PRELIMINARY CONTAMINATION HAZARD ASSESSMENT OF LAND RESOURCES IN CENTRAL BEKAA PLAIN OF LEBANON

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ABSTRACT

The Central Bekaa plain constitutes the main region with prime agricultural land in Lebanon. The agricultural sector is the main consumer of available water resources (up to 70%). Intensive agriculture, urban expansion and industrial activity have been increasingly stressing the limited soil and water resources. In the Central Bekaa, farmers are enforced to use contaminated water to recompense water shortage during the peak crop demands. Water scarcity and mismanagement increased contagion hazards and pressure on soil and groundwater quality. The objective of this study was to provide a synopsis of the assessment methodologies and analyze the soil-groundwater vulnerability to contamination by heavy metals as based on the risks of metal transfer and the degree of protection offered by the soil cover and soil-metal interaction. The soils of the area are distinguished by a high content of clay and relatively high pH that would reduce the danger of heavy metals transfer and mobility. However, throughout the study area, the perched groundwater table is relatively high with a depth varying between 60 and 500 cm making it highly vulnerable to pollution. Metals might be more mobile under reducing conditions. The area of high, medium and low soil and groundwater table vulnerability were determined and spatially located according to international standards. Referring to the German Concept on soil protection effectiveness, the residence time of percolating water carrying soluble pollutants in the unsaturated soil zone was assessed. It varied between several months and 10 years. Zones of high soil and ground water vulnerability risk require special management to establish pollution prevention programs. Results can help land use planning oriented to the choice of suitable crops, promulgate sustainable use of natural resources and environmental preservation.

Keywords: soil contamination, nitrates, heavy metals, soil protection effectiveness, ground water vulnerability, land use impact

INTRODUCTION

Lebanon is located on the eastern coast of the Mediterranean Sea. The relief of the country is dominated by two mountain ranges, the coastal range (Mount Lebanon) and the inner range (Anti Lebanon). The Bekaa plain that lies between the two mountain ranges is at an average altitude of 900 m. This plain is characterized by a series of fertile soils representing the main agriculture resources of the country. The soils have been cultivated extensively for centuries and intensively the last four decades. The most important crops are vegetables, sugar beet, potato, wheat and fruit trees. Some farmers follow a good rotation system, but most of them practice monoculture of cash crops and vegetables. With increasing urban expansion and pressure on limited soil and water resources, increasing signs of contamination have been recorded (Le Houérou, 2002; Sarraf *et al*., 2004). With no effectual wastewater and industrial effluents treatment plants, contaminants go directly into open water streams and probably seep into the subsurface (Halwani *et al*., 1999).

Excess fertilizer input and uncontrolled disposal of refuse may have resulted in soil and ground water contamination with nitrates and heavy metals (Nsouli *et al*., 2004; Darwish *et al*., 2005). Quaternary age sediments from the surrounding mountains cover the central Bekaa plain. The German concept for the determination of ground water vulnerability to pollution (1994) classifies the clay and sand fraction of the soil cover to have the highest and lowest protection effectiveness, respectively.

Apparently, the ground water in the area is relatively deep, wells being at 70 m depth and deeper (Khoury, 2000) while perched water table is much shallower (0.6-5.0 m). Irrigation wells vary in depth between 70 and 100 m exploiting the deep aquifer while traditional Arab wells and earth reservoirs collect the shallow water table. The soils of the plain are deep and mainly of clay texture (Darwish *et al.,* 2006). Both these factors imply a very long residence time of pollutants in the unsaturated soil zone. Implemented as such and not adapted to local conditions, such a general approach could be misinterpreted and ambiguous. Moreover, this misleading assessment representing the soils to have very high protection effectiveness is dangerous, as rainfall is rather torrential and irrigation schedule is not based upon real crop water demands. As a result, the soils of the region, with dominant active clay minerals (Sayegh *et al.,* 1990), swell upon wetting and shrink upon desiccation causing the formation of cracks. The observed cracks are 0.2-3.5 cm wide and 30-120 cm deep. Swelling-shrinking and cracking can enhance the percolation rate and cause a higher percolation factor.

