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Has the water supply network of Sebestia been connected to that of Nablus?

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The nowadays water supply system in Nablus-Sabestia is still based on the same springs that were supplying the two cities with domestic and agricultural water for the past 2000 years. The main springs in the area have been used since Roman times. The question addressed in the present study is whether there has been a connection between the ancient water supply network of Nablus city (Flavia Neapolis) to support the water supply network in Sebestia 12 km northwest of Nablus.

To answer this question, geochemical investigations were performed in the study area. Water and carbonate samples (sinters) were collected from 12 springs, one tunnel, and one aqueduct. Some of the springs were rehabilitated recently and the carbonate sinters have been removed. As opposed to some of the springs, the aqueducts and tunnels still exist and carbonate sinters can be found on them. The tunnel and the aqueduct are located within Nablus city. Laminated carbonate sinters and water samples were analyzed using Thermal Ionization Mass Spectrometry for determining the Sr isotope ratios. For the laminated carbonate samples, 2–5 sample points from the laminated sinters were analyzed for each sample.

The Sr isotope ratios for water and carbonate from the springs showed at least two sources of Sr in groundwater and these two sources differ significantly from each other. Based on the Sr isotope ratio for carbonate samples from the tunnel and the aqueduct one can speculate that in different time periods the two structures were fed by both the Nablus and the Sebestia springs.

The Sr isotope ratios for water and carbonate samples from Sebestia differ significantly in two of the Nablus springs. Thus, based on the present study, it is obvious that the tunnel and the aqueduct were fed by more than one type of water. On the other hand, there is no evidence that Ras al Ein or Qaryon have been used in the Roman time to feed the water network of Sebestia.

Keywords: Nablus, Sebestia, Ijnisinya, springs, aqueducts, carbonate, Sr isotope ratio

1 Introduction

1.1 Background

Palestine is a very complex place because of political, social and ecological reasons. The limited availability of natural resources presently raises the question on how the people could survive in one of the oldest civilizations. The archeological settings are very complicated as several elements are missing. For example archeological sites have been demolished due to poor control and low interest of the successive authorities.

On the other hand, however, archeology and human interaction with the environment are very important topics in this area. As the country is neither politically, nor environmentally, socially or economically sustainable, there is a need to read in the past for improving the future.

1.2 Aim of the study

Field studies, digging and archeological excavation are difficult in this area and will encounter political problems. While geo-archeology is an approach used to bridge the gap between archeology and physical science (Ruddiman, 2013), in this study it is used to overcome the above-mentioned difficulties. So, the aim of this work is to answer some archeological questions through geochemical investigations.

2 Study area

Nablus, Sabestia and Ijnisinya are ancient Palestinian locations in the north-western West bank belonging to Nablus Governorate (Figure 1). The earliest evidences of Nablus city history are from the Iron Age, the settlement started in the Hellenistic era 331 B.C. (Fanni, 1999) and developed into a city in 27 A.D. (Fanni, 2007). Sabestia was constructed by Herod in 27 B.C. Both cities were connected with roads (Chancey & Porter, 2001).

Currently, Nablus Governorate is the second largest Governorate in the West bank with a population of about 377 thousand inhabitants (PCBS, 2014). Nablus city is the largest city in the Governorate with 146,493 people, Sebestia is a village with 3,036 inhabitants and Ijnisinya is a small village with 587 inhabitants (PCBS, 2015a).

Nablus Governorate suffers from a deficit in water suitable for domestic use. In 2013, this deficit was estimated to account for 9.1 million m^3 (PCBS, 2015b). Despite the present water shortage, the area has a sophisticated ancient water system. Until now, the connection between parts of this system has not been clear. In the course of this article the present findings will be explained.

2.1 Ancient water system

The water supply system in Nablus and Sebestia is still based on the same springs that have been supplying the two cities with domestic and agricultural water in ancient times. Some of the springs were rehabilitated recently and the carbonate deposits (sinters) have been removed. In addition to the springs, the water aqueduct and the tunnels are still available as part of the heritage system.

One of the open questions about the ancient water system in Nablus city is whether there was a connection between the water networks in Nablus and Sabestia (Frumkin, 2002). Crowfoot also mentioned the possibility of connections between the water conduit in Ijnisinya and Sebestia (Crowfoot, 1966). The main springs in Nablus are considered and dated as Roman springs. The Sebestia springs Harun and Ijnisinya are also considered as Roman springs (Crowfoot, 1966). All this springs have the same entrance structures and could therefore have a chronological connection. Yet, Harun springs also have several tunnel connections similar to the tunnel found in Nablus below the Roman cardo. So, the question arises whether there has been a connection between the water system in Nablus, Sebestia, and Ijnisinya.

The springs, the aqueduct and the tunnel entrance locations are shown in Figure 1. Unfortunately, the total length of the aqueducts and the tunnel is neither documented nor excavated, so only the sampling locations appear in map. Yet the potential connection between the springs (Qaryon, Ras Al Ein and Harun) and the tunnel path starting from Dafna spring as suggested in literature (Fanni, 1999; Frumkin, 2002) are shown in Figure 1. For simplification, in the map it is drawn as straight line, which was probably not the case in reality (Figure 2) shows the curves in the tunnel.

Harun spring consists of an 80 m long channel; 30 m before the end of the channel there is a room with an inspector chamber similar to Ras al Ein spring (Frumkin, 2002) and Ijnisinya. The water seeps into the room via fractures. The room used to be connected with another water channel that brought the water from another unknown source (Crowfoot, 1966). Crowfoot suggested that Harun spring installation was linked either to Ijnisinya or to the water system in Nablus based on traces of aqueducts (Crowfoot, 1966). Frumkin suggested that Harun spring installation was linked with Ras al Ein spring because of the similarity of the structures and the aqueducts between the two cities. Currently Sebestia city depends on the water sources coming for the water network and Harun spring is used for irrigation.

