Chapter 6
Land Evaluation Interpretations and Decision Support Systems: Soil Survey of Abu Dhabi Emirate

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Abstract The soil survey of Abu Dhabi Emirate was completed in two stages, the extensive (4th-order level) and intensive (2nd-order) levels of USDA-NRCS classification system. Both surveys have generated an enormous amount of primary soils data that is now available to land use planners and decision-makers in the Emirate. The soil information provides farmers, land managers, planners and the like with baseline information upon which they can base future land use and environmental management decisions and policies. As such, the information can be regarded as a great asset for future generations of the UAE. The information is stored in the Abu Dhabi Soil Information System (ADSIS) database that has been designed to provide ready online access to users. In its raw form, the majority of the soil data is only usable by specialist soil scientists and geoscientists. Land evaluation methods provide a mechanism for the soil information to be synthesised, simplified, interpreted and presented to a far wider audience. Several land evaluations were conducted on the extensive and intensive data sets generated by the soil survey of Abu Dhabi

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Emirate. They included assessments to identify soils suitable for the generalised land use irrigated agriculture, which was subsequently used to delineate areas for more detailed examination in the intensive survey. Assessments of other land uses including afforestation, range management, recreation, urban development, construction material and sanitary landfill were also conducted. These assessments can be used to identify the potentials and limitations of soils for the different land uses. However, a more detailed analytical and modelling approach is required to extract the full worth of the data set and solve complex management issues such as sustainable irrigation practices for intensive agricultural development in the Emirate.

Keywords Abu Dhabi Emirate • Land evaluation • Soil survey • Decision support systems • ADSIS

6.1 Introduction

Land evaluation as a discipline is originated from the realisation that mapping of natural resources alone does not provide sufficient information on land use and its consequences. Hence, the voluminous amount of primary soil information collected by the soil survey can only tell part of the story. Further, much of the data is only relevant to specialist soil scientists and geoscientists, therefore restricting the broader application of this valuable wealth of data.

Land evaluation provides a mechanism for the soil information to be synthesised, simplified, interpreted and presented to a far wider audience and, in so doing, expands the utility of the soil data. Land evaluation provides an added dimension to basic resource studies by relating the characteristics of soil, plants and climate to the requirements of different kinds of land use.

This chapter presents a history of the development of land evaluation methodologies internationally and how they can be applied in the Abu Dhabi Emirate context. It will then highlight the land evaluation interpretations undertaken by the soil survey of Abu Dhabi Emirate and discuss their practical application to land use decision-makers in the Emirate. Finally, suggestions for future analysis of the comprehensive data set will be discussed.

6.2 Methods

6.2.1 Soil Survey

The extensive soil survey of Abu Dhabi Emirate was conducted at the fourth-order level at a scale of 1:100,000 according to the standards of the United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS). The Abu Dhabi soil survey results are reported in final publications (EAD 2009a). The extensive soil survey identified the soil families and phases of families and their distribution in the Emirate. The survey objectives included providing a scientific inventory of the Emirate's soil resources, interpreting those soil resources for their suitability for different uses, identifying land with the greatest potential for irrigated agriculture and developing a soil database in a GIS environment. The extensive soil survey area consists of 5.74×10^6 ha covering most of the Emirate but excluding area already used and non-accessible areas.

The subsequent intensive soil survey was conducted in order to develop a more detailed soil map and associated interpretations for 447,906 ha identified from the extensive survey. The survey was undertaken as a second-order survey at a scale of 1:25,000 (EAD 2009b). Four subareas were surveyed including an area extending from Al Ain in the eastern region to near the city of Abu Dhabi (198,596 ha) and three areas in Abu Dhabi's western region, namely, Madinat Zayed (116,146 ha), Ghayathi (105,355 ha) and As Sila' (27,809 ha).

6.2.2 Soil Information System

The information generated by the soil survey is stored in the Abu Dhabi Soil Information System (ADSIS). The ADSIS is a web-based system that facilitates the storage, retrieval, interpretation, analysis and presentation of soils information. The system was developed for the project after consultation with local users and a comprehensive review of existing soil information systems elsewhere in the world.

The ADSIS provides access to all the soil data and interpretations generated during the survey, plus additional functionality to allow users to examine and extract information to suit their individual needs. Users are able to view both the raw soils data and the extensive range of maps that were compiled during the soil survey. This includes being able to select a particular map generated (e.g. one of the soil maps or the map showing suitability for irrigated agriculture), zoom in to select a geographic area of interest and then view the detail for the map units in that area. Maps can be generated based on the data from the 22,000 sites across the Emirate examined during the extensive survey and 33,000 sites in the four subareas surveyed (Fig. 6.1) during the intensive survey. Figure 6.1 also shows the distribution of survey sites across the Emirate (extensive survey).

The ADSIS has a number of analytical tools including thematic map generation, symbolisation, statistical analysis and data extraction. The ADSIS provides output as maps or text and can be delivered to a printer, plotter or external digital file for use in other applications.