Poor-quality effluent contains a high concentration of suspended solids, oxygen demand, nutrients, bacteria and other pathogens (Abu-Sharar *et al*., 2003). In general, all the Litani watercourses are severely affected by domestic wastewater discharge. This is evident from the organic matter concentration, measured as Chemical Oxygen Demand (COD) or Total Organic Carbon (TOC), and from the concentrations of ammonia. The impact from sewage water is also evident from the conductivity of the water (ranging from a few hundred to more than 1,000 µS/cm) and its bacteriological analysis, indicating the presence of pollutants originating from human activities (USAID, 2003; Dib & Issa, 2003). This means that the soil resources in the area are not highly resilient to pollutants derived from the use of low quality irrigation water. Consequently, the concept for ground water vulnerability to pollution should be adapted to the Lebanese conditions by considering water table depth and seasonal percolation rate. This paper aims at evaluating the protection effectiveness of the soil cover of the Central Bekaa through evaluating interaction of the seasonal percolation rate, soil depth and texture and water table depth.

MATERIALS AND METHODS

General characteristics of the area

The study area is located in the Bekaa plain between 33° 47' 00" and 33° 54' 00" latitude, 35° 50' 08" and 35° 56' 38" longitude, totaling about 12753 ha with several rivers crossing it, namely Litani, Berdaouni and Gouzael (Figure 1). The area lies along the eastern foothills of Mount Lebanon chain and extends east through the litany River towards the Anti-Lebanon mountain chain. To the west, the area is characterized by moderately steep to steep mountain slopes and becomes level plain to the east in the Bekaa. The climatic conditions of the area are characterized by an average annual precipitation of 600 mm. The average lowest temperature is in January (2° C), while the average highest temperature is in August (31° C). The area is characterized by an annual potential evapotranspiration (PET) of 1513 mm/year (Atlas Climatique du Liban, 1977; Nimah, 1992; Jaber, 1995).

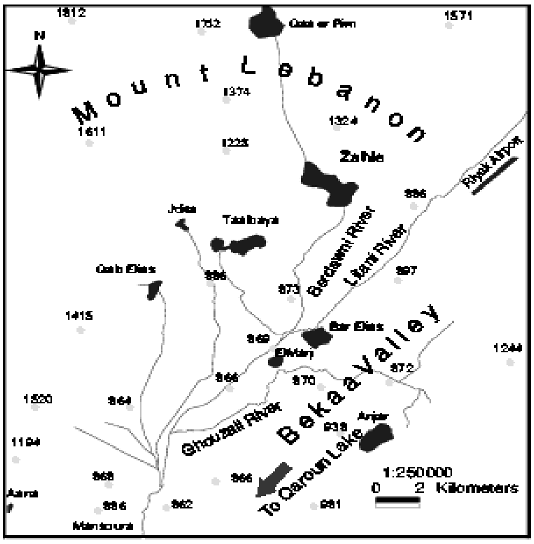

Figure 1. Surface water resources of Central Bekaa.

The valley slopes receive sediment deposits from the wadis outlets and a mixture of colluvial and alluvial material. To the east, old alluvial terraces extend over a large area to contact the riverbanks with recent alluvium. Land cover map (FAO, 1990a) and Spot image of 1998 analyzed for this project showed that agriculture in the plain was practiced mainly with cash, field crops and vegetables. The area to the west was used mainly for terraced fruit trees. For the specific concern of this study, the prime resources were soil and groundwater.

Monitoring and assessment of vulnerability to pollution

A global positioning system (GPS) was used to identify and locate grid sampling. Sites for soil sampling were based on soil type and specific land use. As a result, 43 soil profiles were described down to 200-cm depth or to the perched water table (Figure 2). The soil horizons were described according to the FAO methodology (1990b). The soils were classified following the FAO-UNESCO legend of 1997. Farmers applied 300-500 kg/ha of pure nitrogen as low solubility complex fertilizer with further addition of nitrate or ammonium forms. Fields receiving these two amounts and irrigated with the macro sprinkler system widely used by the Farmers in the Bekaa plain, were monitored for N application and leaching. To compare the nitrate leaching hazards, a potato plot receiving 300 kg N was irrigated by drip system.

