BORON CONTAMINATION OF GROUNDWATER FROM THE COASTAL AQUIFER IN THE GAZA STRIP, PALESTINE

MITSUO YOSHIDA

Environmental Research Laboratory, International Network for Environmental and Humanitarian Cooperation, Nonprofit Inc., Tokyo, Japan
E-mail: mitsuoyoshida@inehc.com

Abstract - Five samples of groundwater collected near Khan Yunis City, Gaza Strip, and five samples of groundwater collected from West Bank, Palestine, were analyzed using an Inductively Coupled Plasma - Mass Spectrometry method. The analytical results indicated that the groundwater samples collected from the Gaza Strip were highly contaminated compared to those from the West Bank. Groundwater in the Gaza Strip was highly saline in four of the five wells, and not suitable for drinking. The salinization is thought to be due to salt water intrusion into the Coastal Aquifer caused by the over exploitation of groundwater. In addition to salinization, the quality of the groundwater in the Gaza Strip is characterized by boron (B), the concentration of which exceeds the regulated value. The result of the correlation between B and six elements (Na, K, Mg, Ca, Sr, and S) suggests that B contamination is caused by the migration of seawater.

Index Terms - Groundwater contamination, Salinization, Boron, Gaza

I. INTRODUCTION

More than 1.9 million people live in the Gaza Strip of Palestine, but because of international conflicts, the border with Israel has been blocked and the movement of people and goods severely restricted. Under these circumstances, basic administrative services and infrastructure such as water supply, sewage treatment, public sanitation, solid waste management, and power supply are not fully functioning, and consequently, the Gaza Strip now faces various environmental problems. One serious problem is related to the water issue. In the Gaza Strip, drinking and agricultural water is provided by pumping groundwater from the Coastal Aquifer. However, for the reasons mentioned above, the deterioration of water quality is significant. Here, a detailed analysis of the water quality is insufficient, because of the difficulty in accessing the area. Boron (B) is widely distributed in the surface water and groundwater at a concentration of up to 0.4 mg/L [1]. In the Mediterranean coastal region, it has been repeatedly reported that the concentration of B in the groundwater is often above the normal level [2], and the origin and mechanism of B contamination is still under debate.

In this paper, the author preliminarily reports on the groundwater contamination by B observed in the Gaza Strip, Palestine.

II. MATERIALS AND METHOD

A. Groundwater Samples

Groundwater samples were collected from five wells in the Gaza Strip and five sites on the West Bank, Palestine (see index map in Figure 1 and detailed map in Figure 2). Samples were collected for drinking and/or local agricultural water (see Table 1).

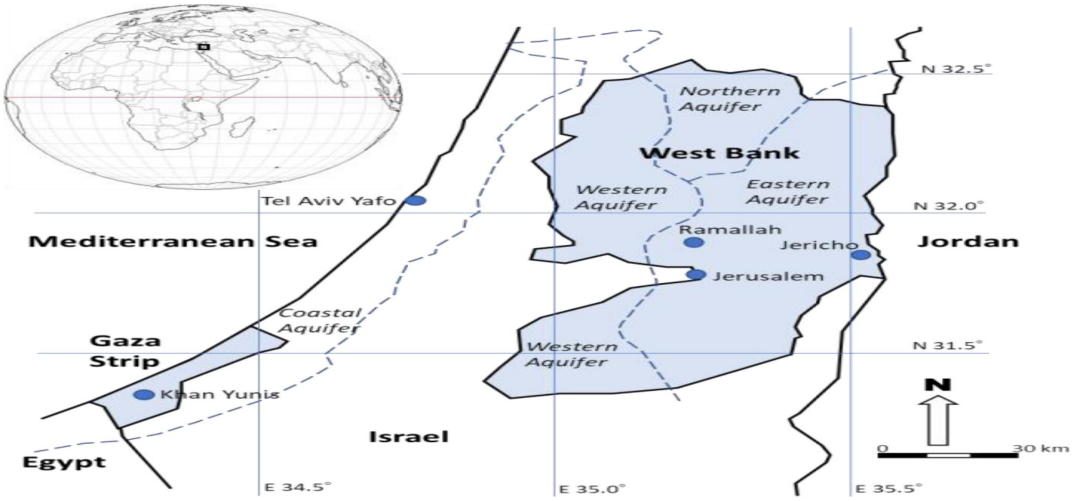


Figure 1: Index map for sampling areas: The Gaza Strip and West Bank, Palestine. Dashed lines indicate the boundary of aquifers (Map

Source: UNEP/GRID-Geneva, 2002).