The tunnel portal was found in the 1970s. According to archeological findings, it is dated to the 2nd century A.D. (Fanni, 1999). As mentioned before, the total length has not been studied, but it was suggested that the water from Dafna spring had been feeding the tunnel (Fanni, 1999). Dafna is located at 560 masl; the tunnel entrance is located at around 560 masl, too. From the entrance 74 steps direct downwards to the tunnel (Fanni, 1999). Going to the east it is possible to reach one shaft well (Dullab) located at 16 m below the street level. The tunnel dimension is variable; in the beginning walking is easy (2 m × 0.6 m); then it becomes difficult to walk due to the smaller dimensions (1.3 m × 0.6 m).

The hypothesis is that six shaft wells tapped the tunnel in the area of Nablus starting from Dafna. Figure 3 shows the Dullab shaft well that is near the entrance of the tunnel. It is not possible to reach the spring Dafna from the tunnel and the hypothesis is based on the presence of successive wells (Fanni, 1999; Frumkin, 2002). On the other hand, at Qaryon spring several tunnel installations were found but no link to any water network system could be determined (Frumkin, 2002). This is why in this article it was also investigated whether only water from the Dafna spring was feeding this tunnel.

So, to answer these questions geochemical investigations of the water system were conducted. The components of the water system include: 12 springs, one aqueduct and a water tunnel. The 12 springs are located in Nablus, Sebestia and the villages nearby. As shown in Figure 1, the tunnel is situated between three springs: Qaryon, Ras al Ein and Dafna, whereas the aqueduct (Wadi Tufah) is located near Beit Alma and Al Subyan springs.

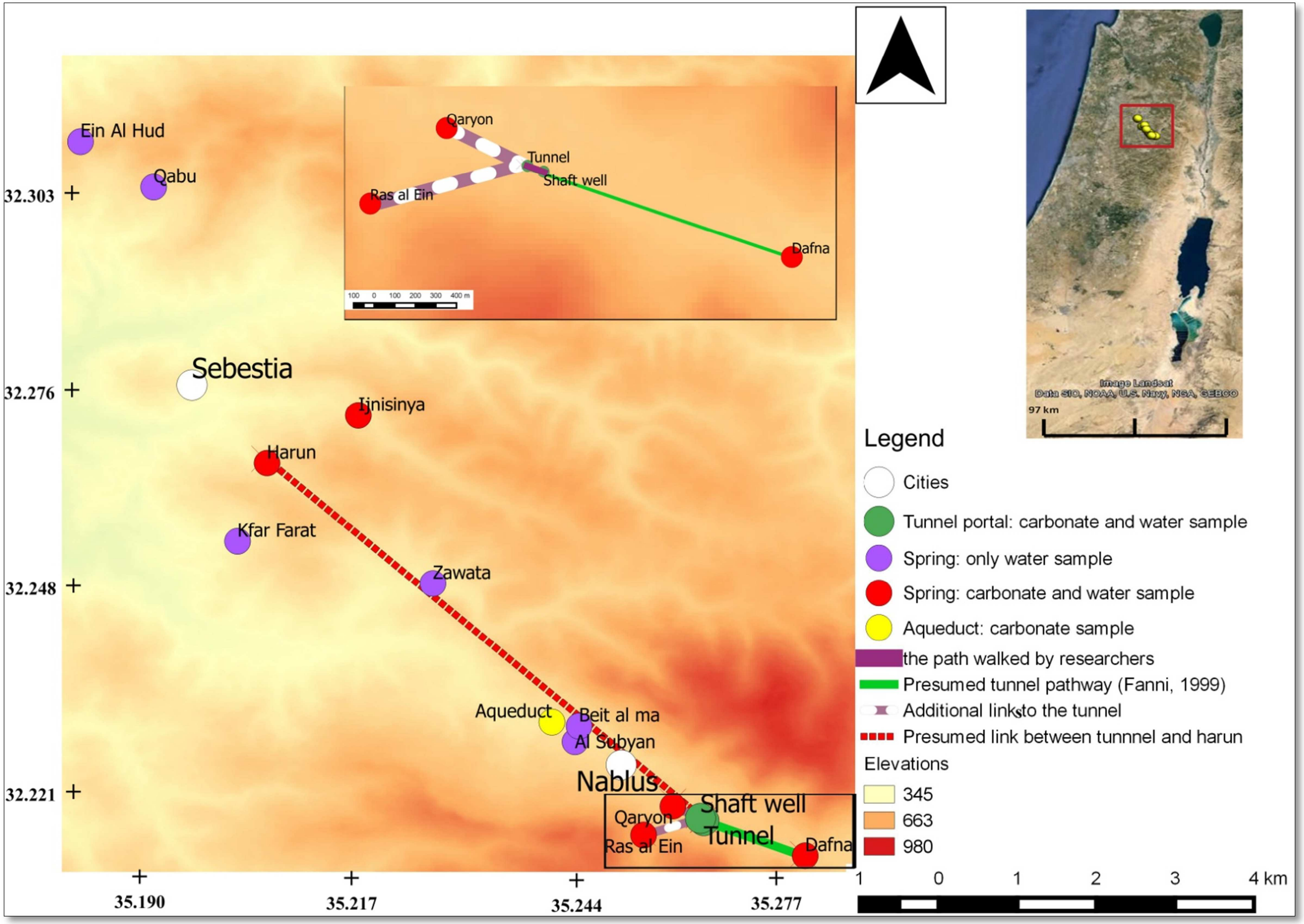

Figure 1: DEM SRTM 90 m resolution (USGS) with sampling location generated by QGIS, the clipping on the top right gives an overview of the Area Palestine location of the study area (Google earth map 2013 Landsat image)

Figure 2: Different cross sections in the tunnel, left showing the tunnel path curved

Figure 3: Dullab Shaft well in the tunnel ca. 100 m to the east from the tunnel entrance (looking upwards)

3 Methodology

Water and carbonate samples were collected in the region of interest. As mentioned before, carbonate sinters are missing at some springs because they have been removed recently due to maintenance works. So, sampling was also dependent on availability. Table 1 below lists the sample types and details on the sampling locations. For all water samples taken, the in-situ parameters pH, temperature, dissolved oxygen, redox potential and electrical conductivity were measured using WTW instruments.