For the evaluation of the farmer's practice of fertilizers and water inputs tensionics (devices which are similar to tensiometers) provided with a ceramic cup specially used to selectively collect nitrates from the soil solution were inserted in three replicates in three different potato fields in the root zone and deeper at 20-cm increment down to 100-cm depth. Soil solution was emptied from the tensionics every eight days, the time of balanced NO3 concentration inside and outside the ceramic cup (Moutonnet & Fardeau, 1997). NO3 concentration in the soil solution was determined using RQ-Flex.

Figure 2. Sampling was done from the water table up to the soil surface to avoid cross contamination of soil samples.

The soil parameters (texture, pH, OM content, depth of unsaturated zone) that determine the ground water vulnerability to pollution were evaluated using the ISO standards (ISO, 1999). Given the rainfall distribution character in Lebanon, precipitation falls in one season. This makes the area different from the European conditions with winter and summer rainfall.

The percolation rate and percolation factor were calculated for the peak of rainy season (December-February) using the model (Table 1) proposed by the German Concept on soil protection effectiveness (1994) to assess ground water vulnerability to pollution. It is based on the difference between precipitation and potential evapotranspiration (ETP). The larger the difference is the more positive is water balance and the highest is the risk of pollutant transfer to groundwater.

TABLE 1

Percolation Rates and the Corresponding Factor Based on the Difference of Precipitation (P) and ETP Pot

P-ETP, mm	<100	100-200	200-300	300-400	>400
Factor	1.5	1.25	1.0	0.75	0.5

The average amount of precipitation during this period is 316 mm for Central Bekaa while the ETP is 117 mm (Atlas Climatique du Liban, 1977). The difference between rainfall and PET ranges within the threshold 200-300 mm/season that yields a percolation factor equivalent to 1. This introduces no modifications to percolation rate based on water balance. In case the difference does not exceed 200 mm, a factor >1 is multiplied by the sum of protection points given to a specific soil (based on its depth and texture) to reflect higher protection effectiveness. In this case the site shows prevalence of dry soil conditions and less leaching hazards. The reverse is true for a difference above 300 mm where a decimal factor is used to stress higher soil-groundwater vulnerability to reflect the conditions of higher leaching risk. Therefore, the soil types of the area do not differ by the percolation rate factor unless excessive irrigation is applied in the dry season. The number of points (Ru) for the protection effectiveness of a given soil was calculated using the recommended assessment of unconsolidated rocks of the German Concept that gives 500 points/1m bed thickness for clay, 240 for clay loam and only 25 for sand. Intermediate texture classes receive proportional number of points. When a soil profile showed variable texture with depth, calculation was carried out for every layer depending on its specific texture and depth and the total amount of points for the whole soil thickness was then summed. Consequently, in the Central Bekaa plain, the major factors determining the soil protection effectiveness are soil texture and depth to water table.

RESULTS AND DISCUSSION

Risks of groundwater contamination

Ground water could be contaminated as a result of anthropogenic induced perturbations of physical, chemical and biological processes occurring at soil cover through the unsaturated zone to the subsurface. Ground-water vulnerability is defined as the tendency or likelihood for contaminants to reach the ground-water system after introduction at some location above the uppermost aquifer (Vrba & Zaporozec, 1994). The vulnerability of ground water to pollution with heavy metals is affected by the soil pH, texture, depth and humus content. Soil infiltration rate and depth to groundwater are determining factors.

The fluctuation of water table level during the wet-dry seasons may complicate the picture and add to the hazards of heavy metals transfer from the soil to the ground water and vice versa. Accordingly, the heavy metals retention by the soil is in the following order: Alluvial (clay) soil > Sandy-silt > Sandy soil (Ibrahim *et al*., 1996). However, there is selective metallic behavior, *e.g*. depending on its charge Cr (oxidation-reduction state) has a high degree of mobility in all soil types, but most pronounced in the sandy soil (Ibrahim *et al*., 1996).

