

Deterioration of Coastal Water Aquifers: Causes and Impacts

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Abstract: Securing water for sustainable development is a major challenge facing the global community. Provision of safe adequate water to meet demands of domestic sector remains a focal objective to be attained for developing countries. Developing countries at present face fundamental environmental pressures induced by high population growth, rapid urbanization, and deficient water sector services reflecting on improper management of water resources. As such, communities seeking to cope with these challenges resort to an overexploitation of groundwater aquifer. The objective of the study is to assess the quality profile of potentially used coastal ground water aquifer and its impacts on public health for three main coastal cities in Lebanon (Beirut, Tripoli and Saida). Water samples were collected during the dry season, from drilled private wells of the indicated coastal cities that exhibit high population density. Water samples were assed for their physiochemical profile that encloses indicators of seawater intrusion (Conductivity, total dissolved solids, temperature, pH, dissolved oxygen, Ca and Mg content, alkalinity, nitrate, and sulphate). The collected data were analyzed using the software "AQUACHEM" interfaced to "PHREEQC" geochemical models, and the SigmaStat statistical Package. Preliminary results expose major progressive increase in water salinity mainly induced by seawater intrusion into the coastal aquifers. These results emphasize the importance of instating integrated water resource management to ensure sustainability and viability of this main water resource.

Key Words: Coastal aquifers, IWRM, Lebanon, seawater intrusion, water modelling.

1. INTRODUCTION

Securing water for sustainable development is a major challenge facing the global community. At present, developing countries face environmental pressures induced by high population growth, rapid urbanization, and deficient water sector services reflecting on improper management of water resources (UN 2003; WHO 2006). As such, communities seeking to cope with these challenges resort to an overexploitation of groundwater aquifers. The overuse of groundwater in coastal areas, due to high population density, results in seawater intrusion into the coastal aquifer. Sea water intrusion is often associated with over pumping in coastal regions, resulting in overdraft conditions and creating an inland gradient of seawater (El Moujabber et al. 2006). The intrusion of saltwater into coastal aquifers is a wide spread phenomena, especially in Mediterranean regions where semi arid conditions lead to excessive pumping, high extraction rate and low recharge (Petalas et al. 2009).

Lebanon is relatively blessed with adequate resources in the region. However, recent attempts to estimate water demands and availability in Lebanon have revealed significant deficit. Domestic water need in Lebanon is estimated at 850,000 m³/day of which only 450,000 m³/day is available. The daily domestic water consumption in Lebanon was estimated at 165 l/c/day in the mid-1990s. This figure is expected, due to population growth, to reach 260 l/c/day in 2015 (El-Fadel et al. 2003; Basma 2004; Korfali and Jurdi 2008). Beyond the impact of population growth, water demand has been rising in response to industrial development, increased reliance on irrigated agriculture, massive urbanization and rising living standards (Jurdi et al. 2003). The problem of water shortage is prominent in the populated coastal cities, and aggravated in the city Beirut (the capital of Lebanon). Furthermore, coastal cities in Lebanon face increased water demand. Securing water for the populated cities in Lebanon, and mainly for the city of Beirut, has lead water authorities to

adopt rationing of water supply of 10 hr every other day (El-Fadel et al. 2003). This water rationing by the Lebanese Water Authorities, as a remedial action, became a firmly established practice during the past four decades. Consumers, as such, resort to private wells for supplementary water. Exploitation of groundwater through private wells in Lebanon is still increasing up to the present time. The rush of uncontrolled drilling of private wells is more prevalent in coastal areas and especially in western part of Beirut city (Lababidi et al. 1987; Acra and Ayoub 2001; Korfali and Jurdi 2008). The excessive exploitation of ground water over the years is progressively leading to the infiltration of seawater and its deterioration. The extent of infiltration of sea water in private wells of Ras-Beirut sector of Beirut city and the resultant deterioration of the fresh water aquifer, has been previously reported (Acra and Ayoub 2001; Korfali and Jurdi 2007, 2008). Thus the objective of this study is to assess the quality profile and extent of seawater intrusion in coastal groundwater aquifers of three main coastal urban populated cities in Lebanon (Beirut, Trippoli and Saida). These three cities exhibit poor management of water resources, high demand for water and variable levels of over pumping of ground water aquifers.