Table 1: Sampling points and corresponding sample types

	Location of the sampling spots		Elevation in meters above sea level	*Sample type*	
Sample names	Eastings	Northings		Water	Carbonate sinters
Springs:					
Dafna	35 16 678	32 12 806	560	×	-------
Ras al Ein	35 15 21.60	32 12 55.86	620	×	×
Qaryon	351535.7	32 13 8.52	470	×	×
Al Subyan	35 14 811	32 13 685	474	×	-----
Beit al ma	35 14 842	32 13 802	560	×	×
Zawata	35 13 657	32 14 944	412	×	-------
Kfar Farat	35 12 081	32 15 293	416	×	-------
Harun	35 12 306	32 15 927	449	×	×
Ijnisinya	35 13 055	32 16 315	445	×	×
Ein Al Hud	35 10 845	32 18 323	478	×	-------
Qabu	35 11 406	32 18 176	503	×	-------
Tunnel	35 15 847	32 13 057	560 (entrance level)	×	×
Aqueduct Wadi Tufah	32 13 50	35 14 37	450	-------	×

The water samples were analyzed using Thermal Ionization Mass Spectrometry (TIMS, Finnigan MAT 262) for determining the Sr isotope ratio; NBS 987 standard was used with an external reproducibility of ±0.00005. The external reproducibility was used as error because it was higher than the internal error of the measurements.

An ICP–MS XSeries-2 Thermo Scientific instrument was used for determining the element concentration in the water samples. Internal standards (5 mg/L Ge, 1 mg/L Rh and 1 mg/L Re) were used to reduce the matrix effect. The reproducibility was 5%. Standard or collision mode was used depending on the manufacturer's recommendations for the measured element.

In addition to that, ion chromatography (IC Metrohm) was used to analyze the cations (Li^+, Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}) using Metrohm column C4/100 and 2 mM HNO_3 plus 0.7mM dipicolinic acid as eluent and to analyze the anions (Cl^-, Br^-, NO_2^-, NO_3^-, SO_4^{2-}) using Metrohm A Sub A 15/150 /4.0 with 3 mM $NaHCO_3$ and 3.5 mM Na_2CO_3 as eluent. Total inorganic carbon was analyzed by non-dispersive infrared spectroscopy (LiquiTOC II).

For the spring water quality (1954-2009) data was collected from different sources: The Palestinian Water Authority database ("Spring water chemsitry," 2011) the 'Nablus District Water Resources Survey: Geological and Hydrological Report' from February 1965 (Raferty, van Bellen, & al-

Markaziyah, 1965) and the monography ‘Nablus Spring Source of Life Through History’ 2015(Alawi, Al-Masry, & Messerschmid, 2015).

PHREEQC was used to calculate the saturation index of calcite, aragonite, dolomite, gypsum, and halite using the WATEQ4F database. Furthermore, K-means cluster, Mann-Whitney test and Box-and-Whisker plots were used for statisctical analysis using STATGRAPHICS Centurion XVI version 16.1.11 and OriginPro 2015. QGIS Valmiera was used for to create fig. 1.

3.1 Carbonate samples analysis

To prepare a sample, it was cut along the growth axis, washed with deionized water and then polished (Dorale, 2004; Spötl & Mattey, 2006). Thereafter, each laminated layer was extracted using a ‘New wave micromill’ drill with the smallest bit diameter (0.5 mm). After each extraction the drill bit was cleaned with ethanol.

For the element concentration measurement, 5 mg of each extracted lamination layer were diluted in 100 µL HNO_3 and subsequently analyzed using ICP-MS.

For the Sr isotope ratio analysis, 2-5 laminations from each sample were selected. For the preparation of the samples it was recommended to wash the powder samples with weak acid to remove secondary carbonates (Bailey, McArthur, Prince, & Thirlwall, 2000; Li, Shields-Zhou, Ling, & Thirlwall, 2011; Ruppel, James, Barrick, Nowlan, & Uyeno, 1996). So, 10 mg of the sample were diluted in 1 mL 0.05 M HCl for 2 hours without heating; then the solutions were centrifuged and the supernatant was discarded. This procedure ensured a 40 % mass reduction of the sample. Then the residue was diluted in 1 mL 0.5 M HCl and subsequently analyzed using TIMS.

4 Results and discussion

The water chemistry of springs in the area is characterized by high Ca and HCO_3 contents. There is a seasonal variation in the water composition (Appendix 1-11), but in general the characteristics of the water do not change. As shown in Figure 4, the water in the tunnel -yellow triangles- has a chemical composition different from all other springs in the area because it is currently polluted with mixed groundwater and surface runoff water (Sabri, Merkel, & Tichomirowa, 2015). The calculation of saturation indices with PHREEQC indicates that calcite is oversaturated in the springs' waters (Table 2). This explains why carbonate has been deposited on the walls of the water supply structures.