Soils vulnerability

The principal soil classes in the Bekaa plain are Regosols, Cambisols, Fluvisols and Vertisols. These are colluvial and alluvial soils that accumulated and evolved along the foot slopes as torrential deposits and in the plain as a mixture of alluvial and colluvial materials. They have relatively deep profiles and could be of claylike or sandy clay loam texture depending on the original material (Table 2). Deep, clay soils received 2500 points which characterize a long residence time of percolating water ranging between 3 years and 10 years.

The dominant clay minerals are interstratified smectite with intermediate amounts of kaolinite (Sayegh *et al.,* 1990). The cracks formed in the soils upon drying and caused by the soil vertic properties, characteristics of the soils in semi-arid region can only accelerate the downward movement of water. Although the capillary rise of water table is interrupted, cracks can open the path to direct contact of any surface contaminant even in non soluble state. This adds to the vulnerability of the system and affects the soil protection effectiveness. The dominant part of soil types is clay texture, but some soil types are of light texture (loam) promoting macro porosity. The presence of high amounts of fine gravels multiplies the risks of pollutant transfer by enhancing infiltration rates. The deeper soil type with clay texture received 1000 points that corresponds to the class 1000-2000 representing moderate protection class and a residence time of percolating water between 3 years and 10 years (Table 2). A lower depth soil having the same clay texture revealed fewer points (696) belonging to the low protection class with a residence time below 3 years. A sandy clay loam soil moderately deep soil collected only 390 points revealing very low protection and short residence time.

TABLE 2

Depth and Texture of Some Soil Types and Their Protection Effectiveness

Profile ID/ and water table depth, m	Depth cm	Clay %	silt %	Sand %	Points/m Thickness*	Number of points per layer	Overall points Ru and Protection Class**	Residence time of percolating water***
Z-1/ > 5m	0-41	54.2	25.5	20.2	500	205	1000-2000 Moderate	3-10 years
	41-75	54.4	24.7	20.7	500	170		
	75-120	67.8	22.2	10.0	500	225		
	120-166	66.4	22.4	11.2	500	230		
	166-200	54.8	21.5	23.7	500	170		
Z-7/ 1.6 m	0-20	75.2	19.0	5.7	500	100	500-1000 Low	Several months to 3 years
	20-35	66.2	29.6	4.1	500	75		
	35-60	82.1	12.5	5.4	500	125		
	60-85	69.4	17.5	13.2	500	125		
	85-120	70.5	18.1	11.3	500	175		
	120-160	23.2	18.1	58.8	240	96		
Z-4/ 1.6 m	0-40	23.3	15.6	61.0	240	96	<500 Very low	A few days to 1 year
	40-85	25.7	16.7	57.7	240	108		
	160-180	44.3	20.9	34.9	500	100		
	120-160	23.2	17.9	58.8	240	86		

* Estimated on the basis of the cation exchange capacity for each of the different types of unconsolidated rocks. ** Each horizon is assessed separately using criteria from the "German Concept" for unconsolidated rocks. The number of points is multiplied by the stratigraphic thickness in meters above the water table. *** Approximate time of the transfer of water-soluble pollutants to the aquifer.

The analysis of the full soil cover representing the area of study showed different degree of groundwater protection secured by the soil cover with significant part having moderate and low protection effectiveness (Figure 3). The available data does not allow judging the continuity in the soil mass. For this reason, it is necessary to distinguish between a soil and a surface deposit. The fractured system (karstic limestone, faults) of the surrounding mountain area implies the necessity to undertake geophysical studies on the depth of ground water, water table and nature of deposits overlying the aquifer in the Bekaa valley.

