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Lebanon's Water Resources Salinity Crisis

Mark Saadeh, Gebran Karam

KREDO, Beirut, Lebanon
Email: saadeh_mark@yahoo.com, gkaram@kredo.net

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Abstract

Lebanon's water sources, be it groundwater, springs, rivers or even tap water are notoriously plagued with a cocktail of contaminants from raw sewage, pesticides and fertilizers just to name a few, but the most salient being seawater intrusion, measured as Total Dissolved Solids (TDS) or Electrical Conductivity (EC). Myriad water sources have been sampled and tested since 2023, for said salinity (TDS), with results exceeding local as well as international drinking water guidelines of 500 milligrams per liter in many instances. This deterioration is compelling most citizens to install costly desalination equipment, purchasing bottled water and paying private tankers for questionable water, forcing households to spend in excess of USD 850 per year. This study aims to assess the quality of multiple water sources including wells, springs and tap water emphasizing the impacts salinity imparts on the Lebanese population as a whole with some practical recommendations.

Keywords

Seawater Intrusion, Groundwater Protection Zones, Total Dissolved Solids, Freshwater Salinization Syndrome (FSS)

1. Introduction

Intrusion of seawater into coastal aquifers is rampant, in Lebanon as well as the Mediterranean basin, due to high extraction rates and low recharge. Due to this rising salinity, household are compelled to seek alternate sources causing water expenditures to exceed 6.5% of incomes, significantly higher than the worldwide averages (Alameddine et al., 2018).

The hydrogeological context of Lebanon is complex and poorly researched in light of the decades-long calamities that never seem to abate, as such, it is beyond the reach of this paper to contemplate elucidation. However, it would suffice to point out that said hydrogeology comprises ten or so aquifers predominantly karstic in nature, and the ones that intersect the 225 km long coastline are subject to the Ghyben-Herzberg principle.

The principle was put forward by Willem Ghijben and Alexander Herzberg at the turn of the twentieth century. They derived said analytical solution to approximate the behavior of seawater intrusion, which is based on a number of broad assumptions that often does not apply to all field cases.

Simply put, when an aquifer crops out beneath the sea, ocean water may enter it under certain conditions. Sea water will be at such a depth that the overlying column of fresh groundwater will exactly balance a column of heavier sea water, according to said principle.

Hence, under static conditions, if the freshwater has a specific gravity of 1.0 and seawater a specific gravity of 1.025, the interface between the heavier sea water and the overlying freshwater in the area is pushed 40 meters below sea level for every meter that the water table stands above sea level. This is a very important point because it means that if the height of the water table above sea level is known, it is possible to calculate the depth to which freshwater is present as in Figure 1 below.

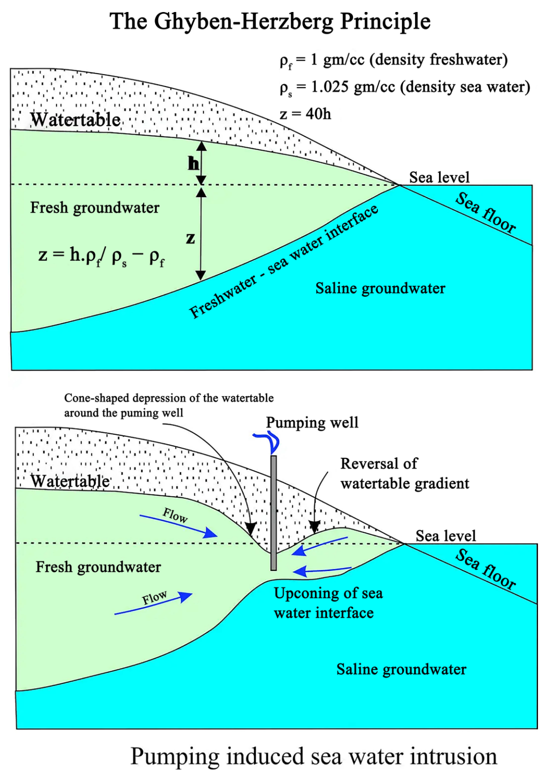

Figure 1. Ghyben-Herzberg Principle (Geological Digressions, 2016).

