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Study of the water assessment in the Alhoujair valley in Lebanon

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Abstract

In this work, we took the case of Al Houjair valley, a protected area of Litani river, located in the south of Lebanon, in order to determine the types and sources of pollution, characterize them, and determine the risks incurred by the riparian populations following the pollution of the river, to propose methods to clean up this fresh water. The results showed that since this fresh water is far from the inhabitants of the region, its pollution maybe the consequence of the various wars waged by Israel against southern Lebanon. Analyses on the sampling series showed that the values of the physicochemical parameters whatever the sampling point are outside the required norms for surface water, so it was a moderate pollution stage. In addition, 15 sites out of 16 are contaminated either by microbiological pollutants or heavy metals. The Houla well was the only exception; it is free of any contamination by any pollutant. The physico-chemical indices at the level of temperature, conductivity and TDS do not exceed the norm, and the tests on cations, anions and heavy metals do not detect any pollution. However, the lead concentration observed at the contaminated sites is very high in the "Al Ghandouriye 2" site (0.3819 mg/l), it reaches 38 times more than the norm (0.01 mg/l). Concerning the microbiological analysis, the obtained results demonstrated the absence of pollution in all sites by *E. coli or Clostridium perfringens* while total coliform was detected.

1. Introduction

According to the WHO, 3.4 million people die each year from water pollution while 2.6 billion people do not have access to sanitation [1]. These figures indicate that the quality and availability of water resources are unquestionably one of the major challenges of our century. Its preservation requires better management of industrial, agricultural and domestic pollutants... but the difficulty lies in controlling and reducing the threat it poses to our environment.

Lebanon enjoys a relatively high rainfall rate and, contrary to most countries in the region, it does not depend on inputs from other countries. Lebanon's renewable water resources are about 900 m^3 / hab / year, allowing it to be slightly below the water deficiency threshold of 1,000 m^3 / hab / year [2]. At the present time, Lebanon is also suffering from a deleterious environmental situation, leading to severe degradation in its aquatic ecosystems. In 2015, the United Nations Development Programme (UNDP) pointed out that Lebanon already had a water balance deficit (gap between needs and renewable resources) of 291 million m^3. This imbalance would even reach 307 million in 2020 and 610 million in 2035 according to another study carried out by the ministry of water and energy in 2012 [3].

Litani, the largest river in Lebanon (length 17 km, water resources of about 764M m^3, basin surface area 2,175 km^2; approximately 20% of the total Lebanese territory), is nowadays undergoing a large number of threats, in particular over exploitation and a high level of pollution. Indeed, the increasing concentration of the Lebanese population around the existing urban agglomerations, especially around the drained surfaces, poses a real problem due to the lack of wastewater treatment systems, insufficient drinking water supply, a remarkable absence of sewerage networks, and inadequate management of solid waste, whose rivers and their surroundings constitute a dumping ground for fatally dangerous compounds such as pesticides and its derivatives. In addition, the river is designed for some irrigation projects for Saida-Jezzine, Marjeeyoun and Beirut, while the regions already irrigated by the river are experiencing serious shortage problems, especially Zahle and the central Bekaa.

The Food and Agriculture Organization (FAO) of the United Nations [4] has been able to demonstrate that a number of aquatic environments in Lebanon are highly concentrated in chemical products, mainly pesticides. In addition, in a recent study, it was shown that the lower part of the Litani basin is highly concentrated in Fe, Cd, Zn, Pb, Co, Cu and Cr in bottom sediments [5]. In another study, it was shown that the metal contents in bed sediment were highest during dry seasons [6]. Also, it was found that the mean concentrations of Cd, Mg, Al, Ba, Ni and Ag were higher in the dry season due to the dilution by rainwater which influences concentration and heavy metal mobility [7]. The increase of Fe, Cr, and Cu content is probably due to mill discharges and domestic purposes [8].

This work consists in diagnosing the water typology of the Al Houjeir valley basin, a derivative of the lower Litani basin, located in southern Lebanon and which maintains its pristine nature, far from inhabitants and pollution sources, through the physico-chemical and microbiological parameters measured in-situ and in the laboratory by principal components analysis, and identifying the most polluted site(s).

The database is provided by the Lebanese University, Faculty of Agronomy. It has been distributed over 26 variables. All data were collected and entered into the SPSS software for statistical analysis.

2. Materials and Methods

2.1. Study site

Located in the Caza of Marjeeyoun in the south of Lebanon, the total area of the Al Houjeir Valley Reserve is about 26 km^2, as for its borders, it extends from north to south of the Litani river course at Qaiqiya al-Jisr below the city of Nabatiyeh, to the city of Aitaroun in the Caza of Bint Jbeil. It is 100 km from Beirut. It is considered the second largest reserve after the Chouf reserve in Lebanon.