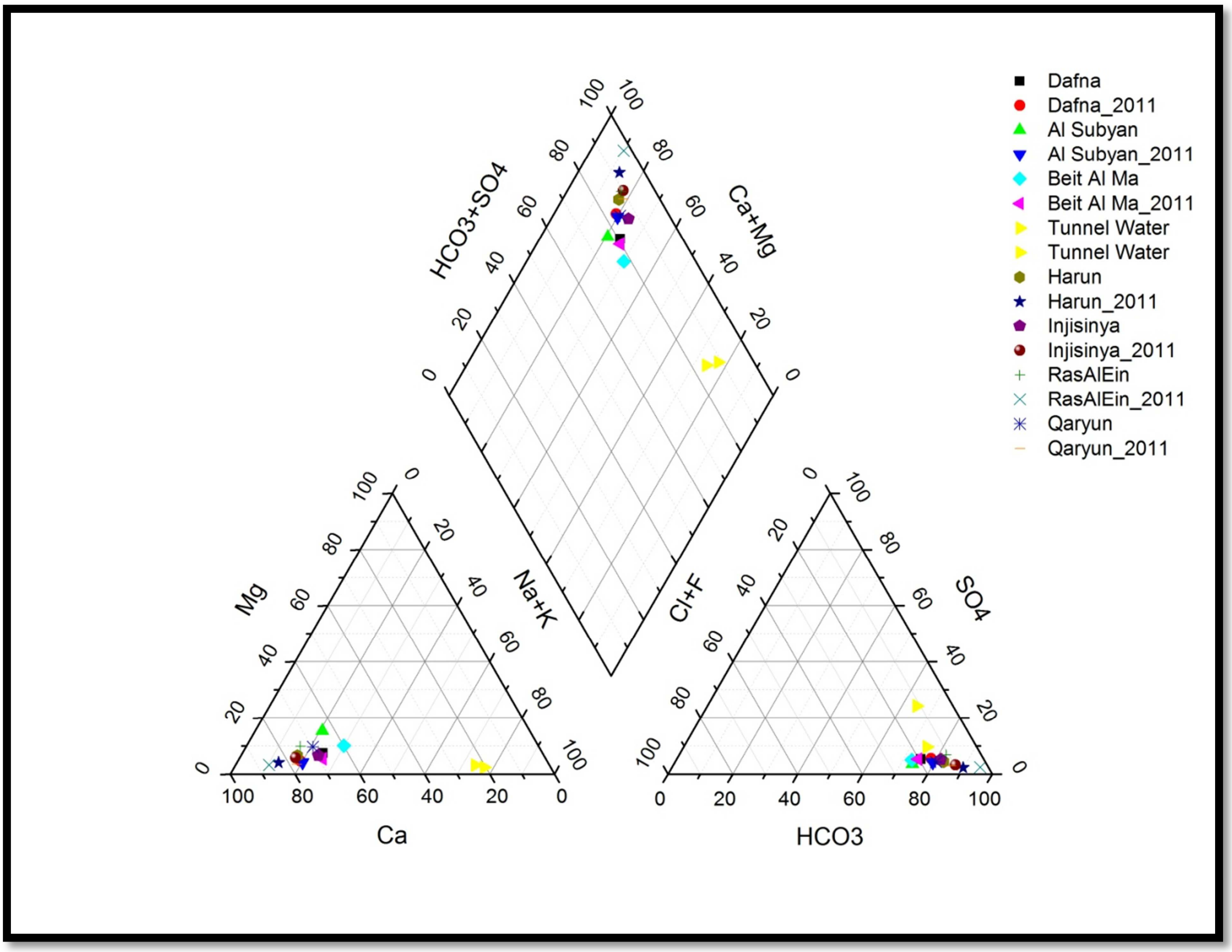

Figure 4: Mean composition of the sampled waters in the study area (1954-2009) and 2011

Table 2: Saturation indices for selected minerals in the springs

	si_Calcite	*si_Dolomite*	*si_Aragonite*	*si_Halite*	*si_Gypsum*
Dafna	0.2819	-0.3762	0.1333	-7.4522	-2.6614
Ras al Ein	0.0632	-1.0288	-0.0857	-8.2507	-3.2826
Qaryon	0.1507	-0.7784	0.0023	-7.6142	-2.9665
Al Subyan	0.8562	0.7401	0.7084	-7.1086	-2.5433
Beit al Ma	0.0277	-0.7582	-0.1199	-7.2256	-2.6988
Watertunnel	0.4803	0.3794	0.3322	-6.2141	-2.2482
Harun	0.2326	-0.5539	0.085	-8.2113	-3.2053
Ijnisinya	0.2211	-0.3903	0.0737	-7.7907	-2.9399

As mentioned before, Sr isotope ratios were determined for both, carbonate and water samples. Based on the current water quality and Sr isotope ratio values, the water supply systems in the area have at least two Sr sources because two groups, one with lower and one with higher Sr ratio, can be distinguished (values of 0.7079 ± 0.00005 and 0.7081 ± 0.00005, respectively) as shown in Figure 5. K-means cluster analysis was done for determining potential Sr isotope ratio groups. Two clusters were defined as shown in Table 3. Cluster 1 includes the samples with higher Sr isotope ratios (0.7080± 0.00005) and cluster 2 includes the samples with lower Sr isotope ratio values (0.7079± 0.00005).

The results of the Mann-Whitney test indicate a statistically significant difference between the two clusters at the 95.0 % confidence level (P= 0.01604). These results are visualized by means of a Box-and-Whisker plot (Figure 6)