With the above in mind, Shaban (2015), postulates that there are no less than 100,000 wells strewn across Lebanon, pumping groundwater at an average rate of no less than 10 liters per day, most being unlicensed. UNDP on the other hand, estimates that there are no less than 80,000 wells across Lebanon with an alarming density of about 8 per square kilometer, the majority of which are also unregistered (UNDP, 2014). With the above in mind, all wells along the Lebanese coastline are subject to the repercussions of the Ghyben-Herzberg principle.

Additionally, an unhindered influx of Syrian refugees into Lebanon since 2011, topped with recurrent periods of drought have placed tremendous stress on an already dwindling resource. These concurrent stressors have inadvertently exacerbated the overall quality of freshwater in Lebanon, demonstrated by an outbreak of cholera that spread like wildfire, from refugee camps, and engulfing the entire nation, killing no less than 50 persons in 2022.

With the above in mind, supply of freshwater to the populated cities of Lebanon like coastal Beirut, has for decades forced the water authorities to adopt rationing to just a few hours per week, leaving civilians to resort to unsustainable measures such as over-pumping of ground water, and relying on dubious water vendors in the shape of tankers and bottled water.

Despite the urgency of these societal and environmental challenges, a better understanding of the impacts of seawater intrusion on different sectors and potential mitigation measures are inadequate.

As such, this paper attempts to identify the extent of salinization across the country's different water sources, with the aim of recommending immediate measures to abate the root-cause of it i.e. seawater intrusion, at least for the immediate future. To this end, existing literature related to seawater intrusion impacts in Lebanon was reviewed, proposing some viable and readily implementable mitigation measures.

Owing to the fact that the endeavor of this paper was an initiative undertaken by like-minded water pundits, with limited resources, the aim of the survey is to simply highlight the severity of salinization using portable equipment. A comprehensive national water quality monitoring program is the inevitable solution, to be carried out by the Lebanese government, namely the Ministry of Energy & Water.

2. Materials and Methods

Sampling and testing of water sources began across Lebanon in the summer of 2023 (**Figure 1**) and continues to the present day, using several portable LaMotte Salt/TDS/pH/Temperature TRACER Pocke Tester.

Tests were carried out in accordance with ASTM, 2019 guidelines, D4448-01 Standard Guide for Sampling Groundwater Monitoring Wells. The test results of the campaign are summarized in the **Appendix**.

Water sources were analyzed *in-situ* for temperature, and Total Dissolved Solids (TDS), thus minimizing errors and costs as opposed to laboratory testing. TDS values are determined by multiplying the conductivity measurement by a known conversion ratio factor. The meter allows the selection of a conversion ratio factor that is typically between 0.5 and 0.7. The stored ratio factor will briefly appear in the lower temperature display when the meter is first turned on or when changing the measurement function to TDS.

Meter accuracy verification was performed on a daily basis. During calibration, the meter was set in the salinity mode to perform calibration for salinity and TDS. The automatic calibration procedure recognizes the conductivity standard of 3000 ppm (3 ppt) for salinity samples within the range of 1000 to 9999 ppm salinity. Samples exceeding this range where diluted with distilled water accordingly then multiplied by the dilution factor to arrive at the estimated TDS value.

In the case of sampling and testing groundwater through wells, they were purged for at least five minutes rather than the equivalent three water columns due to the fact that in many instances, data pertaining to wells was incomplete.

The results were evaluated in accordance with the World Health Organization (WHO) Guidelines for Drinking Water Quality (2020) which stipulates a guideline of 500 mg/L (TDS) as well as other standards, including FAO's for agriculture (FAO, 1994) with a TDS not exceeding 450 mg/L, and finally the American Society for Testing and Materials (ASTM, 2022) prefers potable water standards for concrete batching whenever possible.

ESRI's ArcGIS 10.8.1 was used to generate **Figure 2** of this paper. All water sources sampled in said figures are also found in the **Appendix**.

