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INVENTORY AND MANAGEMENT OF LEBANESE SOILS INTEGRATING THE SOIL GEOGRAPHICAL DATABASE OF EURO-MEDITERRANEAN COUNTRIES

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ABSTRACT

Land management and degradation are among central issues in the 21st century. Several international and local organizations deal with land vulnerability to desertification and have elaborated databases addressing soil information and thematic mapping. Among these are the Global and National Soil and Terrain Database (SOTER), the FAO dbase, the Georeferenced Soil Database for Europe. These procedures are workable at different scales. The FAO-dbase is a soil profile and laboratory database. The remaining methodologies are not strictly a cartographic tool but conceptual models with computerized structure of the data. But, while SOTER uses the available soil maps as support to build the database, the Soil Geographical database of Euro-Mediterranean Countries aims at preparing a geographic database by relegating the problem of the cartographic representation of data to a secondary position.

Extremely variable landform, lithology, climate and vegetation cover characterize the east Mediterranean including Lebanon. From the coastal strip to the high mountains different soil types are spread like Fluvisols, Cambisols, Vertisols, Luvisols, Regosols, Leptosols, and Calcisols. To build the soil database integrating the Euro-Mediterranean methodology, additional information was gathered from old studies of Lebanese soils run between 1950 and 1975. To complement the missing soil information reflecting the great variability of soil association, substantial fieldwork was recently undertaken for soil description and sampling. As a result, a new soil map of Lebanon at 1:1 M. scale was produced. The soil units were mapped using the lithology-landform association as separation criteria for the identification of soil entities. Both dominant and small typological units were maintained to reflect soil diversity and the need for differential land management. Beside the geometric dataset, the semantic dataset contains information on soil geomorphology, main physical and physico-chemical characteristics including land use, management practices and related problems. In this paper the work implemented to build a small scale, but comprehensive, soil database for Lebanon is reviewed. The paper discusses the database suitability for the assessment of current agricultural and environmental practices in relation *to climatic conditions and soil parameters. A detailed analysis of the state and impact of land degradation, potential of land resources in view of geomorphology, land capability, and land vulnerability to desertification is presented.*

Keywords: soil, land management, desertification, thematic maps

INTRODUCTION

With the increasing human pressure on limited land resources, the analysis of land system management and soil degradation gain exclusive interest. An important place is allocated to the impact of land degradation both on local and regional levels. Because the consequences of land degradation are not limited within national borders, response to land management counts across countries. In view of the Euro-Mediterranean partnership, integrating the soil information into the Soil Geographical database of Euro-Mediterranean Countries (Jamagne *et al.,* 2001; Lambert *et al*., 2003) seems crucial for the harmonization of efforts to combat desertification and reverse land degradation. The work program is facilitated by the availability of several databases addressing soil mapping and management. Among these we cite the Global and National Soil and Terrain Database (SOTER, 1995), the FAO dbase (Krone and Utermann, 1998), the Georeferenced Soil Database for Europe (Finke *et al*., 1998).

These procedures are workable at different scales starting from the 1:5 M. until 1:100.000 scale for the SOTER and from 1:1 M. till 1:250.000 scale for the other databases. The FAO-dbase is a soil profile and laboratory frame representing a tool for the organization of field and laboratory investigation. It allows the laboratory data storage and thematic tabular retrieval. The remaining methodologies are not strictly a cartographic tool but conceptual models with computerized structure of the data. Mapping is allowed through the use of traditional soil maps and description of the spatial relationship among objects involving the landform and geology. Building a digital database facilitates its application for major classes, environmental functions, and sensitivity to degrading influxes and land capability classification (Montanarella and Nègre, 2001).

But, while SOTER traditionally uses the available soil maps as support to build the database, with the related eventual loss of some information, the European methodologies aim at preparing a geographic database by relegating the problem of the cartographic representation of data to a secondary position (King *et al*., 1994). The transformation of the European soil map at 1:1 M. scale into database required additional archiving work to make the base operationally usable in European programs (Burrill and King, 1993). Thematic mapping is usually based on the agro-hydrologic model (soil and water assessment tool-SWAT), universal soil loss equation (USLE) and German concept on soil protection effectiveness (1994). Analyzing the soil vulnerability to contamination, impact of the environment and landuse change on water quality, predictive erosion and desertification hazards necessitate the retrieval of spatial data from the database, which allowed, for instance, predicting nitrates fluxes in the soil-groundwater system and elaborating mitigation scenarios (Laurent and Rossignol, 2004).