6.2.3 Techniques for Assessing Complex Map Units

The soil map units defined for the extensive and intensive surveys generally consisted of several components. In order to generate a thematic map or conduct any sort of land evaluation, it was necessary that each soil map unit delineation has a single rating index. Therefore, criteria to process a map unit with multiple components were required.

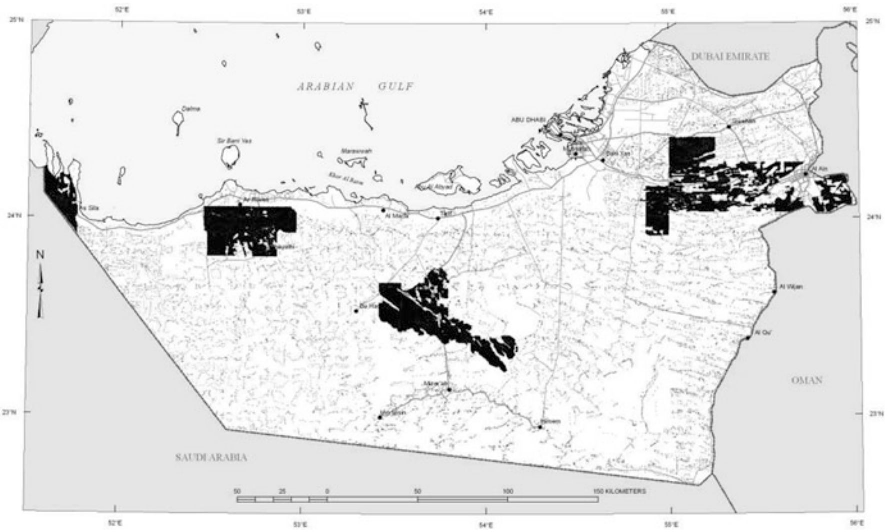

Fig. 6.1 Distribution of 22,000 observation sites for extensive survey and location of four subareas for intensive survey (Abu Dhabi Emirate)

Methods used for this included:

- Dominant rating by percent
- Weighted average of major components
- Presence/absence of a soil property

The dominant rating by percent is allocated to map units as follows:

Step 1: A map unit is selected, and the component soils are listed with their rating and the proportion they make up of the map unit.
Step 2: Starting with the lowest rating (e.g. 1), the soil components with that rating are identified, and the percentages of those are summed.
Step 3: Step 2 is repeated for all ratings.
Step 4: The rating associated with the highest of the summed percentages calculated in steps 2 and 3 is allocated to the map unit as the dominant rating by percent.

Steps 1–4 are repeated for all other map units.

The weighted average method allocates ratings to map units as follows:

Step 1: A map unit is selected, and the component soils are listed with the numeric value of the property under consideration and the proportion they make up of the map unit.
Step 2: For each component, the product of the numeric value of the property under consideration and the percentage of that component are found.
Step 3: The products calculated in step 2 are summed and then divided by 100 to give a weighted average.

Step 4: The weighted average is related to a predefined set of ranges (e.g. EC 0–1.99 is rated as 1 and EC 2–3.99 is rated as 2) and the appropriate rating allocated to the map unit.
Steps 1–4 are repeated for all other map units.

The presence/absence method allocates ratings to the map units as follows:

Step 1: A map unit is selected, and the component soils are listed with the property under consideration being rated as present or absent (as calculated using the rules and criteria) and the proportion they make up of the map unit.
Step 2: Soil components that are shown to have the property as present are identified, and the percentages of those are summed.
Step 3: The calculated percentage area is related to a predefined set of ranges (e.g. 0–9.9% is rated as 1 and 10–19.9% is rated as 2) and the appropriate rating allocated to the map unit.
Step 4: Steps 1–3 are repeated for all other map units.

These techniques allow land evaluations to be conducted on a single rating value per map unit and have been used in all the interpretations (EAD 2009a, b).

6.3 Discussion

The process of estimating the potential of land for one or more kinds of land use is known as land evaluation. Land evaluation as a discipline originated from the realisation that mapping of natural resources alone does not provide sufficient information on land use and its consequences. Land evaluation allows the characteristics of soil, plants and climate to be related to the requirements of different kinds of land use, that is, the requirements of land use are compared with the qualities of the land for a given land use.

Several land evaluations of both agricultural and nonagricultural land uses were undertaken on the 1:100,000 extensive and 1:25,000 intensive scale map data compiled during the soil survey of Abu Dhabi Emirate. These evaluations portray various land management scenarios in the Emirate and serve as base information for land use planning and land management decision-making. These evaluations are only as good as their level of abstraction and do not negate the need for detailed on-site investigation that is a prerequisite for any detailed land use planning.