2. MATERIALS AND METHODS

2.1 Study Area

The study included three coastal urban cities (Beirut, Trippoli and Saida) of variable characteristics with respect to population densities and water bearing succession. Beirut city is the capital of Lebanon. Beirut city and its suburbs (Greater Beirut) are overpopulated; it is the residence of 2.188 million citizens (1/3 of Lebanese citizens) and the population density is about 20,167 persons/km² and projected to be 33,000 persons/km² in the year 2015. Whereas, Trippoli city, 80 km north of Beirut; and Saida city, 42 km south of Beirut are smaller cities and less populated than Beirut. The total number of residence in Trippoli and Saida are 250,000 and 167,000, respectively. The population density of Trippoli is 12,000 persons/km² and that of Saida is 5,000 persons/km² (MEO 2001; ERM 1995). Beirut city is noted for its excessive uncontrolled drilling of private wells. The rush of uncontrolled drilling of private wells in Beirut city has been practiced since the years 1970. In the year 1972, Pathan (1977) noted that for Ras-Beirut sector (small coastal sector of Beirut city) the number of wells was 50 wells/km² and in a recent study (Korfali and Jurdi 2007) it has reached 375 wells/km². However, Literature does not cite the estimated number of private wells in either Trippoli city or Saida city. From our study, citizens in these cities mainly utilize municipality water for their domestic usage. But, recently due to population growth and increased water demand, citizens are resorting to private well drilling.

The geological formations of Beirut city belong to the middle Cretaceous and the Quaternary period. The Cretaceous rocks are mainly of Sannine limestone formation (C4) that constitutes the most important karstic system of Lebanon, the best water bearing tower in Lebanon and classification as excellent aquifer. Whereas, the Quaternary deposits (mainly alluvial deposits) that consists of a sequence of gravel, sand, silt and clay can give minor water quantities. Whereas, the geological formation of Trippoli and Saida are nearly similar with respect to mainly belonging to the Quaternary period and consisting of the quaternary alluvial deposits; and to some extent to the Tertiary Miocene succession (m), the marine succession that is classified as aquifer. But, for Saida city patches of middle Cretaceous period exist constituting of C4 limestone type that is classified as an excellent aquifer.

2.2 Sampling

Well water samples were collected during the dry season. The sampling sites were chosen after preliminary survey based on well availability and acceptance to sample from wells. The number of

samples taken from Beirut city was 120. Whereas, due to the relatively less number of private wells in Trippoli and Saida cities, only 30 well water samples were collected from Trippoli and 21 samples from Saida. Sampling was done in accordance with the recommendations of the Standard Methods for the Examination of Water and Wastewater (APHA 1998).

2.3 Analysis

Parameters sensitive to environmental changes were measured on site. Temperature, electrical conductivity (ECw) and total dissolved solids were measured using the HACH Model 44600 Conductivity/TDS Meter. The pH was measured using the HACH pocket pH Model. Whereas, the following laboratory analysis were performed for the remaining parameters: titration procedure was used for alkalinity (0.02N H₂SO₄), Cl⁻ (0.014N mercuric nitrate), Ca, Mg and total hardness (0.01M EDTA); spectrophotometric SO₄²⁻ (turbidimetry) using the HACH Model ('HACH' Odyssey, DR, 2500); and flame photometer technique ('Thermo' FISHER, PFP7) for the analysis of Na and K.

2.4 Software Used IN Analysis

The statistical analysis of the measured physio-chemical parameters was performed using SigmaStat software. AquaChem interfaced to PHREEQC software was used to calculate the CH (Carbonate hardness) and NCH (Non carbonate hardness) in water samples, the ratio of water parameters related to seawater, and water type prediction.

3. RESULTS AND DISCUSSION

3.1 Water Quality

The mean values for the various measured well water parameters relating to water quality and seawater intrusion of the three studied coastal well cities are presented in Table 1. Well water samples were collected in the dry season. In the dry season, the recharge of ground water is nil. This leads to limited dilution of water parameters at the time when water use is at its highest.