With the absence or weak implementation of landuse planning in several Mediterranean countries including Lebanon, this paper reviews the recent soil mapping to produce the new soil map of Lebanon and derived first soil database in the country using the Euro-Mediterranean methodology at 1:1 M. scale. Despite the small scale, the soil map and database maintained the small units to reflect the soil geomorphologic diversity and the need for a differential approach in land suitability and soil management. Thus, the database evaluates the possibility of using the proposed new geometric and attribute information to estimate the overall land capability, sensitivity of the ecosystems to erosion and desertification. The derived maps assist the elaboration and integration of national policies addressing the decision making on soil management and protection issues that can serve regional planning.

MATERIALS AND METHODS

Lebanon is located at the eastern part of the Mediterranean Sea and represents a mountainous country with Mediterranean type of climate varying from coastal dry to mountain sub-humid and inland semi-arid. The country represents a series of geomorphologic units ranging from level quaternary plains to sloping and steep mountains with alternating soft marl and hard limestone rocks. Basalt and sandstone are intruded here and there. The country is dissected by a series of major and minor faults that add to the complexity of the geomorphology. This variability in landform, mineral substrates and climate resulted in rich vegetation and yielded different soil units like Fluvisols, Cambisols, Vertisols, Luvisols, Regosols, Leptosols, and Calcisols in different associations and proportion.

With the absence of updated soil map of Lebanon, the elaboration of the soil-geographical database for the country used the published data and was mostly based upon extensive recent soil classification project that allowed the enrichment of the database with a detailed attribute data. During 1997-2001, soil mapping based on modern techniques (remote sensing, GIS) and large fieldwork was undertaken. It allowed the excavation of more than 400 profiles, which were described according to the FAO guide (1990) and sampled horizon wise. Samples were analyzed for their main physical and chemical characteristics according to Ryan *et al.,* (1996). Soil types were classified following the Keys to Soil Taxonomy (1996), FAO-Unesco revised Legend (1997) and WRB (1998).

The new soil map of Lebanon was produced keeping the small, non-mappable, soil units notably those complementing nested areas across national borders like the alluvial Bkaiya plain and Knaiceh basaltic plateau of northeast and Marjkhiam plain of South Lebanon. As separation criteria for entities the lithology-landform association was used to identify the soil typological and major mapping units. The database was built according to the Soil Geographical Database of the Euro-Mediterranean Countries, (Lambert *et al*., 2003). The database structure consists of geometric and semantic datasets. The geometric dataset describes the polygons and the soil mapping unit (SMU) they belong to. Each SMU must be composed of at least one soil typological units (STU) having a set of homogenous properties in a given space. When this occurs SMU is called pure unit. Generally one SMU consist of several STU forming soil association.

The semantic dataset links the STU with the SMU. The STU attribute data presents information on soil location, slope, minimal and maximal altitude, parent material, land use, fluctuation of ground water depth, limitation for agricultural use, water regime and water management practices. A given georeferenced and estimated soil profile data corresponds to each STU. The soil profile is described in the attribute database that contains measured and estimated soil data.

In addition to the soil physical and chemical characteristics, the measured data provide information on the depth of impermeable layer, rootable depth and other soil fertility and irrigability parameters. This soil profile database linked to the STU was used for the production of thematic maps on land capability, soil erosion and vulnerability to desertification.

RESULTS AND DISCUSSION

13 Soil Mapping Units (SMU) were identified in Lebanon (Table 1). Two of them consisted of one, pure, Soil Typological Units (STU), three SMU were formed from association of two STU, three SMU represented association of 3 STU, and five SMU consisted of more than 3 STU (Figure 1). The soils of the plains, except the semi-arid northeastern part of Lebanon, represent mainly deep Cambisols, the part of which varied between 35 and 45% of the area, Fluvisols (20-25%), Luvisols and Vertisols (15-20%), and Arenosols (10-15%). Eroded Luvisols, Leptosols and terraced Anthrasols dominate in the mountains. In areas with annual precipitation less than 250 mm Calcaric soil units and Calcisols dominate revealing the direct impact of climate on soil formation and evolution (Dudal and Pecrot, 1980).