2.2. Sampling

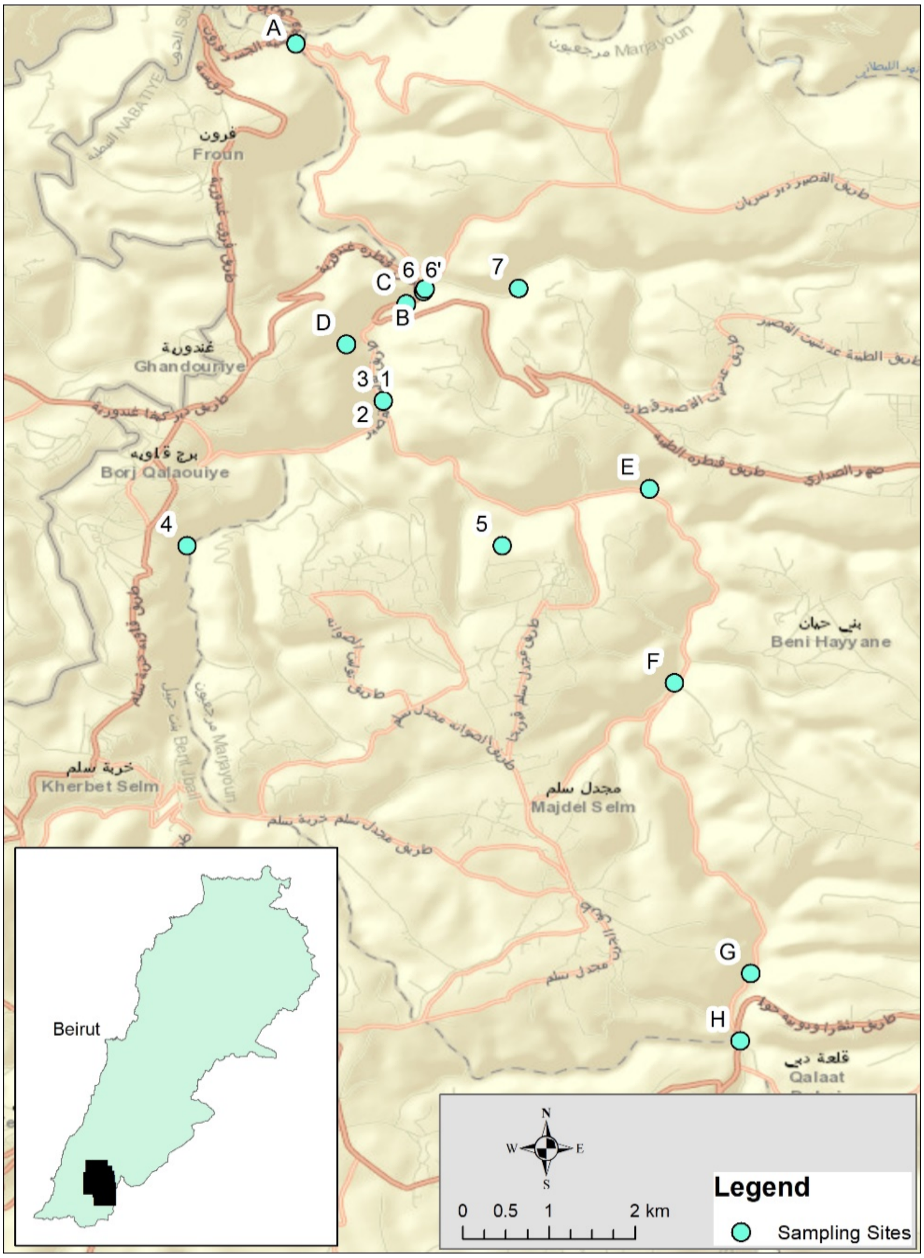
Surveys were conducted at 16 riparian sites, 8 of which are fountains (designated by numbers on the map) and 8 of which are wells (designated by letters) (Figure 1). Stream samples taken at 12 points, 3 times during this study in sterile containers, between 2019 and 2020, were subjected to physicochemical and bacteriological analyses. At each sampling site, approximately 2 liters of raw water were collected.

2.3. Microbiological analysis

Microbiological analyses were performed on five types of bacteria: Total coliforms, *Escherichia coli,* Salmonella, *Clostiridium perfringens* and *Staphylococcus aureus* in the laboratory of microbiology of the Faculty of Agronomy at the Lebanese University.

2.4. Measurements of the physico-chemical parameters of water

The pH was measured with a pH meter. The electrical conductivity (EC) and TDS were measured with a "PockeTester" and the temperature was taken on the phone.



