Chapter 1
Innovative Thinking for Sustainable Use of Terrestrial Resources in Abu Dhabi Emirate Through Scientific Soil Inventory and Policy Development

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Abstract Abu Dhabi is the largest of the seven emirates that comprise the United Arab Emirates (UAE). The total area of the UAE is about 82,880 km^2. Abu Dhabi Emirate occupies more than 87% of mainland plus a string of coastal islands extending into the Arabian Gulf. The Emirate's leaders and population have a close affinity with the land and believe that careful agricultural development will be an important part of its future destiny and should be undertaken on a sustainable basis. With this aim, fourth-order extensive survey of Abu Dhabi Emirate was initiated in 2006 and completed in 2009. The field survey was completed through investigating 22,000 sites covering 5.5×10^6 ha, supplemented with typical profiles description,

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laboratory analyses of soil samples, deep drilling to explore deep terrestrial resources, infiltration, permeability, and penetration resistance measurement. The survey was designed to take advantage of the latest technologies such as geographic information system (GIS), satellite image processing, and statistical analysis to produce *state-of-the-art* soil products. Sixty-two families and phases of soil families and 114 soil map units have been identified. The information were then used to publish soil map (1:100,000 and 1:500,000 scales) and 20 thematic maps at 1:500,000 scale. Using the extensive survey results, irrigated suitability map was prepared that led to delineate 1 million ha area, from which an area of 447,906 ha was surveyed at second-order level of USDA. The information collected will serve as a guide for future research and help to develop strategies that reduce the negative impact of the human activities on the natural surroundings and assist in the wise and sustainable use of its natural resources. In this chapter, methodologies used for extensive survey and results are presented and discussed for various uses. A brief introduction of the Abu Dhabi Soil Information System (ADSIS) developed to host all data for future retrieval, upgradation, and uses is also given, and policy issues are discussed.

Keywords Abu Dhabi • ADSIS • Extensive survey • Irrigated suitability • Soil map

1.1 Introduction

Soil inventory provides information used to facilitate a variety of natural resource planning, development, and implementation activities. Soils, by their nature, are a complex feature of the landscape with different soil properties changing at different rates. Soil surveys can be undertaken by using various survey orders at a variety of scales of final map production. These "orders" of soil survey are defined by Soil Survey Division Staff (1993) and include a range of site observation intensities applicable to the end-use requirements of the soil survey.

The purpose of extensive soil survey of Abu Dhabi Emirate was to have a comprehensive set of digital soil information to aid in broad land use planning and agricultural expansion in the Emirate. The technological advances in remote sensing, computers, terrain analysis, geostatistics, GIS data integration, and instrumentation were expected to make it possible to achieve unprecedented reliability and utility in the digital soil maps. Sound scientific and technical standards based on the United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) were used in the soil classification system, nomenclature, interpretation, and publications. These standards have been used in more than 75 countries of the world and in Gulf Cooperation Council countries such as the Kingdom of Saudi Arabia (MAW 1985), Sultanate of Oman (MAF 1990, 1993a, b, c), State of Kuwait (KISR 1999), and State of Qatar (Scheibert et al. 2005). A comparative soil classification using USDA and FAO systems for Abu Dhabi coastal area is discussed by Abdelfattah and Shahid (2007). A unique anhydrite soil has been discovered by Shahid et al. (2007) in the coastal area of Abu Dhabi Emirate and has now become the focus of change in US Soil Taxonomy at four different levels (EAD-ICBA-USDA 2011). In the past, little information was published on Abu Dhabi soils, and the pioneering efforts have recently been made to describe soils of Abu Dhabi Emirate (Shahid 2007; Shahid et al. 2007; Shahid and Abdelfattah 2008).

The survey was completed in two phases. Phase 1 was the extensive survey of the entire emirate (EAD 2009a), a fourth-order survey (1:100,000) based on the norms and standards of the USDA-NRCS (modified to fit Abu Dhabi conditions) intended to generate soil, thematic, suitability, salinity, and current land use maps (1:100,000; 1:250,000, and 1:500,000). From the interpretation of the phase 1 results, a soil suitability map for irrigated agriculture was prepared that led initially to identify 1 million ha with the highest potential for irrigated agriculture. Later, from this million ha, 447,906 ha was selected for phase 2 – an intensive, second-order survey at a scale of 1:25,000 on a grid basis; the results are presented elsewhere (EAD 2009b). A Soil Information System was included in the project to provide storage, processing, retrieval, and management of soil-related information for the use of a wide range of purposes. Rigorous quality assurance and quality control procedures were built into all aspects of the project with the Project Technical Support team closely monitoring the operations of the project team. A final quality control measure was the implementation of an independent review of the project in November 2008 by two highly experienced soil surveyors from USDA-NRCS. The rigor of the project was endorsed by their announcement that the project met and/or exceeded USDA standard field mapping procedures and data collection protocols.

The extensive survey is the first major soil survey to cover the mainland area of Abu Dhabi Emirate. A smaller soil survey was undertaken in 2004 that covered the coastal area (ERWDA 2004), and the results were incorporated with the new mapping. Preliminary work by the soil survey team began in May 2006 with analysis of remote-sensed satellite imagery (Landsat™) accompanied by targeted field work. The resulting overview of Abu Dhabi Emirate provided a broad categorization of the soils and landscapes and helped to guide the subsequent field survey operations and facilitated an understanding of soil-landscape relationships.

In this chapter, extensive survey results are discussed on a broader scale, including different landscape regions, generalized soil map and soil classification, current land use map and irrigated suitability map, and management issues.

1.1.1 Introduction to Survey Area

The UAE is in the southeast of the Arabian Peninsula and adjacent to the Arabian Gulf (Fig. 1.1). It borders Oman and Saudi Arabia. The total area of the country is about 82,880 km^2, of which Abu Dhabi is the largest of the seven emirates and accounts for 87% of the country's total landmass (National Media Council 2007). The Emirate lies between latitude 22° 29 N and 24° 53 N and longitude 56° 10 E and 51° 37 E. The extensive soil survey area consists of the entire Emirate of Abu Dhabi excluding the urban, industrial, and restricted areas and offshore islands. The total area covered in this survey was 5.5×10^6 ha excluding the coastal survey area, or 5.72×10^6 ha including it.