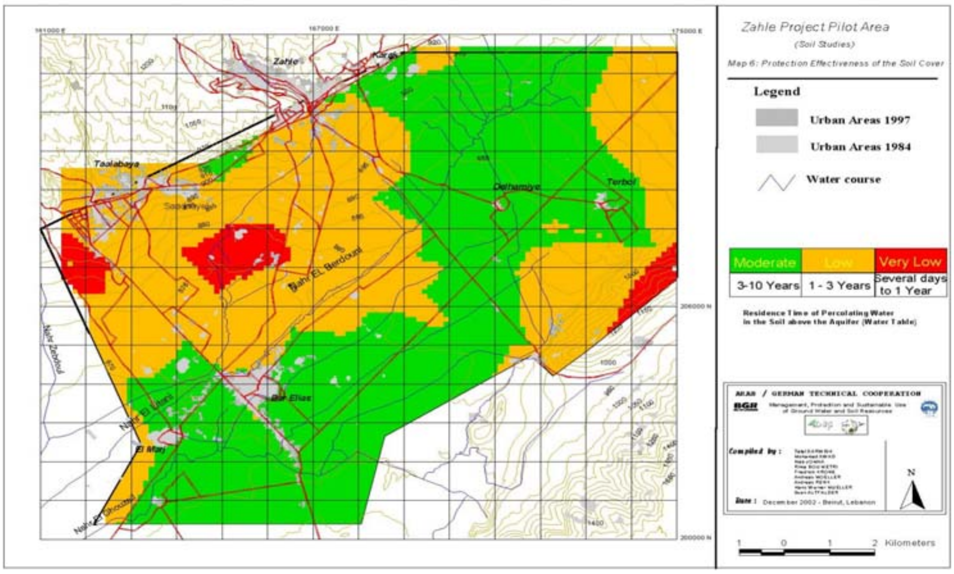

Figure 3. Soil protection effectiveness in Central Bekaa as affected by soil depth, texture, lithology, percolation rate and other soil properties.

In general, the geology of the study area does not have lithologies that host mineralization that could have supplied the derived soils ample amount of heavy metals (Khawlie, 1983). Accordingly, the main source of pollution with heavy metals is derived from human activities. One of the uncontrolled widespread non point source of pollution in the Bekaa plain is agriculture. Intensified agro-practices increased the input of fertilizers and other chemicals. Irrigation consumes almost 70% of the available water that comes mostly from surface and largely from groundwater sources. Studies pointed to the fact that these water resources have become partly polluted (Korfali *et al*., 2006).

Our results showed that in many cases, heavy metals accumulated at the soil surface which can indicate geogenic input from erosion sedimentation or direct input with non treated sewage water (Table 3). However, the range of heavy metal concentration remains within the multifunctional landuse for all metals except Ni and Cr where some limitation related to leaf succulent vegetables must be implemented. In some sites, the relative increase of heavy metal content with depth was not gradual but it was rather abrupt. Therefore, given the soil properties this heavy metal accumulation in the subsoil is unlikely to be related to leaching. It seems that its origin is related to old subsoil sediment derived from other rocks hosting higher mineralization rate. Also, it could be possible that seasonal fluctuation of the contaminated shallow water table could have brought some of these metals, which become more mobile in reduced conditions, to the subsoil in case of open source of pollution like mixing shallow well water and reservoirs with domestic effluents.

TABLE 3

Relative Heavy Metal Accumulation in the Surface Soil Layers
(source: BGR, ACSAD, and CNRS-CRS, Arab-German Cooperation project 1997- 2003)

Profile ID	Soil depth cm	Cd	Co	Cr	Cu	Ni	Pb	Zn	Perched water table depth
		mg/kg							cm
Za-3	0-20	0.28	28.5	93.6	28.6	72.7	15.5	95.7	800
	20-150	0.26	28.1	93.5	28.3	72.8	13.2	97.2	
	150-200	0.24	17.9	60.7	19.2	48.8	7.2	64.4	
Tolerance level		1	30	50	50	40	100	150	

On the other hand, nitrates follow the wetting front and thus, as anion, they are not retained by the negatively charged soil mineral complex. Therefore, they move easily downward with percolated water.