1 Nabeh Al Houjeir 1
2 Nabeh al Jenn
3 Nabeh Al Houjeir 2
4 Nabeh Qalawani
5 Nabeh Al Qantara
6 Ein Abou Sdoun 1
6' Ein Abou Sdoun 2
7 Nabeh Al tafoura
A Froun
B Al Ghandouriye 1
C Al Qantara 1
D Al Ghandouriye 2
E Al Qantara 2
F Talousa
G Majdal selem
H Houla

Figure 1: Sampling sites

Table 1: The right temperature and time for each culture medium

Bacteria	Number of boxes or tubes	Environment	Temperature (°C)	Time (h)	Stocking
Total coliforms	32	Macconkey Agar	37 °C	24	Box\ in surface
E. coli	32	Macconkey Agar	45°C	48	Box \in surface
Salmonella	32	Salmonella shigella Agar (SS)	37°C	24	Box \in surface
S. aureus	32	BP Chapmen	37°C	24	Box \in surface
C. perfringens	16	Tryptose Sulphite Neomycin Agar (TSN)	45°C	48	Tube

2.5. Measurement of major anions

The measurement of Nitrate (NO_3^-), Sulphate (SO_2^-), Phosphate (PO_3^-) and Chloride (Cl^-) was done using the spectrometer and the calculation of the concentration of each element was done using a calibration curve.

2.6. Measurement of cations and heavy metals

The measurement of cations Ca^{2+}, Mg^{2+}, K^+, Na^+, et NH_4^+, and metals (Cd, Fe, Cu et Zn, Cr) was realized using a spectrometer or flame photometer and atomic absorption.

2.7. Statistical analysis

The statistical analysis was determined by the Principal Component Analysis (PCA) method. 6 continuous active variables representing the pollutants whose univariate descriptive analysis showed that these variables exceeded acceptable international standards. The six variables are: total coliforms, salmonella, *S. aureus*, lead, manganese, bromine. For individuals, the Houla site was eliminated from the analysis since all the pollution parameters are null. The SPAD version 5.5 software was used for data processing.

3. Results and Discussion

3.1. Physico-chemical parameters

Water temperature T (°C), pH, conductivity (EC), salinity and total dissolved solids (TDS) taken from different sites are shown in Table 2 .

Table 2: The values of T (°C), pH, TDS and EC of the different sites

Site	T (°C)	EC µS/cm	TDS mg/L	pH
Nabeh Al Houjeir 1	32	460	230	7.17
Nabeh al Jenn	33	530	270	7.25
Nabeh Al Houjeir 2	34	520	260	7.15
Nabeh Qalawani	33	550	270	7.12
Nabeh Al Qantara	32	380	180	7.55
Ein Abou Sdoun 1	35	500	250	7.39
Ein Abou Sdoun 2	35	450	230	7.16
Nabeh Al Tafoura	34	430	220	7.33
Froun	33	450	220	7.32
Al Ghandouriye 1	30	500	250	6.86
Al Qantara 1	31	530	260	7.01
Al Ghandouriye 2	33	320	160	7.23
Al Qantara 2	32	440	220	6.81
Talousa	30	410	200	6.9
Majdalselem	32	220	110	6.96
Houla	33	240	120	7.35

3.2. Temperature

The maximum value of temperature at all sites is 35˚C and the minimum value is 30˚C, and since the acceptable limit according to international standards is 25 ˚C then the minimum value is 5 degrees higher than the limit value, while the maximum value is 10 degrees higher than the limit value (Table 2).

These results indicate the presence of thermal pollution in the area from which the samples are taken. This pollution may be due to urban or industrial hot water discharges into the watercourse. In small streams, it may also be caused by the overflow of ponds on the bank, which, due to their large surface area, act as a "heat pump". In the summer period, at high atmospheric temperatures, the sudden heating by the sun of the water in poor condition in a river with little oxygen can lead to a thermal shock resulting in spectacular fish mortality. The wooded edges of rivers limit the heating of the water, hence the additional interest of conserving them [9].

3.3. The pH

All the sites evaluated have an almost neutral pH, the minimum value found is 7 and the maximum value is 8, so no site is out of the range set between 6.5 and 8.5. Low pH values (acidic waters) increase the risk of metals being present in a more toxic ionic form. High pH values may increase ammonia concentrations that are toxic to fish [10].

3.4. Electrical Conductivity (EC)

Conductivity measurement is a fairly simple means of detecting an anomaly indicating the probable presence of pollution, as large loads of organic pollution increase conductivity. The higher the concentration of dissolved minerals and trace elements, the higher the conductivity will be.

Our obtained results indicated that all sites are non-conductive of electric current, with a normal average of 433.13. All values vary between 550 µs/cm (Nabeh Qalawani) and 220 µs/cm (Majdal Selem), and are all normal according to the WHO standard which is accepted for values between 200 and 1500 µs/cm.

3.5. TDS

All sites have normal TDS concentrations, according to the WHO standard which is between 100 and 750 mg/l. All measured values of the sites vary between 110 mg/l (Majdal Selem) and 270 mg/L (Nabeh Qalawani).

3.6. Concentrations of anions in the water

Concentrations of NO_3^-, SO_4^{2-}, PO_4^{3-}, Cl^-, F^- and NO_2^- in the various sites are presented in Table 3 below. These results indicated that no sites are contaminated with nitrate, chlorine and sulphate as all observed values are well below the standard (45 mg/l and 250 mg/ml respectively). Also, we noticed that no sites were found to be contaminated with fluorine and nitrogen dioxide.

