MONITORING OF GROUNDWATER SALINATION BY SEAWATER INTRUSION ON THE LEBANESE COAST

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ABSTRACT

In order to monitor the effects of the seawater intrusion on the groundwater quality, the coastal region from Choueifat to Rmeyle located south Mount - Lebanon had been chosen to be studied. Six wells have been selected. Water samples have been collected for a period of three years from 1999 to 2002, at the rate of one sample a month. A complete physico-chemical analysis has been done in order to measure the increase in salinity as well as the variation in piezometric level. The results obtained from the study showed that the regions of Choueifat, Jiye and Rmeyle are subject to seawater intrusion. This intrusion is directly and simultaneously related to the pumping period and intensity but poorly related to the amount of rainfall. It also depends on the geologic nature of the study area. Furthermore, the actual intrusion in the study zone aggravates the existing salinity problems. Indeed the salinity rates of well water ranged between 0.7 dS/m and 5.5 dS/m (the majority being above 2 dS/m) resulting in salinity rates not tolerable for crops, thus threatening their growth and production.

Keywords: seawater intrusion, groundwater, salination, Lebanese coast

INTRODUCTION

Water is a vital factor for the development of any community. Therefore, its shortage would threaten the security of many countries, especially those countries along the Mediterranean basin sharing similar limited water resources. The uneven and infrequent distribution of precipitation in time and space along with the confined surface and ground water resources typically characterize the Middle Eastern countries. On one hand, the rapid population growth and its affiliated development causes mounting pressures on the limited water resources. On the other hand, the dwindling availability of water to match the development needs has become a significant regional issue, especially when a number of countries are already facing serious water shortages. Estimation figures assort 9 out of 14

Middle Eastern countries as having a freshwater potential below 1,000 $m^3.person^{-1}.year^{-1}$ (Hamdy and Lacirignola, 1999).

In Lebanon, more than 70% of the average yearly precipitation of 8,600 MCM is lost through different processes leaving 2,600 MCM of potentially available surface and groundwater resources with only 2,000 MCM exploitable currently (El Fadel, 2002). In fact, any reduction in the plant cover due to a high rate of urbanization (Masri *et al.,* 2002), in particular along the coastal regions, would severely affect the water balance. As a result of population growth, industrial development, the expansion of irrigated agricultural land and mainly because of the ever-increasing chaotic exploitation of groundwater resources, water resources are reaching unsustainable levels.

Of all economic sectors requiring water, agriculture is the major consumer as the water withdrawal intended for irrigation was estimated at 68% of the total amount withdrawn. Of these, surface water sources represent 54.3% and the groundwater such as artesian wells, recharge wells and springs 45.7% (FAO, 1996). Due to the government reluctance in the implementation of large-scale irrigation schemes, the amount of groundwater intended for irrigation has increased over the past few years. Individual farmers witnessing water shortages are increasingly relying on water supply from groundwater resources by means of private wells. Around 2000 wells were added, during 1992-1995, to a total already exceeding 10,000 wells especially in the Bekaa central plain as well as in the Southern and Northern hills (FAO, 1996).

In coastal regions, the uncontrolled exploitation of groundwater resources intended for domestic, industrial and agricultural purposes, shifts the dynamic equilibrium between seawater and the flowing groundwater, favoring saltwater intrusion. Under such conditions, saltwater penetration may cause serious repercussions on both the prevailing environmental and economic conditions.

The coastal area of Choueifat-Rmeyle region is one of many districts in Lebanon threatened by the penetration of seawater into the aquifers (El Moujabber and Bou Samra, 2002). Due to the absence of collective irrigation networks in this pilot area, irrigation is mainly secured by private wells. This study area is a typical horticultural region, mainly involved in greenhouse production of strawberries, cucumbers and tomatoes**.**

Despite the importance of the ever-increasing salination issue in that region, not enough data is made available for assessing the groundwater quality. The degradation in water quality will have detrimental effects on agricultural production (FAO, 1985). Therefore, it is very important to quantify salinity increments and its impact on crop production. Moreover, the agricultural practices could also, in their turn, contribute to the deterioration of the water quality. In these intensive production systems, excessive fertilizer utilization and high evaporation could lead to significant build-up of salts in the soil (Atallah *et al.,* 2000; Atallah *et al.,* 1997).