TABLE 4

Relative Heavy Metals Accumulation in the Subsoil
(source: BGR, ACSAD, and CNRS-CRS, Arab-German Cooperation project 1997- 2003)

Profile ID	Soil depth Cm	Cd	Co	Cr	Cu	Ni	Pb	Zn	Perched water table depth
		mg/kg							cm
Z-4	0-40	<0.2	17.3	43.3	17.0	33.7	10.0	62.0	180
	40-85	<0.2	15.7	41.7	16.3	31.7	9.7	62.3	
	160-180	<0.2	25.7	79.1	26.0	53	14.0	84.0	

These results showed that due to the observed in the plain over fertilization and excessive irrigation, nitrate was proved to move downward in the soil profile of irrigated potato fields (Table 5).

Groundwater vulnerability

High water demands in the plain and scarcity of surface water in summer increased farmer's reliance on less polluted water from the deep wells. Now, hundreds of private and uncontrolled wells exist in the area. The hydraulic level in the wells has dropped down and now varies between 10 and 150 m (Hobler & Rajab, 2000). However, shallow ground water table is more common in less exploited and perched areas.

TABLE 5

Average Nitrate Leaching as Affected by the Farmer Practice of N Fertilizer Input and Irrigation Techniques

(Source: Darwish *et al*., 2003)

N input (Kg/ha/year)	Irrigation technique	Concentration of NO3 (mg/l) at different soil depth of potato plots			
		40 cm	60 cm	80 cm	100 cm
500	Macro sprinklers	114	125	227	307
300	Macro sprinklers	132	93	165	166
300	Drip	97	55	Not found	Not found

In the downstream some wells showed an artesian nature. In Central Bekaa, there is ground water deep aquifer and suspended or perched groundwater table close to the surface. Hydrologically, both aquifers are interconnected. The shallow groundwater table is recharged by rainfall and irrigation water and is more vulnerable to landuse impact. The statically high level of the ground water table, *i.e.* its shallowness, makes it extremely vulnerable to bacteriological (Dib & Issa, 2003) and chemical pollution (USAID, 2003) originating from liquid, human and industrial wastes. Irrigation using this water will negatively reflect on soil quality.

A preliminary chemical analysis of the wells and surface water table showed some relative accumulation of Ni and Zn only in the shallow wells and reservoirs (Table 6). Obviously, wherever water is polluted, soil is polluted, and vice-versa. The characteristics of the surface cover, soil parent material and the hydraulic character facilitating lateral and vertical water flow will determine the rate of transfer, extent and nature of pollution.

TABLE 6

Heavy Metal Content in Irrigation Water from Some Wells in Central Bekaa (μg/l)

(source: BGR, ACSAD, and CNRS-CRS, Arab-German Cooperation project 1997- 2003)

Source	Ni	Cr	Cd	Zn	Pb
Shallow open water reservoir, 2m depth	13.9	6.4	0.06	115.2	0.86
Arab well, 8 m	12.5	5.0	0.03	219.5	0.95
Deep well, 70 m	5.0	4.0	0.02	36.8	0.4
Level of Intervention*	15-37	1-26	1.5-6	150-290	15- not defined

* The level beyond which measures should be undertaken to limit hazards of heavy metals input to the soils.

The dynamics of nitrate distribution was closely linked to the irrigation technique with higher nitrate leaching observed in sprinkler irrigation as compared to the drip. The intensive nature of fertilizer application and irrigation techniques based on poor agricultural practices and land use policy, beside the cracks and deep plowing, are the main factors contributing to the potential and actual risk of soluble pollutants transfer to the shallow aquifer in Central Bekaa. Depending on hydrogeology and landuse, the drilled boreholes varying in depth between 3 m and 7 m from Central Bekaa area showed that the part of aquifer near the boundary between the saturated and unsaturated zones is the most sensitive to pollution (Figure 4). In addition to infiltrated water, perched aquifer receives also seeping water from drainage canals with higher mineralization rates.

The study undertaken within the framework of the Arab-German technical cooperation project (BGR, ACSAD, NCRS 1997-2000), on the protection and sustainable use of soils and ground water, proved the concentration of nitrate in the relatively deep irrigation wells of Central Bekaa to reach values higher than 200 mg/l and the salinity to approach 2 dSm/m (Table 7). This proved the relatively deep ground water in Central Bekaa to be vulnerable to nitrate pollution.