Table 1. Mean values measured parameters of studied well water

	Beirut			Trippoli			Saida		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Temperature(°C)	22	26	24	21	23	22	21	23	22
pH	7.1	8.6	7.7	6.3	8.8	7.5	6.7	8.8	7.8
Cond (µS/cm)	900	5931	2415	495	3770	1505	459	4220	1671
Alkal(mg/CaCO ₃ /l)	170	425	292	170	390	303	190	490	298
TH (mg/CaCO ₃ /l)	430	1015	625	210	860	484	240	860	444
CH (mg/CaCO ₃ /l)	160	460	305	115	400	310	185	480	287
NCH (mg/CaCO ₃ /l)	270	555	320	10	490	194	20	490	145
Ca (mg/l)	48	180	110	16	176	100	40	172	105
Mg (mg/l)	10	127	76	12	117	51	4.8	117	48
Na (mg/l)	20	1015	495	53	497	264	29	550	279
Cl (mg/l)	200	2826	1059	200	960	574	150	1150	682
SO ₄ (mg/l)	15	155	78	15	140	55	11	160	50

The three studied coastal areas revealed high mean values for the mineral content of well water; and the highest for Beirut wells. The conductivity, as well as the concentrations of Cl, Na, Ca were above drinking water standards recommended by USEPA (2003) or WHO (2006). The mean value of conductivity levels in Beirut wells was 2415 µS/cm (≈ 2 times higher than the recommended upper limit set by USEPA, 1250 µS/cm). Whereas, the conductivity values of Trippoli and Saida

were respectively 1505 $\mu\text{S}/\text{cm}$ and 1671 $\mu\text{S}/\text{cm}$ (≈ 1.2 times higher than USEPA recommended values). The chloride mean concentration (1059 mg/l) of Beirut wells was four folds those recommended upper level of USEPA (250 mg/l). Whereas, the mean Cl concentration of coastal wells of Trippoli was 574 mg/l and Saida was 682 mg/l (≈ 2.2 to 2.7 higher than set recommended values). This high chloride content for the three coastal cities does not imply a health hazard, but affects the taste of water (WHO 2006). The concentration of Ca in the three studied areas was slightly higher or approaching the recommended value (100 mg/l); the mean Ca concentration for Beirut, Trippoli and Saida were respectively 110 mg/l, 100 mg/l and 105 mg/l. On the other hand, the set recommended value for Mg by USEPA is 30 mg/l. The mean Mg concentration of Beirut wells was 76 mg/l (≈ 2.5 times higher than recommended value); whereas, those of Trippoli and Saida were respectively 51 mg/l and 48 mg/l (≈ 1.6 times higher than recommended values). Though WHO (2006) does not indicate the health hazards resulting from a considerable excess in the ion concentration of Cl, Mg, and Ca, still these ions affect the household infrastructure and impact of corrosion of domestic pipes (WHO 2006). The mean values of pH (7.5-7.8) in the three studied areas are typical of water arising from carbonate bedrock (Stumm and Morgan 1996). However the order of abundance (concentration in mmol/l) of major ions in the studied water wells (cations: $\text{Na} > \text{Ca} > \text{Mg}$; anions $\text{Cl} > \text{HCO}_3 > \text{SO}_4$) do not reflect the major ions arising from carbonate bedrock (cations: $\text{Ca} > \text{Mg} > \text{Na}$; anions $\text{HCO}_3 > \text{Cl} > \text{SO}_4$). This observation was also illustrated in the predicted water type of the wells by the AquaChem software. The AquaChem software predicted for Beirut wells, water type to be 60 % as Na-Cl, 25 % as Na-Ca-Cl- HCO_3 , and 15% as Na-Ca-Mg-Cl- HCO_3 . Ninety percent of samples had Na as highest concentration major cation and 95 % had Cl as highest concentration major anion. Trippoli and Siada showed similar water type about 65 % as Na-Ca-Cl- HCO_3 , 25 % as Na-Ca-Mg-Cl- HCO_3 , and 5% as NaCl. The overall water type of each studied coastal areas and major ion distribution are presented in stiff diagram (Figure 1). The water type of Beirut wells using mean measured values represented a water type similar to NaCl, while those of Trippoli and Saida represented a water type of Na-Ca-Cl- HCO_3 . The predicted well water types of the three coastal areas differ from those arising from the weathering and dissolution of karstic bed rock aquifer (calcite and /or dolomite) that evolve Ca- HCO_3 and Ca-Mg- HCO_3 water type. The revealed occurrence of Na and Cl in the water type (Figure 1) suggests that this factor is primarily due to seawater intrusion, a contaminant factor that prevails the natural environmental setting of the wells.