It is worthy to elaborate on the differences between Electrical conductivity (EC), Salinity and Total dissolved solids (TDS). EC (electrical conductivity) is a measure of a water sample's ability to conduct electric current. It is primarily determined by the presence of dissolved salts and other inorganic substances that ionize in water. Such substances are known as electrolytes, and they conduct electricity due to their positive and negative charges.

The SI unit for conductivity is Siemens per meter (S/m). Conductivity increases with the amount of electrolytes dissolved in water up to a degree, as well as with increases in temperature.

Salinity on the other hand, is related to conductivity as it describes the total concentration of all dissolved salts in a water sample. Salinity is, therefore, commonly derived from specific conductance (conductivity and temperature) for convenience.

Lastly, Total dissolved solids (TDS) are defined as the sum of all particles that can pass through a 2-micron (0.0002 cm) filter. This includes both electrolytes (ions contributing to salinity) and any other non-ionic molecules, such as dissolved organic matter. TDS is reported as a concentration in mg/L. It was traditionally measured by evaporation, but for field measurements, it is normally derived from conductivity measurement using a TDS factor, which is approximated depending on the water type and any known sources of ions and other material.

3. Results and Discussion

Annual renewable water resources per capita in the Arab World is understandably among the lowest in the world, and by 2025, Lebanon's water supply deficit will exceed 1000 MCM/year (Korfali & Jurdi, 2011) placing tremendous strains on demands for water quantity and more importantly, quality.

World Health Organization (WHO) guidelines for drinking water does not express any particular health hazard from TDS concentrations exceeding 500 mg/L, however, the economic impact of aquifers degraded by seawater intrusion on Lebanon's infrastructure is incalculable as highlighted by Alameddine et al. (2018) from accelerated corrosion of Lebanon's infrastructure as well as deterioration of fertile soils.

An additional problem of increase in salt concentrations is a phenomenon called freshwater salinization syndrome (FSS). This syndrome is a result of direct as well as indirect effect of salts that cause other pollutants from soils, groundwaters, surface waters, and pipes to become soluble and mobile (Cooper et al., 2014).

FSS with its direct and indirect effects has serious impacts on surface, ground and drinking water quality, as well as aquatic and terrestrial ecosystem function, human health, food production, and degradation of infrastructure (Sujay et al., 2021).

FSS encompasses several processes such as sodification (increase in exchangeable sodium ions expressed as ESP, impacting soils by reducing their permeabilities), salinization (increase in total water ions expressed as TDS or electrical conductivity EC leading to enhanced corrosion etc.), and alkalinization or the increase in alkalinity or ability of a solution to neutralize acids through carbonates, bicarbonates etc. (Kaushal et al., 2019) impacting ecosystems.

Salts alone can directly impact water quality by increasing the rate of ions mobilized from soils and pipes becoming concentrated in ground and surface waters. Nitrates for instance can be mobilized by FSS thereby leading to harmful algal blooms or HABs destroying freshwater systems as well as coastal waters (EPA, 2022). Nitrates also impact infants with spikes in cases of Blue Baby Syndrome or methemoglobinemia as well as potentially increasing cases of certain cancers, namely gastric cancers (Picetti et al., 2022).

Increased salinity (often expressed as TDS) would render coastal aquifers unsuitable for public supply with only a 2% contamination (Bear, 1999). Normally, a 1% mixing would triple groundwater salinity or TDS, while 5% mixing would increase salinity to the guideline limit of 450 mg/L (Bear, 1999). Hence once freshwater resources are degraded by salt contamination, it will take decades for aquifers to recover, and if positive groundwater recharge conditions are not re-established, they may never do so.

The TDS values summarized in the **Appendix** and labeled into three groups, namely groundwater (expressed as wells and springs), tap water (municipal supply), and surface runoff (rivers and streams).