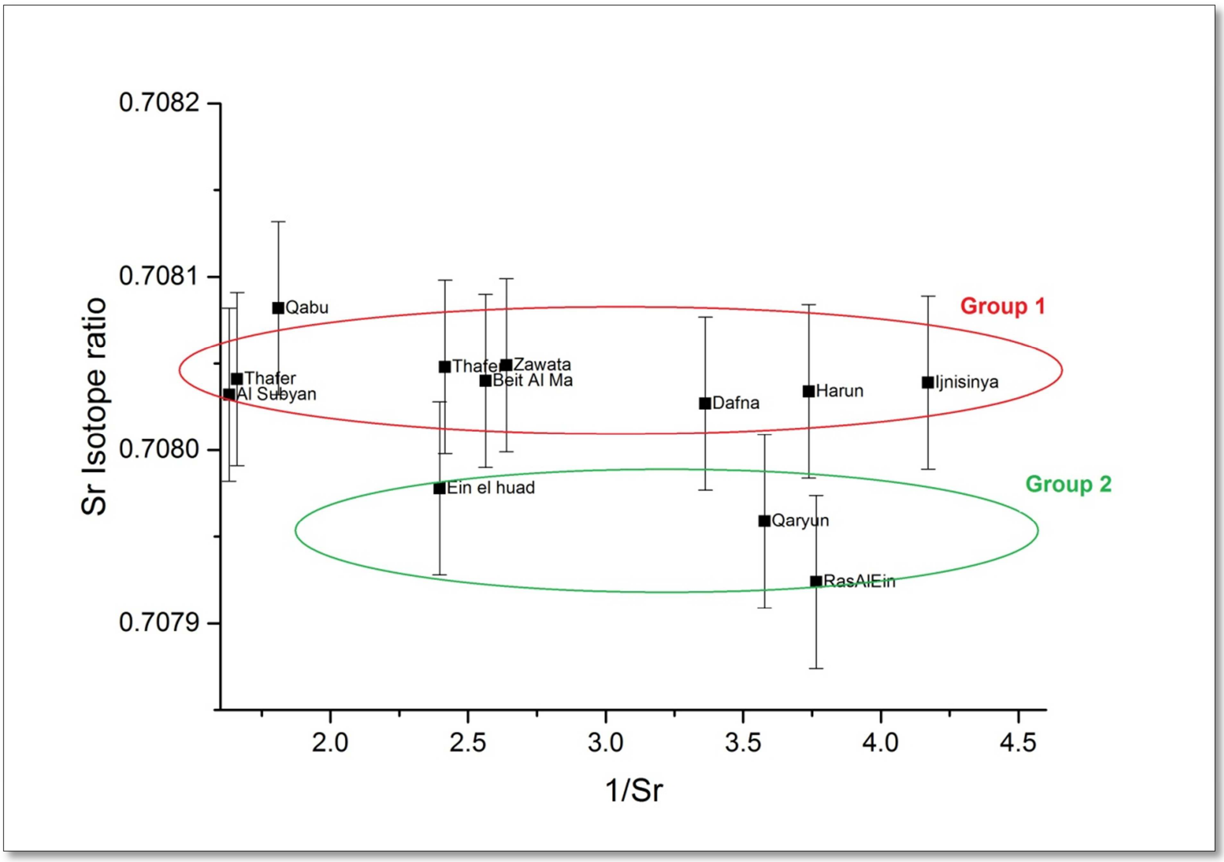

Figure 5: Sr isotope ratios of the springs, clustered into two groups by K-means cluster analysis. The error bars show the total error.

Table 3: Grouping of the water sources based on K-means cluster analysis of the Sr isotope ratio values

Water source	*Group number*
Dafna	1
Tunnel water	1
Ras al Ein	2
Qaryon	2
Al Subyan	1
Beit al ma	1
Zawata	1
Kfar Farat	1
Harun	1
Ijnisinya	1
Qabu	1
Ein Al Hud	2

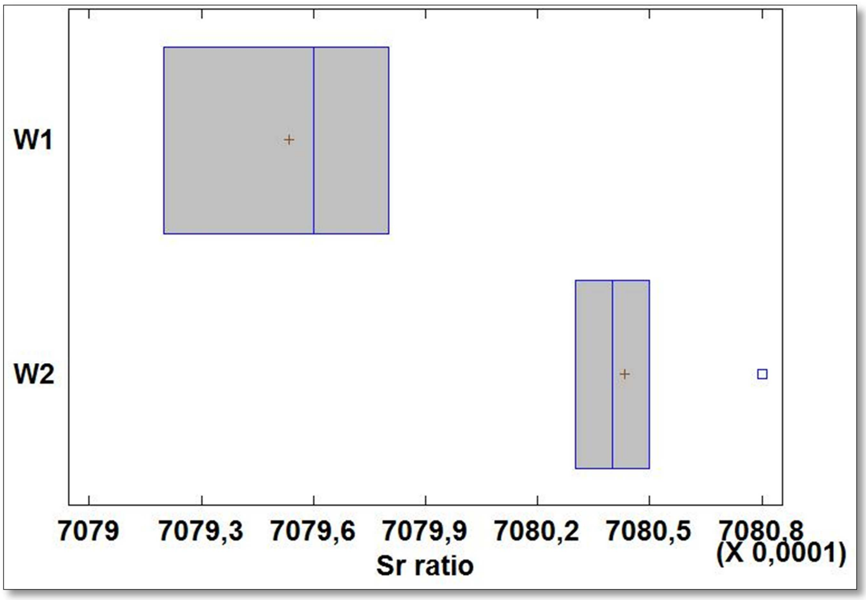

Figure 6: Box-and-Whisker plot of the Sr ratio values of water sample group cluster 1 and 2

Based on the previous results, carbonate sinter samples from springs were clustered into two groups depending on the sampling location similar to clustering of water samples. So, the carbonate sample which was taken from spring group 1 is listed as group 1 and similarly for group 2. Carbonate samples taken from the aqueducts and the tunnel are not included in the analysis

Furthermore, the Mann-Whitney test showed a statistically significant difference between the two distributions of “water group” 1 and “carbonate sinter group” 2 at the 95.0 % confidence level (P = 0.03577). Similarly, “water group” 2 and “carbonate sinter group” 1 (P value = 0.0103), have significantly different Sr isotope ratios. As the carbonate sinter samples have the same Sr isotope ratio as the corresponding background water, there has probably not been a change of the water source during the sinters’ growth. This is shown graphically by the Box-and-Whisker plot in Figure 7.

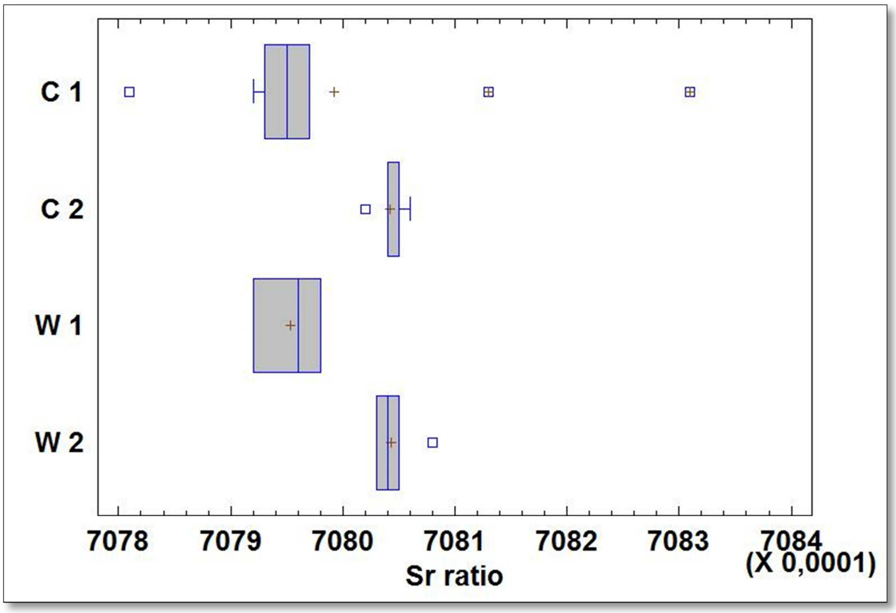

Figure 7: Box-and-Whisker plot of Sr isotope ratio values of the water (W) and carbonate sinter (C) samples of groups 1 and 2

