ESCWA UNEP BGR (MEW)

Distr.
LIMITED
E/ESCWA/ENR/2000/WG.3/8
6 November 2000
ORIGINAL: ENGLISH

ECONOMIC AND SOCIAL COMMISSION FOR WESTERN ASIA

Expert Group Meeting on Implications of Groundwater Rehabilitation for Water Resources Protection and Conservation
Beirut, 14–17 November 2000

WATER AND SOIL VULNERABILITY TO CONTAMINATION IN CENTRAL BEQA'A PLAIN - LEBANON

00-0630

Water and Soil Vulnerability to Contamination in Central Beqa'a Plain-Lebanon

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Abstract

The Central Beqa'a plain constitutes the prime agricultural area of Lebanon. The agricultural sector consumes up to 70% of water through irrigation. Accordingly, any threat to this resource would undermine the country's economy. Intensive agriculture, urban expansion and industrial activity have been increasingly stressing the limited soil and water resources. In the Beqa'a, farmers use low quality polluted water to compensate the shortage in water for irrigation demand. This has caused problems related to soil and aquifer contamination by heavy metals.

The objective of this study is to reflect the impact of land use on the content and distribution of toxic heavy metals in the area, notably the behavior of heavy metals in the soil-ground water system. It also covers the leaching mechanism of nitrates and the analyses of protective effectiveness of the soil cover.

The characteristics of the study area, about 127.5km^2, i.e. location, water bodies, climate, and socio-economics make it vulnerable especially to pollution. Agriculture in the plain is being practiced mainly with cash, field crops and vegetables. The different sources of pollution are excessive dumping of liquid and solid wastes, industrial wastes, and the overuse of fertilizers, pesticides and insecticides. The soils of the area are distinguished by a high content of clay that would reduce the danger of transfer of heavy metals to plants. However, throughout the study area, the water table is shallow with a depth varying between 60 and 500 cm. This makes it easily vulnerable to pollution, especially nitrates, which follow the wetting front. Thus, excessive irrigation and a seasonal water percolation rate of 200-300 mm/year bring pollutants deep towards the aquifer. Increasing salinity and nitrate content, obtained in the deep wells of the area, confirm this finding.

The area of high, medium and low soil and water table vulnerability were determined and spatially located according to the ISO standards. Based on the German concept for ground water pollution vulnerability, calculations for protection effectiveness shows the Quaternary sediments to have higher ranks in comparison with the karstic hard limestone of the surrounding mountains. However, considering the open system, characteristic of the area, and shallow water table level, the soil has a moderate, low and very low overall protective effectiveness. The residence time of percolating water in the soil above the aquifer varies between several months and 10 years.

The produced soil and ground water vulnerability maps could serve as tools for establishing pollution prevention programs. This helps in planning for the appropriate use of land and in decision-making addressing the preservation of the environment.

Key words: Soil contamination, protection effectiveness, ground water vulnerability.

I. Introduction

Lebanon lies on the eastern coast of the Mediterranean Sea. The relief of the country is dominated by the two mountain ranges, the coastal range (Mount-Lebanon) and the inner range (Anti-Lebanon). The Beqa'a 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 soil 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 fallow a good rotation system, but most of them practice the monoculture of cash crops. With increasing urban expansion and pressure on limited soil and water resources, increasing signs of contamination are recorded. With no treatment plants for wastewater and industrial effluents, contaminants go directly into the open water and seep into the subsurface.

Coupled with the misuse of fertilizers and other chemical products, this would have resulted in soil and ground water contamination with heavy metals and nitrates. Quaternary age sediments from the surrounding mountains cover the area. The German concept for the determination of ground water pollution vulnerability

(1994) consider that the clay and sand fraction of the soil cover have the highest and lowest protection effectiveness, respectively. Because the ground water in the area is at 70 m depth and deeper (KHOURY, 2000) and the soils of the plain are mainly of clay texture (Darwish *et al.*, 1999) imply a very long residence time of pollutants in the soils. Such general approach not adapted to the local conditions could be misinterpreted. Moreover, this misleading assessment representing the soils to have very high protection effectiveness is dangerous, as the 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)*, show deep cracks upon dryness that would enhance the percolation rate and a higher percolation factor. This means that the soil resources in the area are not highly resilient to the 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 the water table depth and the seasonal percolation rate. The paper aims at evaluating the protection effectiveness of the soil cover of the Central Beqa'a through evaluating interaction of the seasonal percolation rate, soil cover texture and water table depth.

