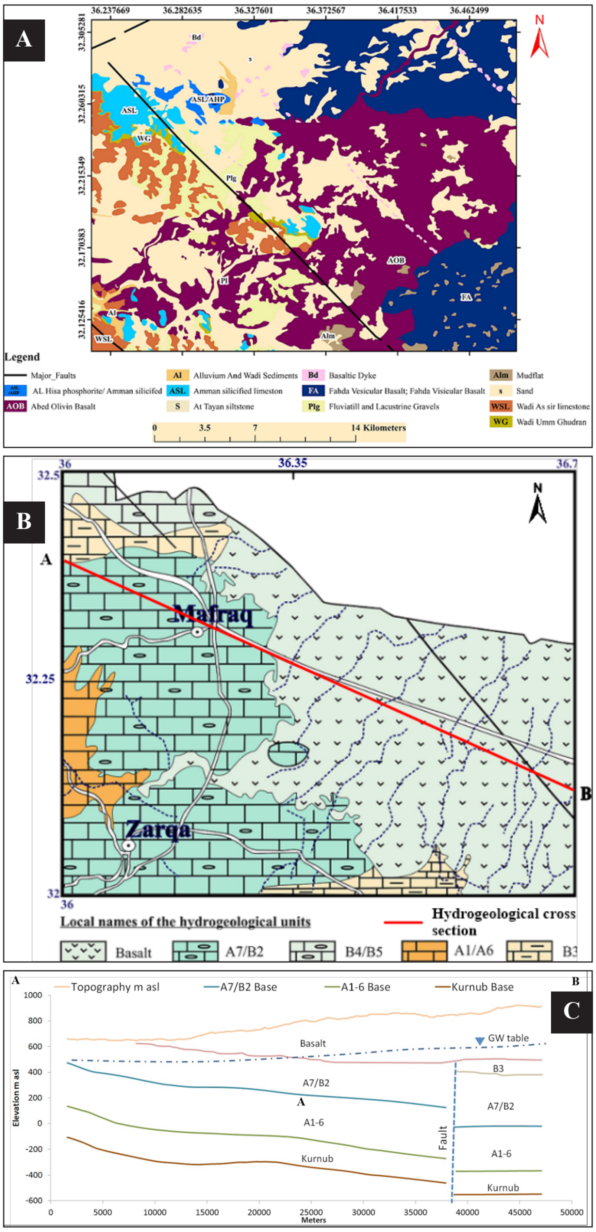

Figure 2. a- Geological map of the study area (After Smadi, 2000; Gharaibeh, 2003) b- Simplified Hydro-geological map of the study area (MWI and BGR, 2019) c. NW-SE Hydro-geological cross-section (For location See Figure 2b).

The soils in the study area are affected by rainfall and relieves. It is immature with silty loam to loamy texture (Al Mahamid, 2005). It is composed of a silty clay loam and clay loam (with a high calcareous content and weakly to moderately saline) with stony silty clay loam (with a content of calcareous material and weakly saline) (Al Mahamid, 2005).

3. Materials and Methods

One-hundred and twenty groundwater samples were collected from August to December of 2017 from thirty different wells located within the ZRC border and its surrounding region. The distribution of groundwater sampling wells is presented in figure1. These groundwater wells are owned by the government, and are largely dug in B2/A7 aquifer, except for wells 2, 3, 5, 8, and 26. After purging, the water samples were collected in one-liter pre-cleaned polyethylene containers (pre-acidified containers were used for trace-metal analysis). Following collection, the samples were kept in an icebox at 4°C and were transported to the water laboratory for subsequent chemical analyses. In addition to the dissolved trace metals, a variety of water quality parameters were analyzed for this assessment (Table 1). Total dissolved solids (TDS) and pH were measured in-situ using portable field meters. Total hardness (TH) and Ca^{2+} were measured with the EDTA titrimetric method and Mg^{2+} by calculations. $HCO_3^-$was determined by potentiometric titration. K^+ and Na^+ were determined by Flame photometer (Jenway Clinical PFP7). Cl^-, NO_3^-, and SO_4^{2-}were analyzed by Ion Chromatography (Dionex DX-120). Trace metals (Fe, Mn, Ni, Cu, Pb, Zn, Cd, and Cr) were measured with inductively coupled plasma ICP-OES (PerkinElmer). E. coli was measured by Colilert*-18 (IDEXX). Measurements and preparation were performed according to the standard methods (APHA 1998), and an ICP multi-element standard solution (from Merck Millipore) was used. All measurements were conducted at the Water, Environment and Arid Regions Research Center, Al al-Bayt University in Jordan.

The water quality data were checked for accuracy by computing the ion balance of major cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) and anions (HCO_3^-, $C1^-$, SO_4^{2-}, NO_3^-) in meq/l. The ionic mass balance was calculated by dividing the difference of the total cations and anions by the sum of cations and anions multiplied by 100. The average ion balance for water samples was -3.16%.

4. Results and Discussion

Results of water quality characteristics (physical, chemical, and biological) of the groundwater wells located within ZRC and its surrounding area are summarized in Table 1. The pH values ranged between 6.6 and 8.4 with an average value of 7.2. These values are generally consistent with open-system carbonate dissolution (Langmuir, 1971). The highest pH level was observed in well 1 which is located in ZRC, whereas the lowest was recorded in well 30 (located adjacent to ZRC). It is noteworthy that well 1, 28, and 29 are located within the border of ZRC (figure 1). These levels of pH values are within the range listed for waters suitable for drinking water (JS, 2008).

Table 1. Summary statistics of water quality parameters for the groundwater wells located in ZRC and its surrounding area (from 8-12/2017) (Alt. Altitude, W.D.: Well Depth, A.N.: Aquifer Name, Y: Yield, W.L.: Water Level, D.D.: Drawdown).