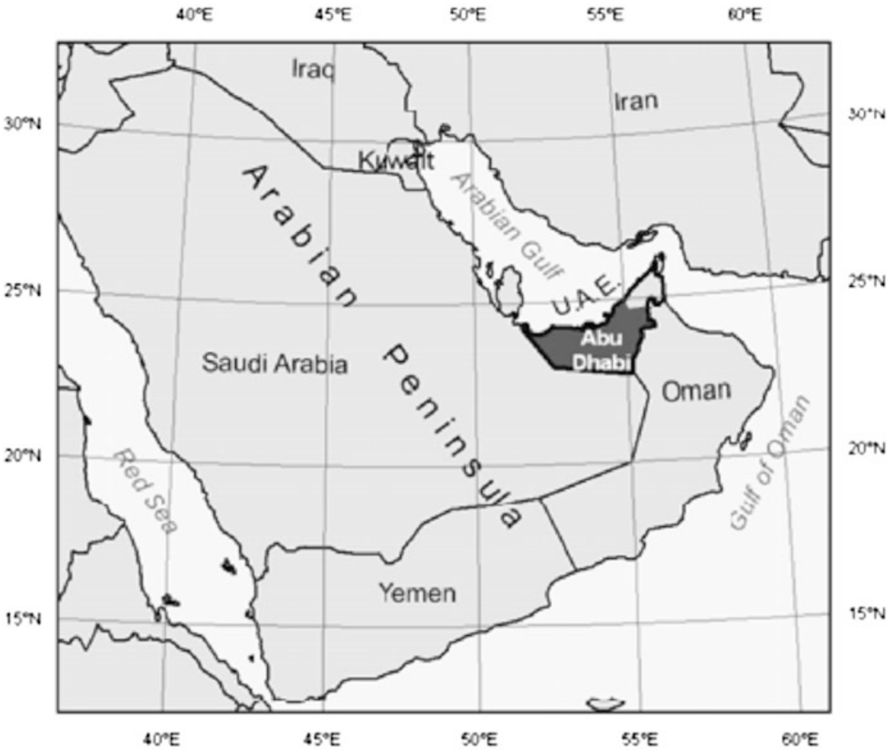

Fig. 1.1 Location of the Emirate of Abu Dhabi

Most of the land in the survey area is owned by the Emirate, with some farms near Madinat Zayed, Liwa, Al Qu', and Al Wijan being privately owned or controlled. There are extensive areas of land designated as oil field concession areas. Generally, only the active oil field areas have any infrastructure development, which is mostly restricted to oil wells, pipelines, gathering centers, and processing facilities. Rangeland and nomadic grazing of camels is the predominant land use, while a significant area is used for irrigated farming. Major concerns in managing the soils for irrigated agriculture are excessive drainage, poor nutrient-holding capacity, salinization, and encroachment of sand across the extensive survey landscape. Scanty protective vegetation has been excessively grazed by livestock, resulting in most of the soil surfaces in Abu Dhabi now being susceptible to wind erosion.

1.1.1.1 Geology

Geologically, Abu Dhabi shares the northeastern corner of the Arabian platform with Oman and has remained relatively stable for millions of years. The Emirate has remained in tropical and subtropical environments since the end of the Paleozoic

Fig. 1.2 Sand dunes and agriculture activities

though it has experienced a variety of climates significantly different to that of today. The surficial geology is dominated by sediments, predominantly eolian dunes, of Holocene and Pleistocene age. Outliers of the Hajar Mountains occur in the eastern parts of the Emirate, displaying the only true hard rock outcrops that occur in the Emirate. The oldest formations in the Emirate are represented by the salt diapirs of the Hormuz Formation seen at Jabal Az Zannah and a number of the offshore islands (e.g., Sir Bani Yas). These diapirs represent Cambrian materials that have been extruded through fissures in overlying materials as a result of the weight of overlying rock. Other minor occurrences of pre-Permian materials have been recorded on the eastern margins of the Emirate to the east of Jabal Hafit. Jabal Hafit comprises limestone and marls of Tertiary age that have been compressed and folded in the formation of the Hajar Mountains. The remainder of the Emirate is dominated by extensive sand and gravel plain with a thick blanket of eolian sand dunes (Fig. 1.2) formed by the prevailing wind.

1.1.1.2 Climate

The climate of Abu Dhabi Emirate is arid with extremely harsh and dry summers. The soil temperature regime of most of Abu Dhabi can be regarded as hyperthermic (Soil Survey Staff 2006). A prolonged dry summer of very high temperatures extends from April to November, followed by a mild to warm winter with a little rainfall between December and March. The wettest month is February, which receives an average of 24.4 mm (Table 1.1). Rainfall in the summer months is close

Table 1.1 Monthly climate characteristics of Abu Dhabi

Month	Mean daily temperature (°C)	Mean daily minimum temperature (°C)	Mean daily maximum temperature (°C)	Mean monthly rainfall (mm)	Monthly extreme rainfall (mm)	Mean monthly evaporation (mm)	Mean maximum monthly evaporation (mm)	Mean hourly wind speed (knots)
January	18.6	12.8	24.3	11.1	68.1	140	276	6.5
February	19.8	14.1	25.6	24.4	202.4	160	364	7.8
March	22.6	16.4	29.1	17.9	109.1	241	576	8.0
April	26.6	19.5	34.1	7.7	56.2	298	556	7.5
May	30.9	23.1	39.1	0.2	4.8	394	613	7.5
June	32.8	25.4	40.8	0.0	0.0	367	575	7.5
July	34.7	28.2	42.2	0.9	18.2	376	613	7.5
August	35.0	29.0	42.6	0.2	3.6	376	603	7.7
September	32.6	26.1	40.4	0.0	0.0	308	502	7.0
October	28.9	22.3	36.3	0.2	5.4	264	446	6.3
November	24.5	18.2	31.0	1.4	18.4	181	311	6.0
December	20.5	14.7	26.4	8.4	54.9	139	294	6.1
Average/total	27.3	20.8	34.3	(72.4)	(541.1)	(3,244)	(5,729)	7.1

Data adapted from Raafat (2006). Evaporation data from an unnamed site. All others represent 24-year data from Abu Dhabi International Airport to zero. Evaporation rate in all months exceeds rainfall many times over. Even during February, evaporation averages 160 mm – more than six times the likely rainfall. This ratio of evaporation to rainfall rises to nearly 400 to 1 from May to August. Around the rest of the Emirate, rainfall typically decreases to the south and west and increases toward the north and east.

1.1.1.3 Geomorphology and Landforms

The landscape of the Emirate is diverse, ranging from level coastal plains and sabkha to undulating desert sand plain; extensive areas of linear, transverse, and barchan sand dunes; and a single mountainous rocky outcrop, Jabal Hafit. This outcrop rises to 1,163 m in the eastern part of the Emirate. It is a mountainous outlier of the Hajar Mountains in neighboring Oman. In the south, the mega-barchans of the Liwa Crescent rise 250 m above the surrounding landscape interspersed with almost level deflation plains and flats. This area forms the northern tip of the Rub' al-Khali, or Empty Quarter of the Arabian Desert, that extends southward into Saudi Arabia. In the west, Sabkhat Matti represents an extensive sabkha formation.

The geomorphology and geology, combined with time and climate, are the main factors that influence the distribution of soils in Abu Dhabi Emirate. Understanding geomorphology is therefore useful in understanding soil patterns. While the current arid climate suggests that wind erosion is the dominant force shaping the geomorphology, this has not always been so. The extensive fold movements that created the Hajar Mountains in neighboring Oman, for example, have left outliers at Jabal Hafit that were eroded by water during the Pleistocene period. Such wetter phases also led to the creation of extensive sand and gravel alluvial fans, remnants of which are still found around the mountain.

Corresponding sea level changes have led to the development of sabkha (salt flats), coastal terraces, and minor scarps (including mesa-like features). The eolian processes of recent millennia have dominated the evolution of today's landscape. A number of dune-forming periods probably occurred in the last 20,000–30,000 years, and older dunes now contain cores of sandstone.

1.1.1.4 Vegetation

Until recently, studies of vegetation within the Emirate of Abu Dhabi were confined to those undertaken by amateur botanical or natural history groups. While the local Bedouin had an intimate knowledge and understanding of the flora, it was only in the later twentieth century that information on the local vegetative became more widely available. More than 667 species of plants are now known from the UAE and adjacent areas of Oman. However, many areas of the Emirate have a naturally sparse vegetative cover due to the harsh climate, and this sparsity of vegetation has been further degraded through overgrazing. Rapid changes in vegetation patterns can occur due to the erratic pattern of annual rainfall.

Table 1.2 Total water production in Abu Dhabi Emirate in 2001

Source	Mm^3 $year^{-1}$	% of total
Falaj	12.0	0.38
Municipal wellfields	12.26	0.39
Forestry wellfields	362.38	11.60
Agriculture wellfields	1,741.43	55.72
Other wellfields	104.85	3.35
Desalination	742.41	23.76
Treated wastewater	149.89	4.80
Total	3,125.22	100%

Source: Dawoud (2008)

Vegetation mapping in the Emirate of Abu Dhabi (EAD 2009a) revealed 11 natural vegetation map units (*Acacietum* 0.3%, *Cyperetum-Haloxyletum-Zygophylletum* 22.7%, *Cyperetum-Tribuletum* 17.3%, *Cyperetum-Zygophylletum* 31.3%, *Halophyletum* 0.7%, *Haloxyletum-1* 9.7%, *Haloxyletum-2* 2.1%, *Panicetum* 1%, *Rhazyetum* 0.5%, *Zygophylletum-1* 0.7%, *Zygophylletum-2* 3.6%) and two modified communities (urban and disturbed area 2.2% and areas of plantations, farms, and oases 0.5% and areas devoid of vegetation 7.4%).