II. Materials and Methods

II.1. General characteristics of the area

The study area is located in the Beqa'a 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 (Figure 1). The area lies along the eastern foothills of Mount Lebanon chain and extends east through the litani River towards the Anti-Lebanon mountain chain. To the west, the area is characterized by moderatly steep to steep mountain watershed and becomes level plain to the east in the Beqaa. The climatic conditions of the area are characterized by 500-700 mm of precipitation. The average lowest temperature is in January reaching 2°C, while the average highest temperature is in August reaching 31°C, and an a nnual PET of 1513 mm/year (Atlas Climatic du Liban, 1977; Nimah, 1992; Jaber, 1995).

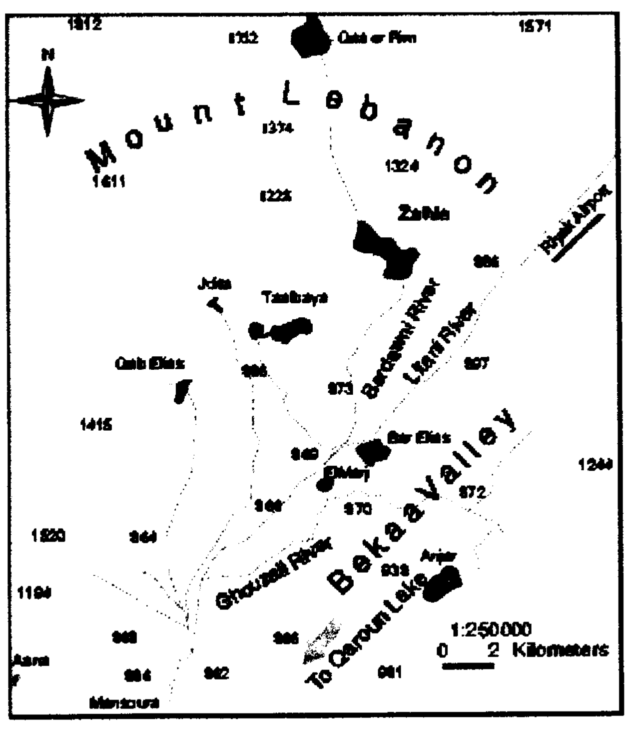

Figure 1. Surface water of Central Beqa'a

The valley slopes receive fan deposits and a mixture of colluvial and alluvial material. To the east, old alluvial terraces extend over a large area to contact the riverbanks with the recent alluvium. According to the land cover map (FAO, 1990a) and Spot image of 1998 analyzed for this project, agriculture in the plain is being practiced mainly with cash, field crops and vegetables. The area to the west is being used mainly for terraced fruit trees. For the specific concern of this study, the prime resources are soil and water.

II.2. Monitoring and assessment for pollution vulnerability

A GPS was used in identifying and locating grid sampling. Sites for soil sampling covered the soil types properly as well as the different land use. 43 soil profiles were described down to 200-cm depth or to the water table. The soil horizons were described according to the FAO methodology (1990b). The soils were classified following the FAO-UNESCO legend of 1997.

For the evaluation of the farmer practice of fertilizers and water inputs a tensionic provided with a ceramic cup was inserted in three replicates in a potato field in the root zone and deeper at 20-cm increment down to 100-cm depth. The farmer applied 300 kg/ha of nitrogen as low solubility fertilizer. The field was irrigated with the macro sprinkler system widely used by the Beqa'a Farmers. The solution was emptied every 8 days, the time of balanced NO3 concentration inside and outside the ceramic cup. NO3 concentration in the soil solution was determined using RQ-Flex.

The soil parameters that determine the ground water vulnerability to pollution were evaluated using the ISO standards (ISO, 1999). Given the rainfall distribution character in Lebanon, where precipitation falls in one season, makes the area different from European conditions. The percolation rate and percolation factor were calculated for the rainy season (December-February) using the German Concept for the calculation of ground water vulnerability to pollution (1994). The average amount of precipitation during this period is 316 mm for Central Beqa'a (Atlas Climatic du Liban, 1977). The potential evpotranspiration is 117. The difference ranges within the threshold 200-300 mm/season. This yields a percolation factor equivalent to 1 (German Concept for the calculation of ground water vulnerability to pollution, Table 2). Therefore, the soil types of the area do not differ by this factor. The number of points (Ru) for the protection effectiveness was calculated using the table 3 for the assessment of unconsolidated rocks of the same concept that gives 500 points/1m bed thickness for clay, 240 for clay loam and 25 for sand. Consequently, in Central Beqa'a soil texture and depth to water table determine the protection effectiveness of the studied soil cover.