Database information, soil conservation and land management
Land capability of the Lebanese territory

The land capability map, produced by combining several layers related to the geomorphology and soil characteristics (depth, texture, organic matter content, drainage and erosion rate), showed four main categories of lands (Figure 2).

Class I represents soils that have slight limitations restricting their use. These are arable lands characterized by a high productivity and spread in the Bekaa valley and coastal plains. Agriculture is dominant in these lands where fruit trees, field crops and vegetables are cultivated.

However, these lands are decreasing in surface due to chaotic urban expansion especially near large cities like Tripoli, Beirut, Saida and Tyr. On the coastal area of Lebanon, 200 Km length and 8 Km width, more than 24% of land is converted into concrete (Huyberts, 1997). Comparing the findings of the database with recent Landsat images from 2001 showed increased proportion of lands consumed by urban sprawl. Urban encroachment on productive lands is a problem faced by several countries. For instance, the use of remote sensing in North Lebanon showed that more than 60% of prime soils were converted into concrete (Darwish *et al*., 2004).

Class II represents soils that have moderate limitations reducing the choice of plants or require moderate conservation practices. These soils are spread in the center of the western Lebanese mountain chain and in South Lebanon. Agriculture is practiced in these areas where terraced fruit trees and vegetables are cultivated; terracing as traditional soil conservation practice is required on eroded soils spread on steep slopes.

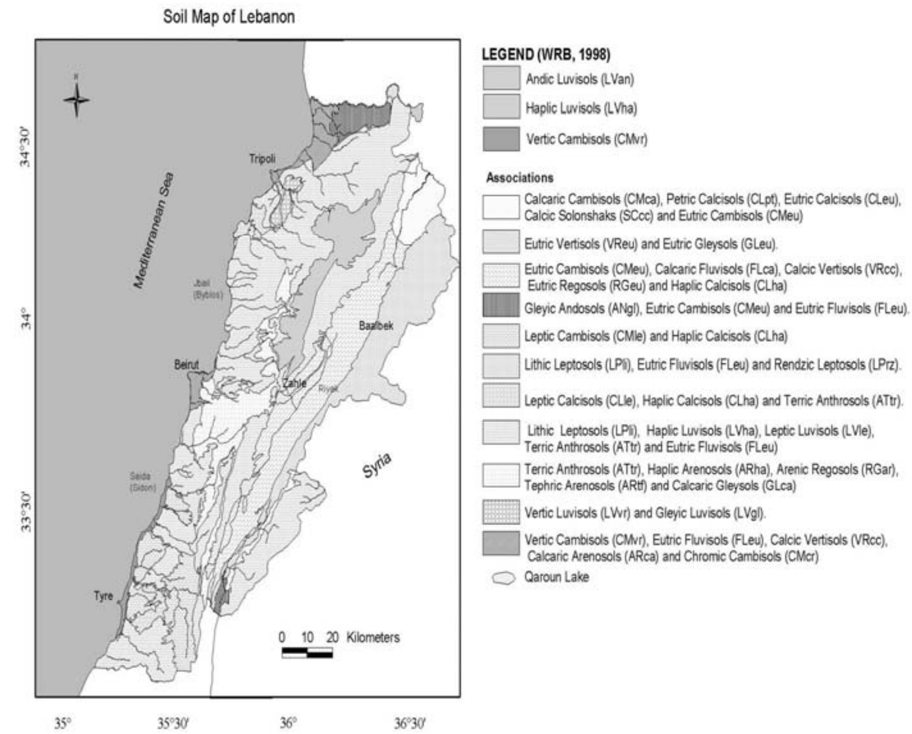

Figure 1. The new soil map of Lebanon at 1:1 M. scale produced using the latest International soil classification systems.

Class III represents soils that have severe limitations reducing the choice of plants or require special conservation practices, or both. These soils are widespread in northern Bekaa, the eastern Lebanese mountain chain and the coastal areas. The main areal distribution of these soils is in the arid and semi-arid areas characterized by low precipitations especially in Hermel areas. Consequently, water is the main limitation for agriculture. The Eastern mountain chain is characterized by the presence of shallow soils which represent a serious problem for agriculture. Landform and rockiness are the main other limiting factors for the development of sustainable agriculture. However, reclamation works to remove boulders and build terraces on slopes transform these lands into fruit orchards, notably in the depressions and fan deposits. Overgrazing and wind erosion are main two causes of land degradation in the area.