All observed values vary between 0.01-0.09 and 0.119 respectively. Although the accepted international standard is 0.7 mg/ml, it is observed that the concentration in the tested sites in its maximum value is 7 times less than this standard. Regarding phosphorus, none of the sites in the first group is out of the norm (between 0.35 and 0.5 mg/l), and all the sites in the second group have a concentration value well below the threshold value (0.0269 < 0.35). Based on the acceptable bromine concentration value of 0.01 mg/l, 8 sites are found to be contaminated by bromine, i.e. 50% of the sites: 2 of them (Nabeh Qalawani and Talousa) have a high concentration exceeding 5 times the norm, a medium concentration (Al Ghandouriye 1) and 5 sites have a low concentration (Nabeh Al Houjeir 1 and 2, Nabeh Al Jenn, Nabeh Al Qantara, and Al Qantara well).

3.7. Cation concentrations in water

Concentrations of K^+, Na^+, NH_4^+, Ca^{2+} and Mg^{2+} in the various sites are shown in Table 4 below.

Table 3 : Concentrations of anions in water at different sites

Site	Site	PO_4^{3-} mg/L	NO_3^- mg/L	SO_4^{2-} mg/L	NO_2- mg/L	Cl^- mg/L	Br^- mg/L	F^- mg/L
1	**Nabeh Al Houjeir 1**	0.39	2.72	0.3632	0.016	1.349	0.012	0.051
2	**Nabeh al Jenn**	0.39	4.43	0.365	0.08	1.182	0.013	0.029
3	**Nabeh Al Houjeir 2**	0.389	1.16	0.379	0.063	1.266	0.012	0.016
4	**Nabeh Qalawani**	0.386	3.952	0.407	0.032	1.388	0.05	0.094
5	**Nabeh Al Qantara**	0.386	2.29	0.641	0	1.822	0.016	0.037
6	**Ein Abou Sdoun 1**	0.387	2.86	0.045	0.034	1.264	0.004	0.038
6'	**Ein Abou Sdoun 2**	0.389	4	0.932	0.07	2.672	0	0.05
7	**Nabeh Al Tafoura**	0.385	2.42	1.317	0.003	2.34	0.006	0.011
A	**Froun**	0.0269	3.57	0.944	0.069	2.142	0	0.045
B	**Al Ghandouriye 1**	0.0269	0.44	1.202	0.083	2.895	0.03	0.075
C	**Al Qantara 1**	0.0269	2.9	1.236	0.102	2.364	0.015	0.023
D	**Al Ghandouriye 2**	0.0269	0.44	0.534	0.037	1.779	0.008	0.019
E	**Al Qantara 2**	0.0269	0.38	0.831	0.006	2.82	0.004	0.038
F	**Talousa**	0.0269	2.07	0.833	0.119	1.641	0.051	0.068
G	**Majdal Selem**	0.0269	1.265	0.628	0.018	1.29	0	0.047
H	**Houla**	0.0269	1.26	0.623	0.013	1.22	0	0.05

Table 4: Concentrations of cations in water in different sites

Site	Site	Ca^{2+} mg/L	NH_4^+ mg/L	Mg^{2+} mg/L
1	**Nabeh Al Houjeir 1**	1.901	0.015	0.173
2	**Nabeh al Jenn**	1.0046	0.022	0.2383
3	**Nabeh Al Houjeir 2**	2.6723	0.22	0.1102
4	**Nabeh Qalawani**	3.7505	0.066	0.106
5	**Nabeh Al Qantara**	3.3988	0.0348	0.1394
6	**Ein Abou Sdoun 1**	3.0788	0.033	0.1138
6’	**Ein Abou Sdoun 2**	2.5632	0.0348	0.2159
7	**Nabeh Al Tafoura**	3.7047	0.033	0.2895
A	**Froun**	1.9895	0.0348	0.3864
B	**Al Ghandouriye 1**	2.8192	0.0348	0.3289
C	**Al Qantara 1**	2.6256	0.0348	0.3869
D	**Al Ghandouriye 2**	2.1222	0.0348	0.1191
E	**Al Qantara 2**	2.929	0.0348	0.276
F	**Talousa**	1.6768	0.0348	0.3815
G	**Majdal selem**	1.9833	0.0348	0.363
H	**Houla**	2.1752	0.0348	0.2934

The results obtained showed that no site exceeds the critical point 0.5 mg/l for NH_4^+. The maximum value observed is 0.22 mg/l for the site Nabeh Al Houjeir 2, and the minimum value is 0.015 mg/l for Nabeh Al Houjeir 1, which indicates the existence of a source of pollution between these two sampling ends. Similarly, no site contained a Ca^{2+} concentration outside the norm (300 mg/l), and the maximum observed is 80 times less than the norm. Concerning Mg^{2+}, the results showed that no site contained a concentration outside the norm (200 mg/l). All values vary between 0.1 and 0.4 mg/l, even the maximum value is almost 500 times lower than the standard.