The land evaluation interpretations conducted on the soil survey data are physical land evaluations. Physical land evaluation assesses the performance of specific land uses in terms of constraints imposed by land but does not consider economic and sociological factors or the influence of existing infrastructure. Performance is rated using a suitability index. Land suitability can be defined as the fitness of a given type of land for one clearly defined homogenous activity. This may be either a major use such as irrigated agriculture or a more specific land utilisation type such as a cropping system in a specific biophysical, technical and socio-economic setting.

Table 6.1 FAO land suitability classes (FAO 1983)

Suitability class	Definition
S1	*Highly suitable* land with no significant limitations to the specified use
S2	*Moderately suitable* land with moderate limitations to the specified use
S3	*Marginally suitable* land with severe limitations to the specified use
n1	*Currently unsuitable* land with severe limitations which cannot be corrected with existing knowledge and technology
n2	*Permanently unsuitable* land with severe limitations which cannot be corrected

The suitability may be determined with respect to the current condition or may suggest potential suitability if components of the system were changed.

In general, land suitability classification schemes currently in use internationally have applied the concepts developed by the Food and Agriculture Organization in its framework for land evaluation (FAO 1976). The FAO system is generally considered a benchmark for land evaluation. The framework does not in itself constitute an evaluation system but is a set of principles and concepts on which the basis of local, regional and national evaluation systems can be constructed. The FAO system has been used as the basis for specific land evaluation applications such as rainfed agriculture (FAO 1983), extensive grazing (FAO 1984a), forestry (FAO 1984b) and irrigated agriculture (FAO 1985). Unlike the USDA land capability classification system (Klingebiel and Montgomery 1961), the FAO framework does not contain preconceived judgements about qualities of land in relation to specific land uses nor any proposed hierarchy of those land uses.

The FAO land suitability classes are listed in Table 6.1. In addition to the suitability class, subclasses indicating the most restrictive characteristics or qualities are noted. These subclasses explain the type of restrictions for a specified land use and assist in identifying management options required to rectify the restriction.

6.3.1 Assessment for Irrigated Agriculture

One of the primary outputs of the extensive soil survey was the identification of areas having the highest percentage of potentially arable and irrigable soils in the Emirate, in order to delineate areas suitable for development of irrigated agriculture. This interpretation of the extensive survey identified the most suitable 1,000,000 ha of land in the Emirate. Of this 1,000,000 ha, 447,906 ha was selected for further investigation at the intensive 1:25,000 scale.

Factors taken into consideration in selecting land for irrigated agriculture in Abu Dhabi Emirate include:

- Profile depth and deep drainage because of the brackish nature of much of the irrigation water available.
- Avoidance of poorly drained areas having a limited capacity to dispose of excess irrigation water.
- Soils need to be permeable in the surface and have deep, free draining subsoil material capable of sustaining a desired leaching fraction.
- Salinity values in the root zone should be below 4 dS m^{-1} ECe or have the potential, via leaching, to be reduced to this level.
- Highly gypsic soils (>10% gypsum) should be avoided due to the risk of subsidence under irrigation as the gypsum is dissolved from the soil.
- Sandy soils require careful water management because of their low water-holding capacity. Sandy surfaces may be susceptible to wind erosion; therefore, wind breaks, mulches and vegetative ground covers are encouraged.

These factors were embedded in the criteria used to assess areas suitable for irrigated agriculture in Abu Dhabi. The criteria (EAD 2009a, b) are presented in Table 6.2. They represent a refinement on criteria previously developed for other surveys in the region including soil surveys of the Kingdom of Saudi Arabia (Ministry of Agriculture and Water 1985), Sultanate of Oman (Ministry of Agriculture and Fisheries 1990) and the State of Kuwait (KISR 1999).

The evaluation results (EAD 2009a, b) reveal that only 2,000 ha or 0.04% of Abu Dhabi has soils rated highly suitable for irrigated agriculture and capable of producing sustained high yields for a wide variety of climatically adapted crops. The landscape needs to be nearly level, with well-drained soils that are characteristically deep, fine sandy-textured or finer and single-grained structure allowing easy root penetration and retention of abundant air and water in the root zone. The soils have low soluble salts, sodicity, gypsum content, calcium carbonate content and a neutral pH.

309,000 ha or 5.40% of Abu Dhabi is moderately suitable for irrigated agriculture. These soils have sandy texture and are single grain or massive structure. They are deep and somewhat excessively or well drained. They are typically very slightly saline, non-sodic, have low gypsum content and can have a hummocky microrelief.

1,550,000 ha or 27.09% of the Emirate is marginally suitable. The soils are moderately deep with a hardpan or water table occurring within 100–150 cm of the soil surface. They have sand to sandy loam textures and are single grained or massive. They are typically slightly saline and have moderate gypsum contents. These soils occur on moderately steep gradient (up to 32%) with moderately high relief (up to 9 m).

$1{,}753 \times 10^3$ ha or 30.63% of soils in Abu Dhabi are currently unsuitable for irrigated agriculture. These soils typically have shallow rooting depths with hardpans within 50–100 cm of the soil surface, high gypsum content close to the surface or high relief (up to 30 m) and steep gradient (up to 56%). These soils have severe limitations that may be corrected with appropriate management strategies.