TABLE 1

Main Coded Attributes of a Part of the Soil Geographical Database of Lebanon

SMU	Number of STU	STU	Percent Cover SMU	WRB[1]	DOMINANT SLOPE[2]	MINIMAL ALTITUDE, m	MAXIMAL ALTITUDE, m	DOM. PAR-MAT[3]	DOM. USE[4]	AG-LIMI1[5]	DOM TEXT-SRF[6]	ROO[7]	IL[8]	WR[9]	WM1[10]
1	5	3	40	CMvr	1	0	30	5410	16	1	4	1	1	1	6
		8	20	Fleu	1	0	30	5410	16	2	4	1	1	1	6
		57	15	VRcc	1	0	30	5300	16	2	4	1	1	1	6
		2	15	ARca	1	0	30	5120	12	12	1	1	1	1	4
		6	10	CMcr	1	0	30	5410	16	1	4	1	1	1	6
5	5	145	35	CMca	1	700	1000	5820	16	2	1	1	1	1	2
		177	34	CLpt	1	700	1000	2140	16	6	2	4	4	1	4
		171	19	CLeu	1	700	1000	1110	16	1	2	1	1	1	4
		M.3	7	SCcc	1	700	1000	1110	12	2	1	1	1	1	4
		162	5	CMeu	1	700	1000	2111	16	2	3	1	1	1	2
6	2	99	50	LVvr	1	50	250	1110	17	1	2	1	1	1	2
		100	50	LVgl	1	50	250	1110	17	1	2	1	1	3	2
7	3	a10	80	LPli	2	1200	2400	2111	4	4	2	1	4	1	2
		a1	15	Fleu	1	1200	2400	5820	12	2	4	1	1	1	2
		a2	5	LPrz	3	1200	2400	5820	12	2	3	1	3	1	2
		221	10	CLha	3	750	880	5000	17	4	0	3	3	1	2

1. Classification by the World Reference Base for Soil Resources (1998);
2. Dominant slope: 1- level (0-8%), 2- sloping (8-15%), 3-moderately steep (15-25%);
3. Dominant parent material: 1110-conglomerates, 2111-hard limestone, 5000-Alluvium; 5120- Quaternary sand, 5300- fluvial sand and gravel, 5410- river clay and silt, 5820- colluvial deposit;
4. Dominant landuse: 4- Westland, 12- orchard, 16-vegetables, 17-olive tree.
5. Agricultural limitations: 1. no limitation, 2- high gravel content, 4- shallow soil, 6- petrocalcic, 12- excessive drainage.
6. Dominant surface texture: 0. No information, 1- coarse, 2-medium, 3-medium fine, 4- fine.
7. Obstacles for roots: 1-no obstacles until 80 cm depth, 3- obstacles for roots between 40 and 60 cm depth.
8. Impermeable layer: 1-no IL within 150 cm, 3- IL between 40 and 80 cm, 4-IL within 40 cm
9. Soil water regime: 1- dry within 80 cm for over 3 months, 3-wet within 80 cm for over 6 months.
10. Water management system: 2- no WM, 4- irrigation, 6- drainage.