3.8. Heavy metal analysis

The results presented in the Table 5 showed that the concentration of lead exceeds the international standard (0.01 mg/l) in all but three of the fountains and among the wells correspond to the standard are: Talousa, Houla and Majdal selem where the minimum concentration (0 mg/l) is observed. Noting that the concentration of lead is very high in contaminated sites with an average of 0.14 mg/l, i.e. the average concentration of lead is 0.14 mg/l, i.e. 0.14 mg/l. 14 times greater than the norm, and which is remarkable that the maximum concentration observed in the Al Ghandouriye 2 site (0.3819 mg/l) is 38 times greater than the norm. While no site is found contaminated by Cu, Zn, Fe and Cd. All concentration values are below the WHO standard (1 mg/l, 4 mg/l, 0.5 mg/l and 0.003 mg/l respectively).

On the other hand, five sites are contaminated by Mn, which constitutes one third of the sites tested, and are all fountains. Not all wells are contaminated. Mn concentration values range from 0 (10 sites) to 0.2301 which refers to Nabeh Qalawani.

Table 5: Concentrations of heavy metals in water at the different sites

Site	Site	Mn^{2+} mg/L	Cd^{2+} mg/L	Fe^{2+} mg/L	Zn^{2+} mg/L	Cu^{2+} mg/L	Pb^{2+} mg/L
1	**Nabeh Al Houjeir 1**	0.1296	0	0	0.0066	0	0.2767
2	**Nabeh al Jenn**	0.1734	0	0	0.0076	0	0.0671
3	**Nabeh Al Houjeir 2**	0.201	0	0	0.0301	0	0.0847
4	**Nabeh Qalawani**	0.2301	0	0	0.3486	0	0.09
5	**Nabeh Al Qantara**	0.1905	0	0	0.335	0	0.087
6	**Ein Abou Sdoun 1**	0.0516	0	0	0.0313	0	0.0974
6	**Ein Abou Sdoun 2**	0	0	0	0.026	0	0.1071
7	**Nabeh Al Tafoura**	0	0	0	0.3376	0	0.1006
A	**Froun**	0	0	0	0.0717	0	0.1969
B	**Al Ghandouriye 1**	0	0	0	0.1525	0	0.1844
C	**Al Qantara 1**	0	0	0	0.0188	0	0.2598
D	**Al Ghandouriye 2**	0	0	0	0	0	0.3819
E	**Al Qantara 2**	0	0	0	0	0	0.3081
F	**Talousa**	0	0	0	0.013	0	0.0000
G	**Majdal selem**	0	0	0	0.0179	0	0
H	**Houla**	0	0	0	0	0	0

To conclude, we have two metals (Pb and Mn) that pollute the water of the sites studied. 13 sites are contaminated by Pb, 5 by Mn, and 5 by both together. While 3 sites were not contaminated by any of the metals (wells of Talousa, Majdalselem and Houla).

3.9. Phytotoxicity test

3.9.1. Germination test on Lepidium sativum seeds

Germination and root elongation are two fundamental steps for plant survival. For this reason, tests have been carried out to observe the effect of our water on the germination of grains in order to judge their phytotoxicity. All sites showed a strong germination and exceeded the limit (Table 6). Among the 16 sites, 12 had high germination, 2 had moderate inhibition (Froun and Nabeh El Jenn), and 2 represented severe inhibition (Ein Abou Sdoun and Al-Ghandouriye)(Figure 2).

Table 6: Classification according to the germination indexes of the phytotoxicity of water

Severe	Strong	Medium	None	Inhibition
<0.4	<0.6-0.4	<0.8-0.6	1-0.8	**Germination Index**

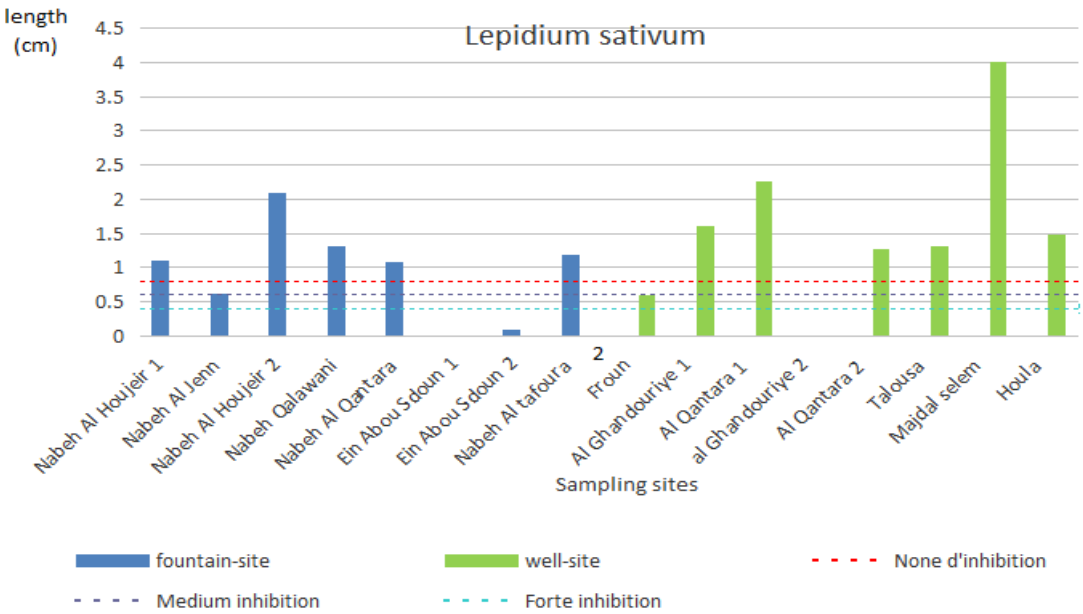


Figure 2: The *Lepidium sativum* germination index obtained according to the sites