Table 6.2 Land suitability rating criteria for irrigated agriculture in Abu Dhabi (EAD 2009a)

Soil characteristic	Sub-class mode	Rating categories (see text for details) S1	S2	S3	N1	N2	Restrictive feature	Definition
Hard pan or rock depth (cm)	m	>200	200 to >150	150 to >100	100 to >50	50 to 0	Restrictive layer	Impervious soil or rock layers inhibit movement of water or roots in soil
Water table depth (cm)	w	>200	200 to >150	150 to >100	100 to >50	50 to 0	Wetness	Soil is wet during the period of desired use
Salinity (ECe dS/m) weighted average for 0 to 50 cm	z	0–4	>4 to 8	>8 to 16	>16 to 40	>40	Excess salt	Excess water-soluble salts in the soil that restrict the growth of most plants
Salinity (ECe dS/m) weighted average for 50–100 cm	z	0 to 4	>4 to 8	>8 to 16	>16 to 40	>40	Excess salt	Excess water-soluble salts in the soil that restrict the growth of most plants
Gypsum – depth to upper boundary of gypsic diagnostic horizon (cm)	y	>200	200 to >100	100 to >50	50 to >20	20 to 0	Excess gypsum	Excess gypsum can result in soil subsidence after irrigation
Texture for surface 0 to 25 cm	t	LS, LFS, LVFS, FS	S				Too sandy	The soil is soft and loose, droughty and low in fertility
Texture for surface 0 to 25 cm	t	SCL					Too clayey	The soil is slippery and sticky when wet and slow to dry
Slope gradient (%)	s	0 to 1	>1 to 3	>3 to 32	>32 to 56	>56	Too steep	Slope limits machinery use and exacerbates erosion risk
Relief – height above surrounding area (m)	r	0 to 1	>1 to 3	>3 to 9	>9 to 30	>30	Too high	The height restricts the ability to re-contour the area

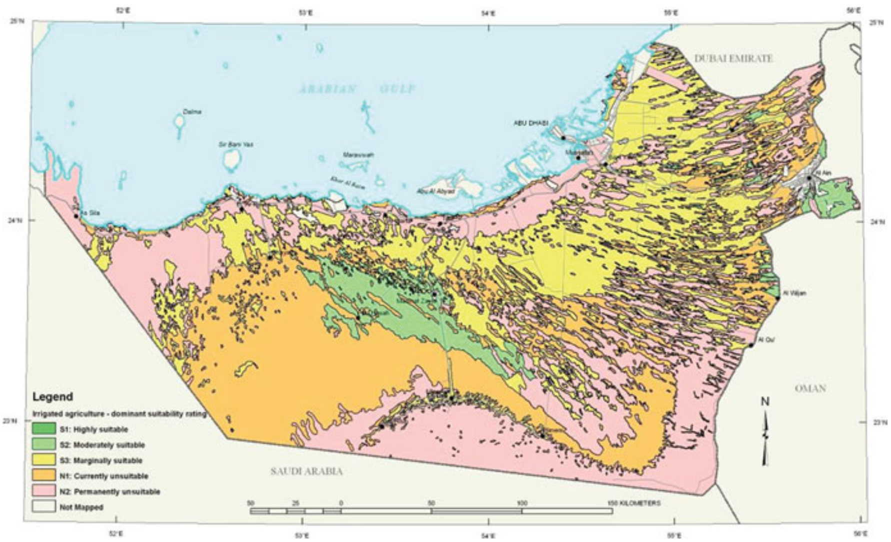

Fig. 6.2 Suitability for irrigated agriculture (EAD 2009a)

Finally, $2{,}109 \times 10^3$ ha or 36.84% of soils in Abu Dhabi are permanently unsuitable for irrigated agriculture according the prescribed criteria. These soils are generally very shallow; occur with rock outcrops, on very steeply sloping land (over 56%); having very high relief (over 30 m); are very poorly drained and strongly saline; or have shallow depth to gypsum. These soils do not warrant further investigation for irrigation purposes.

Well-drained Torripsamments and Haplocalcids with good deep drainage are the preferred soils for irrigated agriculture in Abu Dhabi. Other soils containing low quantities of gypsum and calcium carbonate may also be suitable; however, deep drainage must be adequate to remove excess irrigation water and facilitate the removal of excess salt through leaching. In areas where impermeable layers underlie the aeolian sands at a shallow depth, there is a risk that rising saline water tables may develop. The morphology of the sand dunes is a further constraint to the utilisation of these otherwise suitable soils. Dune levelling is a feasible, though expensive, management option in these areas.

The remainder of the soils in Abu Dhabi is considered unsuitable for irrigated agriculture due to the shallow depth to hardpan (lithic subgroups, Petrogypsids and Petrocalcids), high salinity (Aquisalids and Haplosalids) or shallow depth to gypsum (Haplogypsids).