1.1.1.5 Agricultural Activities

Many forestry projects were established to shelter around cultivated areas and simply "green the desert." The main crops have been the traditional dates plus Rhodes grass and alfalfa (lucerne) as fodder supplements for livestock. Small areas of food crops such as vegetables and melons continue to be developed using water from underground sources.

1.1.1.6 Water Resources

Abu Dhabi has no rivers or lakes. Until the last two or three decades, water requirements were obtained from groundwater delivered from traditional hand excavated wells often via man-made channels. These wells now supply an insignificant amount of the total needs with the main water production coming from various wellfields using deep bores powered by mechanical pumps and supplemented by desalination and wastewater treatment plants (Table 1.2).

Groundwater resources are predominantly brackish or saline (Fig. 1.3). Due to intensive use of these groundwater resources, many aquifers are showing annual declines in groundwater levels of 1–2 m. At current abstraction rates, it is projected that fresh and brackish groundwater resources will be depleted in 50 years. Agriculture is the largest consumer of water resources (56% in 2006), followed by forestry and domestic use. Water use continues to increase.

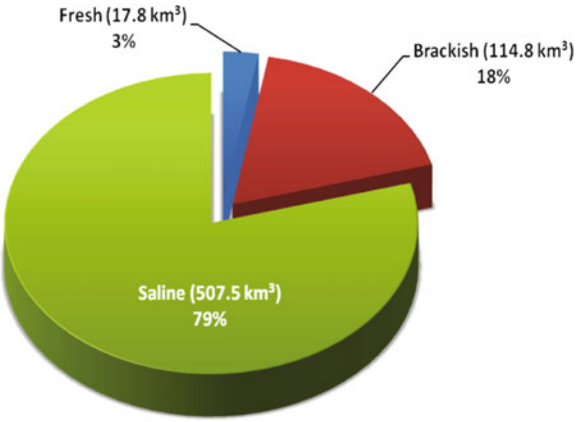

Fig. 1.3 Groundwater reserves in Abu Dhabi (Dawoud 2008)

1.2 Procedures for Extensive Soil Survey

Soils have been described using the "Field Book for Describing and Sampling Soils" (Schoeneberger et al. 2002), and soils have been classified according to the USDA system of Soil Taxonomy (Soil Survey Staff 1999) and the 10th edition of Keys to Soil Taxonomy (Soil Survey Staff 2006). Prior to the commencement of routine survey activities, a preliminary survey was undertaken of the entire survey area, in conjunction with Landsat image interpretation, to identify major landform patterns and soil types occurring within the Emirate. The resulting soil-landscape map was created from the results of ten transects across various parts of the Emirate to check soils and image interpretation.

The extensive survey has been completed using the latest norms and standards required of a fourth-order USDA soil survey (Soil Survey Division Staff 1993). There have, by necessity, been minor amendments to these standard procedures to meet the wider demands of the project. Considerable additional information has been collected. For example, a standard procedure includes full descriptions of soil profiles using soil augers to describe the diversity of soils; typical soil profiles (500) to characterize the soils and from which samples are collected for a broad range of physical, chemical, engineering, and mineralogical analyses; and check-sites that gather just sufficient information to enable a site to be allocated to a classification. For this soil survey, no sites were considered to be check-sites only; rather, all auger sites were fully described. Furthermore, soil information is normally only collected for the top 100 cm, but to ensure greatest potential use for the most stakeholders, soil information was recorded for the top 200 cm or until an impenetrable layer was struck. A sandspear developed in Western Australia was used to retrieve soil sample where it was not possible to explore depth to 200 cm. Fourth-order surveys for field mapping and publication from 1:63,360 to 1:250,000 may range in scale. A working scale of 1:50,000 was chosen for the present survey, and soil maps were published at scales of 1:100,000 and 1:500,000.

The extensive survey was completed by describing one site after every 250 ha. The survey area covers the entire mainland of Abu Dhabi excluding offshore islands, urban, industrial, military, and other restricted areas and totals about 5,500,000 ha and 22,000 observations sites. Further, field procedures permit plotting of soil boundaries by interpretation of remotely sensed data. The soils are identified by traversing representative areas to determine soil patterns and composition of map units. Transects are made in selected delineations for verification. According to USDA, most map units may be associations, some complexes, consociations, and undifferentiated groups. Components of map units are soil families and phases of families, and the minimum size of a map unit that can usefully be represented on a map is 40 ha.

A deep drilling (10 m) program was undertaken to provide information to assist developing thematic maps and an understanding of the landscape and soil development, determine occurrences of slowly permeable layers, and determine depth to water table to identify areas at risk of secondary salinization. The deep drilling program provided information on potential resources within the Emirate.

Statistical analyses allowed the final description of soil map units and the soil mapping process to meet the most rigorous standards possible. The statistical results included soil map unit purity, error rate of soil map units, partitioning of soil classes between soil map units, likelihood of property occurrence (water table, calcic, gypsic, petrocalcic, petrogypsic, salic, and hardpan layers), and comparison of soil map unit means for depths to diagnostic horizons, relative variance, and the associated relative variance between soil map units.

1.2.1 Satellite Imagery, Digital Elevation Model, and Projection Parameters

A more detailed visual interpretation of the satellite imagery was undertaken, supplemented by the results of image classification and a digital elevation model generated from the Shuttle Radar Topography Mission of 2006 data. This was used to delineate potential map units that were then captured on-screen using GIS. The map units so defined were overlain on 1:25,000 A3 size field maps using the Landsat imagery as the backdrop and incorporating a roads data layer provided by Environment Agency, Abu Dhabi. As a general rule, the complex areas were allocated 30–60 % more observations than areas considered to represent uniform sand plains or dunes. Field teams operated by conducting traverses over parts of the map sheets considered to be representative of wider areas and selecting observation sites according to the patterns and textures observable on the field map and in the field. Where appropriate, the soil surveyor also added map unit boundaries or adjusted those identified through pre-survey image interpretation.

The Landsat ETM data from the Global Land Cover Facility was geometrically transformed to the WGS84 datum and a user UTM projection. Precision checks were made using ground control points and differential GPS fixes to ensure the reliability of the transformations. Further adjustments to the selected images were performed to reduce the impacts of atmospheric scattering and to create a seamless image.

The projection parameters for this system are:

Projection	Transverse Mercator
Central meridian	54° 00 00″ E
Scale factor at the central meridian	0.99995
False easting of the origin	500,000 m
False northing of the origin	0 m
Reference spheroid	WGS84

1.2.2 General Site Description: Surface Landscape Features

The site features, where appropriate, were described (slope, slope class, slope morphological types, landscape, landform, relief model slope class, erosion type, runoff, land use, vegetation cover, surface condition, drainage and Ksat classes, moisture condition, surface coarse fragments, and moisture regime) using USDA procedures described in Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002).

1.2.3 Morphological Description

The auger hole, sandspear, and typical profiles were described, where appropriate, for the following morphological characteristics for each soil layer identified: soil color, mottles, field texture, structure, consistence, segregations, coarse fragments, pores, roots, boundary condition, field EC, and pH (1:1 soil-water), using USDA procedures described in Schoeneberger et al. (2002).

1.2.4 Soil Map Units and Kinds of Map Units

Soil survey involves the simplification of a complex reality and the representation of that simplification through soil maps and reports. The success with which this representation is achieved reflects the usefulness of the final product for its intended purpose which in turn is dependent on the purity with which map units have been delineated and the accuracy with which they have been defined. The presence of inclusions within a map unit does not detract from the usefulness of the map so long as the map unit components have been appropriately defined and reflect the true variability of soils within the landscape. In an extensive survey, we recognize that map units are mostly associations with some complexes (Soil Survey Division Staff 1993) and consociations. Soil components are taxonomic families and phases of families.