Table 1: List of groundwater samples

Sample ID	Sampling location	Area
170913-1	Al Na'eem groundwater well	Gaza Strip
170913-2	Al Rahma Groundwater Reservoir	Gaza Strip
170913-3	Kweit groundwater well	Gaza Strip
170913-4	Al Sanabel groundwater well	Gaza Strip
170913-5	Tahdy groundwater well	Gaza Strip
170916-1	Bottled mineral water in Jericho	Jericho
170916-3	Tap water in Ramallah (Ankars Hotel, Ramallah)	Ramallah
170917-1	Tap water in Al Bireh (Ministry of Local Government; MoLG)	Ramallah
170917-2	Well water in MoLG compound, Al Bireh	Ramallah
170917-3	Well water in Betunia	Ramallah

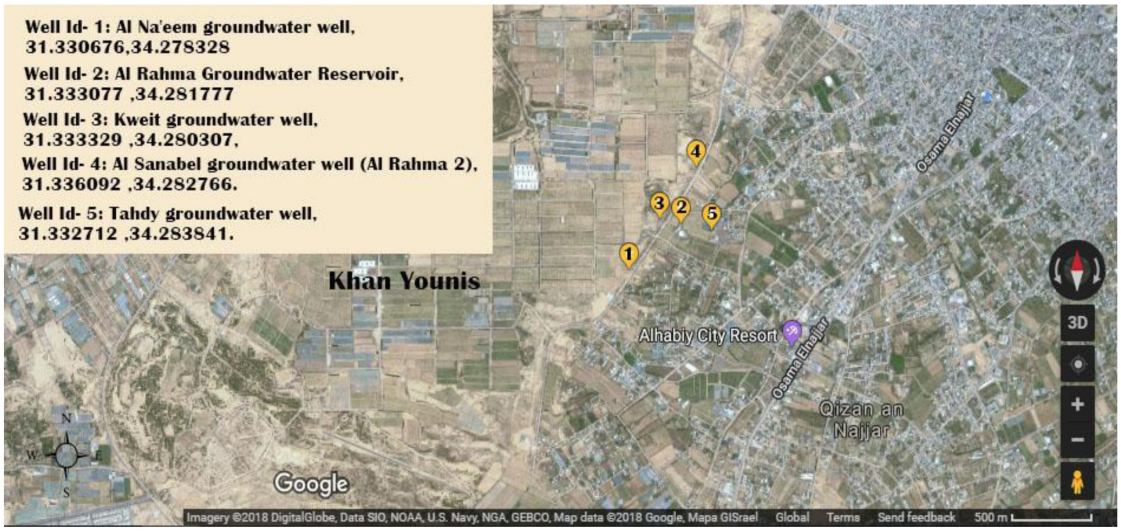


Figure 2: Detailed location map of groundwater wells in Kahn Yunis, Gaza Strip, plotted on Google Earth™.

As shown in Figure 1, there are four major aquifers, namely the Coastal Aquifer, Western Aquifer, Eastern Aquifer, and Northern Aquifer in Palestine territory [3]. The groundwater samples for the present study were obtained from the Coastal Aquifer in the Gaza Strip and Eastern Aquifer in the West Bank. Field sampling was performed in September 2017.]

B. Analytical Method

Major and trace elements in the groundwater samples were analyzed using a Parkin Elmer ICP-MS (Inductively Coupled Plasma - Mass Spectrometry). If the given groundwater sample contained high total dissolved solids (TDS) (> 0.1%), the sample was diluted 10 times with deionized water to minimize the mask effect. The groundwater samples were filtered and directly analyzed using ICP-MS.