Well No.		pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	TDS	TH	E.Coli	Alt. (m)	W.D. (m)	A.N. (Aquifer Name)	Y. (m^3/h)	W.L. (m)	D.D. (m)
			mg/L																
1	Mean	8	131.8	4.8	38.5	41.7	154.3	11.1	60	209.9	530.3	247	<1	-	-	-	-	-	-
	Max	8	172.9	7.1	48.1	51	168.7	14.7	60.4	210	579	270							
	Min	8	94.5	3.1	29.5	31.6	135.4	7.9	59.2	209.9	488	230							
	STD	0	39.3	1.9	7.8	8	17.1	3.4	0.7	0.1	38.2	21							
2	Mean	7	121.4	9.6	50.3	46.7	278.7	25.9	86.4	109.3	758.5	318	<1	790	373	B2/A7	85	268	1
	Max	7	131	15.9	64.1	48.6	287.9	27.6	96.9	131.2	780	330							
	Min	7	108.3	5.7	36.1	41.3	265.4	24.2	78.8	78.7	745	290							
	STD	0	11.7	4.8	11.5	3.6	11.8	1.7	9.4	27.3	16.5	19							
3	Mean	7	88.7	3.1	27.7	13.2	74.7	6.6	44	183.7	378.5	123	<1	732	400	BA	87	212	4
	Max	8	102.6	4.2	34.7	17	84.4	8.2	51.7	209.9	391	140							
	Min	7	69.7	1.8	20	5.7	69.5	4.9	39.6	170.6	365	110							
	STD	0	17	1.2	6	6.5	8.4	1.7	6.7	22.7	10.8	15							
4	Mean	7	94.7	5.4	35.2	17.7	132.5	19.4	30.4	135.6	453	153	<1	706	305	BA	63	183	3
	Max	7	112.9	9.3	44.1	19.4	143.9	21.2	36.2	144.3	462	170							
	Min	7	71.2	2.3	24	14.6	124.1	16.5	27.2	131.2	443	140							
	STD	0	21.4	3.3	8.3	2.7	10.3	2.6	5.1	7.6	8	15							
5	Mean	7	81.8	2.7	24.2	12.1	60.7	15.9	32.1	170.6	328.3	100	<1	693	293	B2/A7	83	169	2
	Max	8	95.1	4.3	28.6	17	69.5	18.2	33.8	183.7	337	110							
	Min	7	64.7	1	16	7	50.5	12	31.3	157.4	321	90							
	STD	0	15.6	1.6	5.8	4.1	9.6	3.4	1.4	13.2	6.9	10							
6	Mean	7	111.8	6.1	59	54.5	295.3	28.8	98.4	98.4	842.3	365	<1	798	395	BA	44	277	5
	Max	7	129.9	6.4	64.1	55.4	307.7	29.1	100.4	118.1	870	370							
	Min	7	82.8	5.8	56.1	53.5	282.9	28.5	96.4	85.3	827	360							
	STD	0	25.4	0.4	4.4	1.3	17.5	0.4	2.8	17.4	24	7.1							
7	Mean	7	89	4.8	28.2	19.4	86.5	7	38.4	168.4	388.3	150	<1	726	450	B2/A7	67	208	23
	Max	7	107.4	8.1	32.6	29.2	89.3	7.7	39.5	183.7	394	200							
	Min	7	69.7	3	24	14.3	81.9	5.8	37.3	157.4	386	130							
	STD	0	18.9	2.8	4.8	6.7	4	1.1	1.1	13.7	3.9	34							
8	Mean	7	140.2	7.8	30.2	25.4	162.3	26.6	80.2	160.7	560.8	180	<1	920	580	B2/A7	55	402	6
	Max	8	162	10.4	40.1	34	188.6	31.1	91.4	183.6	656	240							
	Min	7	112.3	5.8	20	19.4	119.5	22.1	69.6	131.2	475	130							
	STD	0	22.8	2.2	9.7	6.1	37.4	4.5	10.9	22.4	79.4	47							
9	Mean	7	86.6	3.3	56.8	43.5	136.5	24.7	49.8	240.5	574.3	303	<1	642	382	A4	47	169	41
	Max	7	106.3	5.2	68.1	48.6	138.9	30.5	51.3	262.4	587	340							
	Min	7	59.7	2.4	50.9	37.7	134	16.4	48.2	196.8	558	280							
	STD	0	24.1	1.3	7.9	6	3.5	7.4	2.2	37.9	13	32							
10	Mean	7	110	3.4	41.1	33.9	171.8	31.8	44	113.7	374.3	128	<1	606	292	B2/A7	119	86	1
	Max	7	178.6	4.7	83.3	78.3	259.1	32.7	68.6	131.2	412	140							
	Min	7	71.2	1.8	20	15.8	84.4	30.8	19.4	91.8	337	115							
	STD	0	59.6	1.5	36.5	29.7	123.5	1.3	34.8	20.1	37.5	13							
11	Mean	7	88.9	3.7	22.2	13.9	73	14.5	30.4	159.1	331	113	<1	695	444	B2/A7	60	194	7
	Max	7	98.9	5.4	28.6	19.4	89.3	16.7	31.8	183.7	337	150							
	Min	7	83.6	2.2	16	4.5	60.2	13	29.6	131.2	326	90							
	STD	0	8.7	1.5	7.1	6.6	14.9	1.9	1.2	21.7	5.8	26							