Since the Choueifat-Rmeyle region presents all the above-cited particularities, it was selected as a pilot area in this work. In this region, all the outcropping formations belong to the Upper and Middle Cretaceous except in the Choueifat region and in some specific zones in the Jiye and the Rmeyle regions where the formations are overlaid by the superficial coastal deposits, belonging to the Quaternary. These formations show a moderate inclination toward the sea. According to a study by El Moujabber and Bou Samra (2002), several of the 14 wells studied in the region showed similarities in salinity changes. The difficulty in measuring the piezometric level in some wells and the similarity of salinity levels restricted the focus of this study to 6 wells only. The objective of this study was to monitor about the dynamics of seawater intrusion. Hence, the effects of rainfall on the salinity evolution and piezometric levels (Z) of groundwater were studied. The piezometric level was included as its continuous increase is an indicator of the transition towards a status of saltwater intrusion (FAO, 1997). Finally, the impact of water salinity on the soil physical properties using the sodium absorption ratio (SAR) was also assessed.

MATERIALS AND METHODS

The study is carried out in the Choueifat-Rmeyle region, south of Beirut. This region of the southern coastal hills is a typical horticultural area with large-scale greenhouses production of strawberry, tomato, and cucumber. The pilot study area pulls water exclusively from groundwater wells due to the absence of any collective irrigation network.

In total, 6 wells were chosen in Choueifat, Jiye and Rmeyle (Figure 1). The geographical position of each well was determined with a GPS (Global Positioning System) (Table 1). Water was sampled on a monthly basis for ten months (July till April) for 3 years starting from 1999 till 2002. This period of the year was expected to reveal the maximum and the minimum values of water salinity.

Rainfall data was obtained from the weather station of the Meteorological Department of the Directory General of Civil Aviation in the Lebanese ministry of Public Works and Transport. Periodic sampling of water pumped from the wells was carried out once a month. The samples were taken after 30 minutes of pumping and conserved directly in a portable refrigerator. All samples were stored in a freezer at -10°C until analysis. A measure of the piezometric level was obtained by using an electric wire giving a signal upon touching the water.

TABLE 1

Geographical Positions of the Wells

Location	Wells	Elevation (m)	Distance from the sea (km)	Latitude (North)	Longitude (East)
Choueifat	C_1	23	4	33°49’06’’N	35°30’59’’ E
	C_2	31	5.5	33°48’17’’ N	35°29’43’’ E
	C_3	49	6	33°48’03’’ N	35°29’42’’ E
Jiye	J_1	55	2	33°41’07’’ N	35°25’33’’ E
	J_2	50	2	33°39’53’’ N	35°25’19’’ E
Rmeileh	R	39	3	33°36’22’’ N	35°23’28’’ E

Analysis included the measurement of the electrical conductivity (EC) as well as the determination of calcium, magnesium and sodium concentrations for the sodium absorption ratio (SAR). These cations were determined according to Ryan *et al.* (1996).

Three classes of salinity of irrigation water are recognized: <0.75 dS/m; 0.75-3 dS/m and >3 dS/m (FAO, 1985), with the risk growing from low to moderate to increasing. In parallel to the salinity of irrigation water, another parameter related to the risk on soil physical properties is the sodium absorption ratio. The SAR thresholds vary according to the EC. For EC>2 dS/m, the recommended threshold of SAR is equal to 20, for EC>1 dS/m, SAR<10 (cited by Bar-Yosef, 1999). Correlation coefficients were calculated between two parameters (EC vs Rainfall; EC vs Piezometric; Rainfall vs Piezometric) for each site. For the number of observations (n=20), the calculated coefficients are significant for r>0.423 at $p<0.05$ (Bailey, 1981).

As for water depleted from wells, it was determined according to the determination of crop water requirements using climatic data (El Moujabber and Abi Zeid Daou, 1999) and taking into account efficiency on farm level which according to several studies in the region showed values around 50%.