III. Results and Discussion

III.1. Ground water Vulnerability

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 and Zaporozec, 1994). The vulnerability of ground water to pollution with heavy metals is affected by the following:

1. Soil pH reaction: Soil ability to neutralize effects of pollutant increases with increasing pH value. This has a positive correlation with CaCO3 content. The soil retention capacity reaches its maximum in the pH interval 6.8 -8.0. This criterion has high importance and weight in the assessment for heavy metal transfer to groundwater.
2. Texture: As a parameter affecting soil cation exchange capacity and permeability, texture plays a moderate role in assessing the impact of groundwater vulnerability to pollution.
3. Thickness of the soil and rock cover above the aquifer.
4. The presence in the soil of microorganisms that are capable to draw the heavy metals deep (Van Bladeletal, 1998).
5. Humus content: The high positive correlation of the distribution of organic matter and heavy metals implies an important role in the vulnerability of ground water. However, Following the ISO standards (1999), organic matter is given an intermediate role and weight, i.e., less than that given to soil pH.

6. Infiltration rate: is affected by the soil physico-chemical characteristics (structure, porosity, texture, pH). The leaching of heavy metals is related to the soil porosity, permeability, gravel contents, percolation rate and reworking conditions.
7. Depth to ground water: This factor is the most important parameter to which a very high weight is given by ISO. The most vulnerable areas are those with a shallow water table depth. The fluctuation of its level during the wet-dry seasons may complicate the picture and add to the hazards of heavy metals transfer to the ground water and vice versa.

Accordingly, the order of retention of heavy metals by the soil is the following: Alluvial soil > Calcareous soil > Sandy-silt > Sandy soil (Abdel Sabani and Soliman, 1990 cited by Ibrahim *et al.*, 1996). However, there is selective metallic behavior, e.g. Cr has a high degree of mobility in all soil types, but most pronounced in the sandy soil (Ibrahim *et al.*, 1996).

III.2. Soils Vulnerability

The principal soil classes, but the most pronounced vulnerability according to the FAO-UNESCO Legend (1997) are Regosols, Cambisols, Fluvisols and Vertisols. These are colluvial and alluvial soils that accumulate along the foot slopes as torrential deposits and in the plain as a mixture of alluvial-colluvial material. They have relatively deep profiles, and could be of clayey or sandy clay texture depending on the original material (Table1).

Table 1. Texture of some soil types and their protection effectiveness

Profile ID	Upper Depth cm	Lower Depth cm	Clay %	silt %	Sand %	Soil texture	Points/m Thickness*	Overall points Ru and Protection Class**	Residence time of percolating water***
	0	41	54.2	25.5	20.2	Clayey	500		
	41	75	54.4	24.7	20.7	Clayey	500		
Z-1	75	120	67.8	22.2	10.0	Clayey	500	1000-2000 Moderate	3-10 years
	120	166	66.4	22.4	11.2	Clayey	500		
	166	200	54.8	21.5	23.7	Clayey	500		
	0	40	23.3	15.6	61.0	Sandy clay loam	240		
	40	85	25.7	16.7	57.7	Sandy clay loam	240	<500 Very low	
Z-4	160	180	44.3	20.9	34.9	Clayey	500		a few days to 1 year
	120	160	23.2	17.9	58.8	Sandy clay loam	240		
	0	20	75.2	19.0	5.7	Clayey	500		
	20	35	66.2	29.6	4.1	Clayey	500		
Z-7	35	60	82.1	12.5	5.4	Clayey	500	500-1000 Low	several months to 3 years
	60	85	69.4	17.5	13.2	Clayey	500		
	85	120	70.5	18.1	11.3	Clayey	500		
	120	160	23.2	18.1	58.8	Sandy clay loam	240		

* Estimated on the basis of the cation exchange capacity for each of the different types of unconsolidated rocks.
** Each horizon is assessed separately using table 3 in 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 dominant clay minerals are interstratified smectite with intermediate amounts of kaolinite (Sayegh *et al.*. 1990). Given the shallow water table, and based on the weight of the soil textural class, the assessment of the residence time of percolating water showed that nitrates and other water soluble pollutants can reach the water table in a short time varying between several months and 10 years. The cracks formed in the soils upon drying can only accelerate the downward movement of water. The capillary rise of water is interrupted. This adds to the vulnerability of the system and affects the soil protection effectiveness (Map 1).

The available data indicates that there is an open system, with a medium percolation rate. It is not certain concerning the continuity in the soil mass. For this reason, it is necessary to distinguish between a soil and a surficial deposit. The fractured system (karstic limestone, falts) of the surrounding area implies the necessity to undertake geophysical studies on the depth of ground water, watertable and nature of deposits overlying the aquifer in the Beqa'a valley.