12	Mean	7	109.4	7.4	53.8	42.1	246.1	23.7	79.9	105	710.8	290	<1	795	423	B2/A7	85	287	2
	Max	7	117.7	10.3	68.1	46.2	277.9	23.9	82	118.1	724	300							
	Min	7	100.2	5.9	46.8	36.5	227	23.4	78.4	91.8	697	280							
	STD	0	8.8	2.5	9.8	4.3	27.7	0.4	1.9	13.2	12.8	10							
13	Mean	8	114.4	7.6	47.3	40.3	245.7	23.3	79.5	135.6	763.3	277	<1	790	415	B2/A7	83	280	3
	Max	8	138.4	11.1	56.1	41.3	258.1	25.2	90.5	144.3	881	290							
	Min	7	77.8	5.7	40.1	38.4	233.3	21.3	71.7	118.1	693	270							
	STD	1	32.2	3.1	6.7	1.7	17.5	2.8	9.8	15.1	83.5	12							
14	Mean	7	148.1	6.1	35.8	36.8	232.4	25.2	62.7	144.3	747.3	233	<1	740	497	B2/A7	52	260	21
	Max	7	175.1	8.5	44.1	37.3	248.2	27.2	64.9	157.4	770	240							
	Min	7	96.9	4.8	28.1	36.5	223.3	23.1	60.1	131.2	720	220							
	STD	0	44.4	2.1	6.6	0.5	13.7	2.1	2.4	13.1	21.1	12							
15	Mean	7	211.5	7.5	43.2	56.1	395.4	34.3	73.1	154.2	1078.5	308	<1	580	315	B2/A7	77	77	21
	Max	7	240.5	11.6	64.1	65.6	441.7	36.6	76	170.6	1120	330							
	Min	7	162.6	4.7	20	30.4	362.3	32.7	70.2	131.2	1030	285							
	STD	0	42.6	3.3	24.2	17.2	41.3	2	4.1	19.7	37.1	23							
16	Mean	7	178.7	11.5	81.9	71.5	499.2	40	156.2	114.8	1274.8	490	<1	759	400	B2/A7	60	255	1
	Max	8	209.5	19.7	92.2	73.5	518.7	52.2	164.2	131.2	1295	500							
	Min	7	125	7.3	71.1	70.5	451.6	33.8	144.6	91.8	1246	480							
	STD	0	46.6	7.1	8.8	1.7	31.9	10.5	10.3	19.7	20.7	10							
17	Mean	7	90.1	2	56.8	38.4	141.4	20.7	50.8	255.8	622.3	300	<1	650	415	B2/A7	0	0	0
	Max	7	106.3	2.3	68.1	43.7	143.9	22.6	51.1	301.7	691	340							
	Min	7	70.2	1.7	50.9	34	138.9	17	50.4	209.9	582	270							
	STD	0	18.3	0.3	7.9	4.8	3.5	3.2	0.5	46.1	49.7	32							
18	Mean	7	74.7	3.6	17.1	12.7	39.7	12.8	22	131.2	272.5	95	<1	590	124	B2/A7	91	79	0
	Max	7	88.6	4.8	24.5	19.4	64.5	13.4	22.2	131.2	280	130							
	Min	7	62.2	3	12	7	14.9	11.8	21.7	131.2	263	80							
	STD	0	13.3	1	6.2	5.1	35.1	0.9	0.4	0	7.1	24							
19	Mean	7	165.4	10.5	52.3	50.3	352.8	24.6	110.1	121.5	936.3	338	<1	741	352	B2/A7	70	252	2
	Max	7	195.1	17.4	56.1	58.3	367.3	26.9	123.7	131.2	945	380							
	Min	7	112.9	7	48.1	43.3	327.6	22.2	101	118.1	919	300							
	STD	0	45.6	5.9	4.4	7.9	21.9	3.3	9.7	6.5	11.7	44							
20	Mean	7	226.5	11.3	91	88.8	541	29.3	144.8	96.2	1477	593	<1	911	624	B2/A7	23	417	8
	Max	7	261.1	16.1	93.4	106.9	610.4	30.3	163.7	105	1722	670							
	Min	7	194.3	8.8	88.2	72.9	486.4	28.4	128.6	91.8	1337	520							
	STD	0	33.5	4.1	2.3	17.8	63.3	1	18.1	7.6	172.5	79							
21	Mean	7	187.2	11.2	80.9	83.8	418.6	21.1	146.6	164	1222.8	507	<1	832	428	B2/A7	35	307	7
	Max	7	188.9	18.8	88.2	99.6	456.6	22.3	157.4	209.9	1309	550							
	Min	7	185.3	7.2	69.1	71.7	377.2	19.2	128.6	131.2	1132	460							
	STD	0	1.8	6.6	8.6	14.3	39.8	1.7	15.7	39.4	75.1	45							
22	Mean	7	94.1	5.6	24.2	14.9	81.9	13.1	23.5	192.4	349	122	<1	800	424	B2/A7	55	308	4
	Max	7	112.9	10.2	28.6	26.7	89.3	13.3	23.6	209.9	355	180							
	Min	7	69.2	3.2	16	5.7	74.4	12.9	23.4	170.6	346	90							
	STD	0	22.5	4	7.1	10.8	10.5	0.3	0.1	20	5.2	51							
23	Mean	7	92.9	5.6	24.2	15.7	81.9	10.9	22.7	192.4	345	125	<1	805	492	B2/A7	55	308	1
	Max	7	109.1	10.2	24.5	29.2	89.3	12.7	22.7	196.8	349	180							
	Min	7	73.7	3	24	7.3	74.4	9.1	22.6	183.7	342	90							
	STD	0	17.9	4	0.3	11.8	10.5	2.5	0.1	7.6	3.6	48							
24	Mean	7	84.4	5.3	19.5	16.9	59.6	9.2	21	179.3	311	118	<1-3.1	825	470	B2/A7	55	328	4
	Max	7	99.7	9.8	26.5	29.2	59.6	11.4	21	183.7	313	160							
	Min	7	67.7	2.8	16	8.2	59.6	6.9	20.9	170.6	309	95							
	STD	0	16	3.9	6.1	10.9	0	3.2	0.1	7.6	2	36							
25	Mean	8	96.4	6	48.9	61.4	245.7	25.7	77.3	105	744.3	318	<1	794	500	B2/A7	50	296	0
	Max	8	108.4	6.6	72.1	75.3	248.2	26.5	83.8	118.1	751	325							
	Min	7	77.3	5.3	30.6	52.2	243.2	24.9	70.7	91.8	732	310							
	STD	0	16.7	0.9	21.2	12.2	3.5	1.1	9.3	18.6	10.7	11							
26	Mean	7	138.6	7.3	39.8	26.2	212.2	13.2	69.1	147.6	697.5	223	<1	585	243	B2/A7	30	104	0
	Max	7	164.1	10.4	48.1	31.6	213.4	14.3	69.8	157.4	714	250							
	Min	7	92.8	4.1	20	22.7	210.9	12.5	68.3	131.2	688	210							
	STD	0	39.8	3.5	13.3	4.7	1.8	1	1.1	12.5	11.6	23							
27	Mean	7	177.9	8.6	61.1	51.1	459.9	34	114.3	154.2	1178	383	<1	695	454	B2/A7	37	277	0
	Max	7	234.3	12.9	72.1	60.8	516.2	36.8	131	183.7	1442	470							
	Min	7	108.4	5.5	40.1	36.5	357.3	30	93.3	118.1	828	250							
	STD	0	64	3.5	18.2	12.9	89	3.6	15.9	29.1	312.8	117							
28	Mean	8	86.4	4.2	30.2	44	114.2	5.6	51.9	259	418.8	263	<1	644	430	B2/A7	36	219	55
	Max	8	102.8	6.3	48.1	62	124.1	6.2	52	275.5	455	280							
	Min	7	67	3	10	26.7	104.2	4.9	51.8	236.1	383	230							
	STD	1	18.1	1.6	19.2	14.9	14.1	0.9	0.1	16.5	29.4	29							
29	Mean	8	88.3	3.7	42.5	32.9	98.7	8.4	48.8	236.2	449	230	<1	652	430	B2/A7	55	203	39
	Max	8	107.7	5.6	56.1	44	114.1	11.1	52.1	275.5	575	270							
	Min	7	64.8	2.9	35.6	24.3	77.8	5.7	42.8	209.9	335	200							
	STD	1	21.7	1.3	9.3	10.1	18.8	3.8	5.2	32.1	99	36							
30	Mean	7	86.7	3.3	51.8	41.6	161.3	17.2	57.3	221.4	598.8	297	<1	670	434	-	50	193	0
	Max	7	110.1	3.9	56.1	48.6	178.7	23	65.4	249.3	624	330							
	Min	7	58.2	2.7	46.8	36.5	143.9	8.6	49.2	157.4	575	280							
	STD	0	26.3	0.6	3.8	6.3	24.6	7.6	11.5	43	21.3	29							
Average	Mean	7	119.9	6.1	43.8	38.2	208.5	20.1	66.9	164.3	657.2	256	<1	729.9	406.3	-	58.9	228.2	9.0
	Max	8	261.1	19.7	93.4	106.9	610.4	52.2	164.2	301.7	1722	670							
	Min	7	58.2	1	10	4.5	14.9	4.9	19.4	78.7	263	80							
	STD	0	48.1	3.8	21.1	22.4	150.5	9.6	40.2	51.1	330	133							