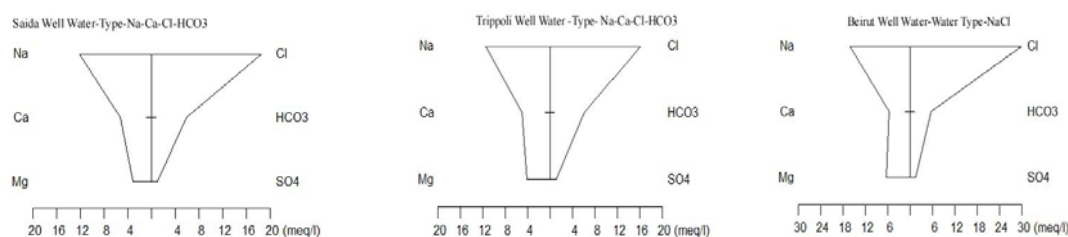


Figure1 Comparison of water type and major ions of the three studied areas.

2.2 Sea Water Intrusion-Indicators

Seawater in general has a uniform chemistry with the prevalence of Cl^- and Na^+ possessing a molar ratio of 0.86 (mass ratio= 0.55). Sea water solutes are specifically characterized by excess Cl^- over alkali ions (Na^+ and K^+) and Mg^{2+} greatly in excess of Ca^{2+} . In contrast continental fresh ground waters are characterized by variable chemical composition, the predominant anions are HCO_3^- , SO_4^{2-} and Cl^- , and the primary main cations are Ca^{2+} and Mg^{2+} and to lesser extent the Na^+ and K^+ . In most cases Ca^{2+} predominates over Mg^{2+} . Whereas, the chemical composition of groundwater in many coastal aquifers subjected to seawater intrusion deviates from simple conservative seawater-fresh water mixing (El Moujabber et al. 2006). Several criteria are suggested

to be used as indicators for seawater intrusion into coastal aquifers. Revelle (1941) pointed out that the increase in total dissolved salts (electrical conductivity) is not sufficient proof of occurrence of seawater intrusion. Seawater intrusion involves mixing between saline and fresh water. Owing to its considerable salt content, a small fraction of sea water would dominate the chemical composition of groundwater mixture. The most obvious indication of seawater intrusion is an increase in Cl^- concentrations. Another important indicator related to the predominance of Cl^- in seawater is the ratio of chloride to carbonate and bicarbonate ions which is known as Simpson ratio (El Moujabber et al. 2006), bicarbonate and carbonate ions are present only in very small amount in sea water. Others (Acra and Ayob 2001) have used beside Chloride increase, the increase in values of conductivity, total hardness (TH), magnesium hardness (MgH) and non carbonate hardness (NCH) as indicators for seawater intrusion, since they are higher in seawater when compared to those of groundwater. Moreover seawater intrusion is characterized by the ratio of Na/Cl. The Na/Cl ratios of coastal aquifers subjected to seawater intrusion are usually lower than the marine values, since when salt water enters into fresh aquifers, an exchange of cations occurs and Na^+ is taken by the exchanger (Petalas et al. 2009). Finally, the ratio of Na/Ca and Mg/Ca may be used as indicator owing to the fact that Na and Mg are higher in seawater than fresh ground water.

The seawater intrusion of the studied areas are assessed using the above indicated seawater intrusion indicators. Table 2 provides a comparison of the mean values of well water parameters from this study, the seawater samples and average wells in Lebanon adapted from Acra et al. 1883. Table 3 presents the ratios of the parameter that indicate seawater intrusion. Note that calcium hardness is CaH, magnesium hardness is MgH, carbonate hardness is CH, and noncarbonate hardness is NCH, all of these have the unit as mgCaCO_3/l .

Table 2. Comparison of major well water parameters to seawater and ground water

	Cond. $\mu\text{S}/\text{cm}$	CaH* mg/l	MgH* mg/l	CH* mg/l	NCH* mg/l	Cl mg/l	Na mg/l
Beirut well water (n= 120)	2,415	306	306	305	320	1,059	495
Trippoli well water (n=30)	1,505	279	205	310	194	574	264
Saida well water (n=21)	1,617	270	190	287	145	682	279
Wells-Lebanon (n=225)	1,028	280	71	271	80	162	24
Sea water-Lebanon (n=15)	55,850	1,245	5,595	127	6.711	2,2815	12,320