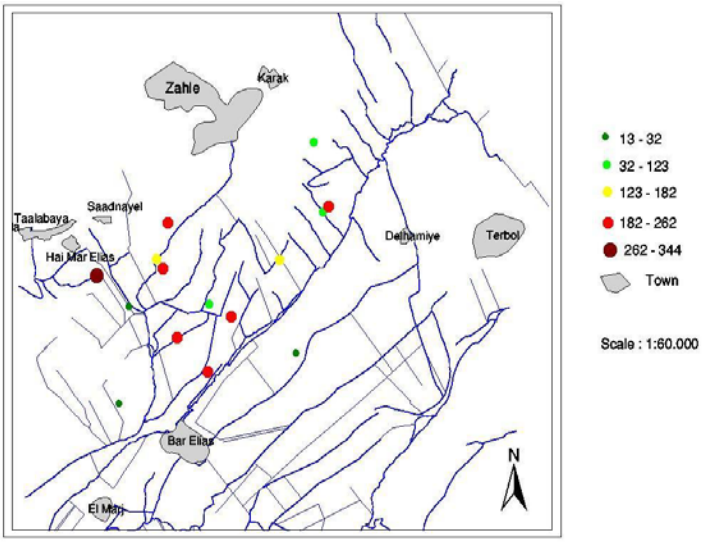

Figure 4. Nitrate concentration in the shallow (perched) groundwater table of the Central Bekaa Valley (Spring 2002).

(source: BGR, ACSAD, and CNRS-CRS, Arab-German Cooperation project 1997- 2003)

Dense sampling from a limited area (one well/4 km2), with originally no natural salinity hazards demonstrated the perilous impact of current land use on soil and ground water quality. This characterizes agriculture as diffusive non point source of nitrate pollution.

TABLE 7

Status of Nitrates and Salts in the Deep Wells of Central Bekaa
(source: BGR, ACSAD, and CNRS-CRS, Arab-German Cooperation project 1997- 2003)

<table>
<tr><th>Number of wells</th><th>NO₃ mg/l</th><th>N of wells</th><th>Electrical Conductivity dSm/m</th><th>Total dissolved salts mg/l</th></tr>
<tr><td>10</td><td>>200</td><td>13</td><td>1.0-2.0</td><td>650-1300</td></tr>
<tr><td>6</td><td>100-200</td><td>4</td><td>0.6-1.0</td><td>400-650</td></tr>
<tr><td>8</td><td>40-100</td><td rowspan="2">13</td><td rowspan="2"><0.6</td><td rowspan="2"><400</td></tr>
<tr><td>6</td><td>10-40</td></tr>
</table>

CONCLUSION

Agriculture activities like the overuse of fertilizers and other chemicals, beside the different sources of pollution like dumping non treated liquid, solid and industrial wastes into open channels make the soil and ground water highly vulnerable to pollution. The ISO counts for the main effect of soil pH, texture and organic matter content in the interpretation of the soil attitude to fix heavy metals in non mobile form. The German methodology evaluates ground water vulnerability to pollution by considering factors like soil textural class and soil depth to groundwater. It estimates the annual percolation rate as the difference between the annual precipitation and annual potential evapotranspiration. The seasonal nature of precipitation in Lebanon and shallow water table, beside the open system of the area, imply partial adaptation of the concept to fit the Lebanese conditions, like the use of seasonal water percolation rate or perhaps include the annual input of irrigation water. Such an adapted approach revealed the soils of the area to have moderate, low and very low protection effectiveness. The residence time of percolating water in the soil above the aquifer varies between several months and 10 years. The shallow, perched, groundwater table was more vulnerable to the impact of surface landuse. While deep aquifer seems well protected against heavy metal contamination, there is indication on higher vulnerability to nitrate contamination. Fortunately, local population and authorities are aware of drinking water quality and therefore do limit the use of this kind of water to irrigation. Appropriate land use planning based on adequate agricultural policy, relying on land capability and suitability and water management practices and addressing the protection of the ground water, is essential to prevent further deterioration of the limited soil and water resources in the country.

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