In total, 70 elements (Ag, Al, As, Au, B, Ba, Be, Bi, Br, Ca, Cd, Ce, Cl, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Hg, Ho, In, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pd, Pr, Pt, Rb, Re, Rh, Ru, S, Sb, Sc, Se, S, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, and Zr) were measured. The reliability of the analytical value was secured by verification of the standard sample, a blank test, and multiple measurements of the same sample.

III. RESULTS OF THE ANALYSIS

The results of the ICP-MS analysis are provided in Table 2. The following 36 elements could not be detected/measured in all samples: Ag, Be, Bi, Ce, Cs, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Hg, Ho, In, La, Lu, Nb, Nd, Pb, Pd, Pr, Pt, Re, Ru, Sc, Sm, Sn, Ta, Tb, Th, Ti, Tl, Tm, and Yb.

Four samples from the Coastal Aquifer in the Gaza Strip (Samples 170913-2, 3, 4, and 5) presented very high salinity, and a 10 times dilution was applied for the pretreatment. The results indicated that the groundwater samples collected from the Coastal

Aquifer in the Gaza Strip were generally very contaminated by various elements compared to those from the Eastern Aquifer in the West Bank. Among the groundwater samples from the Coastal Aquifer in the Gaza Strip, Sample 170913-1 indicated Cl = 570 ppm, and another four samples indicated a higher concentration, which could not be measured through current methods because of the high salinity. Possibly, salinization is caused by the over-exploitation of groundwater from the coastal aquifers and salt water intrusion from the Mediterranean Sea. According to the Palestinian Water Authority [2], two cones of depression have occurred in the northern and southern areas of the Gaza Strip, measuring water levels of 6 m and 19 m below sea level respectively, after continuing intensive groundwater abstraction. The sampling sites around Khan Yunis, Gaza Strip are located at a part of the southern depression cone, indicating that the hydrogeological condition is favorable for salt water intrusion into the Coastal Aquifer. Relatively high concentrations of B could be observed in the groundwater samples of the Coastal Aquifer in the Gaza Strip, where four of the five samples (Samples 170913-2, 3, 4, and 5) exceeded the EU's regulation value of Bn concentration (<1,000 ppb). Sample 170913-5 had 264 ppm of S concentration, which exceeded the maximum concentration level (MCL, 250 ppm). On the other hand, the groundwater samples collected from the West Bank area indicated a relatively lower Cl concentration between 34 to 47 ppm, and the concentrations of B and S were low and below the regulated levels. The relationship between the concentration of B and six elements—Na, Ca, K, Mg, Sr, and S—is illustrated in Figure 3 for the groundwater samples from the Coastal Aquifer in the Gaza Strip. There are strong positive linear correlations between B and the other six elements, in which the coefficients of determination (r^2) were 0.78 to 0.99 (see Table 3). This means that B contamination in the Coastal Aquifer is closely related to the migration of six elements, namely Na, Ca, K, Mg, Sr, and S.

Table 2: Results of ICP-MS analysis of groundwater samples, Gaza Strip and West Bank, Palestine