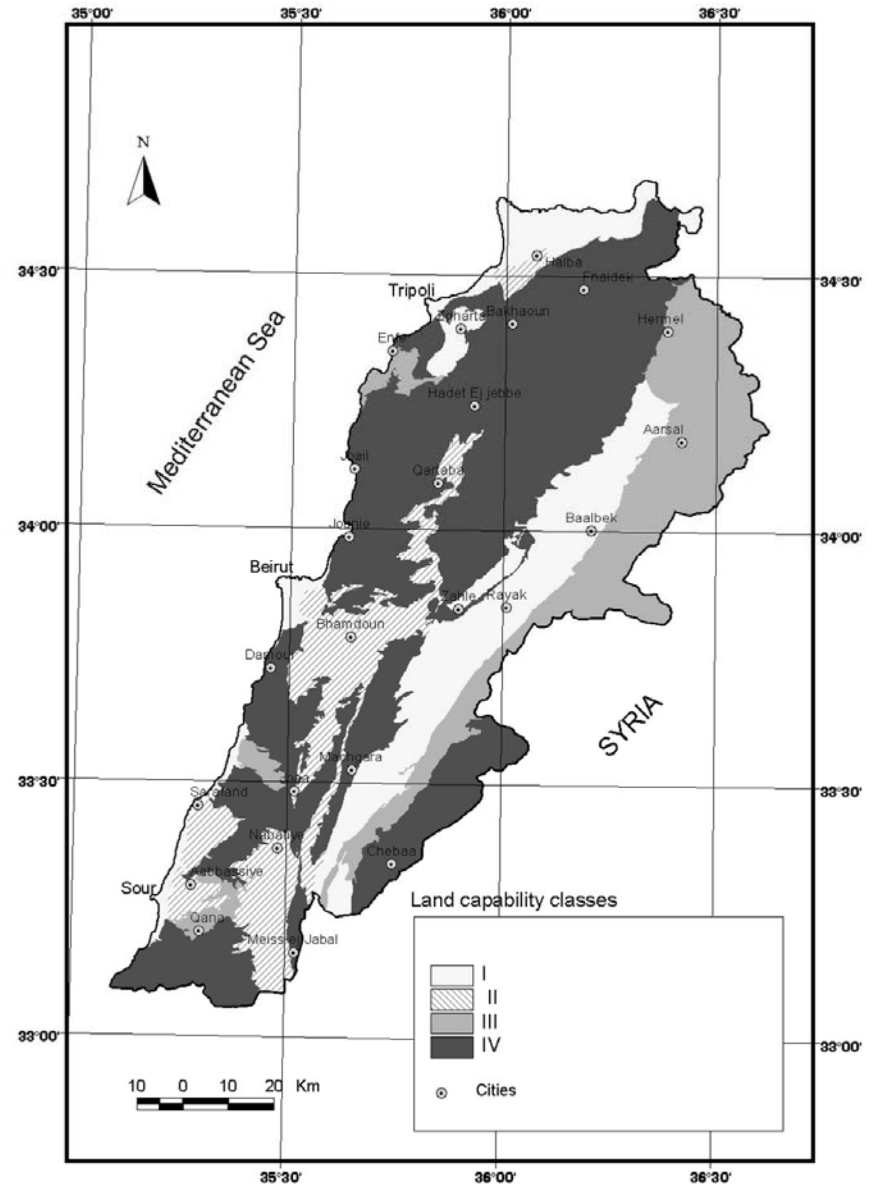

Figure 2. Land capability map of Lebanon.

Class IV represents soils that have severe limitations restricting the choice of plants or require very careful management, or both. These soils are spread mainly on the steep slopes of the western Lebanese mountain chain and the southern part of the eastern Lebanese mountain chain. These are marginal lands that can be safely used for forestry, recreation, urban expansion and wildlife. But, if terraced they become of better productivity and thus might be planted with fruit trees. But land reclamation requires large investment cost.

Land management on level plains

The main problems of soil management to combat land degradation in the STU of the SMU 1 and 13 identified on level plains are:

1. Land use of arable soils of the plains consists of fruit trees, cash field crops and vegetables. Increasing concern on deteriorating soil quality is due mainly to poor rotation and monoculture that usually result in secondary soil salinization, reduce yield potential and enhance soil born diseases (Darwish *et al*., 2005). Several workers have stressed the deterioration of land quality associated with the weak performance of the agricultural sector (Khatib *et al*., 1998; Atallah *et al*., 2000; Darwish *et al*., 2002, 2003). The state of the art on farming practice proves the necessity to introduce simple rotations consisting of field crops alternating with legumes and feed crops (Moeller *et al*., 2003).

2. Relating the fragile soil-groundwater system to the farming practice allowed the prediction of possible soil contamination as a result of mismanaged fertilizer input. A general practice in the region is the application of 500-600 kg N/ha/season under vegetables or irrigated field crops that could be hazardous in term of nitrate build-up in the soil and groundwater (Darwish *et al.,* 1999, 2004).