The distribution of areas suitable for irrigated agriculture is shown in Fig. 6.2. The most suitable areas for irrigated agriculture (green-shaded areas in Fig. 6.2) in the Emirate include a large elongated area of undulating sands running northwest to southeast, lying to the south of Madinat Zayed. A second area is located east of Jebel Hafeet. Other smaller areas lie near Al Ain and Al Wijan. Extensive areas of marginally suitable land (yellow-shaded areas) occur inland from the coastal plains from the northeast of the Emirate, westwards to Sabkhat Matti.

6.3.2 Other Land Evaluations

The soil survey of Abu Dhabi Emirate (EAD 2009a, b) undertook several other land evaluation interpretations including assessments of soil and land properties that impact on land use, including salinity in two soil layers (0–50 cm and 50–100 cm), shallow water tables (shallower than 200 cm from the soil surface) and shallow hardpans (or rock). Potential construction and other material resources that were evaluated included gypsum, gravel, clay, calcium carbonate, sand, sweet soil and anhydrite. Assessments of land degradation were made based on criteria developed for Abu Dhabi Emirate's desert conditions. Other land use suitabilities included broad-scale assessments of rangeland, wildlife habitat and forestry. Finally, assessments were made for landfill disposal. These interpretations are not exclusive. They were targeted at the immediate needs of Emirate land managers. Future pressures for development in the Emirate will necessitate new and enhanced evaluations and interpretations of the comprehensive data sets.

6.3.2.1 Soil Salinity

Evaluations of soil salinity were made for the 0- to 50-cm and 50- to 100-cm layer depths to provide information throughout the rooting zone of most shallow-rooted crops. The assessments are based on electrical conductivity of the soil saturation extract (ECe). High concentrations of neutral salts, such as sodium chloride and sodium sulphate, may interfere with the absorption of water by plants because the osmotic pressure in the soil solution is nearly as high as or higher than that in the plant cells. Salts may also interfere with the uptake of nutrient ions, thereby causing nutritional deficiencies in plants.

The EC values measured in the field (EC 1:1) were used to calculate an average EC value (weighted for horizon thickness) for the first two 50-cm layers of soil at each site. EC values (1:1) were converted to ECe by multiplying with a factor of 3. These values were then used to calculate the median ECe value for the 0- to 50-cm layer and 50- to 100-cm layer for each investigation site. The weighted average method was then used to calculate an ECe value for each map unit, which was then categorised according to the ranges specified in Table 6.3.

The results of these assessments on the extensive survey data set for 0- to 50-cm and 50- to 100-cm layer are shown in Figs. 6.3 and 6.4, respectively. The maps show that highly saline soils (purple-shaded areas) are confined to the coastal plain and areas of deflation plain and inland sabkha where groundwater levels approach the surface, creating large areas of Aquisalids. These soils are unsuitable for all plants except salt-tolerant halophytes or most other land uses. The coastal flats extend several kilometres inland in a band from Abu Dhabi City westwards to Sabkhat Matti. Other saline areas (red- and pink-shaded areas) include the low-lying area of Sabkhat Matti, the sabkha flats amongst the mega barchan dunes around Liwa and many of the deflation plains in the east and southeast of the Emirate. Surface salt

Table 6.3 Salinity categories (EAD 2009a)

Rating categories	Electrical conductivity (ECe dS/m)	Yield restriction
Nonsaline	0 to <2	Salinity effects mostly negligible
Very slightly saline	2 to <4	Yields of very sensitive crops may be restricted
Slightly saline	4 to <8	Yield of many crops restricted
Moderately saline	8 to <16	Only tolerant crops yield satisfactory
Strongly saline	16 to <40	Only a few very tolerant crops yield satisfactory
Very strongly saline	40	Halophytes are the only option
Total		

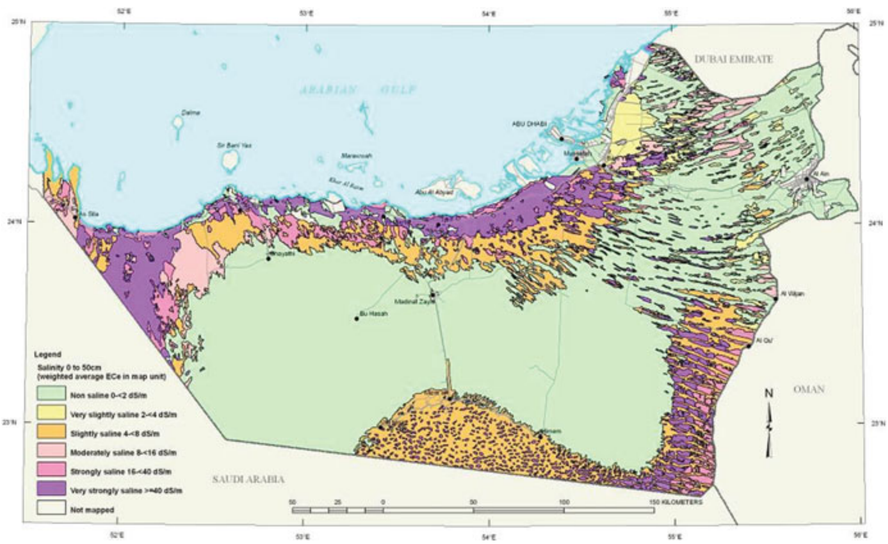

Fig. 6.3 Salinity in the top 50 cm of the soil profile (EAD 2009a)