1.2.4.1 Map Unit Legend Development

Depending on whether the map unit is a consociation, complex, or association, one or more soil taxonomic subgroup names are used to name the map unit together with a brief reference to the topography or landscape which dominates or is particularly characteristic of the map unit. In addition, each map unit is given a code. A total of 114 soil map units have been identified and described elsewhere (EAD 2009a). A typical map unit (TTP06) is described below.

1.2.5 TTP06 Typic Torripsamments, Consociation, and Rolling Dunes

This map unit consists of rolling dune fields that range in relative relief between 9 and 30 m. Some areas of deflation plains and closed depressions within the dune fields have calcareous sandstone fragments and pale brown sands over calcareous sandstone below 100 cm depth. The map unit occurs as small scattered polygons in the northeastern part of the Emirate in the nearby vicinity of Bida Hamama and to the east of Siwehan to Al Ain road. Polygons range in size from 93 to 28,464 ha. The land is used as low-density grazing. Vegetation in this map unit is dominated by *Cyperus conglomeratus* and *Zygophyllum* spp. The map unit forms part of the *Cyperetum-Haloxyletum-Zygophylletum* vegetation community. The soils of this map unit are dominated by Typic Torripsamments, mixed, hyperthermic (85%) in the rolling dune fields. Other components are Typic Haplocalcids, sandy, mixed, hyperthermic (5%); Typic Torripsamments, carbonatic, hyperthermic (5%); and Typic Torripsamments, mixed, hyperthermic, lithic phase (5%), all of which occupy the interdunal areas of the unit. Presence of high rolling dunes is the main limitation for irrigated agriculture in this unit. The unit covers an area of 118,698 ha (2.02% of the Emirate).

1.2.6 Map Series Published in Extensive Survey

Following maps (Table 1.3) have been published during the extensive survey. Details can be seen elsewhere (EAD 2009a); however, in this chapter, emphasis is given on the soil, irrigated suitability, current land use, and generalized soil-landscape region maps. The irrigated agriculture suitability map highlights potential areas where future agriculture can be expanded to bridge the gap between food import and local production.

Table 1.3 Maps published in the extensive soil survey

Title of map	Sheet size	Scale of publication	[a]No. of sheets
Soil map – satellite imagery	A1	1:100,000	29
Soil map – satellite imagery – subgroups	A0	1:500,000	1
Soil map – colored fill – subgroups	A0	1:500,000	1
Soil map – colored fill – great groups	A0	1:500,000	1
Generalized soil-landscape regions	A0	1:500,000	1
Current land use	A1	1:100,000	29
Current land use	A0	1:500,000	1
Vegetation map	A0	1:500,000	1
Suitability for irrigated agriculture	A0	1:500,000	1
Salinity in the 0–50-cm soil layer	A0	1:500,000	1
Salinity in the 50–100-cm soil layer	A0	1:500,000	1
Depth to water table	A0	1:500,000	1
Depth to hardpan	A0	1:500,000	1
Gypsum sources	A0	1:500,000	1
Gravel sources	A0	1:500,000	1
Carbonate sources	A0	1:500,000	1
Sand sources	A0	1:500,000	1
Sweet soil sources	A0	1:500,000	1
Anhydrite sources	A0	1:500,000	1
Land degradation	A0	1:500,000	1
Rangeland suitability	A0	1:500,000	1
Wildlife habitat suitability	A0	1:500,000	1
Forestry suitability	A0	1:500,000	1
Landfill (area) suitability	A0	1:500,000	1
1 million ha most suitable for irrigated agriculture	A0	1:250,000	4

[a] Number of sheets to cover study area in Abu Dhabi Emirate

1.2.7 Abu Dhabi Soil Information System (ADSIS)

To ensure that the information created in the soil survey is readily available to any potential user, a computer-based online information system was developed that links to the comprehensive soil database that resulted from the collection of survey information. The system was developed after broad consultation with a wide range of stakeholders who use soil information in Abu Dhabi and a review of the major existing soil information systems in other countries (United States of America, Australia, Canada, and Europe). Based on the needs identified, the system was created to support a wide range of information users and to provide tools for soil survey teams working on similar projects in the future. The Abu Dhabi Soil Information System (ADSIS) (Fig. 1.4) displays all the maps produced during the survey, with the powerful functionality of allowing a user to view particular locations of interest and extract data related to all the map units and observation sites described during

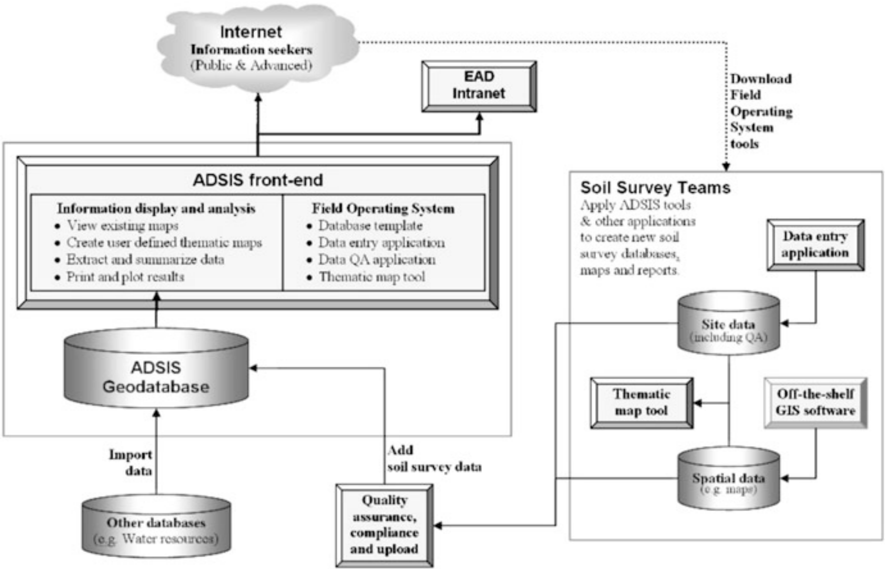

Fig. 1.4 Architecture of the Abu Dhabi Soil Information System

the survey. If registered as an advanced user, it is possible for a user to tailor the criteria for thematic maps based on the soil map properties or that of individual observation sites.

1.2.8 Laboratory Analytical Procedures

Laboratory analyses of soil samples are necessary to verify field observation data, to determine properties and characteristics that cannot be estimated accurately by field observations, and to help to characterize typical profiles. Standard USDA procedures (USDA 1954; USDA-NRCS 1995; Burt 2004) were used except where otherwise specified. Detailed particle-size distribution analyses were made using standard pipette method supplemented with wet sieving to quantify sand fractions, very coarse (1–2 mm), coarse (0.5–1 mm), medium (0.25–0.5 mm), fine (0.1–0.25 mm), and very fine (0.05–0.1 mm) sands. Using the proportion of sand, silt, and clay, the soil texture class was determined using USDA specifications (Soil Survey Division Staff 1993).

Soil moisture; total pretreatment loss; loss on acid treatment; carbonate equivalents; gypsum; extractable cations (Na, K, Ca, Mg); cation-exchange capacity (CEC); exchangeable sodium percentage (ESP); saturation percentage; soluble cations and anions; electrical conductivity of the soil saturation extract (ECe); pH of saturated soil paste; sodium adsorption ratio (SAR); osmotic potential (OP); engineering data (Unified Soil Classification System, American Association of State Highway and

Transportation Officials classification); Atterberg limits (plastic limit and liquid limit); water retention at 10, 33, and 1,500 kPa; organic carbon; whole soil and clay mineralogy (XRD analysis); elemental and oxides composition (XRF); and thin section study (soil micromorphology) in polarizing microscope were determined using standard USDA procedures (Burt 2004).