	Analyte		Al	As	Au	B	Ba	Br	Ca	Cd	Cl	Co	Cr	Cu	K	Li	Mg	Mn	Mo
	Unit		PPB	PPB	PPB	PPB	PPB	PPB	PPM	PPB	PPM	PPB	PPB	PPB	PPM	PPB	PPM	PPB	PPB
	Detection L.		1	0.5	0.05	5	0.05	5	0.05	0.05	1	0.02	0.5	0.1	0.05	0.1	0.05	0.05	0.1
Sample ID		DR																	
170913-1	Water	1	<1	7.3	0.11	697	160.37	2700	74.36	0.08	570	<0.02	33.1	2.2	3.37	8.6	64.58	1.53	5.7
170913-2	Water	10	<600	<3000	<500	1600	<80	*	163.40	<700	*	<300	<300	<80	8	<1000	156	<50	<300
170913-3	Water	10	<600	<3000	<500	1218	102	*	141.80	<700	*	<300	<300	<80	7	<1000	145	<50	<300
170913-4	Water	10	<600	<3000	<500	1582	<80	*	106.50	<700	*	<300	<300	<80	8	<1000	111	<50	<300
170913-5	Water	10	<600	<3000	<500	2478	<80	*	221.50	<700	*	<300	<300	<80	10	<1000	203	<50	<300
170916-1	Water	1	3	1.3	<0.05	35	27.46	116	84.93	<0.05	45	0.09	12.8	0.4	3.18	1.0	33.50	<0.05	0.6
170916-3	Water	1	11	1.2	<0.05	212	22.96	162	53.63	<0.05	47	<0.02	8.1	3.7	1.79	1.9	15.07	0.15	0.5
170917-1	Water	1	8	1.2	<0.05	212	23.19	173	51.89	<0.05	45	<0.02	7.5	2.1	1.79	1.7	14.53	0.63	0.4
170917-2	Water	1	6	<0.5	<0.05	210	16.23	148	44.50	<0.05	34	<0.02	5.7	0.4	1.45	1.0	10.57	<0.05	<0.1
170917-3	Water	1	15	0.7	<0.05	204	20.46	141	51.99	<0.05	41	<0.02	7.6	14.5	1.64	1.3	14.42	0.18	0.3
WHO Guideline			(100)	10		2400	700			3	5		50	2000					
NPDWRs(MCL)				10			2000	10 bromate		5	4 Cl_2		100 total	1300					
NSDWRs			50 to 200											1000				50	
EU Directive			200	10		1000				5			50	2000				50	

	Analyte		Na	Ni	P	Rb	Rh	S	Sb	Se	Si	Sr	Te	U	V	W	Y	Zn	Zr
	Unit		PPM	PPB	PPB	PPB	PPB	PPM	PPB	PPB	PPB	PPB	PPB	PPB	PPB	PPB	PPB	PPB	PPB
	Detection L.		0.05	0.2	10	0.01	0.01	1	0.05	0.5	40	0.01	0.05	0.02	0.2	0.02	0.01	0.5	0.02
Sample ID		DR																	
170913-1	Water	1	469.87	3.2	<10	1.18	0.07	69	<0.05	14	6616	2815.63	0.05	1.13	20.5	0.06	<0.01	41.7	<0.02
170913-2	Water	10	1183	<300	<4000	*	*	170	<2000	*	*	6792	*	<3000	<200	<2000	*	<300	*
170913-3	Water	10	1031	<300	<4000	*	*	123	<2000	*	*	5457	*	<3000	<200	<2000	*	988	*
170913-4	Water	10	1115	<300	<4000	*	*	155	<2000	*	*	4069	*	<3000	<200	<2000	*	<300	*
170913-5	Water	10	1689	<300	<4000	*	*	264	<2000	*	*	8629	*	<3000	<200	<2000	*	<300	*
170916-1	Water	1	38.10	<0.2	99	0.86	<0.01	10	0.46	1.1	5526	144.02	<0.05	0.41	2.9	0.03	0.04	65.9	0.04
170916-3	Water	1	42.77	<0.2	<10	0.89	<0.01	9	<0.05	0.8	3117	199.28	<0.05	0.20	2.1	0.03	<0.01	39.6	<0.02
170917-1	Water	1	41.53	0.2	<10	0.75	<0.01	8	<0.05	1.0	3057	195.32	<0.05	0.16	1.5	<0.02	<0.01	149.2	<0.02
170917-2	Water	1	33.99	<0.2	<10	0.59	<0.01	7	<0.05	0.6	2261	120.62	<0.05	0.15	0.9	<0.02	<0.01	107.0	<0.02
170917-3	Water	1	38.80	1.8	<10	0.69	<0.01	8	<0.05	0.9	2933	148.55	<0.05	0.15	1.8	<0.02	<0.01	42.3	<0.02
WHO Guideline									20	40				30					
NPDWRs(MCL)									6	50				30					
NSDWRs								250 sulfate										5000	
EU Directive			200					(250)	5	10									

Detection L.: Detection limit
DR: Dilution rate by deionized water; DR = 1 (no dilution), DR =10 (10 times diluted by deionized water)
*: Because of the interference of other elements, reliable data could not be obtained.
WHO Guideline: Guidelines for drinking water quality 4th Edition (GDWQ)
NPDWRs (MCL): National Primary Drinking Water Regulations (Maximum Contamination Level) defined by USEPA [1]
NSDWRs: National Secondary Drinking Water Regulation defined by USEPS [2]
EU Directive: Council Directive 98/83/EC on the quality of water intended for human consumption[3]