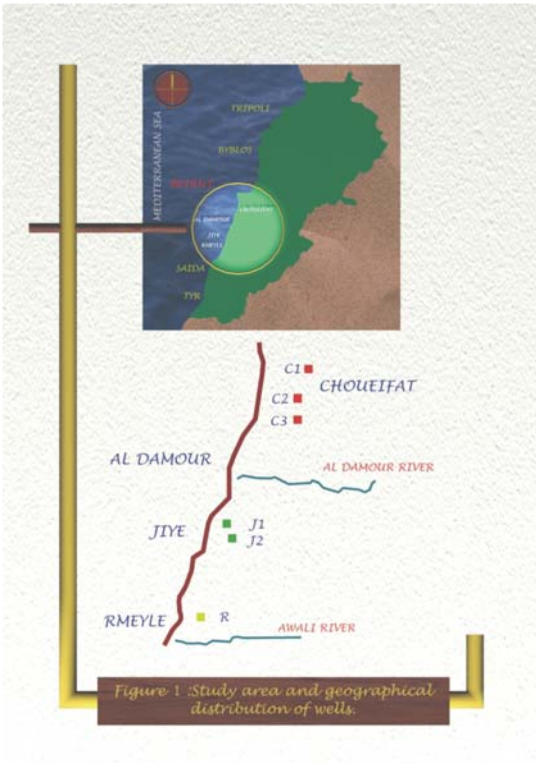

Figure 1. Study area and geographical distribution of wells.

RESULTS AND DISCUSSION

Water electrical conductivity and pumping duration

In the first year of study, where 14 wells were taken, several attempts were made to verify the variability of water salinity over one pumping period. Therefore, water samples were collected at 0, 15, 30, 45 and 60 minute intervals of pumping in all wells. The EC values were monitored in order to verify the short-term indicative capacity trends of the nourishing reservoir. For instance, the wells J2 and C3 showed that the evolution of salinity in each pumping period was almost linear despite the slight increase in C3 (Figures 2 a & b). This result is coherent with Bonnet *et al.* (1967) who demonstrated that only prolongated period of pumping might affect water level and water salinity. This indicator depends on the hydrology and lithology of the watershed area, well location and depth. Based on these results, all water sampling was done 30 minutes after the pumping started. These values could be considered as representative of the aquifer status.

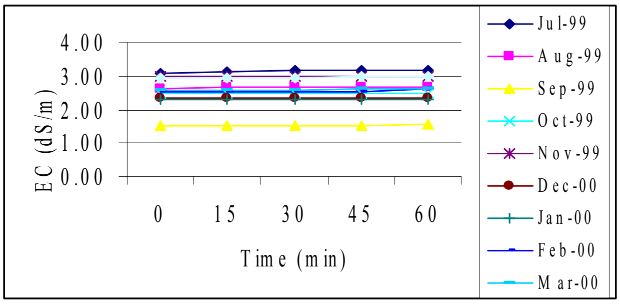

Figure 2a. EC variation in one hour period of pumping for J2 for ten months between July and March.

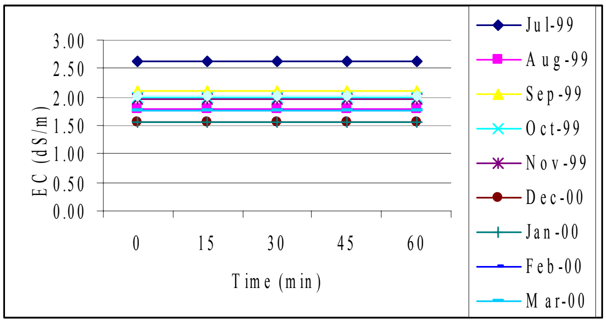

Figure 2b. EC variation in one hour period of pumping for C3 for ten months between July and March.

Dynamics of seawater intrusion

In the Choueifat - Rmeyle region, the dynamic of seawater intrusion was studied by means of time variations of EC, piezometric levels and rainfall. These three variables were combined together for each well.

For the C_1 well (Choueifat region) most of the EC values varied between 1.2 dS/m and 2.5 dS/m (Figure 3), indicating a moderate problem of salinity in term of water quality. During the first period of observation, an increase in the EC values was observed till November 1999 (2.27 dS/m) followed by an almost steady state till January 2000 (2.04 dS/m), independently of the rainfall intensification and the reduced pumping rates. After this date, EC started to decrease till reaching a minimum value of 0.9 dS/m in April 2000. In the second period, a peak value (3.18 dS/m) was observed in December 2000, indicating the transition toward a more severe salinity problem. Then, EC returned to a moderate level of salinity till the end of the second period. During the third year, EC increased to a maximum value in December 2001 (4.13 dS/m). After this period and like the previous years, EC values started to decrease.