crusts were observed on most sabkha surfaces but were thicker and more widespread in coastal locations and in Sabkhat Matti.

6.3.2.2 Construction Materials

Soils are a potential source of material for a wide range of applications in the construction industry. However, different applications such as road base, bricks and cement have their own unique requirements, and relatively few soils have profile characteristics that meet defined criteria and performance standards for specific purposes.

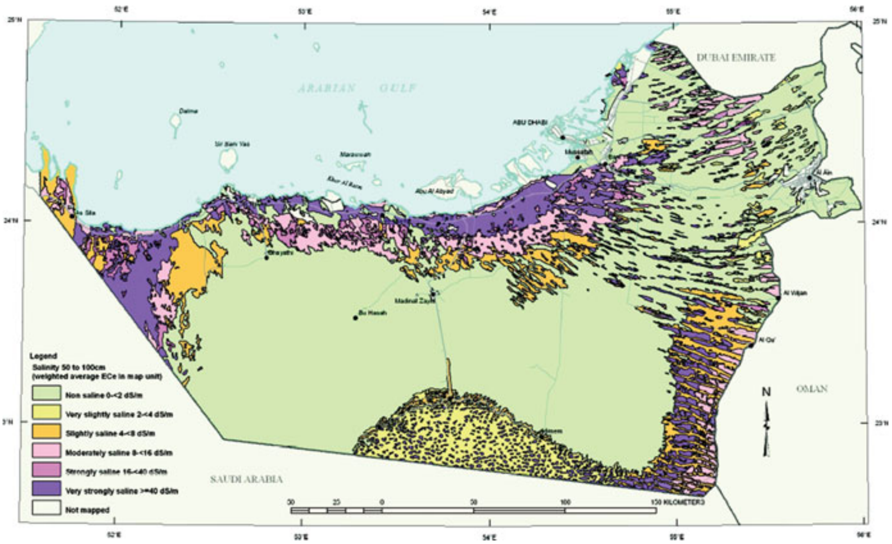

Fig. 6.4 Salinity in the 50 to 100-cm soil layer (EAD 2009a)

The soil survey results provide a useful guide for selecting potential sources of construction materials for further evaluation. Each soil was rated in its existing condition. Assessments were made against a number of criteria including soils as sources for sand, sweet soil (suitable for agriculture and landscape purposes), clay, carbonate, gravel, road-fill and topsoil. Suitability ratings of good, fair or poor and restrictive features were given for soils used as a source of sweet soil, clay, road-fill and topsoil. Ratings of probability based on presence or absence of suitable material in soils rated as a source of sand, carbonate and gravel. Such assessments are useful when looking for stockpiling materials for borrow pits and land reclamation; source material used to rehabilitate areas of soil disturbance; and cover material for parking areas, roads, tracks and other uses.

These assessments help to minimise the need for random exploratory investigation by pinpointing potential areas. Final site evaluation and selection requires field inspections of the areas to quantify the suitability of the materials for the intended purpose. Ultimately, individual soils or groups of soils may be selected as potential source materials because their source is close at hand, is the only source available or meets some or all of the physical or chemical properties/composition required for the intended application.

The assessment of gravel sources serves to demonstrate the utility of the information. For the purposes of the evaluation (EAD 2009a), gravel as a construction material is defined as particles ranging in diameter from 4.76 mm (sieve no. 4) to 75 mm. Gravel is used in great quantities in many kinds of construction, and the specifications for each purpose vary widely. The intent of the assessment undertaken in Abu Dhabi was to show the probability of finding material in any given map unit. The suitability of the gravel for specific purposes is beyond the scope of the data set and requires follow-up targeted site assessment.

Table 6.4 Frequency of occurrence of potential gravel sources (EAD 2009a)

Rating categories: % of map unit area with gravel 'present'
None or rare (0–9.9%)
Low probability (10–29.9%)
Moderate probability (30–49.9%)
Common (50–100%)
Total

The assessment for gravel source was based on the presence/absence method. It assessed the likely occurrence of coarse fragments in the appropriate size range, or the presence of rock that may be crushed to produce gravel. Thus, gravel was evaluated as being present, if:

1. Family particle size class is skeletal.
2. Suitable rock is assessed present using the following criteria:
   (a) Component is rock outcrop or the subgroup is lithic.
   (b) Bedrock kind is conglomerate, calcareous sandstone, claystone, dolomite or limestone.