Elevated levels of TDS in the groundwater samples were observed. The average TDS concentrations varied from 263 mg/L (well 18) to 1722 mg/L (well 20) with an overall mean concentration of about 657 mg/L (Table 1). Eleven wells showed average TDS concentrations below 500 mg/L (freshwater), whereas the remaining groundwater wells are classified as brackish (>500-30,000 mg/L). Although drinking water containing more than 500 mg/L is undesirable, such water, commonly used in this region as less mineralized water, is rare or not available.

The TDS values are likely elevated due to uncontrolled and intensive pumping. In addition, the dissolution of aquifer materials, leaching soluble salts following irregular rainfall events (enhanced probably by evaporative concentration) are contributing factors to high TDS levels. It is noteworthy to mention that carbonate and evaporite rocks are widespread in the study area. While seasonal variations have not been investigated, higher TDS levels are expected during summer seasons, when the demand for water increases and over-abstraction of groundwater becomes widespread.

The concentrations of water quality parameters in different wells are plotted in figure3. Higher levels were consistently observed in wells 16, 20, and 27. The average concentration of TDS in wells 16, 20, and 27 exceed the permissible limits of 1000 mg/L based on Jordan standards for drinking water (JS 2008). These wells are extensively abstracted for public use, livestock farming and irrigation as they are located in close proximity to human settlements. Total Hardness (TH) of the groundwater samples varied from 80 to 670 mg/L, with the highest value observed in well 20 and the lowest in well 18 (Table 1 and Figure3).

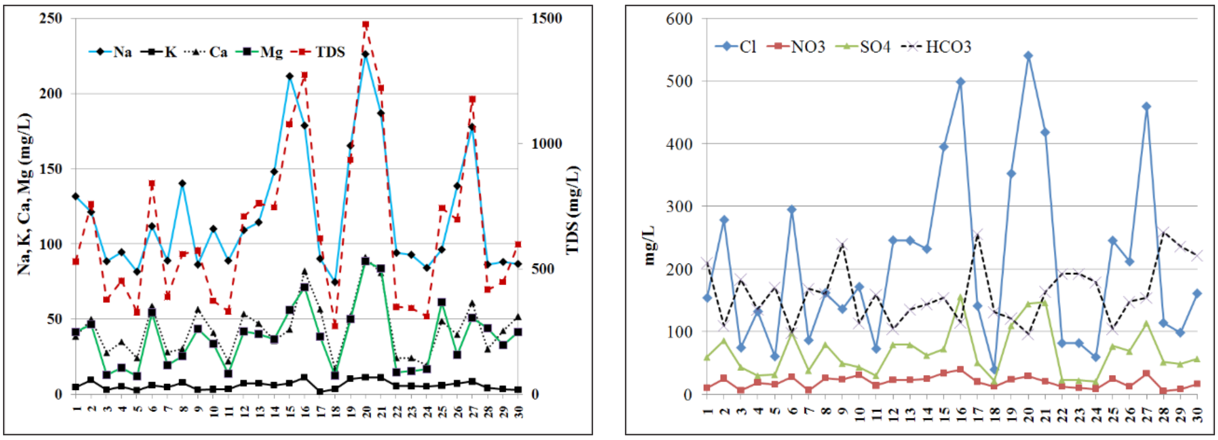

Figure 3. Concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+} (left), Cl^-, NO_3^-, SO_4^{2-}, and HCO_3^- (right) in the water wells of ZRC and its surrounding areas.

Similarly, the average concentrations of Na^+, K^+, Ca^{2+} and Mg^{2+} varied widely from 58.2-261.1, 1-19.7, 10-93.4 and 4.5-106.9 mg/L, respectively (Table 1).Groundwater wells 15 and 20 showed Na^+ levels that are in excess of standard limits for drinking water (200 mg/L). Well 27 exhibited a relatively high average value for Na^+, but it agrees with the standard limit for drinking water.

Cl^- concentrations in groundwater samples ranged between 14.9 and 610.6 mg/L (Table 1), exceeding the permissible limit of 500 mg/L for drinking water set by Jordan, in well 20 (541 mg/L). Increased concentrations of Cl^- were measured in well 16, but they are still within the acceptable limit for drinking purposes. SO_4^{2-} in the water wells ranged in concentration from 19.4 to 164.2 mg/L. None of the thirty wells exceeded the Jordan drinking water limit of 500 mg/L (Table 1). The concentrations of SO_4^{2-} are likely derived from the dissolution of evaporite deposits (gypsum and anhydrite).

Nitrates (NO_3^-) are widespread throughout the aquifer and present in all of the samples, where the concentrations increased in some areas, although not all. NO_3^- concentrations ranged between 4.9 mg/L (well 28) and 52.2 mg/L (well 16), with a mean concentration of 20.1 mg/L. Few groundwater samples from well 16 exceeded the NO_3^- permissible limit for drinking water of 50 mg/L, though the average level in well 16 was 40 mg/L. The relatively high NO_3^- levels found in several samples are probably related to the leaching of agricultural nitrogen (especially the use of inorganic fertilizers and manure) with irrigation drainage or during flash floods. Farm livestock also produce nitrogen-containing waste that possibly contributes to groundwater.