To investigate whether the tunnel was fed only by Dafna spring, K means cluster analysis was done for the Sr isotope ratios for the carbonate sinter in the tunnel. Two clusters were found for: cluster 1 with the higher Sr isotope value of 0.7081 ± 0.00005; and cluster 2 with the lower Sr isotope value of 0.7077 ± 0.00005. This means that the tunnel was fed by several sources. Ras Al Ein with the higher Sr value is located at higher altitude (620 masl) than Dafna spring (560 masl) and it could have been connected with the tunnel through open gravity channels. Qaryon spring (470 masl) is located at lower elevation.

5 Conclusions and recommendations

The Sr isotope ratios of water and carbonate sinter samples from Sebestia and Ijensinia significantly differ from those from Qaryon and Ras al Ein springs. Thus it is rather unlikely that there has been a direct connection between both water supply systems. Yet, the Sr isotope ratios of the tunnel and the aqueduct carbonate sinter samples prove that the different sources (Harun, Ijensina, Qaryon and Ras al Ein) were used to feed the water system. One may assume that additional water was needed in the area and so, more than one spring was developed. Dating the samples with e.g. the U/Th method will tell which spring was used first.

It was not possible to confirm or reject the Crowfoot theory of a linkage that existed in the past between Harun and Ijensina by using Sr isotope ratios because both springs and the carbonate sinter samples have the same Sr isotope ratio. It is clear, however, that the city Sebestia has not been linked with Nablus city via Ras Al Ein spring or Qaryon. But again it is not possible to confirm or reject the linkage between Sebestia and Nablus via Dafna spring.

So, it is recommended to repeat the geochemical analyses and to examine another isotope’s ratio to prove or disprove the connection between Sebestia and Ijensinia ancient water systems. As opposed to the water network in Nablus, Ijensinia is only briefly mentioned in literature. Furthermore, what makes it hard to clearly answer the question on the connection is the fact that the spring and water system is neither excavated nor documented. Therefore, for a better understanding it is recommended to start excavations of the Ijensinia water system. So, even if the geochemical analyses lead to helpful results, they cannot replace traditional archeology.

6 Acknowledgements

This work could not have been done without the help of Nablus municipality and the department of archaeology in Nablus and Ramallah cities. They facilitated the entrance for the tunnel and the springs for samples collection. Also we wish to thank Seif Shenawy, Isam Maqbool and Salameh Shebib for the technical support during sampling.

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Appendix 1: Dafna spring water quality (temperature T is in °C)

Date	Dataset	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Na+K mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	Cl+F mg/l	TDS mg/l	pH	T
28.01.1961	Raferty 1965	90	6	27.5		29.5	231.8	62	60	62	436	7.4	
24.04.1962	Raferty 1965	72	11	21		23	209.8	44	60	44	326	7.6	
15.12.1962	Raferty 1965	74	3	16	2	18	183.0	30	11	30	280	7.4	
08.08.1963	Raferty 1965	73	4	13	1	14	176.9	34	5	34	290	7.8	
05.05.1991	Palestinian Water Authority 2011	94.5	7.5	30.5	2.1	32.6	242	50	17.5	50			
14.11.1992	Palestinian Water Authority 2011	77	7.1	25.6	1.4	27	209	48	14	48			
20.12.1993	Palestinian Water Authority 2011	91.4	7.2	29.2	1.6	30.8	245	50	15	50			
23.10.1995	Palestinian Water Authority 2011	57	5	24	1	25	130	49	10	49			
01.07.1996	Alwai 2015	114.2	6.1	32.9	3.4	36.3	221.2	94	0	94	297	7.2	
01.02.1998	Alwai 2015	73	12	52	2.6	54.6		80.4	8.5	80.4	400	7.4	
20.04.1999	Palestinian Water Authority 2011	95	7	23	1.7	24.7	240	56	14	56	268	7.1	18.6
12.10.1999	Palestinian Water Authority 2011	45	8	21	1.9	22.9	215	46		46	253	7.7	
11.04.2000	Palestinian Water Authority 2011	93	7	24	3	27	193	55	10	55	225	7.7	
28.01.2001	Palestinian Water Authority 2011	96	11	28	5.6	33.6	258	94	7	94	475	7.1	
01.07.2003	Alwai 2015	60	12.5	32.4	2.3	34.7	191	59.9	5	59.9	326	7.2	
01.06.2004	Alwai 2015	61	14.6	34.9	2.2	37.1	230	57.6	7.7	57.6	340	7.4	
01.09.2006	Alwai 2015	62	15	35	1.5	36.5	220	59.9	8	60	350	7.5	
01.08.2011	--	104.8	6.6	24.9	1.6	26.5	255.2	52.3	17.9	52.4	415	7.3	18.5

Appendix 2: Ras Al Ein spring water qauility. (temperature T is in °C)