Table 3. Mean values for ratios used as seawater intrusion indicators

	Cl/Cond.	NCH/CH	Cl/carbonate	Na/Cl	Na/Ca	Mg/Ca
Beirut well water (n= 120)	0.32	1.09	2.64	0.48	3.7	0.63
Trippoli well water (n=30)	0.32	0.82	1.88	0.44	2.9	0.46
Saida well water (n=21)	0.35	0.5	1.6	0.41	2.6	0.32
Wells-Lebanon (n=225)	0.16	0.3	0.6	0.13	0.21	0.15
Sea water-Lebanon (n=15)	0.41	53	147	0.55	24.73	2.69

The intrusion of seawater into wells of the studied coastal cities is obvious in Table 2. The conductivity, magnesium hardness, noncarbonate hardness, chloride and sodium are higher than the average values of Lebanon's wells. These parameters are higher in seawater than groundwater, and the highest values are for Beirut wells. This can be attributed to the fact that there is more number of drilled coastal wells/ km^2 in Beirut city and the well extraction rate is higher. In addition, the coastal aquifer of Beirut belong to Cenomanian, Sannine formation (C4) karstified hard limestone susceptible to seawater intrusion (El Moujabber et al. 2006). While the number of wells in Trippoli city and Saida city are less and the coastal aquifer is mainly Quaternary alluvial deposits that enhance horizontal seawater intrusion. What are more explicit for the seawater intrusion of the studied wells are seawater ratios (Table 3). Contamination by seawater may be classified by Simpson classification ratio of $\text{Cl}^-/(\text{HCO}_3^- + \text{CO}_3^{2-})$. This classification included five classes: 0.5 for good water quality, 1.3 for slightly contaminated water, 2.8 moderately contaminated, 6.6 injuriously contaminated, and 15.5 highly contaminated water (Todd 1959). Consequently, Trippoli

and Saida wells ratio of $\text{Cl}^-/\text{HCO}_3^- + \text{CO}_3^{2-}$ are respectively 1.88 and 1.6 are slightly contaminated. Very few wells revealed values of 2.8 (moderately contaminated). Whereas, Beirut wells according to classification (ratio of $\text{Cl}^-/\text{HCO}_3^- + \text{CO}_3^{2-}$ is 2.64) are moderately contaminated. Nevertheless, some wells had a ratio of 8.8 and are above injuriously contaminated wells. In regard to the ratio of Na/Cl , the ratio of studied wells is much higher than average Lebanon's groundwater and is approaching seawater (Table 3). The highest ratio is for Beirut wells (0.48). The lower ratio for the other two coastal cities (Trippoli and Saida) could also be attributed to these coastal aquifer formation, the alluvial deposits consisting of clay (exchanger) and Na^+ is taken by clay particles (Petalas, 2009). Though Mg/Ca is much below the seawater ratio, yet being higher than Lebanon's groundwater (Table 3) indicates the seawater intrusion into well waters. The deduction of seawater intrusion through ratio of Na/Cl is more explicit than Mg/Ca ratio due to Mg reactivity and solubility. Magnesium forms insoluble carbonates that allow it to exist at a lower apparent concentration than sodium compounds that occur in soluble form (Drever 1997). The seawater intrusion is further proven through the AquaChem software model and Stiff diagram (Figure 1) that predicted occurrence of Na and Cl as prime major ion water type. The intrusion of sea water into Beirut aquifer is so aggravated that the predicated water type of Beirut coastal wells to be of $\text{Na}-\text{Cl}$ type.

4. MANAGEMENT PLAN

Based on the results of the study, the deteriorative condition of the coastal aquifers is evident and is highly aggravated in the coastal aquifer of Beirut city. The results emphasize the importance of instating integrated water resource management plan to ensure sustainability and viability of coastal aquifers (Lebanon's main water resources). The absence of a management plan is obvious in studied area due to the over pumping resulting in seawater intrusion. Management plans should secure adequate sufficient water to meet domestic needs and halt the progressive deterioration of coastal aquifers. As such, the proposed management strategy addresses three issues: legislative, water quantity, and water conservation.