3.9.2. Germination test on Cucumis sativus grains

In this study, cucumber was chosen because of its sensitivity to the presence of heavy metals. Among the 16 sites, 10 sites showed inhibition of cucumber root elongation. This indicates the presence of heavy metals in these sites (Figure 3).

3.10. Microbiological analysis

Total coliforms are a group of bacteria that occur naturally on plants, in soils and in the intestines of humans and warm-blooded animals. In this context, their presence in treated water does not necessarily imply an imminent risk to public health since most of these bacteria are not fecal in origin, but may be an indicator of water quality degradation and the potential presence of human enteric viruses [11] (Table 7).

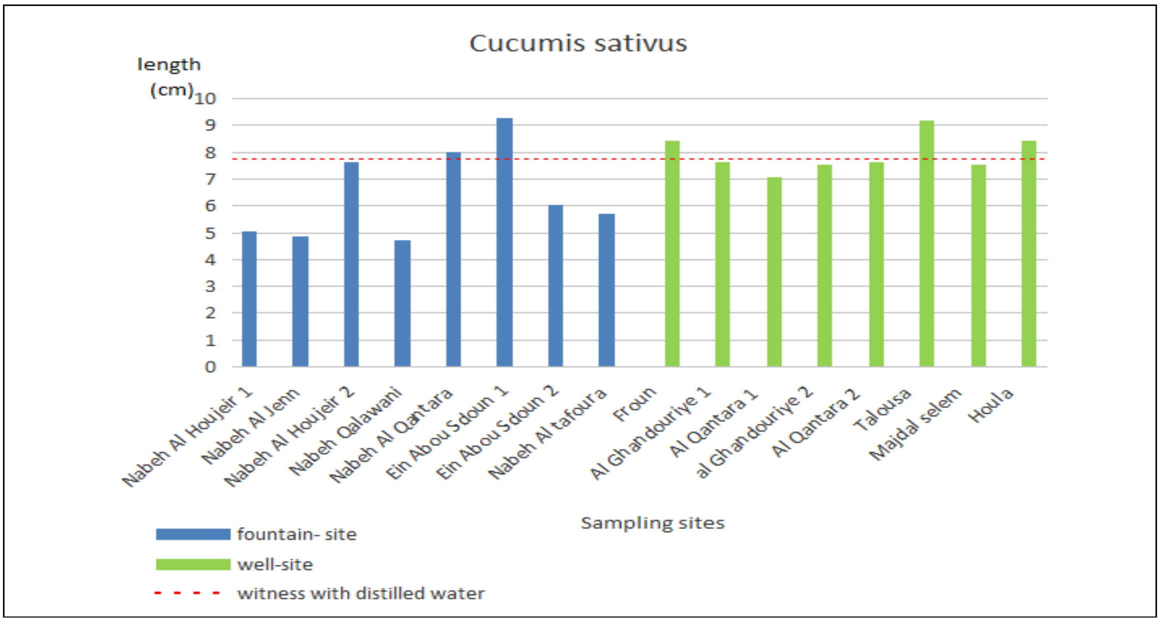


Figure 3: **The *Cucumis sativus* germination index obtained according to the sites**

Table 7: **The number of bacterial colonies**

Site	Site	Total Coliforms (CFU)	*E. coli* (CFU)	*SS* (CFU)	*S. aureus* (CFU)	*Clostridium* (CFU)
1	**Nabeh Al Houjeir 1**	10000	0	0	0	0
2	**nabeh al Jenn**	14000	0	0	10000	0
3	**Nabeh Al Houjeir 2**	0	0	>20000	>20000	0
4	**NabehQalawani**	8000	0	>20000	0	0
5	**Nabeh Al Qantara**	2000	0	0	1000	0
6	**EinAbouSdoun 1**	1800	0	0	0	0
6'	**EinAbouSdoun 2**	1000	0	0	0	0
7	**Nabeh Al tafoura**	20000	0	4000	4000	0
A	**Froun**	8000	0	0	0	0
B	**Al Ghandouriye 1**	>20000	0	0	0	0
C	**Al Qantara 1**	1200	0	0	0	0
D	**Al Ghandouriye 2**	0	0	0	0	0
E	**Al Qantara 2**	6000	0	0	0	0
F	**Talousa**	0	0	0	0	0

E. coli is the only member of the total coliform group found exclusively in the intestines of mammals including humans. It is also found in the intestines of some animals. Most types of *E. coli* are harmless. However, some strains can cause diarrhea [12]. After enumeration of these bacteria, all sites were found to be infected with total coliforms, with the exception of Nabeh Al Houjeir 2, while no sites were found to be contaminated with *E. coli.* As a result, all position and dispersal criteria give a zero value. The absence of *E. coli* generally indicates that it does not contain pathogenic intestinal bacteria, since it is the only member of the total coliform group found exclusively in human fecal matter.