For each map unit, the percentages of the components with gravel present were summed to obtain the percentage presence for the map unit. Table 6.4 describes the classes to which each percentage presence of gravel was allocated.

Figure 6.5 depicts the distribution of gravel sources in Abu Dhabi against the categories specified in Table 6.4. The majority of soils found across the Emirate are Typic Torripsamments developed in windblown sands, a process not conducive to the accumulation of gravels. In some areas, deflated sands have led to a surface accumulation of fine gravels that then protect the underlying sand from further erosion. This surface lag probably represents an accumulation from a considerable thickness of sand and rarely is it representative of a significant gravel source deeper within the soil profile. The only areas of significant gravel accumulation (green-shaded areas) in the Emirate occur in the far west near Sila and in the east and southeast. At Jabal Hafit, the surrounding piedmont plains contain large stones and boulders nearer to the mountain with more gravel-sized material further from the mountain. These limestone gravels are often intermixed with darker-coloured gravels washed down from the Oman Mountains. Smaller quantities of fine gravels were also recorded on the various deflation plains between Sweihan and Al Ain and south around Al Wijan and Al Qu'. However, deep drilling data indicated that these occurrences are relatively thin.

6.3.3 Modelling and Decision Support Systems

Whilst the various land evaluations reported in the final report (EAD 2009a, b) and highlighted above serve to enhance the soil survey data, they do not go into the next realm of predictive interpretation or modelling, specifically crop modelling and

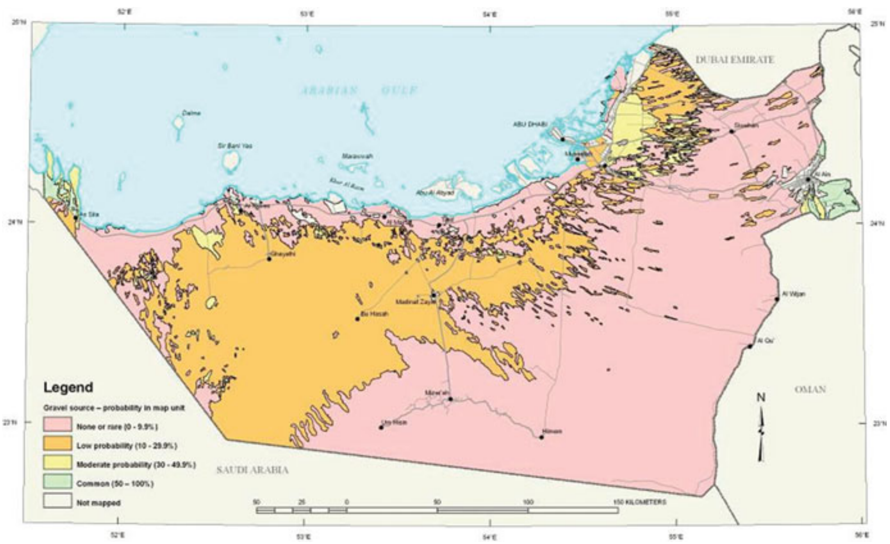

Fig. 6.5 Gravel sources (EAD 2009a)

irrigation management for agricultural planning purposes. This leap can be achieved by combining the survey's comprehensive soil data sets with climatic information and crop characteristics/requirements to generate (1) crop potential modelling, resulting in a quantifiable assessment of crop suitability and yield determination; (2) crop water requirement (which combined with crop areas determines irrigation water requirements); (3) economic assessments/scenario planning; and (4) ultimately some form of decision support system (DSS) designed to better manage agricultural and irrigation development against multiple objectives including maximisation of profit, optimisation of water use and/or deriving environmental benefits. The author of this chapter developed and applied such an approach in Uttar Pradesh (UP), India, in the development of a DSS for the Uttar Pradesh Irrigation Department (UPID) to better plan and manage the ageing state irrigation infrastructure (SMEC International Pty. Ltd. 2005a, b). The DSS developed for the UPID allows decision-makers to review alternative planning scenarios or options and make informed decisions and develop solutions to complex and competing land uses and the allocation of scarce water resources.

The approach used in UP calculates an achievable yield which then in turn provided base line data for an economic appraisal of land use and future land use patterns, which in turn drove water demand. The PlantGro™ model was commissioned to undertake this task. It used soil and climatic information, matched with crop requirements to assess crop suitability and compute achievable yields for selected crops.

The assessment of crop water requirements is required for carrying out water balance computations and quantifying irrigation requirements for various cropping patterns and crop rotations. Crop water requirements for selected crop types in the Ghaghra-Gomti Basin in Uttar Pradesh were determined from the FAO CropWat model and ET-DSS. CropWat and ET-DSS are essentially decision support systems in their own right. CropWat was developed by the Land and Water Development Division of FAO for planning and management of irrigation (FAO 1998, 1999a and 1999b). It was designed as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements and the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions and the assessment of production under rainfed conditions or deficit irrigation.