3. High water table in the spatial distribution of some soil types belonging to SMU 1 and 13 implies high vulnerability of the soil-groundwater system. The uncontrolled agricultural practice is coupled with a short residence time of nitrates leached towards the groundwater. In fact, increasing indications on nitrates buildup in the groundwater have been reported in the country (Halwani *et al*., 1999; Darwish *et al*., 2002). The torrential nature and uneven distribution of rainfall in the country aggravate the risks to groundwater quality.

4. Information on the type of water management systems permits to relate the possible impact of irrigation techniques and mismanagement of water input on soil quality and water use efficiency. For instance, the large use of conventional irrigation techniques like flooding and overhead sprinkler might cause a loss of water and nutrients. The monitoring of such problem using soil solution extractors at the end of a potato season showed a pick of leached nitrates at 100 cm under farmer's watering practice. Conversely, fertigation using drip irrigation techniques allowed for higher N recovery and agronomic water use efficiency (Darwish *et al.,* 2000).

5. The soil classification is accompanied by a series of landscape and soil indicators characterizing agricultural potential. These are slope gradient, limitations for agricultural activities (stones and gravels content, soil depth, salinity, erosion status, flooding hazards) and other soil properties (Table 2). Such detailed and comprehensive information allow for the integration and evaluation of the economic situation in the rural areas and crop optimal distribution and yields in connection with socio-economics and market conditions.

TABLE 2

Some Measured Physico-Chemical Properties of the Soil Retrieved from the Database

Country CY	STU N	Structure *	COLOR	Texture – Fractions %		OM, %	Total CaCO3, %	pH in water	Exchangeable Bases cmolc/kg				
				Clay	Silt				Ca	Mg	K	Na	BS
LB	1	5	7.5YR3/2	58	7.9	3.6	3	7.6	23.0	1.7	1.0	0.5	26.2
		5	7.5YR3/2	17.5	69	2.9	2	7.8	30.3	2.0	1.1	0.5	33.9
		5	7.5YR3/4	40	27	3.3	4	7.7	36.6	1.9	1.1	0.4	40.0
LB	2	5	7.5YR4/4	45	27	3.2	20	7.9	32.0	3.1	0.8	0.5	36.4
		5	7.5YR4/6	42.5	25.6	1.4	15	7.7	28.5	4.3	0.5	0.4	33.7
		5	7.5YR4/6	32.5	39.7	1.5	22	7.6	28.4	3.0	0.4	0.4	32.2
LB	3	5	10YR3/3	45	27	1.3	2	7.5	40.9	7.9	1.1	0.7	50.6
		4	10YR3/2	42.5	25.6	0.9	3	8.0	35.0	9.2	0.6	0.7	45.5
		4	10YR3/3	32.5	39.7	0.8	5	8.0	32.8	13.5	0.5	0.8	47.6
		5	10YR3/3	41	33.0	1.1	9	8.0	43.8	17.5	0.9	0.5	62.7
LB	4	8	10YR4/2	18	26.0	3.0	31	7.4	22.3	3.1	0.5	0.3	26.2
		8	10YR4/4	17	20.0	1.0	31	7.8	22.1	2.7	0.3	0.3	25.4
		8	10YR4/3	16	1.3	0.7	26	7.9	21.5	7.6	0.3	0.2	29.6
		8	10YR4/3	15	2	0.3	33	8.0	21.8	4.3	0.2	0.2	26.5
LB	5	5	7.5YR3/4	33	4.7	4.6	5	7.8	27.1	2.3	0.7	0.4	30.5
		4	7.5YR3/2	46	37.0	2.7	7	7.8	34.8	2.3	1.0	0.4	38.5
		4	7.5YR3/4	54	39.5	3.3	4	7.9	22.9	2.6	0.8	0.5	26.8
		5	7.5YR4/4	46	26.1	4.7	11	8.0	46.8	2.3	0.9	0.5	50.5

* Structure: 4-angular blocky; 5- subangular blocky; 8- massive

Soil inventory and problems in the semi-arid zone

On the other hand, the mismanagement of Eutric and Petric Calcisols and Calcaric Fluvisols of the SMU 5 classified under semi-arid climate by copying the same production practice of the more humid areas, increased secondary soil salinization. Locally, salinity reached critical values for field crops (Khatib *et al.,* 1998) and resulted in the local appearance of solonchaks in the area. Land abandonment leads to undesired socio-economic results. Knowledge of water regime, available from the database, as well as the water management systems and rootable depth, would alleviate the impact of soil salinity. Integrating the soil vulnerability with the appropriate choice of crop sequence and irrigation practice in view of climatic demands allow preventing such soil deterioration trends.