In addition, our results showed the absence of *Clostridium perfringens* in all sites examined.

Concerning *Staphylococcus aureus,* it was found that four sites (Nabeh Al Houjeir2, Nabeh Al Jenn, Nabeh Al Tafoura, Nabeet Al Qantara) were contaminated by this bacterium and are out of the norm.

Similarly, the results showed that three sites were contaminated by salmonella and are out of the norm. More than 20000 salmonellae in 100 ml for Nabeh Al Houjeir2 and Nabeh Al Qantara, 4000 salmonellae in 100 ml for Nabeh Al Tafoura.

3.11. Correlation

Once the variables have been selected, the calculation of the correlation matrix allows the analysis of the bilateral relations existing between the different variables selected. The matrix allows observing a strong positive correlation between Salmonella and Manganese, Salmonella and Staphylococcus, and Staphylococcus and Manganese (Table 8).

Table 8: **Correlation Matrix**

Br	Mn	Pb	Staphylococcus	Salmonella	Total Coliforme	
					1.00	**Total Coliformes**
				1.00	-0.05	**Salmonella**
			1.00	0.57	0.01	**Staphylococcus**
		1.00	-0.27	-0.24	0.04	**Pb**
	1.00	-0.27	0.52	0.65	0.00	**Mn**
1.00	0.31	-0.27	-0.08	0.38	0.09	**Br**

Week Correlation <0.2 0. Medium Correlation<0.5 StrongCorrelation <0.8

3.12. Choice of factorial axes

The software's diagonalization of the initial data matrix gives a histogram of proper values indicating the share of the total information contained on each factor, or main component. The proper values table shows that the first two factors or factorial axes are significant (having an proper values $\lambda>1$) and express 59.55% of the total inertia with axis 1 representing 40.8% and axis 2 representing 18.75% (Table 9).

Table 9: **Proper values**

Percentage Cumulative	Percentage	Proper value	Axis
40.80	40.80	2.4477	**1**
59.55	18.75	1.1253	**2**

3.13. Correlation circle

The reading for each of the selected factors then makes it possible to determine their concrete signification and to obtain a better representation of the distances between the variables on one side and the sampling sites on the other side. For the factorial axis C1: Salmonella, manganese and *S. aureus* are closely correlated and represent the axis on the positive side, while lead affects this axis on the negative side. For the factorial axis C2: bromine has the largest positive influence, with a positive average influence for total coliforms and a negative one for *S. aureus* (Figure 4).

3.14. Relationship between sites and sources of pollution

Analysis of the C1 × C2 factor map (Figure 5) identified four classes of samples. The class (1/4) and the class (3/4) are located on the positive side of C1 and C2, but the former is close to the center while the latter is close to the extremities. While the class (2/4) is located on the negative side of C1 and C2.