III.3. Land use impact, nitrates, and toxic heavy metal distribution in the soils

In general, the geology of the study area does not have lithologies that host mineralization that could have supplied these heavy metals (Khawlie, 1983). Accordingly, the main source of pollution with heavy metals are human made. In the plain downstream, where agro-practices increase, irrigation consumes almost 70% of the water that mostly comes from surficial sources. These have become more polluted. As a result, heavy metals accumulate at the surface (Table 2). This has resulted in increasing demand on less polluted water from the subsurface. 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 and Rajab, 2000). Shallow ground water is more common in less exploited areas.
Nevertheless, some wells downstream show an artesian nature. The statically high level of the ground water, i.e.its shallowness, makes it vulnerable to bacteriological and chemical pollution originating from liquid, human and industrial wastes (Table 3). As the increase of heavy metal content with depth is not gradual, therefore is not probably due to migration, the seasonal fluctuation of the contaminated water table could have brought these metals to the subsoil.

Table 2. Heavy metal accumulation in the upper soil layers with low quality irrigation water

Profile ID	Soil depth cm	Cd	Co	Cr	Cu	Ni	Pb	Zn	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	

Table 3. Relative heavy metals accumulation in the subsoil.

Profile ID	Soil depth Cm	Cd	Co	Cr	Cu	Ni	Pb	Zn	Water table depth
		mg/kg							cm
Z-4	0-40	62	10	17.3	<0.2	33.7	43.3	17	180
	40-85	62.3	9.7	15.7	<0.2	31.7	41.7	16.3	
	120-160	51	7.3	18.3	<0.2	34.7	43	15	
	160-180	84	14	25.7	<0.2	53	79.1	26	

Chemical analysis of the wells and surface water showed some accumulation of Cr in the water (Table4). Obviously, wherever water is polluted, soil is polluted, and vice-versa. The characteristics of the surface cover, parent soil material and the hydraulic character facilitating the water flow laterally and vertically, will determine the rate of transfer and, therefore, the extent and the nature of pollution.

Table 4. Analysis of water from some wells in the Central Beqa'a Valley (µg/l)

Source	Ni	Cr	Cd	Zn	Pb
Shallow open water reservoir, 2m depth nourished from water table seepage.	13.9	6.4	0.06	115.2	0.86
Surficial well (Arab Well) 8 m.	12.5	5	0.03	219.5	0.95
Deep well 70 m.	5	4	0.02	36.8	0.4
Level of Intervention*	15-37	1-26	1.5-6	150-290	15- to be defined

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

On the other hand, nitrates follow the wetting front and thus move easily as an anion not retained by the negatively charged soil exchange sites. Due to over fertilization and excessive irrigation, nitrate was proved to move down in the soil profile of an irrigated potato field (Table 5).

Table 5. Average nitrate leaching as affected by the farmer practice of N fertilizer input and irrigation technique

N input (Kg/ha/year)	Irrigation technique	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	-	-

The intensive nature of fertilizer application and irrigation techniques based on poorly adequate agricultural land use policy, beside the cracks and deep plowing, are the main factors contributing to the pollutants transfer to the aquifer in Central Beqa'a. 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 wells of Central Beqa'a to reach values higher than 200 mg/l and the salinity to approach 2 dSm/m (Table 6). This proves the ground water in Central Beqa'a to be highly and medium vulnerable to pollution.

Table 6. The status of nitrates and salts in the deep wells of Central Beqa'a (source: BGR, ACSAD, and NCRS, 2000)

Number of wells	NO3 content mg/l	N of wells	Electrical Conductivity dSm/m	Total dissolved salts mg/l
10	>200	13	1.0-2.0	650-1300
6	100-200	4	0.6-1.0	400-650
8	40-100	13	<0.6	<400
6	10-40			

This dense sampling from a limited area (~one well/4km2), with originally no natural salinity hazards, in general, demonstrates the hazardous impact of current land use in term of pollution of the soil-ground water system.

IV. Conclusion

Agriculture activities like the overuse of fertilizers and other chemicals, beside the different sources of pollution such as dumping of liquid, solid and industrial wastes make the soil and ground water easily vulnerable to pollution. The currently used German methodologies of assessing ground water vulnerability to pollution relying on the estimation of the percolation rate as the difference between the annual precipitation and potential evapotranspiration, textural class and depth to groundwater, should be adapted to Lebanese conditions. The seasonal nature of precipitation in this country and shallow water table, beside the open system of the area, imply the use of seasonal water percolation rate, textural class of the soil cover and water table depth. 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.

An appropriate land use planning based on adequate agricultural policy, which relies on land capability and suitability and water management practice addressing the protection of the ground water, is essential. This would help to prevent further pollution of the limited soil and water resources in Central Beqa'a.