To begin with, groundwater TDS results, especially with coastal sources clearly indicate contamination by seawater in several wells in Saida (99), coastal Chouf (30), and Keserouane (39). As for Greater Beirut, the severity of seawater intrusion has been long established by the author's doctoral dissertation undertaken between 2004-08 and again in subsequent articles, that measured groundwater

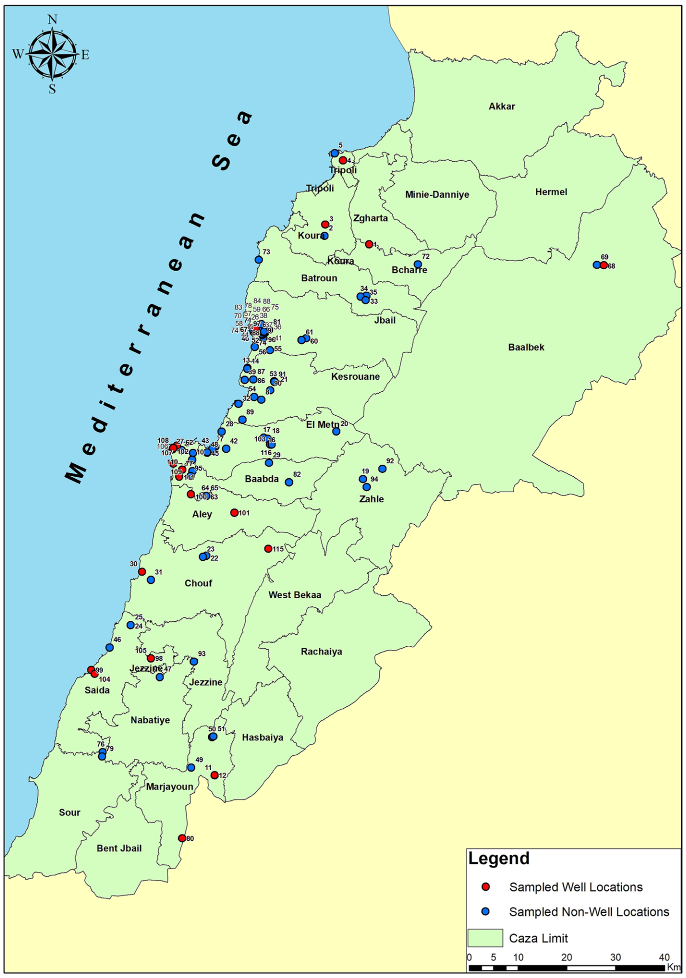

Figure 2. Locations of sampled water sources across Lebanon.

quality including TDS in a multitude of wells indicating severe seawater contamination (Saadeh, 2008).

As for the tap water provided by local public utilities, most notable include Beirut (#45) at about 2200 mg/L, Jbail (#57 & #59) at 2300 and 2050 mg/L respectively, and Baabda (#95) at a staggering 5500 mg/L, all of which deleteriously exceeding permissible guidelines for drinking water, concrete batching and agricultural irrigation.

Lastly, surface runoff (streams, rivers etc.) like those measured in samples #14 and #55, are generally still within acceptable guidelines for TDS of 500 mg/L as per drinking water, concrete batching and irrigation.

4. Recommendations

Once freshwater has been afflicted with elevated Salinity/TDS (Korfali & Jurdi, 2010), like most metropolitan centers along Lebanon's coastline, combating these effects may take decades to undo, as per notable studies including Bear (1999), and again Barlow (2003). Even though, aquifer recharge is often employed for contaminated coastal aquifers worldwide, only potable water standards should provide a reference point for recharging said aquifers, a commodity which is already acutely scarce in Lebanon and the region.

By no means are the following recommendations a panacea for ensuring water efficiency and quality for any Integrated Water Resources Management Plan (IWRM), nevertheless, experts alike agree that they are integral to any successful water management plan, from the eminent Tony Allan (2011) to Klaus Balke and many others.

4.1. Water Metering

Once water sources are assessed for their sustainability and quality, domestic water networks must then be accounted for by the installation of meters along the entire supply chain. Unsurprisingly, Lebanon has the unique distinction of being among the few states globally that has yet to do so.

With myriad conflicting sources of literature, it is of little surprise that estimates wildly differ as to the exact amount of water losses in the networks, be they real or apparent, but most experts would agree that said losses are staggering, attributed mostly to leakages from an antiquated network, compounded by illegal tapping by a large swath of the population.