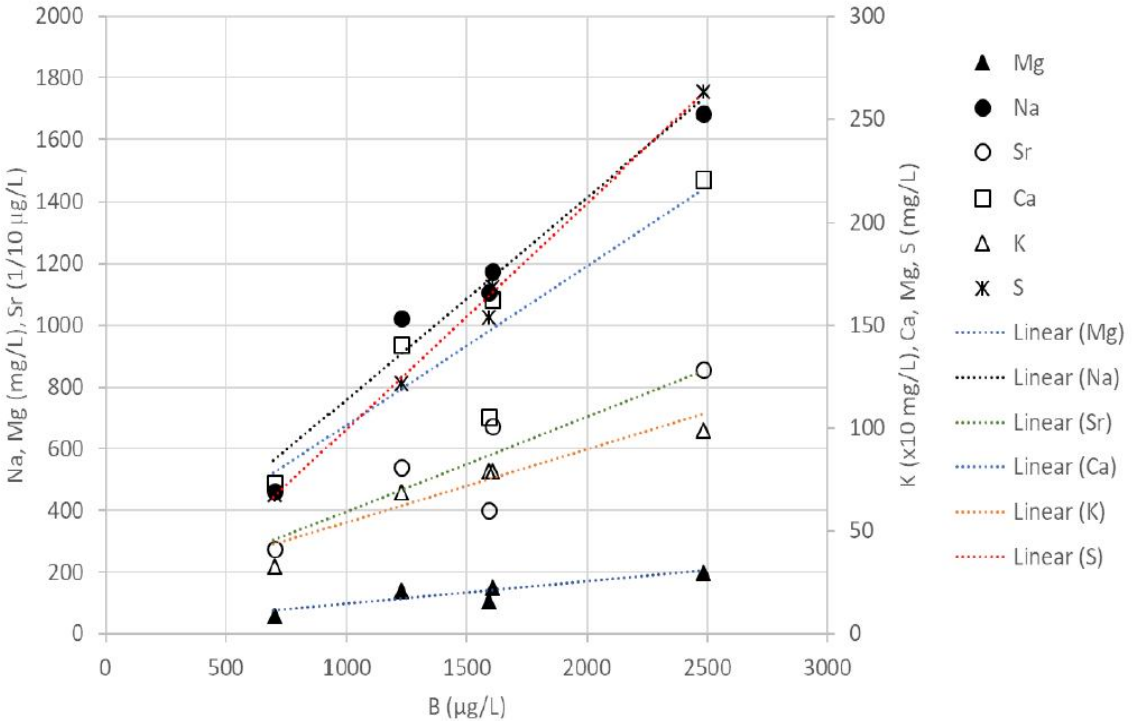


Figure 3: Relationship of concentration between B and other elements (Na, Ca, K, Mg, Sr, and S) in groundwater samples collected from the Gaza Strip, Palestine. Dashed lines show the fitted curves of each correlation.