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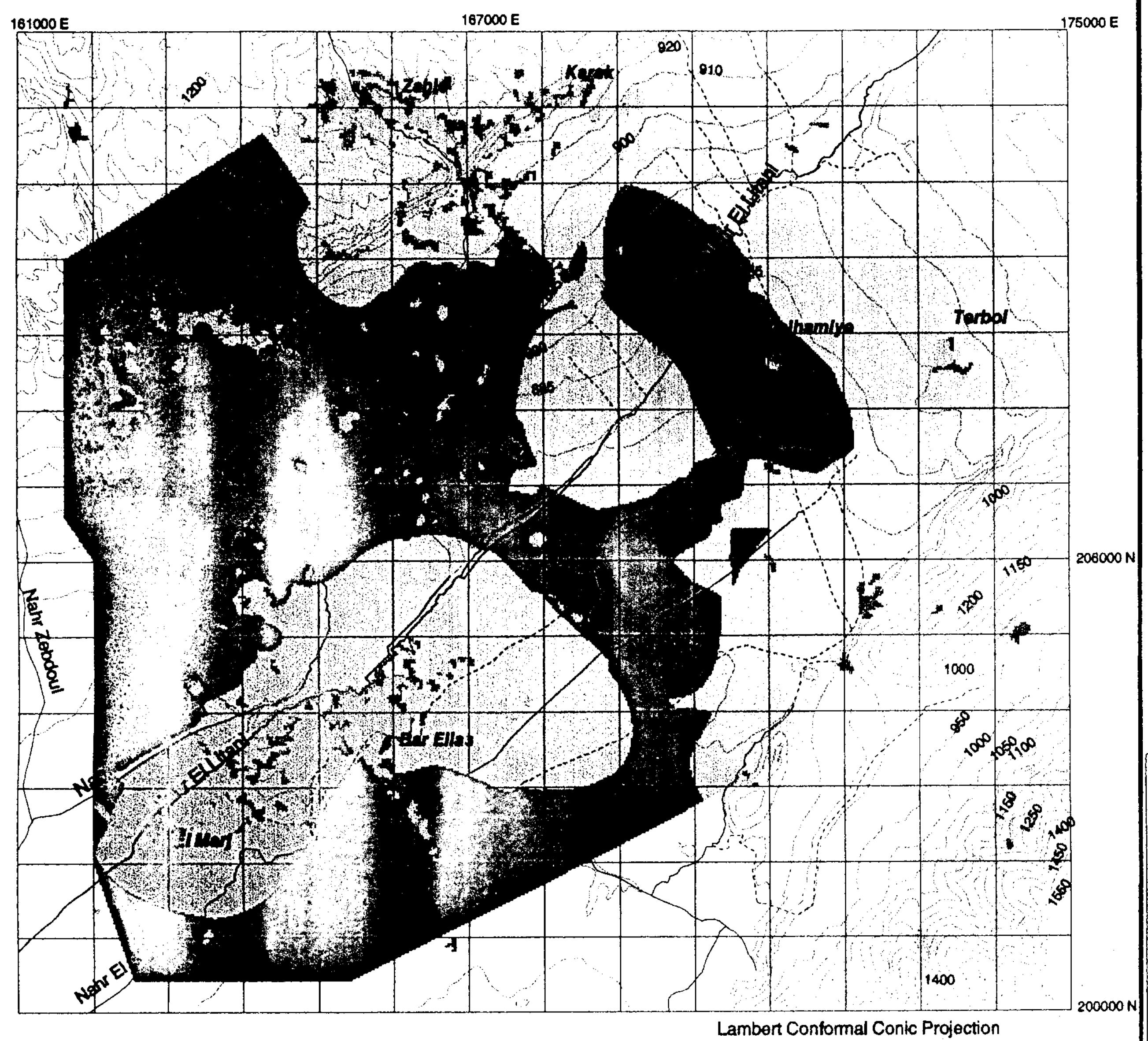

Zahle Project Pilot Area

(Soil Studies)

Protection Effectiveness of the Soil Cover

Legend

- Urban Areas 1984
- Urban Areas 1997
- Surface Water
- Drainage Network
- Contour Line
  Contour Interval 5 meter

Moderate	Low	
3-10 Years	1 - 3 Years	< 1 Year

Residence Time of Percolating Water in the Soil above the Aquifer (Water Table)

1 0 1 2 Kilometers

ARAB / GERMAN TECHNICAL COOPERATION

BGR Management, Protection and Sustainable Use of Ground Water and Soil

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Date : October 2000 - Beirut, Lebanon