1.2.9 Field Tests: Infiltration Rate, Soil Permeability, and Penetration Resistance

Various determinations, such as saturated infiltration at the soil surface using a double ring infiltrometer (McKenzie et al. 2002), unsaturated permeability at the surface using a disc permeameter (McKenzie et al. 2002), and subsurface saturated permeability using a Guelph permeameter (Soil Moisture Corp 2005) were made beside the typical profile of each family identified. Penetration resistance of soil profiles was accomplished using a Bush penetrometer to a depth of 50 cm or to a hardpan. The information was collected at an interval of 2 cm.

1.3 Results and Discussion

In this section, extensive survey results are presented in broader perspectives to give overall view of Emirate landscapes, soils, current land uses, and areas having potential for irrigated agriculture. Restrictions to irrigated agriculture and management options as well as policy issues are discussed. More details can be seen elsewhere (EAD 2009a).

1.3.1 Generalized Soil-Landscape Regions

During the extensive survey, preliminary investigations of the landscapes recognized 27 generalized soil-landscape regions (Fig. 1.5). These regions have been identified on the basis of likely soils and characteristic landforms and are broadly consistent with major subdivisions identified by other researchers (Boer 1999):

1. *Sila* region presents what appear to be remnant alluvial fans. At its western margin, this unit is bound by a distinct scarp, and the ground surface typically has a gravely surface lag deposit.
2. *Sabkhat Matti,* a complex low-lying region, is characterized by saline flats and slightly better-drained gypsic rises. Groundwater levels are typically within 200 cm, and there is often a saline crust several centimeters thick on the soil surface. The Sabkhat Matti unit includes areas of a gilgai-type microrelief, often distinguishable on the satellite image by their darker appearance, plains

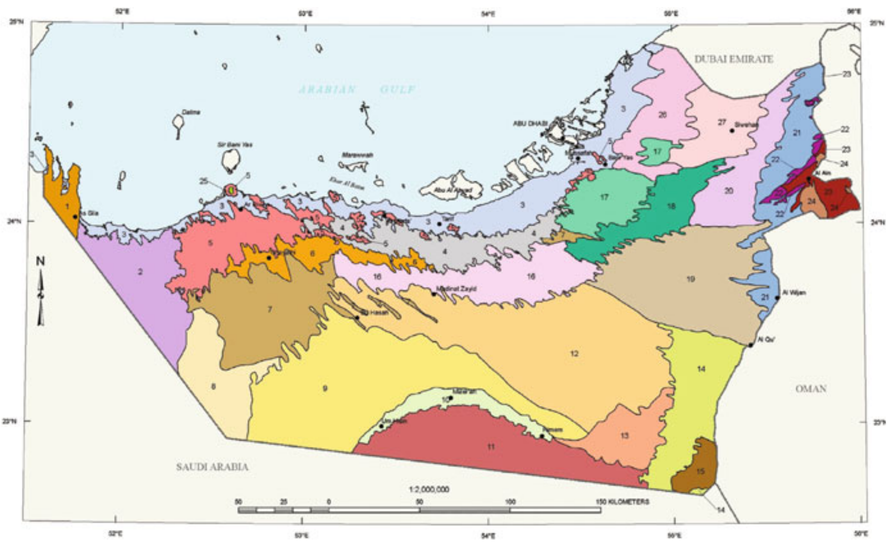

Fig. 1.5 Generalized soil-landscape regions. *Note: This map is not an authority on international or inter-emirate boundaries; it represents the extent of the extensive survey area

with lag gravels, and rock outcrop. Limited dune development has occurred in some areas resulting in low transverse dunes, known as Zibars, in an apparent “herringbone” pattern.

3. *Coastal flats* represent the low-lying coastal flats dominated by saline soils and slightly higher gypsic rises but including some areas of carbonatic sand sheets underlain by miliolite.
4. *Primary sand sheet* lies adjacent to the coastal plain in central parts of the Emirate. It represents carbonatic sand sheets with minor areas of saline soils. Some flat-topped mesas are capped by evaporate deposits from earlier soil-forming periods and left upstanding by erosion.
5. *Baynunah tertiary complex* lies in the north of the Emirate near Ghayathi. It comprises eroded Quaternary and Miocene sediments often with a deflation regolith of fine gravels.
6. *Baynunah red beds* lie to the south of Region 5. An area of undulating rises with small raised tablelands and associated scarps is capped by more resistant evaporite deposits.
7. *Baynunah barchanoid complex* occurs to the south of Ghayathi. It comprises extensive areas of barchanoid dunes occasionally partially overlain by paler carbonatic dunes. Interlayering of pale carbonatic sands with redder, coarser sands is common. Outcrops of miliolite are scattered and presumably underlie much of the dune systems.
8. *Al Maghrib* lies on the southern border with Saudi Arabia. It constitutes linear dune fields consisting of interlayered white carbonatic and red quartzite sands with minor exposure of Quaternary dunes and interdune formations.

9. *Liwa dunes* lie in the south of the Emirate and to the north of the Rub' al-Khali at Liwa. It comprises medium to high and rolling to steep linear and transverse dune systems that, in some areas, have been partially overlain by more recent barchanoid dunes. Scattered small deflation plains and sabkha flats are prominent in some areas.
10. *Liwa Oasis* lies in the south of the Emirate adjacent to the Rub' al-Khali. It comprises rolling to steep high mega valleys that have frequently been graded and developed for irrigated agriculture. Occasional interdunal depressions are deflated to the capillary fringe resulting in saline sabkha flats.
11. *Liwa mega-barchans* lies in the south of the Emirate and represents the northern extent of the Rub' al-Khali. It comprises high, often steep mega-barchans, frequently overlain by smaller barchan dune fields and associated intervening sabkha flats dominated by saline soils.
12. *Al Humrah* is an extensive region in central parts of the Emirate. It comprises older stable north linear dunes and intervening deflation flats. Occasional nested barchanoid dunes occur where more recent windblown sands have accumulated. The region includes broad, gently inclined sand ramps which may display a partial cover of fine lag gravels.
13. *Ramiat ar Rabbad* lies in the south and comprises sand sheets and relatively low relief transverse dunes comprised of red quartzite sands.
14. *Al Manadir rectangular dunes* occur in the south and comprise dune ridges set in a roughly rectangular pattern and comprising a mix of barchan, seif, and star dunes together with intervening deflation flats and inland sabkha. Surface lag gravels are common on many of the flats and often extend partway up the gently sloping windward face of the dune ridges.
15. *Al Manadir complex* occurs in the extreme south. It comprises rectangular dune ridges as for Region 14 but which overlie deflated lacustrine sediments including limestone. The region has a distinctive pale color on Landsat imagery.
16. *Table lands* occur in the center of the Emirate around Madinat Zayed. It comprises undulating to rolling terrain with frequent yardangs, mesas, and associated minor sabkha.
17. *Abu Dhabi complex* lies inland from Abu Dhabi City. It comprises lithified miliolite dunes and Quaternary to Miocene evaporites predominantly covered by eolian carbonatic sands that form low dunes and thin sand sheets. Deflation plains and sabkha flats are scattered throughout the region which has undergone significant human modification evidenced by extensive excavations and dumps.
18. *Abu Dhabi sand sheet complex* occurs to the east of Region 17 and has been identified as a separate unit on the basis of more even topography. It comprises sand sheets that overlie Quaternary and Miocene sediments and is generally less impacted by human activity.
19. *Bida Hamam* occurs in the east of the Emirate to the south of linear dune systems of moderate to high relief that partially overlie narrow interdunal flats and sabkhas.
20. *Al Khatam* occurs in the north Siwehan. It comprises linear dune systems of moderate relief with intervening broad plains and deflation flats.