Furthermore the piezometric levels showed, during each period, a declining trend but of greater intensity in the second and the third period. This could be partly attributed to the rainfall effect, as a mild negative correlation (-0.38^{ns}) was found between the rainfall and the piezometric levels (Table 2). However, the major factor responsible for this decrease is undoubtedly a significant reduction in water pumping. In fact every year, in December/January, the grower mixed (first year) or substituted (second and third years) the water of this well with another of better quality (less saline). With the ease in pumping, EC values decreased each year after the month of January. Rainfall had little impact on the EC values, as the correlation analysis between them did not give a significant positive correlation ($r=0.37^{ns}$) (Table 2). Between the EC and the piezometric levels, no significant correlation ($r=0.11^{ns}$) was found neither. This could characterize the relatively lower transmissibility of the Quaternary deposits of Chouaifat area in comparison with older hard rocks forming part of the Lebanese mountains.

In the well C_2 based on the EC values, the water quality could create a moderate problem of salinity (Figure 4). Starting by the first year of observation, the maximum value of EC was scored in July 1999 (2.62 dS/m), followed by a gradual decrease to a minimum value of 2.07 dS/m. During the second year, EC showed a similar pattern. Values decreased till January followed by a reverse trend till the end of the period. In 2001, EC readings increased from July 2001 till November 2001 with values oscillating between 0.75 dS/m and 1.92 dS/m. Between November 2001 and February 2002 (EC=1.61 dS/m) the salinity values decreased. This trend during the winter months could not be linked to the rainfall expansion (Table 2) but once more the grower practice. Here in this location during winter, the owner of the well mostly depends on open field cultivation rather than on greenhouse cultivation, hence the reduction in pumping and the fluctuations in EC values.

The piezometric levels did not show any important variation except for the third year when a decreasing trend of 2.5 m was observed. No affinity between the piezometric level and the rainfall nor the EC values was found (Table 2). Therefore, the variations in the piezometric levels could be related to some pumping activity.

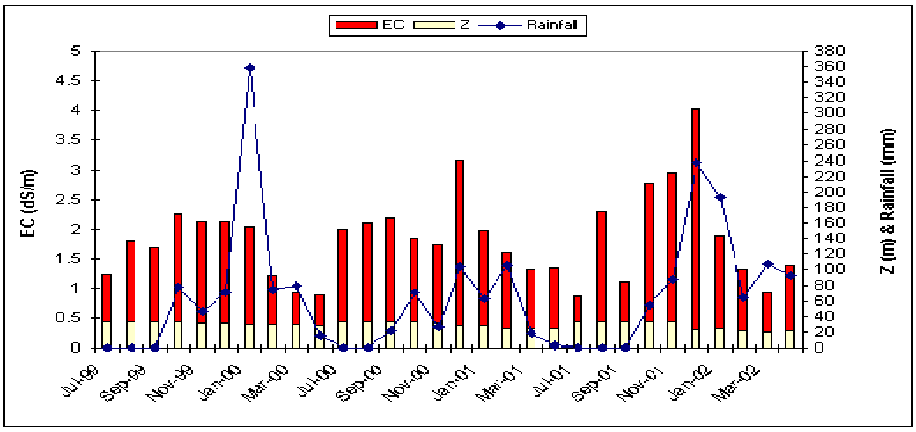

Figure 3. Time variations in rainfall, EC and piezometric levels at the well C_1 in Choueifat region.

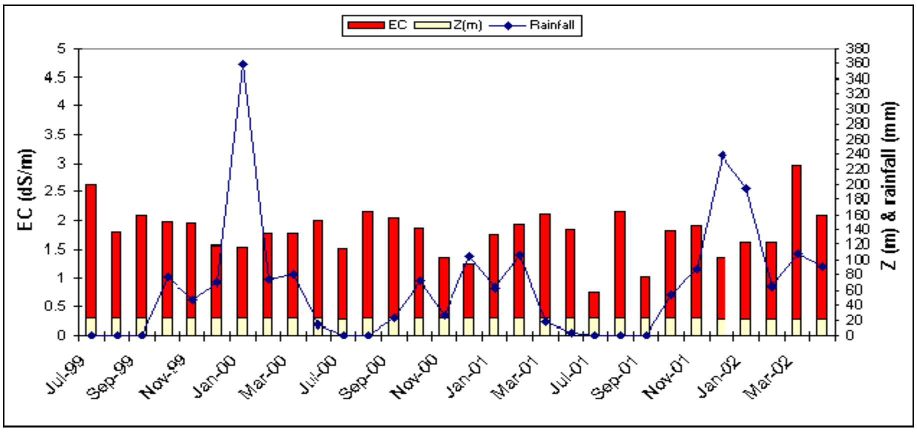

Figure 4. Time variations in rainfall, EC and piezometric levels at the well C_2 in Choueifat region.