Date	Dataset	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Na+K mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	Cl+F mg/l	TDS mg/l	pH	T
23.01.1954	Raferty 1965	68	6	8	0.5	8.5	259.86	23	5	23	323		
28.01.1961	Raferty 1965	66	6	11	0.5	11.5	239.12	24	145	24	239		
24.04.1962	Raferty 1965	76	6	10	0.5	10.5	168.36	24	51	24	245		
15.12.1962	Raferty 1965	64	6	9	0.5	9.5	195.20	16	8	16	235	7.5	
05.05.1991	Palestinian Water Authority 2011	72	2.5	10	0.3	10.3	186	20	6.5	20			
14.11.1992	Palestinian Water Authority 2011	52.6	3.3	16.5	0.4	16.9	152	22	5.5	22			
20.12.1993	Palestinian Water Authority 2011	86.2	32.3	20.1	0.5	20.6	206	34	9.5	34			
23.10.1995	Palestinian Water Authority 2011	72	8	16	1	17	244	31	5	31			
01.06.1996	Alwai 2015	78.1	2.4	24.3	0.31	24.6	244.2	49.5	0	49.5	198	7.0	
12.10.1999	Palestinian Water Authority 2011	76	10	14	0.9	14.9	201	42		42	252	8.2	20.1
11.04.2000	Palestinian Water Authority 2011	70	7	9	1	10	165	43	5	43	235	7.7	
28.01.2001	Palestinian Water Authority 2011	68	10	4	1	5	194	31	3	31	222	7.5	
01.07.2003	Alwai 2015	45	13.5	18.1	0.38	18.5	239.73	30.1	4.5	30.2	231	7.5	
01.06.2004	Alwai 2015	47	12.5	19	0.9	19.9	213.5	34	13.1	34.1	265	7.7	
01.09.2006	Alwai 2015	51	12	17	10	27	215.57	32	7	32.1	258	7.6	
01.09.2009	Alwai 2015	53	13	21	1.5	22.5	226.92	40	8	40	270	7.4	
01.08.2011		89.29	3.4	10.5	0.075	10.6	243.50	20.6	6.4	6.5	289	7.3	18.1

Appendix 3: Qaryon spring water quality. (temperature T is in °C)

Date	Dataset	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Na+K mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	Cl+F mg/l	TDS mg/l	pH	T
02.12.1960	Raferty 1965	40	21	17	1	18	239.12	35.5	5		288	7.3	
28.01.1961	Raferty 1965	70	10	14	1	15	213.5	27	57		262	7.3	
24.04.1962	Raferty 1965	72	5	10	1	11	206.18	24	19		237	8.2	
15.12.1962	Raferty 1965	66	4	11	1	12	189.1	20	8		245	7.5	
08.08.1963	Raferty 1965	66	3	10	1	11	189.1	20	9		240	7.4	
05.05.1991	Palestinian Water Authority 2011	72.5	3.5	16	1.2	17.2	201	26	9.5	26			
14.11.1992	Palestinian Water Authority 2011	63.9	4.4	19.8	1.9	21.7	168	35	16	35			
26.12.1993	Palestinian Water Authority 2011	75.5	4.6	20.7	2.8	23.5	203	45	9.5	45			
23.10.1995	Palestinian Water Authority 2011	64	4	15	2.0	17	188	28	5	28			
01.07.1996	Alwai 2015	76.1	9.7	19.3	1.8	21.1	221.2	49.5	1	49.5	231.68	7.3	
01.02.1998	Alwai 2015	62	10.5	28	2	30.1	198	53.6	1	53.6	300	7.5	
17.05.1999	Palestinian Water Authority 2011	54	4	15	2.1	17.1	186	37	13	37	221	6.8	19.8
11.04.2000	Palestinian Water Authority 2011	71	3	13	3	16	161	27	6	27	204	7.4	
01.07.2003	Alwai 2015	57	12.9	18.6	1.45	20.1	191	39.9	5.5	40	270	7.2	
01.05.2004	Palestinian Water Authority 2011	31	29	14	1	15	185	35	12	35.1	254	7.2	19
01.09.2006	Alwai 2015	57	13.7	19.5	1.9	21.4	190	45	6	45.2	290	7.2	
01.08.2011		92.2	4.2	19.1	3.1	22.2	271.8	35.7	9.5	35.8	364.8	7.2	18.7

Appendix 4: Al Subyan spring water quality. (temperature T is in °C)

Date	Dataset	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Na+K mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	Cl+F mg/l	TDS mg/l	pH	T
08.04.1999	Palestinian Water Authority 2011	57	21	15	1.9	16.9	237	39	12	39	289	6.8	
10.10.1999	Palestinian Water Authority 2011	33	21	26	0.7	26.7	222	62		62	287	6.8	19.4
07.05.2000	Palestinian Water Authority 2011	41	18	18	4	22	191	29	15	29	230	7.0	20
20.08.2001	Palestinian Water Authority 2011	91	21	12	3	15	239	38	3	38	286	7.4	20.5
01.08.2011		150.4	8.4	38.0	2.0	40.1	386.2	78.8	20	79.0	587	7.6	19.5

Appendix 5: Beit al ma spring water quality, (temperature T is in °C)

Date	Dataset	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Na+K mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	Cl+F mg/l	TDS mg/l	pH	T
23.01.1954	Raferty 1965	69.16	8.41	18.00	6.0	22.4	70.2	62.00	14.64	15.12	395		
15.12.1962	Raferty 1965	63.86	6.02	44.00	6.0	30.1	70.9	88.00	4.71	24.36	510	7.3	
08.08.1963	Raferty 1965	64.54	7.80	33.00	6.0	27.7	74.3	70.00	3.21	22.45	440	7.4	
12.05.1991	Palestinian Water Authority 2011	63.10	5.17	41	5.0	31.7	74.4	61	6.6	19.1			
14.11.1992	Palestinian Water Authority 2011	62.26	6.61	34.9	4.2	31.1	71.5	62	6.0	22.5			
26.12.1993	Palestinian Water Authority 2011	63.35	6.16	37.6	5.0	30.5	74.4	60	5.5	20.1			
23.10.1995	Palestinian Water Authority 2011	57.66	8.11	33	5.0	34.2	68.9	58	5.0	26.1			
20.04.1999	Palestinian Water Authority 2011	65.79	6.23	34	6.4	28.0	66.5	93	5.4	28.1	306	7.1	
11.04.2000	Palestinian Water Authority 2011	67.52	11.11	22	3.0	21.4	66.4	70	3.8	29.8	265	7.6	
28.01.2001	Palestinian Water Authority 2011	63.57	10.08	30	4.0	26.4	76.2	59	2.2	21.6	347	7.2	
01.07.2003	Alwai 2015	52.99	20.51	28.3	2.7	26.5	69.5	69	3.7	26.9	346	7.1	
01.09.2006	Alwai 2015	54.58	16.29	32	2.7	29.1	73.1	71	3.3	23.6	390	7.2	
01.08.2011		68.67	5.50	33.73	3.6	25.8	74.4	65.7	5.4	20.2	449	7.1	19.8