Additionally, tariffs on this most contentious resource still remain fixed at a flat rate. Any attempt to install water meters and operate them, have often been hindered by the public and politicians alike. Metering is nevertheless critical since it is widely accepted that metered cities consume at the very least 15% less water than their unmetered counterparts (Ratnayaka et al., 2009).

Lastly, groundwater recharge rates have been estimated to be anywhere between 4700 and 7200 million cubic meters (MCM) annually. The discharge rates on the other hand are estimated to be around 2500 MCM. Therefore, the water balance varies positively between 2200 MCM to over 4700 MCM annually (UNDP, 2014). With over 100,000 wells across Lebanon, and the majority of which are unregistered (IWMI, 2017), priority must be given to bringing unlicensed wells into the fold and immediately through strict enforcement of the letter of the law.

4.2. Integrated Water Resources Management

An Integrated Water Resources Management (IWRM) plan is the way forward for efficient, equitable and sustainable development and management for all the world’s scarce freshwater resources.

In Lebanon, a national IWRM plan is yet to be effectively implemented. In its place, a perfunctory document that many consider to be a national integrated water management plan, called the National Water Sector Strategy Update (2020) by the Ministry of Energy & Water.

Said document presents abstract plans, strategies, and policies relevant to potable water, irrigation and wastewater (UNDP, 2014). This aforementioned strategy is struggling to get off the ground in light of the ongoing 2019 financial crisis, compounded by the conflict with Israel that has put on hold all forthcoming international assistance.

For the success of any IWRM policy, coastal aquifers afflicted by seawater intrusion, should be prioritized for effective and immediate counter measures by relevant authorities, namely the Ministry of Energy and Water (MoEW) through proven interventions; including the implementation of an immediate moratorium on coastal wells, coupled with stricter regulations on all pending well permits. Secondly, the aforementioned existing national strategy would greatly benefit from an overhaul which is beyond the scope of this or any other paper for the time being.

4.3. Groundwater Protection

To manage Lebanon's groundwater resources, it is absolutely imperative to delineate protection zones around springs and public wells. Within these water protection zones, water resources take priority over all other competing interests of land use.

A typical area where groundwater would be protected against contamination may be divided into three zones akin to what is adopted in the EU as well as Germany (Balke et al., 2008):

Protection Zone I: protects the direct vicinity of a wells or springs against any form of contamination. Said wells and springs would be encircled by fences with a radius of tens of meters preventing any unauthorized entry and any form of agriculture or construction.

Protection Zone II: categorized as zones vast enough to eliminate microorganisms introduced into the groundwater after 50 days. The "50-day-line" is the connection of all sites within an aquifer for which groundwater requires 50 days until it arrives at a well or spring.

Protection Zone III: in this protected zone, most if not all sources of pollution are forbidden whether from the agricultural, industrial or domestic sector.

4.4. Water Conservation

Any IWRM plan must first and foremost involve the local community, directing them to savings techniques such as efficient household water use, installing household metering systems, as well as a complete overhaul of existing water tariffs. The conservation of water at the household level can be achieved by the establishment of proven methods to influence people's attitudes and re-orient their praxis to water savings.

Such activities should focus but are certainly not restricted to the following:

1) Public awareness campaigns that focus on water conservation in order to reduce water demand at household levels through media, and lectures at schools and universities alike;

2) Involvement of all the stakeholders including grass root citizens in IWRM plans;

3) Water conservation to be integrated into school and university curricula; and

4) Water conservation attained by the use of water metering systems as mentioned previously, as well as using household water saving appliances like toilets, washing machines and showers just to name a few.

5. Conclusion

The results of the ongoing water quality campaign, sharply focus the deleterious effect of seawater intrusion on Lebanon's most precious water resource, groundwater, however, more alarming is the fact that elevated values of TDS have now been detected in all major coastal cities, namely Beirut, Saida, Tripoli and Byblos (Jbeil) alike.