Management of the mountainous lands

Concerning the SMU of the Lebanese mountain chains, the main problem of the soil cover remains water erosion. Information provided on landform and parent materials allows assessing the potential risk of erosion in connection with soil texture, presence of impermeable layer, vegetation cover and climate. Moreover, the actual erosion rate could be assessed based on the data provided in the directory on dominant and secondary parent material, soil types and the percentage of the area of each soil typological unit. This is especially pressing in the Eastern Mountains (SMU 7) and in the karstic areas (SMU 9) with dominant Leptosols (Table 1).

The assessment of soil water erosion in the karstic region using remote sensing and GIS techniques allowed building a model to assess the potential and actual soil erosion risks (Faour *et al.,* 1999). It was based on soil erodibility, rock infiltration capacity and landform, rainfall erosivity and land cover-land use. The output map showed that 88% and 6% of central Lebanese lands are having medium and high actual erosion risk respectively (Bou Kheir *et al.,* 2001). Defining the areas subject to erosion-deposition hazards helps elaborating preventive and remediation measures and scenarios for more sustainable land uses.

Extrapolating the results to the eastern Lebanese mountains, with bare lands and almost no vegetative cover could mean 100% of highly vulnerable lands to water erosion. Indeed, this area is subject to regular flash flood causing extreme damage. Estimates based on biophysical parameters indicate that only 25% of lands in North Africa and Europe and 33% of lands in Lebanon (Table 3) belong to the class of soils with low vulnerability to desertification. Research for better land resources management with special care to socioeconomic aspects is a prerequisite to reduce pressure on sustainable landuses. Remote sensing revealed to be a powerful and workable tool to derive indicators of country vulnerability to desertification (Khawlie and Faour, 2003).

Impact of desertification risks on landuse planning

Desertification is a complex phenomenon resulting from several climatic, soil and vegetation factors. The soil depth, organic matter content, structure and water reserve capacity are main indexes characterizing the soil behavior and resilience to changing climate and type of vegetation. Combining the soil and climatic factors showed more than 80% of the Lebanese territory to be prone to desertification (Figure 3). More than 55% of soil resources in Central and Western Bekaa and on the coastal strip are subject to low water and nutrient holding capacity, seasonal and long moisture deficit. About 10% of lands spread in Baalbeck-Hermel area are subject to severe moisture deficit and salinization.

The western aspects of the Central mountain chain are distinguished by a low vulnerability to desertification. However, it is expected to become the most populated area. A proper settlement policy and a gradual introduction of more tolerant wood species, which are less susceptible to dryness, and the improvement of water harvesting practices appear to be prominent in view of greening efforts.