Appendix 6: Zawata spring water quality. (temperature T is in °C)

Date	Dataset	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Na+K mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	Cl+F mg/l	TDS mg/l	pH	T
19.10.1999	Palestinian Water Authority 2011	68.91	8.40	13	0.5	22.69	142	43			200		
10.04.2000	Palestinian Water Authority 2011	74.03	7.79	13	1	18.18	166	29	5		204		
01.08.2011		79.43	5.45	12.34	0.57	15.12	87.4	21.4	3.5	9.1	262		

Appendix 7: Kfar Farat spring water quality. (temperature T is in °C)

Date	Dataset	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Na+k mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	Cl+F mg/l	TDS mg/l	pH	T
05.05.1991	Palestinian Water Authority 2011	67.5	5	17.5	1.7	19.2	208	24	8.5	24			20
19.11.1992	Palestinian Water Authority 2011	66.8	5.4	16.6	2.3	18.9	174	26	8.5	26			19
01.12.1993	Palestinian Water Authority 2011	68.1	6.5	18.5	2.2	20.7	206	27	7	27			22.5
23.10.1995	Palestinian Water Authority 2011	33	8	16	2	18	123	28	5	28			22
21.05.1997	Palestinian Water Authority 2011												
29.11.1998	Palestinian Water Authority 2011												
19.04.1999	Palestinian Water Authority 2011	52	6	20	3.6	23.6	186	46	8	46	202	7.0	20.4
12.10.1999	Palestinian Water Authority 2011	33	9	13	2.1	15.1	177	52		52	196	7.8	20.4
22.04.2000	Palestinian Water Authority 2011	68	4	15	2	17	160	36	8	36	194	6.8	20.1
01.08.2011		78.4	5.5	14.0	1.9	15.9	253.5	23.3	8.6	23.5	306	7.4	20.5

Appendix 8: Harun spring water quality. (temperature T is in °C)

Date	Dataset	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Na+K mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	Cl+F mg/l	TDS mg/l	pH	T
27.06.1963	Raferty 1965	60	2.5	9	0.6	9.6	175.68	12	38	12	266	7.8	
30.09.1963	Raferty 1965	60	5	12	0.6	12.6	206.18	27	11	27	284	8.2	
05.05.1991	Palestinian Water Authority 2011	66.5	3	12.5	0.6	13.1	194	20	6.5	20			
19.11.1992	Palestinian Water Authority 2011	61.2	3.6	13.2	1	14.2	178	22	5.5	22			
01.12.1993	Palestinian Water Authority 2011	64.4	4.6	14.5	1	15.5	191	24	6	24			
23.10.1995	Palestinian Water Authority 2011	49	5	13	1	14	147	23	5	23			
19.04.1999	Palestinian Water Authority 2011	54	4	15	1.9	16.9	178	44	8	44	185	7.2	20.9
12.10.1999	Palestinian Water Authority 2011	39	8	11	1	12	163	42	5	42	201	7.7	20.1
10.04.2000	Palestinian Water Authority 2011	61	7	11	1	12	162	35	3	35	198	7.0	19.6
08.08.2011	--	74.9	3.7	11	0.6	11.6	234.1	20.2	6.2	20.3	278	7.4	19.8

Appendix 9: Ijnisinya spring water quality. (temperature T is in °C)

Date	Dataset	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Na+K mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	Cl+F mg/l	TDS mg/l	pH	T
31.12.1960	Raferty 1965	86	10	25		26	334	34	35	34	464	7.6	
24.04.1962	Raferty 1965	44	5	18		19	172	24	15	24	247	7.9	
05.05.1991	Palestinian Water Authority 2011	76	5	23	0.9	23	218	28	10	28	231		20
19.11.1992	Palestinian Water Authority 2011	82	6	22	0.9	23	202	33	11	33	255		19
01.12.1993	Palestinian Water Authority 2011	67	6	25	0.8	26	198	33	9	33	247		
23.10.1995	Palestinian Water Authority 2011	56	5	25	1.0	26	174	43	7	43			
17.05.1999	Palestinian Water Authority 2011	25	6	20	1.2	21	162	30	14	30	231		20
18.11.1999	Palestinian Water Authority 2011	52	3	17	0.7	18	182	36	7	36	255		20
08.08.2011	--	90	7	19	1.1	20	282	31	10	32	1144	7.3	20

Appendix 10: Ein Al Hud spring water quality. (temperature T is in °C)

Date	Dataset	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Na+K mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	Cl+F mg/l	TDS mg/l	pH	T
12.10.1963	Raferty 1965	56	6	23	6	29	179.34	27	38.5		305	8.4	
08.08.2002	Palestinian Water Authority 2011	77	8	23	6.1	29.1	151	37				7.8	22.5
01.08.2011	--	100.4	12	32	6	38	292	61	31	61	893	8.1	23.1

Appendix 11: Qabu spring water quality. (temperature T is in °C)

Date	Dataset	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Na+K mg/l	HCO3 mg/l	Cl mg/l	SO4 mg/l	Cl+F mg/l	TDS mg/l	pH	T
24.04.1962	Raferty 1965	58	5	30	4	34	176	52	34	52	323	7.4	
12.10.1963	Raferty 1965	52	5	32	6	38	144	41	50	41	304	8.3	
01.08.2011	--	66	7	33	1	34	156	62	15	62	1137	7.8	22