Any water management strategy is by no means a "one size fits all" approach, and each has to be fine-tuned to its required set of goals, nevertheless, the aforementioned recommendations are a fundamental step in the right direction. As such, this paper emphasizes first and foremost the urgency for the implementation of an updated national comprehensive integrated water resources management plan (IWRM) with immediate enforcement ensuring that coastal aquifers are disencumbered by the Ghyben-Herzberg principle. This will decouple the impacts of salinization from coastal aquifers on which the majority of Lebanon's population relies.

All of Lebanon's aquifers, on the other hand, must also be protected by adopting the recommended three protection zones coupled by a metering the nation's entire water supply network from source to tap. Only then can water conservation proceed in tandem with water efficiency.

As a final note, the late eminent professor Tony Allan warns that "wherever we irrigate, society always runs out of water", a declaration that will certainly not bode well with agriculture pundits.

Lebanon, and the Middle East continues to rely heavily on irrigation, consuming around 70% of its renewable freshwater resources, to that end, an improvement of only 10% in irrigation efficiency could potentially double the resources available for public water supply according to TWORT's, an avenue well worth pursuing in Lebanon and the region, where agricultural practices remain stubbornly adamant to proven and efficient irrigation methods.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Point	Caza	Latitude	Longitude	TDS (mg/L)	Source
1	Bcharre	34.2854228	35.9014213	273	Well
2	Koura	34.298324	35.801625	315	Tap
3	Koura	34.3191154	35.8024002	500	Well
4	Tripoli	34.43955	35.837219	5000	Well
5	Tripoli	34.452507	35.817951	39,000	Seawater
6	Jbail	34.1154864	35.6732696	440	Tap
7	Beirut	33.90044	35.57582	1054	Tap
8	Kesrouane	33.9903966	35.6732807	372	Tap
9	Jbail	34.10458	35.67332	225	Tap
10	Beirut	33.8746	35.52502	582	Tap
11	Marjayoun	33.29107	35.59902	364	Well
12	Marjayoun	33.29116	35.59882	361	Well
13	Kesrouane	34.04853	35.64056	233	Tap
14	Kesrouane	34.04687	35.63996	260	Stream
15	Jbail	34.12199	35.65574	290	Well
16	El Metn	33.9206046	35.6814523	110	Spring
17	El Metn	33.920543	35.681504	370	Spring
18	El Metn	33.9189142	35.6907697	360	Spring
19	Zahle	33.849722	35.9041666	183	Tap
20	El Metn	33.9364	35.8422	153	Tap
21	Kesrouane	34.025338	35.700492	325	Tap
22	Chouf	33.697993	35.563921	325	Tap
23	Chouf	33.695628	35.556102	186	Tap
24	Saida	33.564561	35.402367	580	Tap
25	Saida	33.564561	35.402367	490	Tap
26	Jbail	34.113558	35.668193	240	Tap
27	Beirut	33.8931317	35.4804838	510	Tap
28	Beirut	33.9287184	35.5879482	385	Tap
29	Baabda	33.8739974	35.6949623	190	Tap
30	Chouf	33.663842	35.42282	1000	Well
31	Chouf	33.64947	35.443075	150	Tap
32	Kesrouane	33.98149	35.62299	270	Tap
33	Batroun	34.189977	35.898596	260	Spring
34	Batroun	34.188168	35.886293	280	Spring
35	Batroun	34.181549	35.897071	300	Spring
36	Jbail	34.12112	35.65657	1230	Tap