21. *Al Ain region* occurs in the east of the Emirate, north and south of Al Ain. It comprises linear, transverse, and seif dune systems of moderate to high relief with associated interdunal flats.
22. *Outwash complex 1* occurs around Al Ain. It comprises gently inclined pediments and alluvial fans with a surface lag of fine gravels. In some areas, a partial covering by low to medium dunes is common.
23. *Outwash complex 2* occurs predominantly to the east of Jabal Hafit. It comprises almost level plains and pediments adjacent to the main mountain outcrops. Fan and gravely outwash deposits showing strong depositional stratification are common.
24. *Jabal Hafit Mountain* is in the east of the Emirate, near Al Ain. It comprises the rocky hills and mountains that represent outliers of the Hajar Mountains.
25. *Salt dome* is one small unit on the mainland at Jabal Az Zannah and comprises a salt dome against which eolian sediments have accumulated.
26. *Tawi Ghufar sand sheets* in the north of the Emirate comprise undulating carbonatic sand sheets that often overlie semi-lithified remnants of older dune systems with intervening sabkha flats and deflation plains.
27. *Tawi Ghufar desert plain* occurs around Siwehan in the northeast. It comprises branching linear dune systems of low to medium elevation with intervening broad deflation flats.

1.3.2 Current Land Use Map

Records of the current land use were also collected at all 22,000 observation sites and boundaries drawn on field map sheets. Existing digital land use information was also acquired from EAD. This information was combined with Landsat imagery and a reassessment of boundaries performed on-screen, leading to a draft map with a high level of confidence. Broad land use includes urban, farming, rangeland, oil fields, cemeteries, etc. Current land use maps were published at scale of 1:100,000 and 1:500,000 (Fig. 1.6). Table 1.4 shows area under each land use category. The information is a way forward for policy makers to make decisions to balance land uses in the Emirate.

1.3.3 Classification of Emirate Soils

Soil classification is used by pedologists to group and order components of a complex natural environment into categories that can be used for interpretation, evaluation, and planning purposes. One of the most widely accepted international systems is that of Soil Taxonomy: A Basic System of Soil Classification and Interpreting Soil Surveys (Soil Survey Staff 1999) and subsequent editions of the Keys to Soil Taxonomy (Soil Survey Staff 2006) that have been adopted for the extensive soil survey of Abu Dhabi Emirate. Soil Taxonomy is a classification system that uses

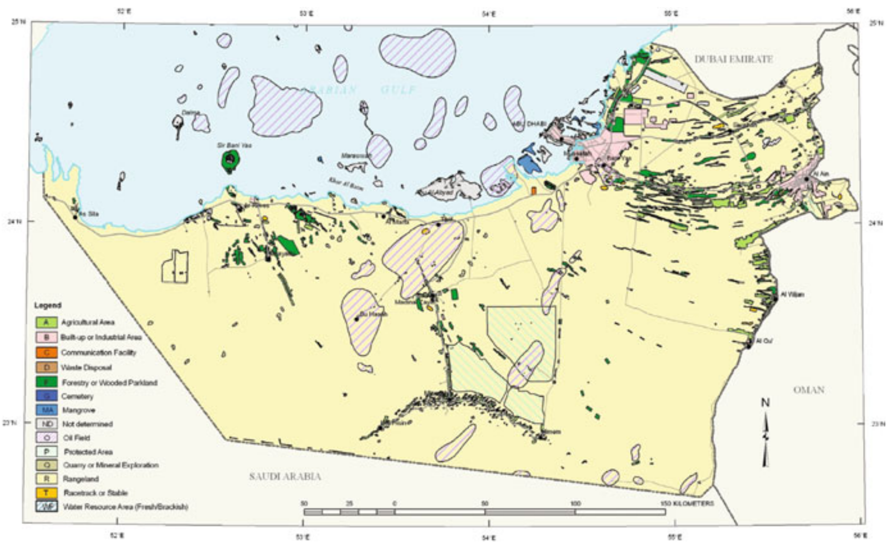

Fig. 1.6 Current land use map of Abu Dhabi Emirate. *Note: This map is not an authority on international or inter-emirate boundaries; it represents the extent of the extensive survey area

readily identifiable soil characteristics to define many of its classes at various levels of classification. By adopting the USDA Soil Taxonomy within Abu Dhabi, the Emirate is consistent with its neighbors (Kingdom of Saudi Arabia, Sultanate of Oman, State of Kuwait, and State of Qatar) who have utilized the same system, thereby allowing knowledge sharing, transfer of technology, and understanding throughout the region.

US Soil Taxonomy is a hierarchical system of soil classification that identifies six levels – order, suborder, great group, subgroup, family, and series. The soil order is the highest level of classification, and worldwide 12 different orders are recognized. Two orders have been recorded within Abu Dhabi during this survey – Aridisols and Entisols. The soil orders are subdivided into suborders according to properties that influence genesis or plant growth. Sixty-four potential suborders have been defined worldwide; only five have been identified in this survey; they are in order Aridisols (Calcids, Gypsids, and Salids) and Entisol (Orthents and Psamments). Soil great groups are defined on the basis of similarities in kind, arrangement and degree of profile development, soil moisture, and temperature status. The fourth level of classification is the subgroup.

Each great group has a typic subgroup that is considered to be the central concept of that great group. Other subgroups represent a range of other properties intergrading with other great groups. Soil families are established within a subgroup on the basis of physical or chemical properties that might affect management. For the soil survey of Abu Dhabi Emirate, they include particle-size class, mineralogy, soil temperature class, and a soil depth class. Soils have been classified at the family level of Soil Taxonomy according to the criteria defined in Soil Survey Staff (2006).

Table 1.4 Legend for 1:100,000 current land use map (as at 2007)

Code	Name	Description
Land uses other than oil fields and protected areas		
A	Agricultural areas 110,951 ha (1.87%)	Irrigated agriculture including open-field cultivation (fodder and horticulture, including date plantations), greenhouse cultivation, nurseries, and areas under animal farms
B	Built-up or industrial areas 126,935 ha (2.14%)	Populated places comprising residential, business and industrial centers, and associated infrastructure. These areas were excluded from the soil survey
C	Communication facility 845 ha (0.01%)	Only the larger and more important facilities are identified and indicated separately from the B unit (built-up or industrial area). The main facility is a base located 35 km southwest of Abu Dhabi City
D	Waste disposal 502 ha (0.01%)	Areas used for the disposal of waste. These sites vary from local disposal of waste to large facilities to receive the waste from the city of Abu Dhabi. Materials disposed of include household and industrial waste
F	Forestry or wooded parkland 134,948 ha (2.27%)	Includes the most extensive wooded park areas used for environmental objectives, recreation and camping, and zones of forest found on the outskirts of built-up areas or adjacent to major roadways
G	Cemeteries 65 ha (<0.01%)	Major cemeteries outside the built-up areas (B unit)
Q	Quarries or mineral exploration 9,111 ha (0.15%)	Ranges from open pit rock and gravel quarry and crusher operations to areas of borrow pits and associated tailings
R	Rangeland 5,469,636 ha (92.06%)	Represents the background land use unit. Small settlements, isolated buildings, etc., may be included in the unit which is used extensively for traditional animal grazing. Important secondary land uses include recreational activities and sporadic camping
T	Racetracks and stables 7,348 ha (0.12%)	Comprises camel and horse racing facilities located outside built-up areas
WF	Water resource areas 330 ha (0.01%)	Areal extent of unit delineations includes water wells, small reservoirs, pipelines, and power lines associated with the water fields
ND	Not determined 80,799 ha (1.36%)	The land use in some areas was not able to be determined using remote sensing and was either outside the scope of the ground-truthing component of this project (e.g., offshore islands) or was otherwise inaccessible (e.g., secure military areas)
Total area	5,941,441 ha (100.00%)	Note that as the oil fields and protected areas have coexisting land uses, their areas are not included in this total
Oil fields and protected areas		
O	Oil fields 292,608 ha (4.92%)	Represents the areal extent of oil fields comprising wells and associated infrastructure. Secondary land use periodically consists of animal grazing. The core oil fields were excluded from the soil survey. Oil fields were delineated on the basis of boundaries provided by the Abu Dhabi Company for Onshore Oil Operations (ADCO), where those areas coincided with land (mainland or islands)
PA	Protected areas 230,795 ha (3.88%)	Comprises designated protected areas. Land use includes recreation and sporadic camping. Some areas are intensively managed for the conservation of native wildlife of the Emirate