No evidence of wastewater pollution has been observed, where the E. coli has been not detected / or remained constantly below 1 MPN/100 ml, except for well 24 (Table 1). Having said this, cesspools are widespread and a septic system failure is likely to occur. However, the high depths of groundwater levels (Table 6) for the majority of wells make it difficult to detect the faecal bacteria indicator (E. coli) in the water samples.

HCO_3^- concentrations ranged between 78.7 and 307.1 mg/L (Table 1). The majority of water quality parameters showed similar ups and downs in the same well simultaneously, except for HCO_3^-. Bicarbonate levels exhibited different trends, where the concentrations fluctuated independent of other ions patterns. For example, it decreased in wells 16, 20, and 27, though other parameters have exhibited exceptionally higher values. These observations may suggest that HCO_3^- was originated from different sources (which is less likely) or has been precipitated.

For a better assessment and characterization of the spatial distribution of water quality data, groundwater wells were clustered into four groups (Figure 1), and the results are presented in Table 2. The average values of pH in the groundwater wells were noticeably equal in all groups. The relatively highest values of all water quality variables were consistently observed in group 1 (G1), except for HCO_3^-. Interestingly, the groundwater samples collected from the wells located in ZRC and its nearest areas showeda relatively better water quality, with the majority of water quality parameters exhibiting lower levels in these wells (with few exceptions i.e. $HCO_3^-$and TH, though they remain within the acceptable limits for drinking purposes). This finding opposes the initial thoughts in this study and challenges the public opinion that groundwater wells in the vicinity of ZRC would probably be of a low quality.

Table 2. Average concentrations of a variety of water quality parameters clustered in four groups compared to Jordan guidelines for drinking water (data collected from August-December 2017).

Group No.	pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	TDS	TH
		mg/L									
G1	7.2	174.2	9.3	58.6	56.0	361.2	26.8	109.8	140.2	1020.4	372.2
G2	7.3	103.3	6.0	39.0	31.5	175.8	18.9	58.6	146.4	569.9	218.6
G3	7.1	133.7	5.5	35.3	32.2	204.8	23.0	52.1	136.7	605.7	188.7
G4	7.4	95.0	3.6	46.1	40.4	134.4	14.6	53.1	237.1	532.3	273.3
JS 286/2008***	6.5-8.5	200	-	-	-	500	50	500	-	1000	500

****: Jordanian standards for drinking water.* *-: not required*

Data in Table 2 also show apparent spatial variations. The spatial distribution of TDS in groundwater illustrates that high occurrences of TDS are located further north-northeast (G1) with an average concentration of 1020.4 mg/L, slightly above the Jordan standards for drinking water of 1000 mg/L. However, the lowest values were measured in G4. Again, these results collectively indicate that the groundwater wells in the ZRC are probably better managed and controlled compared to others.

In addition to the dissolved salts from evaporite formation and carbonate layers, the excessive withdrawal of the groundwater coupled with the high evaporation and low rate of recharge (due to prevailing arid climate) are potentially the main contributors to the increased groundwater salinity, particularly in G1 wells. Agricultural discharges following excessive irrigation are probably not a major contributing cause to salinity due to the large depth of the groundwater levels (Table 3). Additionally, water flow directions (Figure1) are not a significant factor influencing groundwater salinity. Wells located down-gradient contain lower TDS values compared to the upper-gradient ones.

Table 3. Pearson Correlation matrix for groundwater wells characteristics.

	Well depth (m)	Yield (m^3/h)	Water level (m)	Drawdown (m)
Altitude (m)	0.73	-0.15	0.91	-0.28
Well depth (m)		-0.45	0.74	0.13
Yield (m^3/h)			-0.14	-0.17
Water level (m)				-0.08

This assessment of TDS distribution pattern in groundwater aids public water supplies and regulatory agencies in targeting zones of lower groundwater TDS concentration by relocating wells or by mixing multiple groundwater sources. In addition, TDS trends also help in quantifying the optimum groundwater abstraction rate without a major increase in salinity for a sustainable utilization of this water source, especially in areas where human settlements are in a close proximity to the groundwater wells and where over-extraction of water is common.

Similar to TDS, the average concentrations of Na^+, K^+, Cl^-, NO_3^-, and SO_4^{2-} showedsimilar spatial distribution patterns with the highest values observed in G1 and the lowest occurring in G4. Ca^{2+}, Mg^{2+}, and TH exhibited elevated levels in G1, but lower concentrations were measured in G3. In the north-northeastern wells (G1) of the study area, the average TH concentration was 372.2 mg/L; it became 188.7 mg/L in the southern groundwater wells. In general, the high values of TH are primarily attributed to the introduction of Ca^{2+} and, to a lesser extent, Mg^{2+} into the groundwater system. Ca^{2+} is derived from the dissolution of Ca^{2+} bearing minerals from the aquifer material (carbonates and evaporites) (Batayneh et al., 2014). Mg^{2+} is likely derived from the dissolution of dolomitic limestone (Batayneh and Al-Taani, 2015). In contrast, the HCO_3^- average level was highest in G4 (237.1 mg/L) compared to other clusters, which showed relatively fairly comparable values. In general, all groups showed groundwater quality values that are within the acceptable limits based on the Jordanian standards for drinking water (JS, 2008), except for TDS levels in G1.

The hydrochemical data (Table 1) and correlation analysis (Table 4) suggest that most of ions in groundwater are probably originated from similar sources. Positively moderate to strong correlations have been observed among water quality parameters (Table 1), except for HCO_3^- and pH. The resultant matrix showed weak correlations of pH with all variables. Likewise, HCO_3^- showed negatively weak to moderate correlations with most of the water quality variables.

Table 3. Correlation matrix for groundwater quality parameters.

Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	TDS	TH	
-0.02	0.10	-0.10	0.08	-0.02	-0.21	0.07	0.05	-0.03	0.04	pH
	0.82	0.67	0.74	0.90	0.65	0.81	-0.42	0.90	0.74	Na^+
		0.65	0.69	0.85	0.57	0.85	-0.59	0.83	0.72	K^+
			0.92	0.86	0.66	0.89	-0.28	0.89	0.96	Ca^{2+}
				0.88	0.63	0.89	-0.30	0.90	0.97	Mg^{2+}
					0.78	0.94	-0.51	0.98	0.90	Cl^-
						0.68	-0.57	0.73	0.61	NO_3^-
							-0.45	0.94	0.92	SO_4^{2-}
								-0.43	-0.26	HCO_3^-
									0.93	TDS

TDS plotted against $Na^+/(Na^+ + Ca^{2+})$ (Gibbs, 1970) to assess the source of dissolved ions in groundwater (Figure4). This revealed that the weathering of rocks is a primary process liberating ions in water. Evaporation is a minor contributor.

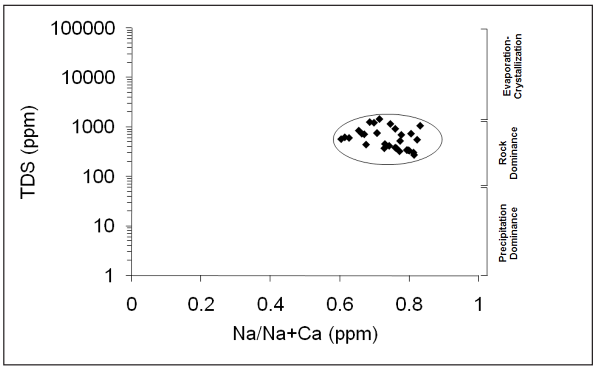

Figure 4. Plot of TDS vs. $Na^+/Na^+ + Ca^{2+}$ of groundwater samples.

Ca^{2+} is positively correlated with Mg^{2+}, and TDS with r = 0.90 and 0.89 respectively. It is believed to have been derived from limestone and dolomite, where these rocks cover a significant portion of the study area. Na^+ and Cl^- concentrations showed consistently similar ups and downs in groundwater wells (figure3). The average correlation coefficient for both ions is 0.90 (Table 4) suggesting common sources for both ions (Batayneh et al., 2014). Mineral dissolution is possibly their major source, where evaporites, particularly halite, are common in the area.

Groundwater is dominant by Na^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, and SO_4^{2-}.It is evident from piper plot (Piper, 1944) that all the samples belong to the Ca-Mg-HCO_3type (figure5). The graphs also demonstrate the dominance of alkaline earths over alkali (Ca+Mg>Na+K), and weak acidic anions exceed strong acidic anions (HCO_3>Cl+SO_4).The hydrochemical processes suggested by Chadha (1999) indicate recharging water (Ca-Mg-HCO_3 type). Recharging waters are formed when water enters into the ground from the surface carrying dissolved carbonate in the form of HCO_3^- and the geochemically mobile Ca^{2+}.

Table 1 provides information regarding the sampling groundwater wells. Wells 8 and 20 are located in higher altitudes with an elevation of 920m and 911m above sea level (a.s.l.), respectively. Whereas groundwater wells 18 and 26 lie in low-lying areas with elevations of 590m and 585m a.s.l., respectively.

It has been observed that the altitudinal variations (governing the surface drainage pattern) have no clear impact on groundwater quality. For example, wells 18 and 26 located in low-laying areas were found with a relatively good water quality, though it is expected that the intense rainfall, salts, and dissolved minerals from the surrounding soils and geologic formations are transported down-gradient (following the general flow direction) to end up in these groundwater wells.

Moreover, wells 18 and 26 have shallower depths compared to others, with about 124m and 243m deep, respectively. This also suggests that these two groundwater wells are more vulnerable to water quality deterioration. Groundwater wells 10 and 18 with relatively shallow depths have generally high water yields, among others. Groundwater table drawdown is largest in wells 9 and 28. All groundwater wells are drilled in B2/A7 aquifer except for wells 3, 4, 6, 9, and 27.

Correlation analysis tabulated in Table 3 shows that the characteristics of groundwater wells are not generally related, except for the following pairs: well depth and altitude (r =0.73), water level and altitude (r = 0.91), and water level and well depth (r = 0.74).

Drawdown factor was neither related to yields nor to water levels. Previous data for groundwater quality before ZRC were established (prior to 2012) and compared to the results obtained from this study. Figure 6 demonstrates the variations between the current results and those of studies before 2012.

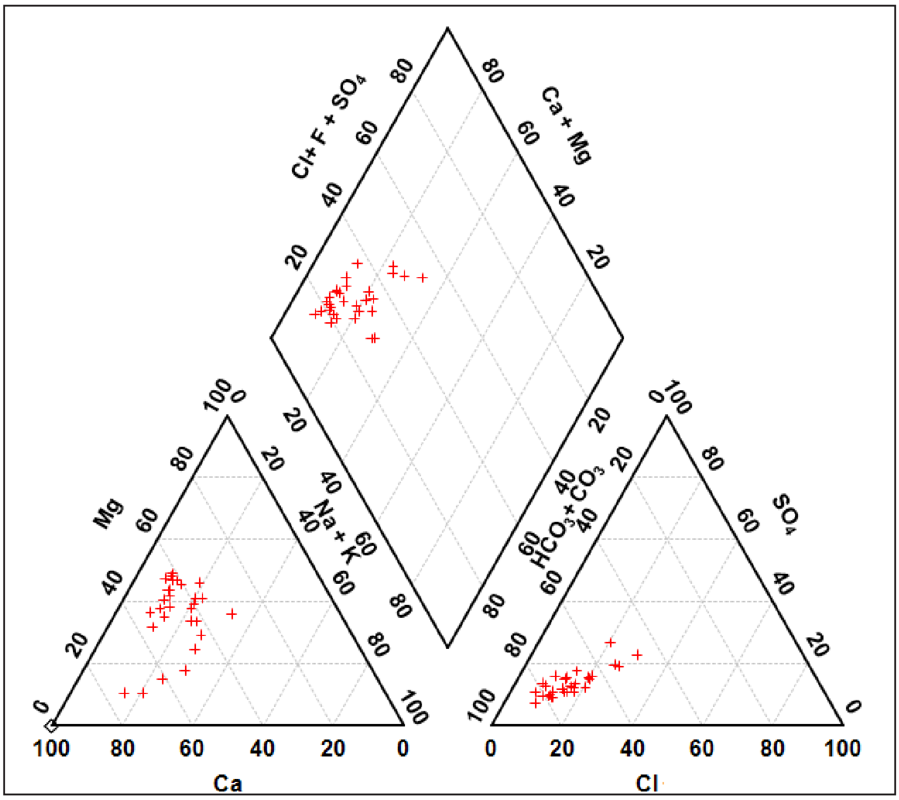

Figure 5. Hydrochemical facies shown on Piper's trilinear diagram along with dominant anions and cations and the classification of the water sample.