Continued

37	Jbail	34.11456	35.67648	333	Tap
38	Jbail	34.1155	35.67408	390	Tap
39	Kesrouane	34.026499	35.634892	970	Spring
40	Jbail	34.115202	35.651525	280	Spring
41	Jbail	34.115393	35.673965	1020	Tap
42	Beirut	33.897435	35.5988732	1115	Tap
43	Beirut	33.8966903	35.5685056	400	Tap
44	Jbail	34.1155614	35.6744347	390	Tap
45	Beirut	33.88863	35.55766	2200	Tap
46	Saida	33.52146	35.35228	440	Tap
47	Nabatiye	33.46988	35.4707	380	Spring
48	Beirut	33.88965	35.55732	140	Tap
49	Marjayoun	33.304	35.547	520	Spring
50	Marjayoun	33.362	35.59	450	Spring
51	Marjayoun	33.363	35.593	460	Spring
52	Jbail	34.115417	35.6741296	970	Tap
53	Kesrouane	34.0247222	35.7022222	260	Spring
54	Kesrouane	33.9953499	35.6573473	230	Spring
55	Jbail	34.0828692	35.6884774	230	River
56	Jbail	34.08794	35.65431	200	Tap
57	Jbail	34.124	35.665	2300	Tap
58	Jbail	34.124	35.665	170	Tap
59	Jbail	34.124	35.665	2050	Tap
60	Jbail	34.107005	35.768282	180	Spring
61	Jbail	34.1039092	35.7582074	350	Tap
62	Beirut	33.8919806	35.5003013	500	Tap
63	Aley	33.8086789	35.5590712	234	Tap
64	Aley	33.8088246	35.5591024	410	Tap
65	Aley	33.8088377	35.5593193	400	Tap
66	Jbail	34.1113865	35.6705346	170	Tap
67	Jbail	34.12111	35.64806	420	Tap
68	Baalbek	34.258961	36.424646	370	Well
69	Baalbek	34.259556	36.409124	258	Tap
70	Jbail	34.119049	35.667263	691	Tap
71	Jbail	34.123	35.6519	215	Tap
72	Bcharre	34.25111	36.01111	315	Tap
73	Batroun	34.25	35.65	410	Tap

Continued

74	Jbail	34.1116216	35.6703656	360	Tap
75	Jbail	34.1149151	35.6726855	300	Tap
76	Sour	33.3267983	35.3510079	320	Tap
77	Baabda	33.8535978	35.5259794	555	Tap
78	Jbail	34.1165101	35.6759528	430	Tap
79	Sour	33.3187217	35.3496571	235	River
80	Marjayoun	33.17213	35.53212	160	Well
81	Jbail	34.12091	35.68532	210	Tap
82	Baabda	33.83934	35.74087	230	Spring
83	Jbail	34.130579	35.667183	160	Tap
84	Jbail	34.130579	35.667183	160	Tap
85	Jbail	34.115367	35.673729	310	Tap
86	Kesrouane	34.0275	35.654166	180	Tap
87	Kesrouane	34.0275	35.654166	160	Tap
88	Jbail	34.11611	35.674444	310	Tap
89	Kesrouane	33.9522424	35.632911	540	Spring
90	Kesrouane	34.0086396	35.691949	280	Spring
91	Kesrouane	34.0242896	35.7012685	290	Spring
92	Zahle	33.86974	35.94634	180	Spring
93	Jezzine	33.50061	35.54452	520	Tap
94	Zahle	33.835001	35.912718	270	Tap
95	Baabda	33.844618	35.522522	5500	Tap
96	Jbail	34.117149	35.674289	830	Tap
97	Jbail	34.117149	35.674289	460	Tap
98	Saida	33.50397	35.44975	400	Well
99	Saida	33.47852	35.319189	1600	Well
100	Aley	33.811	35.525	500	Well
101	Aley	33.77963462	35.62216843	500	Well
102	Beirut	33.88773	35.52618	360	Tap
103	El Metn	33.90809	35.69618	160	Tap
104	Saida	33.471081	35.326563	1350	Spring
105	Saida	33.50397	35.44975	450	Well
106	Beirut	35.489792	33.899559	23,000	Well
107	Beirut	35.490363	33.900256	6770	Well
108	Beirut	35.482357	33.895089	24,200	Well
109	Baabda	35.483302	33.866375	8750	Well
110	Baabda	35.503593	33.855521	37,500	Well

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111	Baabda	35.497638	33.842585	22,000	Well
112	Tripoli	34.40705	35.81530	450	Well
113	Bekaa	33.87414	36.07942	300	Well
114	Bekaa	33.68354	35.79539	260	Well
115	Bekaa	33.714344	35.894823	450	Well
116	El Metn	33.908608	35.699867	440	Tap