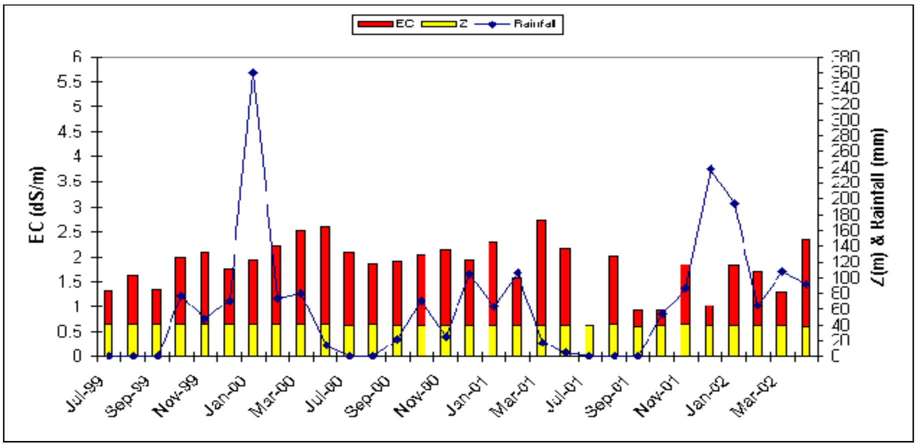

Figure 5. Time variations in rainfall, EC and piezometric levels at the well C_3 in Choueifat region.

Similarly to C2, the EC values of the well C_3 (Figure 5) reflected a moderate salinity problem during the entire observation period. During the first year, a regular increase in the EC values - 1.33 dS/m and 2.60 dS/m- was observed. During the second year, EC presented a mild increase during the period extended from July 2000 till January 2001 and the values oscillate between 1.86 dS/m and 2.29 dS/m. After this, a sudden drop in EC values occurred (1.57 dS/m) corresponding to a maximum rainfall value (106.3 mm). Then in March 2001, EC restarted to increase and scored a value of 2.74 dS/m. In the third year the EC minimum values were observed in July 2001 (0.61 dS/m), October 2001 (0.91 dS/m) and November 2001 (0.92 dS/m). From December 2001 till March 2002, EC values increased and ranged between 1.3 dS/m and 1.88 dS/m with a maximum value of 2.35 dS/m in April 2002. No meaningful correlation was detected between the rainfall and the EC evolution. To the contrary, during rainy months increments in the EC values were observed. This fact could be attributed to an overexploitation of the well during the winter season, as protected strawberries, tomatoes, cucumbers and cut flowers call for continuous and frequent irrigation from October till June.

The piezometric levels did not show any important variations with values ranging between 40.3 m and 40.65m. These levels were maintained in the second season, as the values oscillated between 39.8 m and 40.17 m. During the third year, the piezometric levels measured were much more important than the two previous ones oscillating between 38.4 m and 40.31 m. Low correlation coefficients existed between the piezometric level and the rainfall and EC (Table 2), however the piezometric levels tend to change in the same direction with EC (0.26) and in opposite direction with the rainfall (-0.20).

TABLE 2
Correlation Coefficients Between EC, Piezometric Levels (Z) and Rainfall (n=20)

	C_1	C_2	C_3	J_1	J_2	*R*
EC / Rainfall	0.37	-0.13	-0.03	-0.11	-0.05	-0.15
EC / Z	0.11	-0.17	0.26	0.44*	-0.07	0.15
Z / Rainfall	-0.39	-0.22	-0.20	0.09	-0.22	-0.39

* : significant (p<0.05).