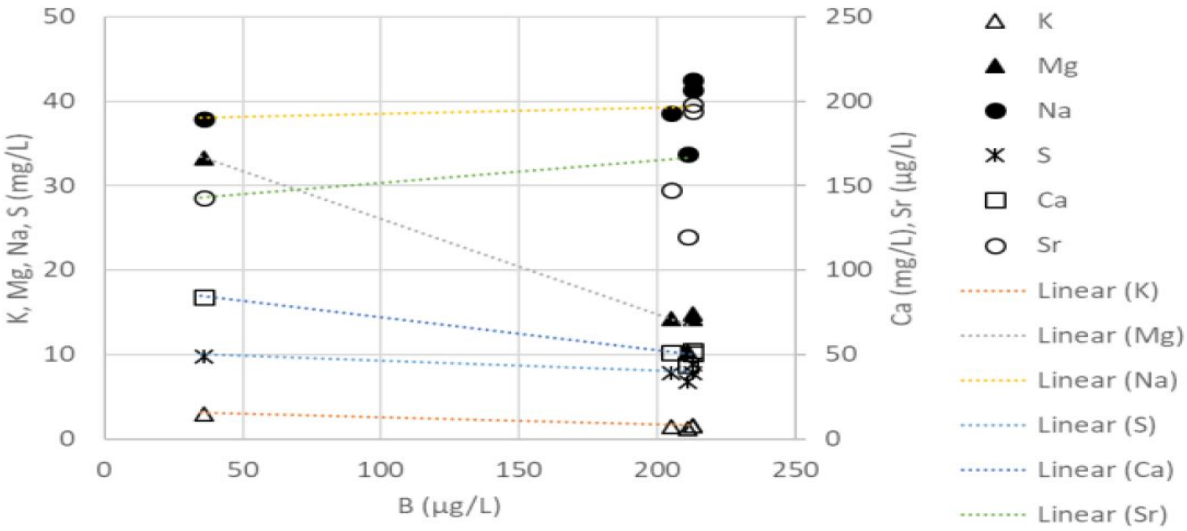


Figure 4: Relationship of concentration between B and other elements (Na, Ca, K, Mg, Sr, and S) in groundwater samples collected from the West Bank, Palestine.

[1] National Primary Drinking Water Regulations (NPDWRs) that set mandatory water quality standards for drinking water contaminants. These are enforceable standards referred to as the "maximum contaminant level (MCL)."
[2] National Secondary Drinking Water Regulations (NSDWRs) that set non-mandatory water quality standards for 15 contaminants.
[3] Council Directive 98/83/EC of November 3, 1998 on the quality of water intended for human consumption.

In contrast, groundwater from the Eastern Aquifer in the West Bank had a lower concentration of B and no clear correlation between B and the other five elements (Na, Ca, K, Sr, and S; see Table 3), except between B and Mg (see Figure 4). This suggests that the origin of B in the Western Aquifer in the West Bank differs from that in the Coastal Aquifer in the Gaza Strip.

Table 3: Coefficients of determination (r^2) for the linear correlation between B and the other six elements in the groundwater of the Gaza Strip and West Bank

Linear Correlation with B	Groundwater in the Coastal Aquifer, Gaza Strip	Groundwater in the Eastern Aquifer, West Bank
Na	0.9630	0.1636
S	0.9949	0.5641
Ca	0.8068	0.5682
Mg	0.7975	0.9702
K	0.8947	0.0800
Sr	0.7806	0.0941

The six elements (Na, Ca, K, Mg, Sr, and S) as well as Cl and B are typical constituent elements of seawater [4], suggesting that the contamination of groundwater in the Coastal Aquifer in the Gaza Strip is caused by the intrusion of seawater therein. Thus, the B and S contamination observed in the Coastal Aquifer in the Gaza Strip is possibly caused by the migration of seawater.

IV. BORON CONTAMINATION

In 1998, the European Union (EU) revised its Drinking Water Directive, which regulates the quality of water in the EU intended for human consumption. At that time, the EU defined the new standard for B concentration in drinking water as less than 1 mg/L. B in drinking water can be lethal at high concentrations (200 to 300 mg/kg). At a level of 20–25 mg/kg, the effects include gastrointestinal tract distress, vomiting, abdominal pain, diarrhea, and nausea [5] [6]. The B contamination detected in the groundwater collected from the Coastal Aquifer, Gaza Strip indicates that although this concentration is not high enough to cause immediate health damage, it is beyond the EU's regulation. Whether the regulation value (1.0 mg/L) set by the EU Directive (1999) is valid is still discussed [7], but attention is required from the standpoint of precautionary principles. Continuous drinking or agricultural use of groundwater from the Coastal Aquifer in the Gaza Strip is not recommended. Similar B contamination has been reported for the groundwater of the coastal aquifer in Israel. Based on geochemical and oxygen isotope studies, Vengosh and his team proposed a model for the groundwater contamination mechanism, namely as upcoming "underlying natural saline water" from the over-exploitation of fresh groundwater [8]. The present study, which was conducted in the Gaza Strip, could not discuss the source and contamination mechanism of B in the Coastal Aquifer. However, the results of this study are consistent with the proposed model.

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