4.1 Regulation and Legislation

The Lebanese government since 1967 legislated a law (86/87, December) that prohibits ground water exploitation, for private usage, in Greater Beirut. The law was never implemented. Proper tools and instrumentations for the execution of the legislation by the respective authorities should be tackled, and be of high priority in the management and protection plans of water resources. The legislations and regulations governing the use of private wells should address the whole coastal zones of Lebanon. Recently Lebanese authorities enacted many legislations relating to environmental protection, but no mention to the protection and preservation of ground water aquifers (MEO 2001). In addition, the licensing of private well drilling, as a whole in Lebanon, should be approved based on adequacy and quality of water, number of wells in the area and abstraction rate. Additionally, water authorities should set strict enforcement rules on the permissible abstraction rate and adopt water metering systems and pricing for private well water utilization (Korfali and Jurdi 2008).

4.2 Water Quantity

Instating an integrated water resources management (IWRM) plan would result in an increase in water quantity and availability, and decrease the exploitation of coastal aquifer and quality deterioration. Integrated water resource management is a systematic process for the sustainable development, allocation and monitoring of water resources use in the context of social, economic

and environmental objectives. It involves integrating the work of a number of water sub-sectors, such as hydropower, water supply and sanitization, irrigation and drainage. One of the management's instruments of IWRM is the measure designed to manage water supply and demand (supply/demand water assessment). In Lebanon, there is yet, no set national IWRM plan. The only document that could be considered as an IWRM is "Work Plan of the Ministry of Energy and Water years 2000-2009". This work plan presents plans, strategies, and policies relevant to potable water, irrigation and waste water (UNDP 2004). The document satisfies several aspects according to the guidelines for IWRM development. However, the document focuses on domestic water supply instead of integrated water resource management. Still, this plan is not yet implemented and is mostly on going activities (part of which was accomplished is the rehabilitation of networks of water and wastewater). Therefore, the problem of supply and demand should be addressed more effectively by authorities through rapid interventions; such as, adopting a more rapid process for implementing the need for 16-20 dams through out the country (Amery 2002), and instating the rain harvesting water plan. In addition, adoption of artificial recharging of ground water should proceed. Recharge of ground water was practiced by the Ministry of Water and Electric Resources from the year 1968 to 1975. Recharging proved to be quite effective especially in controlling seawater intrusion in aquifer of coastal /Beirut area then. The operations were discontinued because of civil war. A new feasibility study for artificial recharge of coastal aquifers should be adopted. Moreover, a plan to protect water resources in Lebanon is of utmost need to increase water availability and reduce the projected deficient in water supply. Additionally, water resources in Lebanon are subjected to contamination resulting from haphazard management of municipal solid wastes and wastewater (Korfali and Jurdi 2008). Therefore, policies and plans for integrated management of solid wastes should be an integral part of national water management plans and should be among the identified priorities.

4.3 Water Conservation

Water conservation must address the community and can be achieved by household water use, household metering systems, and by revisiting water pricing.

The conservation of water at the household level can be achieved by the establishment of appropriate mechanism to change people's attitudes and reorient their behaviour with respect to water use. Such activities should focus on: a) public awareness to reduce on water demand at household through media, lectures at schools and universities, b) involving the citizen in IWRM plan, c) water conservation to be part of school activities, and d) the use of water saving appliance.

Water conservation could also be attained by the use of water metering system. Municipality water in Lebanon is not metered. Most cities do not have water meters and a country wide levy is applied. The levy is a flat rate tariff that is independent of the level of water use and provides no incentive for conservation. Therefore, the adoption of a water metering system as a substitute for the existing system would decrease the wastage of water within household, since the consumer pays according to his consumption. Furthermore, the pricing policy in Lebanon does not take into account water amount usage, nor it covers operation and maintenance costs. Thus, water pricing should be adjusted to be based on usage. Implantation of a new water pricing policy should be looked upon as an incentive for improving water use efficiency.

5. CONCLUSION

The results of the study reflect the deteriorative water quality profile of the coastal aquifers of Saida and Tripplou cities and on the aggravated and high deteriorative profile of Beirut city aquifer resulting from seawater intrusion. Consequently, these results emphasize the necessity for the development of an integrated water resources management plan to ensure sustainability and viability of coastal groundwater. Furthermore, the study emphasizes the importance of water

resource assessment to sustain the provision of safe adequate water to meet the demand of the domestic sector.

ACKNOWLEDGEMENT

This study was supported by the University Research Council, Lebanese American University under contract #s (URC-c2006-02 and URC-F2006-21) and the Lebanese National Council for scientific Research (CNRS).

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