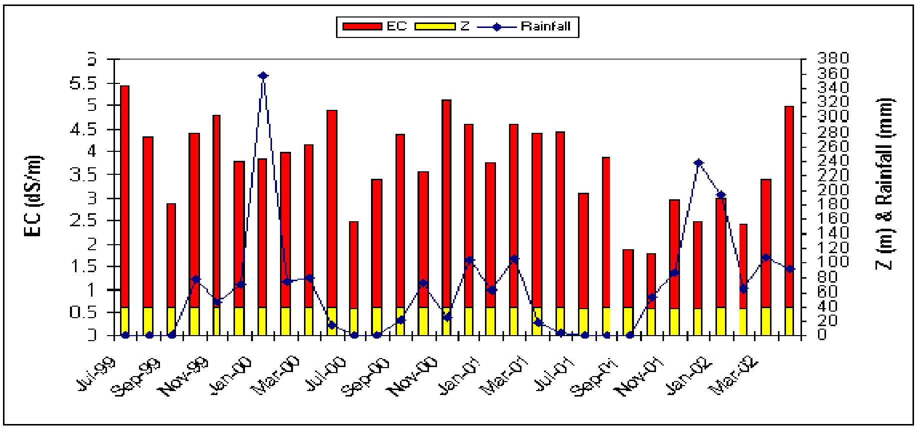

Figure 6. Time variations in rainfall, EC and piezometric levels at the well J_1 in Jiye region.

In the well J_1 of the Jiye region (Figure 6), the situation completely differed from Choueifat as a severe problem of salinity dominated the first two years and to a lesser extent in the third year. Starting by the first year, the maximum and the minimum values of EC were respectively scored in July 1999 (5.44 dS/m) and in September 1999 (2.88 dS/m). The other values ranged between 3.77 dS/m and 4.89 dS/m indicating always a severe problem of salinity. During the second year, one moderate EC value (<3 dS/m) was observed in July 2000 (2.47 dS/m). After this, all EC values belonged to the risk class (> 3 dS/m) with a maximum value of 5.11 dS/m reached in November 2000. In the third year, EC values were smaller than the two previous years with a decreasing trend between July 2001 and November 2001 with a transition from a severe salinity problem towards a moderate one. After this date, a steady state was observed till March 2002 where EC started to increase and a severe problem of salinity reappeared once more.

In the first year, the values of the piezometric level ranged between 39.02 m and 40.15 m. The correlation analysis indicated that the piezometric levels tend to change in the same direction as the EC (0.44*) and in opposite direction with the rainfall (-0.2) (Table 3). Whereas the latter did not show any sign of affinity to EC evolution (r= –0.11). EC values still increased during the rainy periods as clearly shown in the first and second years. The reduction in the EC values during the third year was related to the decreased use of the well water. Due to the presence of a severe salinity problem, the grower mixed the water from the well with a freshwater source that he carries from the neighborhood. This lead to the reduction in the rates of pumping, and consequently the EC and piezometric levels drop.

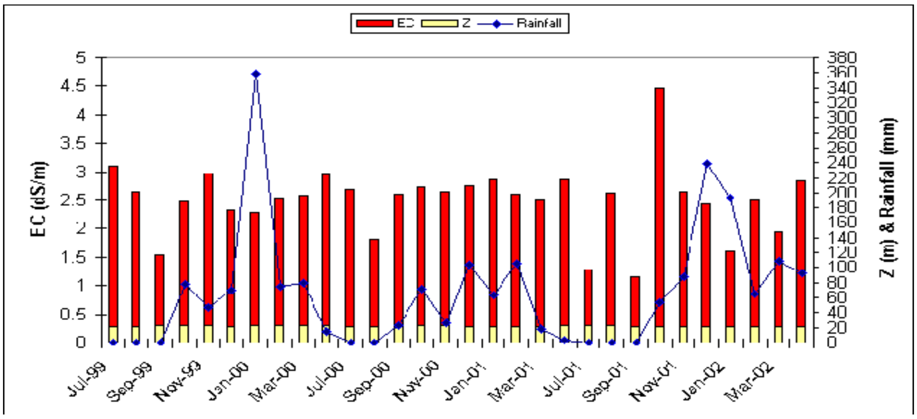

Figure 7. Time variations in rainfall, EC and piezometric levels at the well J_2 in Jiye region.

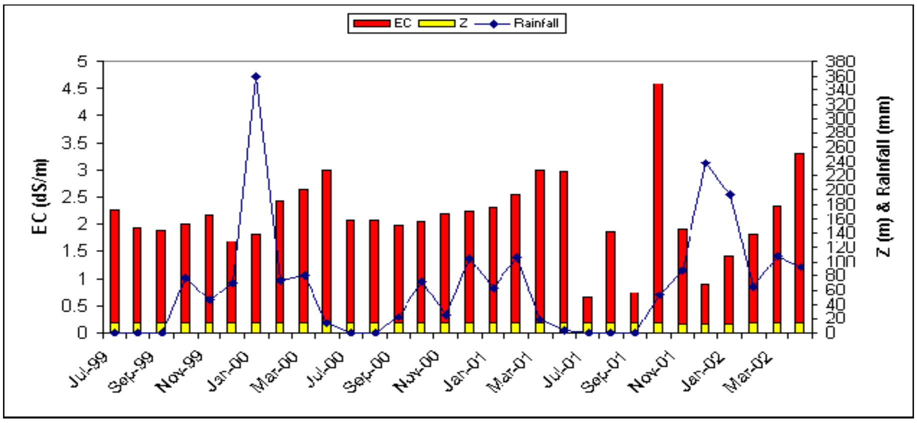

Figure 8. Time variations in rainfall, EC and piezometric levels at the well R in Rmeyle region.