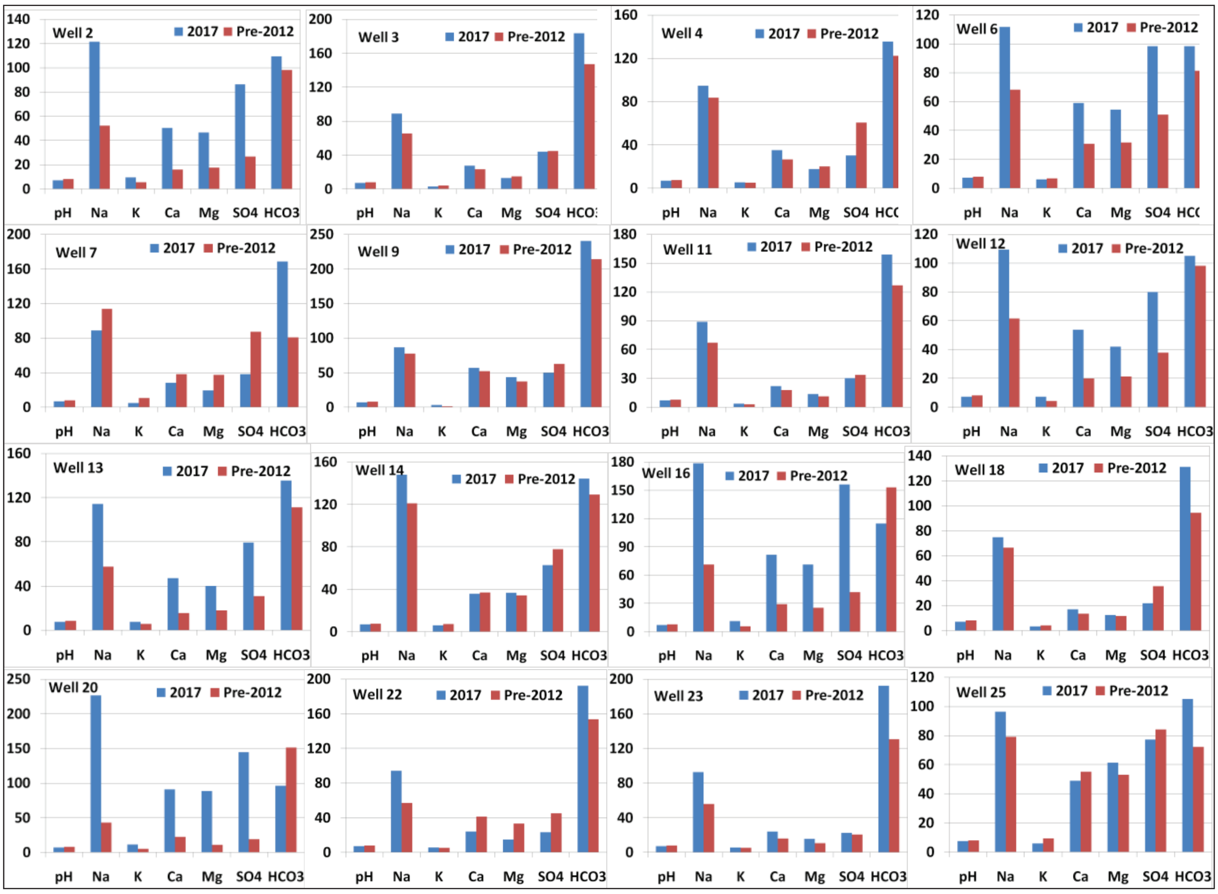

Figure 6. Comparison of water quality data (mg/L) for selected groundwater wells before ZRC was established vs. current results.

It has been noticed that the majority of water quality variables showed similar patterns, with the lower values found in the pre-2012 data and elevated levels recorded in 2017. These findings highlight the importance of drafting a proper management plan of groundwater wells, particularly, regulating groundwater pumping and designating zones for the protection of wells. The inflow of Syrian refugees has certainly increased the demands for drinking water which exacerbated the water quantity problems and would inevitably cause groundwater quality to deteriorate.

Water samples from groundwater sampling wells were analyzed for selected trace metals. The statistics of trace metals are given in Table 5. Metal contents in the groundwater samples were consistently low in all of the sampling wells. These concentrations are largely within the range listed for waters suitable for drinking water (JS, 2008). Pb contents in the water samples showed slightly higher levels than the Jordan standard guidelines for drinking water of 0.01 mg/L (Table 5). Additionally, well 15 showed a mean Mn content (0.304 mg/L) above the acceptable level of 0.01 mg/L. Cd content in well 12 (0.017 mg/L) exceeds the safe limit of 0.003 mg/L. Also, Cr levels in wells 18 (0.073 mg/L) and 21 (0.058 mg/L) are above the permissible limits for drinking water of 0.05 mg/L (JS 2008).

Table 5. Trace-metal content (mg/L) in water samples collected from wells in ZRC and the surrounding area over the period from August to December 2017.