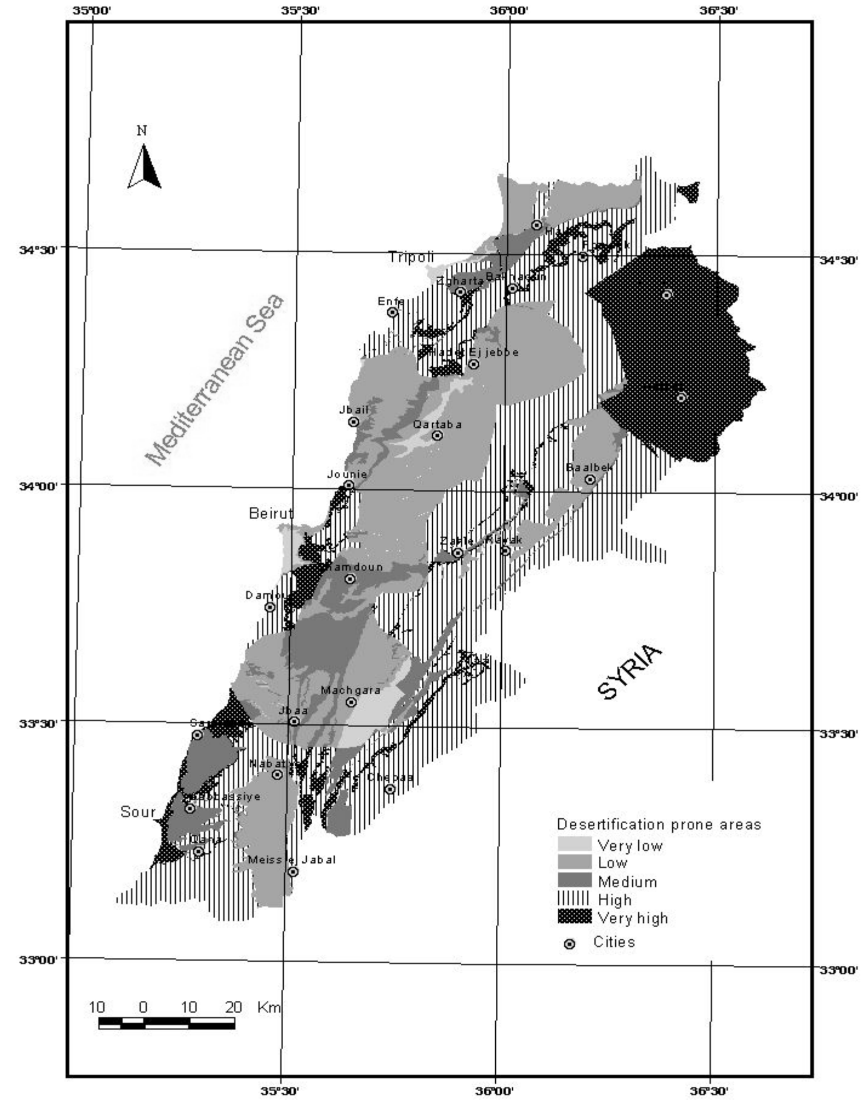

Figure 3. Desertification map of Lebanon.

TABLE 3

Areas Vulnerable to Desertification in the Regions with Xeric Soil Moisture Regime

Vulnerability class	**North Africa-Europe Eswaran and Reich (1999)**		**Lebanon**	
	Area, Km^2	% of total area	Area, Km^2	% of total area
Low	659900	24.8	3452	33.0
Moderate	797000	29.9	4800	45.9
High	1167800	43.4	1600	15.4
Very High	5500	0.2	600	05.7
Humid area are not vulnerable	36000	1.3	0.0	0.0
Total	2666000	100	10452	100

Desertification risk puts more pressure on limited soil and water resources. Excess irrigation with increasing water demands will deteriorate water and soil quality. Updating the database by monitoring the major changes in land use patterns provides the ground for the elaboration of scenarios oriented to prevent further loss of prime lands. Such extrapolated output represents a relevant material for the decision-makers to facilitate land use planning and propose guidelines to support land management.

CONCLUSION

Using the information of the soil geographical database at 1:1 M. could be beneficial in term of assessing the inventory of main soil resources, managing their potential productivity and problems, and directing the attention towards the fragile agro and ecosystem. Areas prone to desertification by chaotic urban sprawl and low ago-practices and regions vulnerable to land degradation are highlighted that promote the participatory approach and allow the decision-support system to draw prevention and remediation measures.

Information provided on soil formation factors like parent material is coded and the database offers the type of rocks. Knowledge of the parent material typology and lithology is important for the estimation of the drainage conditions at the subsoil system level that affect water run-off, soil vulnerability to water erosion and the groundwater contamination risks.

The sustainability of current land use is assessed in view of soil potentiality and capability from soil parameters like depth, texture and other physico-chemical properties. Water regime and textural change with depth are important factors to predict soil workability, and manage crop water balance. Rootable depth and other limitations for agriculture dictated by soil conditions allow for the elaboration of rehabilitation plans. Geographical and tabular information provided by the database allow deriving the agricultural potential of land resources and highlighting a comprehensive overview on soil management. However, the main implementation of such database, dictated by the small scale, could be the integrated national and regional planning based on main soil geomorphologic, agronomic characteristics and interactive degradation trends. Nevertheless, elaborating a soil database with larger scale still remains a necessity for future national and regional efforts

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