The second Jiye well (J_2), presented lower EC values than J_1 (Figure 7). The quality of water indicated a moderate salinity problem over the observation period, where most of the values are higher than 2.3 dS/m. During the first year, the maximal and the minimal values were respectively scored in July 1999 (3.10 dS/m) and September 1999 (1.53 dS/m). The remaining values ranged between 2.28 dS/m and 2.98 dS/m. During the second year, except for the lowest value found in August 2001 (1.86 dS/m), EC readings varied between 2.49 dS/m and 2.97 dS/m. In the third year, an increasing trend was observed from July 2001 till October 2001 when the salinity problem became severe. After this, EC decreased down to a moderate level of salinity.

The piezometric levels showed an increasing trend from July 1999 (21.5 m) till October 1999 (23.5 m), and then it decreased down to a value of 22.5m in April 2000. In the second year, a similar behavior was observed. To the difference of the two previous years, a decreasing trend was observed during the third season. The EC evolution could not be linked neither to the piezometric level nor to the rainfall (Table 3).

The well R of the Rmeyle region showed a range of EC values that could create a moderate problem of salinity (Figure 8). In the first year, a light decreasing trend was observed from July 1999 (2.27 dS/m) till December 1999 (1.70 dS/m). Then, EC started to increase independently from the rainfall augmentation and scored at the end of this period a maximum value of 3 dS/m. During the second period, EC readings raised gradually and the values vary between 1.99 dS/m and 2.99 dS/m. In the third year of observation, fluctuations were observed between July 2001 and December 2001. After this, EC steadily increased reaching higher EC values than those of the two previous years.

The piezometric levels varied within an interval of 1 m. It seems that the piezometric levels tend to increase in opposite direction with the rainfall as they were negatively correlated (-0.39) (Table 3). No important correlation could be detected between the piezometric levels and EC (0.15) nor between EC and the rainfall (-0.15). If the rainfall had an important effect, EC should continue to decrease during the entire rainy period. Therefore, EC values are dependant upon another factor. In fact, EC tend to be important whenever the evaporative demands of the crops are high and require higher pumping rates. Here again, as in Choueifat and Jiye, the growers rely on water from other sources. In this case, the farmer mixed extra- freshwater, drinking water, with the water of the well and thus depending on the availability of this extra-freshwater, the pumping from the well was modified.

Effects on crop production

In Lebanon, Choueifat is considered among the largest regions producing strawberry. This crop is sensitive to low levels salinity. According to Rhoads *et al.* (1992), an EC value greater then 0.7 dS/m leads to a gradual reduction in yield. During the whole study period, the wells of Choueifat displayed values largely exceeding 0.7dS/m. Therefore, the prevailing state of salinity in Choueifat threatens the production of strawberry much like pepper, lettuce and onions of similar response to salinity constraints. Whereas tomatoes and cucumbers exhibit more tolerance to salinity up to 1.7 dS/m where the production gradually drops (Rhoads *et al,*.1992).

In Jiye the situation is much more critical. The figures are higher than 2.3 dS/m. This state of salination hampers production of many horticultural crops, especially tomatoes and cucumbers. A proper management of irrigation frequency and rationalization in the use of fertilizers would be necessary in order to minimize the salt effects on crops.

As for Rmeyle, the well R showed threatening values of EC for the successful production of tomatoes and cucumbers.

Eventually, the study area, as compared to other coastal regions (Solh *et al.,* 1987; Atallah *et al.,* 1997) suffers from pronounced salinity hazards affecting crop production especially during the stage of germination. The poor affinity between rainfall and salinity evolution can be attributed to an overall recharge problem in the coastal area. In fact plant cover reduction associated to the high rate of urbanization leads to severe consequences on the total water balance of the area by increasing surface runoff at the expense of the vertical infiltration to ground water.