Well No.	Fe	Mn	Ni	Cu	Pb	Zn	Cd	Cr
1	0.046	0.003	<DL	<DL - 0.028	<DL - 0.005	<DL	0.002	0.058
2	0.023	0.002	<DL	<DL - 0.019	<DL - 0.018	<DL	0.001	0.021
3	0.006	0.002	<DL	<DL	<DL - 0.019	<DL - 0.019	0.002	0.002
4	0.013	0.001	<DL	<DL - 0.027	<DL - 0.013	<DL	0.002	0.023
5	0.008	0.001	<DL	<DL - 0.012	<DL - 0.013	<DL	0.002	0.008
6	0.093	0.006	<DL	<DL	<DL	<DL - 0.019	0.001	<DL - 0.021
7	0.027	0.002	<DL	<DL - 0.012	<DL - 0.025	<DL - 0.045	0.002	<DL - 0.01
8	0.102	0.003	<DL	<DL - 0.008	<DL - 0.041	<DL - 0.887	0.002	0.026
9	0.092	0.011	<DL	<DL - 0.019	<DL - 0.006	<DL - 0.013	0.002	0.015
10	0.109	0.004	<DL	<DL - 0.014	<DL - 0.02	<DL - 0.001	0.001	0.003
11	0.016	0.001	<DL	<DL - 0.022	<DL - 0.021	<DL	0.002	0.032
12	0.021	0.003	<DL	<DL - 0.006	<DL - 0.038	<DL	0.017	0.016
13	0.125	0.003	<DL	<DL - 0.029	<DL	<DL - 0.083	0.002	0.017
14	0.025	0.002	<DL	<DL	<DL	<DL	0.001	0.017
15	0.859	0.304	<DL	<DL - 0.059	<DL - 0.034	<DL	0.001	0.043
16	0.013	0.001	<DL	<DL - 0.003	<DL	<DL - 0.015	0.001	0.012
17	0.089	0.003	<DL	<DL - 0.012	<DL - 0.009	<DL - 0.002	0.002	0.032
18	0.188	0.007	<DL	<DL - 0.032	<DL - 0.029	<DL - 0.361	0.002	0.072
19	0.018	0.002	<DL	<DL - 0.018	<DL	<DL	0.001	0.023
20	0.110	0.004	<DL	<DL	<DL	<DL	0.002	0.018
21	0.091	0.010	<DL	<DL	<DL - 0.002	<DL	0.002	0.058
22	0.034	0.003	<DL	<DL	<DL - 0.017	<DL	0.002	0.032
23	0.013	0.002	<DL	<DL - 0.013	<DL - 0.029	<DL	0.001	0.034
24	0.020	0.002	<DL	<DL - 0.025	<DL - 0.023	<DL	0.002	0.014
25	0.142	0.003	<DL	<DL - 0.007	<DL - 0.007	<DL - 0.107	0.001	0.032
26	0.011	0.003	<DL	<DL - 0.033	<DL - 0.006	<DL	0.002	0.019
27	0.047	0.005	<DL	<DL	<DL	<DL - 0.041	0.002	0.040
28	0.025	0.004	<DL	<DL - 0.044	<DL - 0.056	<DL - 0.237	0.002	<DL - 0.022
29	0.075	0.002	<DL	<DL - 0.011	<DL - 0.04	<DL - 0.032	0.002	<DL - 0.007
30	0.195	0.198	<DL	<DL	<DL - 0.005	<DL	0.002	0.056
JS 286/2008*	1	0.1	0.07	1	0.01	4	0.003	0.05

These low trace-metal concentrations measured in the groundwater samples probably indicate a gelogenic origin. It is believed that the primary source of dissolved metals to groundwater is not probably metals leached from the surrounding rocks and soils, but rather released from aquifer materials (water-rock interaction). It can also be suggested that the groundwater aquifer is not significantly recharged from the surface runoff; the recharge rate from the surface water is low or negligible. This is consistent with the low and erratic annual precipitation rate occurring in the region.

On the other hand, metals may have been released from aquifer sediments and/or leached from soils during events of intense rainfall (occurs as flash flood),They have been either precipitated due to near-neutral pH and oxidizing conditions, or adsorbed onto metal oxides and clays. Metal release from aquifer sediment is affected by pH and salinity, where the lower pH and salinity are, the higher the metals that are released (Gambrell et al., 1990; Lau and Chu, 1999). Therefore, the mobilization of the metals from aquifer materials to groundwater is not preferential due to the coupling effect of the relatively high levels of salinity and pH in the water. In addition, flash rainfall events occurring in the region do not allow metal release from rocks as the flow path is rather short.

Previous data were obtained in regard to trace-metal contents in some groundwater wells (Table 6) representing the period before ZRC was established. While both data exhibited low levels of trace metals in the water samples, slightly higher contents were constantly observed in the current study compared to previous data.

Table 5. Available data about trace metals (mg/L) in water from selected wells prior to the ZRC establishment.

Well No.	Fe	Mn	Ni	Cu	Pb	Zn	Cd	Cr
2	-	<0.01	<0.01	<0.01	<0.01	-	-	0.01
3	<0.1	0.04	<0.01	0.1	<0.01	-	-	0.02
4	-	<0.10	<0.02	<0.02	<0.02	-	<0.06	-
5	-	<0.01	<0.01	<0.01	<0.01	-	-	0.01
6	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
7	<0.10	<0.02	<0.02	<0.02	-	<0.06	-	0.01
9	0.06	0.01	<0.01	0.01	0.05	0.09	-	<0.02
10	0.02	<0.005	<0.01	<0.02	<0.005	<0.02	<0.003	0.006
11	<0.10	<0.02	<0.02	<0.02	-	0.06	<0.003	0.02
12	-	<0.01	<0.01	<0.01	<0.01	-	-	0.01
16	-	<0.01	<0.01	<0.01	-	-	<0.003	<0.01
17	-	0.007	<0.01	<0.01	<0.01	-	<0.003	<0.01
18	0.08	0.02	<0.01	0.01	-	<0.04	-	0.0142
20	<0.1	<.01	<0.01	<0.01	<.01	<.06	-	<.01
22	<0.1	<0.02	<0.02	<0.02	-	<.06	-	<.02
23	-	<.01	<0.01	<0.01	<.01	<.06	-	0.02
24	<0.1	<.01	<0.01	<0.01	<.01	<.06	-	0.01
25	<0.1	<.01	<0.01	<0.01	<.01	<.06	-	0.01

5. Conclusions

This study was conducted to assess the groundwater quality within ZRC and the surrounding areas. ZRC is the largest Syrian camp in Jordan and was built within the Amman-Zarqa Basin, a major groundwater aquifer system in Jordan. With few exceptions. The majority of water quality parameters showed values that are within the permissible limits based on Jordan standards for drinking water. Groundwater quality is impacted by the weathering of rocks, uncontrolled and intensive pumping, dissolution of aquifer materials and the leaching of soluble salts following irregular rainfall events. This study confirms that groundwater wells located in ZRC and its nearby area are generally of a better quality compared to others. These wells are properly controlled and managed with the aid of the UN and other humanitarian agencies. Having said this, evidences of water quality deterioration were observed in the current study compared to data before 2012 (before ZRC was established).The inflow of Syrian refugees has certainly increased the demand for water, which exacerbated the water supply problems and will inevitably impact groundwater quality, though immediate risks to groundwater quality are not very likely.

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