1.3.3.1 Soil Mineralogical, Particle Size, and Depth Family Classes

Soil mineralogy refers to the mineralogical composition of the soil. Gypsic, carbonatic, and mixed mineralogical classes were identified for Abu Dhabi Emirate soils:

- Gypsic – any particle-size class and more than 40% (by weight) carbonates (expressed as $CaCO_3$) plus gypsum with gypsum constituting more than 35% of the total weight of carbonates plus gypsum, either in the fine earth fraction or in the fraction less than 20 mm in size, whichever has a higher percentage of carbonates and gypsum
- Carbonatic – any particle-size class and more than 40% (by weight) carbonates (expressed as $CaCO_3$) plus gypsum and gypsum is less than 35% of the total weight of gypsum plus carbonates, either in the fine earth fraction or in the fraction less than 20 mm in size, whichever has a higher percentage of carbonates plus gypsum
- Mixed – other than gypsic or carbonatic class and also silica content is less than 90%

Sandy, sandy-skeletal, loamy, coarse loamy, and fine particle-size classes are identified in Abu Dhabi Emirate soils. The term "shallow" is added to the soil family name when a hardpan is encountered at or above 50 cm from the soil surface. This is applied in all soil subgroups except where the term is made redundant by the soil name as in Lithic subgroups.

1.3.3.2 Phases of Soil Families

Lithic, shallow, petrogypsic, anhydritic, calcic, and aquic phases are recognized:

- Lithic – when lithic contact occurs between 50 and 200 cm
- Petrogypsic – when petrogypsic horizon occurs between 100 and 200 cm
- Calcic – when a calcic horizon occurs between 100 and 200 cm
- Aquic – when water table occurs between 100 and 200 cm
- Anhydritic – when anhydrite was rich in soil profile in the upper 100 cm

A total of 62 soil families and phases of soil families have been identified in the extensive survey of Abu Dhabi Emirate (Fig. 1.7). A typical example of family description is shown below. Typical profile and associated landscape are shown in Fig. 1.8, and analytical results are presented in Table 1.5; details of other families and phases can be consulted elsewhere (EAD 2009a).

1.3.3.3 Soil Family: Typic Torripsamments, Mixed, Hyperthermic

Typic Torripsamments, mixed, hyperthermic are deep, sandy soils with mixed mineralogy. They occur on almost level plains to mega transverse and barchanoid dune fields and are widespread throughout the Abu Dhabi Emirate. They are typically

Order	Suborder	GreatGroup	Subgroup	Family/Phase of family
Aridisols		Haplocalcids	Typic Haplocalcids	sandy, carbonatic, hyperthermic
				sandy, carbonatic, hyperthermic, lithic phase
				sandy, mixed, hyperthermic
	Calcids			sandy, mixed, hyperthermic, lithic phase
				sandy -skeletal, mixed, hyperthermic
		Petrocalcids	Typic Petrocalcids	sandy, carbonatic, hyperthermic, shallow
		Calcigypsids	Typic Calcigypsids	sandy, mixed, hyperthermic
				sandy, mixed, hyperthermic, lithic phase
				sandy, mixed, hyperthermic, petrogypsic phase
		Haplogypsids	Leptic Haplogypsids	sandy, gypsic, hyperthermic
				sandy, gypsic, hyperthermic, lithic phase
				sandy, mixed, hyperthermic
	Gypsids			sandy, mixed, hyperthermic, lithic phase
				sandy, mixed, hyperthermic, petrogypsic phase
				sandy -skeletal, mixed, hyperthermic
			Lithic Haplogypsids	sandy, gypsic, hyperthermic
			Typic Haplogypsids	sandy, mixed, hyperthermic
				sandy, mixed, hyperthermic, petrogypsic phase
		Petrogypsids	Calcic Petrogypsids	sandy, mixed, hyperthermic
			Typic Petrogypsids	loamy, gypsic, hyperthermic, shallow
				sandy, gypsic, hyperthermic
				sandy, gypsic, hyperthermic, shallow
				sandy, mixed, hyperthermic
				sandy, mixed, hyperthermic, shallow
		Aquisalids	Gypsic Aquisalids	fine, gypsic, hyperthermic, anhydritic phase
				sandy, gypsic, hyperthermic
				sandy, mixed, hyperthermic
	Salids		Typic Aquisalids	sandy, carbonatic, hyperthermic
				sandy, mixed, hyperthermic
				sandy, mixed, hyperthermic, lithic phase
		Haplosalids	Gypsic Haplosalids	coarse -loamy, mixed, hyperthermic
				coarse -loamy, mixed, hyperthermic, lithic phase
				loamy, mixed, hyperthermic, shallow
				sandy, gypsic, hyperthermic, aquic phase
				sandy, mixed, hyperthermic
				sandy, mixed, hyperthermic, aquic phase
				sandy, mixed, hyperthermic, lithic phase
			Petrogypsic Haplosalids	coarse -loamy, mixed, hyperthermic
				loamy, gypsic, hyperthermic, shallow
				loamy, mixed, hyperthermic, shallow
				sandy, gypsic, hyperthermic
				sandy, gypsic, hyperthermic, shallow
				sandy, mixed, hyperthermic
				sandy, mixed, hyperthermic, shallow
			Typic Haplosalids	coarse -loamy, mixed, hyperthermic
				sandy, carbonatic, hyperthermic, aquic phase
				sandy, mixed, hyperthermic, aquic phase
				sandy, mixed, hyperthermic, lithic phase
				sandy, mixed, hyperthermic, shallow
Entisols	Orthents	Torriorthents	Lithic Torriorthents	sandy -skeletal, mixed, hyperthermic
			Typic Torriorthents	sandy -skeletal, mixed, hyperthermic
	Psamments	Torripsamments	Lithic Torripsamments	carbonatic, hyperthermic
				mixed, hyperthermic
			Typic Torripsamments	carbonatic, hyperthermic
				carbonatic, hyperthermic, calcic phase
				carbonatic, hyperthermic, lithic phase
				carbonatic, hyperthermic, shelly phase
				mixed, hyperthermic
				mixed, hyperthermic, calcic phase
				mixed, hyperthermic, lithic phase
				mixed, hyperthermic, petrocalcic phase
				mixed, hyperthermic, petrogypsic phase

Fig. 1.7 Soil Taxonomy hierarchy of extensive survey of Abu Dhabi

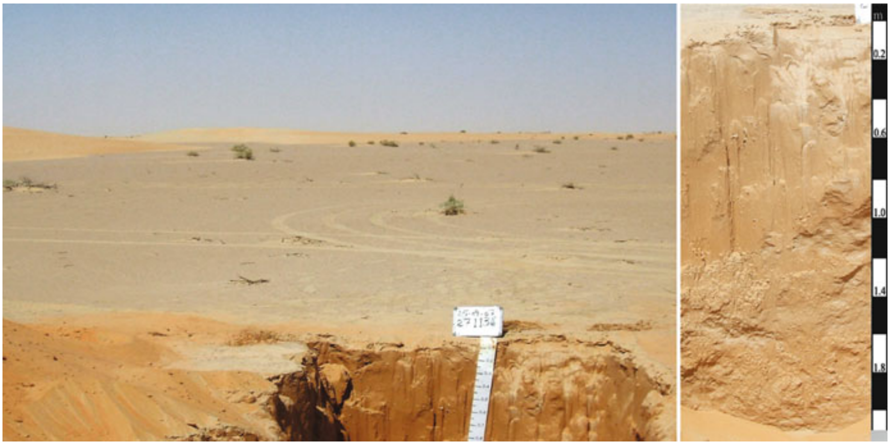

Fig. 1.8 Typical soil profile and associated landscape for Typic Torripsamments, mixed, hyperthermic

excessively drained or somewhat excessively drained and have rapid or very rapid permeability.