A significant correlation exists between salinity (EC) and pumping intensity (Q) from the aquifers (Figure 9). Water depleted from J2 to irrigate 1 ha (long-season tomato between September and April) of protected tomato (Table 3) and its salinity was determined. The correlation revealed to be at the level of significance (r = 0.55).

TABLE 3
Water Requirements of Long-Season Tomato (mm.day^{-1})

Oct	Nov	Dec	Jan	Feb	March	April	May	June
0.73	0.77	0.75	1.18	1.95	2.89	3.88	4.43	5.4

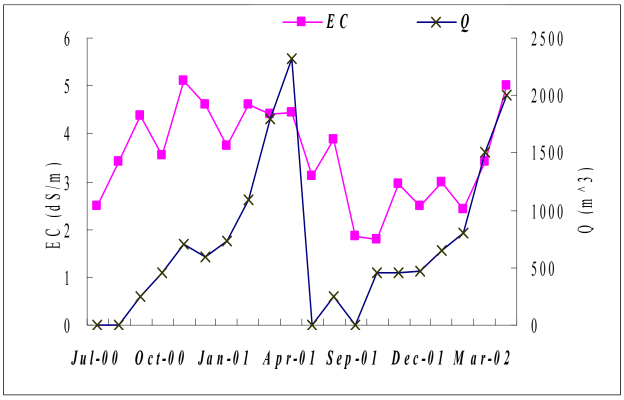

Figure 9. Time variation of EC and water depleted (Q) from J2.

Based on the updated geological map of Lebanon (1:50000 scale) and field verification, the Cenomanian limestone of the Jieh area is characterized by a prevailing dip of bedding planes towards the sea. It is cut by a set of faults in E-W direction. However, groundwater flow is almost seaward (Shaban, 2003). Such background characterizing the main part of Jieh watershed explains the stability of the high EC value registered in the well J2. At the same time, an intensive water pumping by reducing the number of submarine springs along the coastal area renders this system fragile and vulnerable (CNRS, 2002).

Effects of the water quality on soil permeability

The permissible value of the SAR is a function of the salinity (FAO, 1985). High salinity and notably sodicity levels increase and aggregate breakdown (dispersion) and reduce water infiltration. Therefore, in order to assess the potential hazards of water quality on soil physical properties both EC and SAR figures were listed where values threatened soil structure (Table 4).

TABLE 4
EC and SAR Values of the Well J_1, J_2 and R During the Period 1999-2002

	J_1		J_2		R	
	EC(dS/m)	**SAR**	**EC (dS/m)**	**SAR**	**ES (dS/m)**	**SAR**
Jul-99	5.44	**12.52**				
Aug-99	4.32	**23.26**				
Oct-99	4.41	**18.64**				
Dec-99	3.77	**15.44**				
Jan-00	3.83	**20.56**				
Feb-00	3.99	**18.38**	2.53	**10.54**		
Mar-00	4.15	**18.79**				
Apr-00	4.89	**17.79**			3.00	**11.18**
Aug-00	3.42	**12.43**				
Sep-00	4.39	**12.91**				
Nov-00	5.11	**13.65**				
Dec-00	4.61	**12.39**				
Jan-01	3.76	**11.14**				
Feb-01	4.60	**12.99**				
Mar-01	4.40	**10.89**				
Apr-01	4.44	**11.42**				
Jul-01	3.10	**11.95**				
Aug-01	3.87	**12.74**				
Oct-01	1.80	8.06			4.60	**10.15**
Mar-02	3.40	**12.70**				
Apr-02	4.99	**14.36**				

The long-term accumulation of salts partly enriched with Na, coupled with mismanaged irrigation, will result in the formation of saline and saline-sodic soils. The saturation of the soils with sodium will occur at the expense of the coagulant Ca. Such a situation will result in negative consequences on soil structural stability. Monitoring of water quality and improving the recharging of vulnerable groundwater are prerequisites for the sound management of water resources. This will prevent soil and land degradation and deterioration.

CONCLUSION

Water for horticulture in the study area is not sustainable in the short to medium terms. From Choueifat to Jieh and Rmeileh, water quality affects negatively crop production. This impact is strongest in Jieh where salinity is the highest of the studied sites. Water salinity fluctuations could not be correlated with rainfall, or with the piezometric levels. It was simply linked to the intensity of well-water pumping, because in the studied wells demand and extraction exceed recharge rates. In view of raised salinity levels, the growers of the region have learnt not to rely only on water from these wells, but supplement them through other available sources.

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