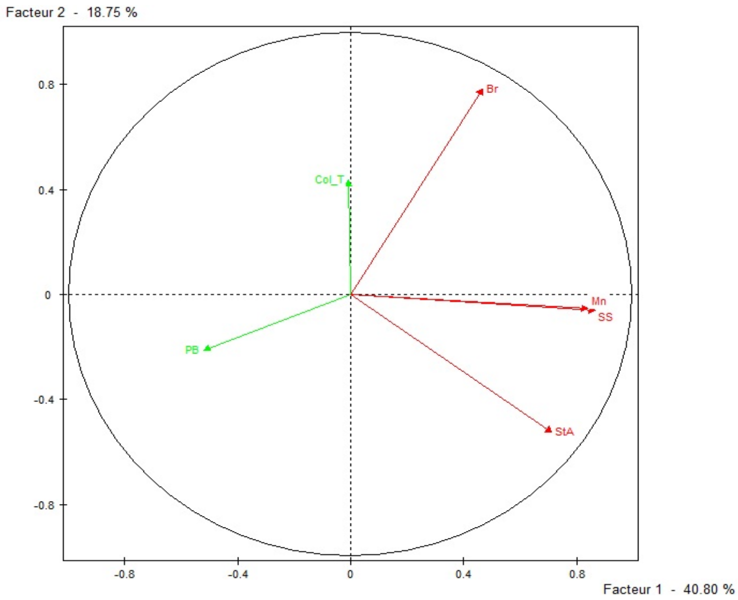


Figure 4: **Correlation circle of factor 1 and 2 variables**

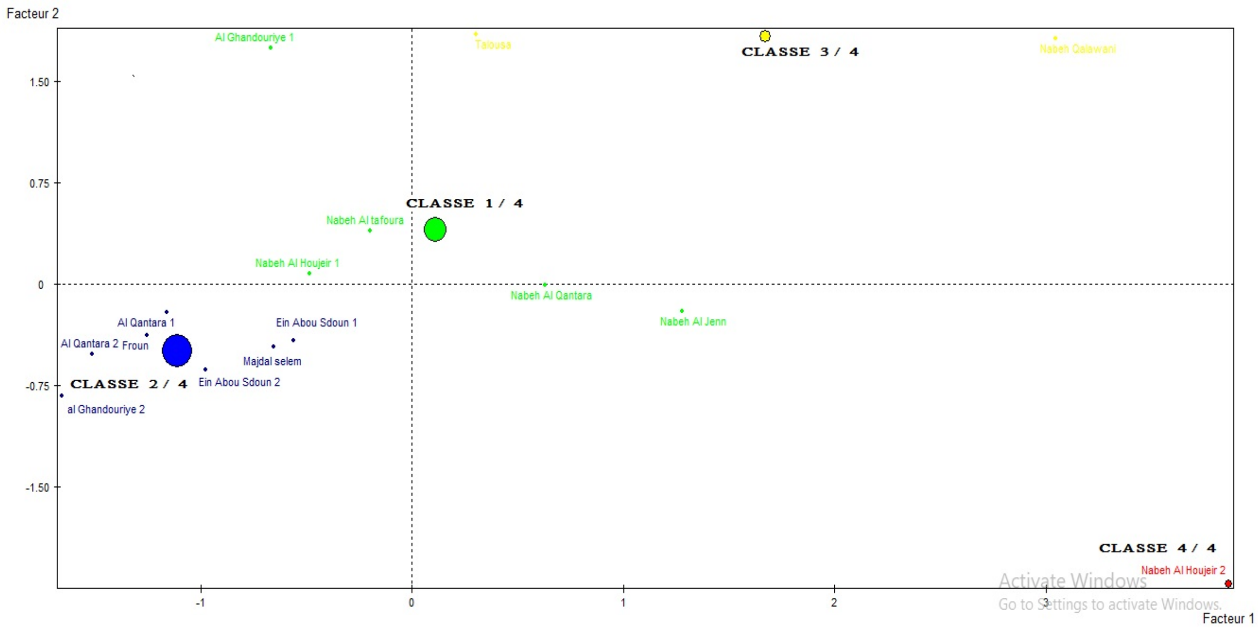


Figure 5: **Classes of individual**

Finally, the class (4/4) is located on the positive side of C1 and the negative side of C2.

- Class (1/4): includes the sites : Nabeh Al Houjeir 1, Nabeh Al Jenn, Nabeh Al tafoura, Al Ghandouriye 1 and Nabeh Al Qantara. These sites are characterized by high concentrations of total coliforms and lead.
- Class (2/4): Includes sites : Froun, Ein Abou Sdoun 2, Al Qantara 1, Ein Abou Sdoun 1, Al Qantara 2, Al Ghandouriye 2, and Majdal selem, which are characterized by high concentrations of total coliforms and lead, but zero concentrations of Salmonella and Staphylococcus aureus.
- Class (3/4): includes sites : Nabeh Qalawani and Talousa which are characterized by high concentrations of bromine.
- Class (4/4): includes a single site Nabeh Al Houjeir 2 which is characterized by a very high concentration of Salmonella, Staphylococcus aureus and Manganese.

Conclusion

The study showed that 15 sites out of 16 are contaminated by one of the pollutants, either microbiological or heavy metal pollution. The Houla well was the only exception, it is not contaminated by any pollutant although its physico-chemical indices at the level of temperature, conductivity and TDS do not exceed the standard and the tests on cations, anions and heavy metals do not detect any pollution.

In terms of microbiological analysis, no site is polluted by *E. coli* or *Clostridium perfringens*. The presence of total coliforms with the absence of E. coli is an indication that the pollution is not fecal in origin, since it is the only member of the group of total coliforms found exclusively in human feces. The presence of Salmonella may still be an indication of fecal pollution, but the correlation test with total coliforms indicates that they are not correlated with each other. Similarly for Staphylococcus, it may be a pollution source but not human.

In terms of physico-chemical analysis, no sites are contaminated with copper, zinc, magnesium, calcium, iron, fluorine, cadmium, chlorine, nitrogen dioxide or nitrate, but they are contaminated with lead, manganese and bromine. The concentration of bromine is almost close to the norm except at two sites (Talousa and Nabeh Qalawani) where the concentration is five times higher than the norm. Manganese concentration exceeds twice the standard in 3 of 5 contaminated sites. But what is remarkable is the very high concentration of lead observed at the contaminated sites with an average of 14 times the standard, and this concentration reaches in the site "Al Ghandouriye 2" 38 times the standard. However, these results support our hypothesis that we are suggesting a source of pollution linked to the Israeli wars and the repeated attacks on Lebanon.

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