Calculations of crop water requirements and irrigation requirements in CropWat are carried out with inputs of climatic, crop and soil data. Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO (1977, 1979). CropWat uses the Penman-Montieth (FAO 1993) method for calculating reference crop evapotranspiration. CropWat can also be used for developing irrigation schedules and irrigation practices using various options for water supply and irrigation management. As such, it could be used for detailed planning of irrigated agriculture in Abu Dhabi.

The DSS-ET is a software package for estimating reference crop evapotranspiration (Swarnakar 1999). The DSS-ET allows assessment of time-series data sets against some 20 ET methodologies. It also appraises the suitability of input data and ranks the performance of various ET assessments against the data, before calculating ETm for all suitable methods.

Assessment of potential crop production is integral to the development of a DSS, because potential crop production or yield is the driver for irrigated water use. It is also linked to environmental issues such as fertiliser leaching and water body eutrophication, pesticide/herbicide leaching and subsequent water body contamination. The assessment of potential crop production provides (1) a measure of crop production which is unlikely to be exceeded however good management may be; (2) a benchmark against which to measure current production levels and estimate the scope for improvement; (3) a uniform assessment that can be used to compare the relative performances of parts of a catchment or study area; (4) a way of defining the suitability of the present crop production systems and identifying presently unrecognised opportunities for crop production; and (5) a basis for determining cropping patterns and crop water use.

Considerable effort has been devoted around the world to developing methods for land evaluation for crop production. They have resulted in a number of systems that estimate plant productivity by taking land characteristics and matching them with the requirements of crops to estimate suitability for plant production. In FAO's agro-ecological zones (FAO 1978), the methodology uses a two-step process involving (1) estimating potential (constraint free) productivity and (2) estimating the effects of constraints in reducing productivity below its defined potential. The work in UP followed the FAO methodology. It combined estimates of potential biomass and yield with a crop response function methodology for estimating limitations to crop production imposed by land characteristics. The framework is implemented as a computer model called PlantGro™ (Topoclimate Services 2005).

PlantGro™ attempts to quantify crop response to climatic and edaphic factors using the simple plant response function approach developed by Hackett (1991). It takes plant, soil and climate information and produces (1) limitation ratings for plant productivity based on the known (or estimated) plant responses to the soil and environmental factors believed to influence productivity and (2) an estimate of achievable yield obtained by reducing the potential yield in proportion to the greatest limitation rating during the growing season.

PlantGro™ provided a level of sophistication in crop modelling appropriate for the DSS of the Ghaghra-Gomti Basin. It does not have the considerable data requirements of more detailed crop simulation modelling. The model, whilst simple enough to be readily used, makes use of the very large store of existing information about crop requirements. It estimated achievable yield for a specific crop and calculated the climatic and soil limitations associated with a particular soil or land unit. Output from the model provided input to the DSS and other project assessments such as agricultural economics.

PlantGro™ was a suitable tool for the work in UP. It may also have application in Abu Dhabi given that the methodology is universal, that is, it matches measured environmental and soil properties with crop response, to the best resolution of the data. However, at some level of assessment, and for some very detailed applications, the approximations inherent in the biomass calculation and in the semi-quantitative limitation rating may mean that more mechanistic simulation models, such as the CERES set of crop simulation models formatted by IBSNAT into the DSSAT package, are required to give more realistic results. For these models to be used, their demanding data requirements need to be met, and the ability to calibrate mechanistic simulation models against experimental data will need to be attained. Such a level of sophistication may or may not be warranted in the Abu Dhabi context.

6.4 Conclusions

There is considerable potential to significantly add value to the results of the soil survey of Abu Dhabi Emirate with land evaluation interpretations. Land evaluation has the ability to integrate disparate disciplines, all the time building on the primary data sets, enhancing the utility of the information and widening the potential audience for the information. The land evaluation process is explicit, using rules and criteria to make a decision. These criteria can be modified as new information becomes available or to investigate alterative scenarios. Land evaluation has the ability to produce land use planning results and scenarios in its own right or to provide input to more thorough analysis such as the development of detailed DSS capable of conducting multiple objective evaluations to maximise profits, optimise water use and/or derive some form of environmental benefit for a biological or cropping system.

In order to analyse the complex and voluminous amount of data captured by the soil survey of Abu Dhabi Emirate in an integrated land evaluation exercise, it is imperative to have the necessary tools and techniques. The techniques and interpretations conducted on the Abu Dhabi soil data sets generate useful information for regional assessment and planning. They enhance the raw soils data and provide a perspective on restrictions or suitability for the particular land uses. However, they are by no means site-specific and do not eliminate the need for detailed on-site investigation. Further, there are many land evaluation tools available that can be applied to elevate the analysis of the soil survey results to a predictive level and, in so doing, aid in complex land management decision-making and planning in the Emirate.

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