Site no.	: 271136		
Observation type	: Typical profile	Date	: Sep. 25, 2007
Described by	: Taj Muhammad		
Geographic coordinate in UTM	: 438347 E	2655622 N	
Physiography		**Soil properties**	
Slope	: 2%	Surface condition	: Loose
Slope class	: Nearly level	Microfeature	: Hummock
Slope morphological type	: Simple slope	Drainage class	: Excessively drained
Landscape	: Plains	Permeability class	: Very rapid
Landform	: Deflation plain	Ksat class	: Very high
Relief/modal slope class	: Undulating plain	Hydrological soil group	: A
Water table depth (cm)	: None	Root restriction depth (cm)	: Very deep
Erosion	: Wind erosion evident	Moisture condition	: 0–110 cm dry 110–200 cm moist
Runoff	: None	Surface coarse fragments	: 10% gravel (2–75 mm) mixed rock fragments
Land use/cover	: Rangeland (greater than 5% vegetation cover)	Moisture regime	: Torric

(continued)

(continued)

Morphological description		
Horizon	Depth (cm)	Description
Ak	0–20	Reddish yellow (7.5YR 6/6) dry, strong brown (7.5YR 5/6) moist, deflation crust; loamy sand; massive; soft, dry; very friable, moist; very weakly cemented by carbonates; nonsticky; nonplastic; low excavation difficulty; no roots; strongly effervescent; diffuse smooth boundary; EC (1:1) 0.256 dS m^{-1}; pH (1:1) 8.5
Ck1	20–70	Reddish yellow (7.5YR 6/6) dry, strong brown (7.5YR 5/6) moist, loamy sand; massive; soft, dry; very friable, moist; 6% fine (<2 mm) carbonate concretions; weakly cemented by carbonates; nonsticky; nonplastic; low excavation difficulty; common fine (1–2 mm) roots throughout; strongly effervescent; diffuse smooth boundary; EC (1:1) 0.367 dS m^{-1}; pH (1:1) 8.53
Ck2	70–110	Strong brown (7.5YR 5/6) moist, loamy sand; massive; very friable, moist; 5% fine (<2 mm) carbonate concretions; weakly cemented by carbonates; nonsticky; nonplastic; low excavation difficulty; common fine (1–2 mm) roots throughout; strongly effervescent; diffuse smooth boundary; EC (1:1) 0.25 dS m^{-1}; pH (1:1) 9.34
Ck3	110–160	Strong brown (7.5YR 5/6) moist, loamy sand; massive; very friable, moist; 8% fine (<2 mm) carbonate concretions; weakly cemented by carbonates; nonsticky; nonplastic; low excavation difficulty; common fine (1–2 mm) roots throughout; strongly effervescent; diffuse smooth boundary; EC (1:1) 0.493 dS m^{-1}; pH (1:1) 9.41
Ck4	160–200	Strong brown (7.5YR 5/6) moist, loamy sand; massive; very friable, moist; 7% fine (<2 mm) carbonate concretions; weakly cemented by carbonates; nonsticky; nonplastic; low excavation difficulty; no roots; strongly effervescent; EC (1:1) 0.555 dS m^{-1}; pH (1:1) 8.86

1.4 General Soil Map at Great Group Level

Nine soil great groups have been recorded as dominant map units (Fig. 1.9). Some great groups may also occur as subdominant soils in other map units. This generalized soil map, together with the following statements under each great group heading, is a summary of information that can be seen elsewhere (EAD 2009a). This section is useful for providing an overview of the soils of Abu Dhabi, and statements herein should be considered as broad generalizations. Reference to other soils refers to other great groups used to name the map units. Proportions of the map unit are given as part of the entire survey area including the coastal area (EAD 2009a).

1.4.1 Haplocalcids

This unit comprises 0.40% of the Emirate. It consists of deep to very deep well to somewhat excessively well-drained sandy to coarse loamy soils showing evidence of secondary calcium carbonate deposition. The unit occurs on flats and deflation plains across the Emirate. Other soils associated with this map unit include Torripsamments where windblown sands have accumulated, Calcigypsids in which accumulations of gypsum occur as well as carbonates, and Torriorthents that show little profile development but often contain significant amounts of gravel. This unit is used for rangeland grazing for livestock. It has moderate potential for irrigated agriculture being limited by the sandy nature of the soils.

1.4.2 Petrocalcids

This map unit has limited extent and comprises 0.04 % of the Emirate. It consists of shallow to moderately deep sandy or loamy soils with an indurated horizon cemented by calcium carbonate within the top 100 cm. It occurs in isolated deflation plains. Other soils associated with this unit include Haplosalids, usually occurring in lower landscape positions and containing high levels of accumulated salt. This unit is used for grazing of livestock. It has limited suitability for irrigated agriculture due to depth to hardpan.

1.4.3 Calcigypsids

This map unit has limited extent and comprises only 0.24 % of the Emirate. It consists of well to somewhat excessively drained sandy to coarse loamy soils that show accumulations of both calcium carbonate and gypsum. The unit occurs as deflation plains frequently partially obscured by windblown sands. Other soils associated with this map unit include Torripsamments where windblown sands have accumulated.

Table 1.5 Detailed characteristics (physical, chemical, mineralogical) and field test results of typical soil profile

Typic Torripsamments, mixed, hyperthermic										
Site number – SSEAD				271136						
Physical data										
				Total			Silt		Sand	
Horizon	Depth cm	Texture	Field moisture	Clay <.002	Silt .002–.05	Sand .05–2	Fine .002–.02	Coarse .02–.05	VF .05–.10	F .1–.25
				% of <2 mm						
Ak	0–20	FS	–	1.1	1.2	97.5	0.1	1.3	11.0	71.5
Ck1	20–70	FS	–	1.2	0.7	98.1	–	0.7	8.3	77.0
Ck2	70–110	FS	–	1.0	–	99.0	–	–	5.6	63.2
Ck3	110–160	FS	–	0.7	1.4	97.9	0.1	1.3	9.2	61.2
Ck4	160–200	FS	–	0.8	1.2	98.0	–	1.2	9.5	62.9
Chemical data										
		Extractable cations				CEC		ESP	Saturation extract amounts	
Horizon	Depth cm	Ca	Mg	Na	K				Ca	Mg
		cmolc kg^{-1}						%	meq L^{-1}	
Ak	0–20	18	0.9	0.4	0.2	0.1		1	10	3
Ck1	20–70	16	0.9	0.4	0.3	0.1		3	3	1
Ck2	70–110	15	0.7	0.5	0.2	0.1		4	5	3
Ck3	110–160	16	0.8	0.8	0.2	2.0		11	5	2
Ck4	160–200	16	0.7	0.8	0.3	3.0		9	4	2
Engineering Data										
		Particles	Passing	Sieve	Number	Atterberg limits			Engineering class	
Horizon	Depth cm	4	10	40	200	Ip			USCS	AASHTO
		%								
Ak	0–20	100	98	96	2	np			SP	A-3
Ck1	20–70	100	100	99	9	np			SP-SM	A-3
Ck2	70–110	100	100	93	11	np			SP–SM	A-2-4
Ck3	110-160	100	100	98	2	np			SP	A-3
Ck4	160–200	100	99	96	2	np			SP	A-3
Whole soil mineralogical data										
Horizon	Depth cm	Quartz	Plagioclase	Calcite	Palygorskite	Uncertain				
Ck1	20–70	D	Mi	Tr	Mj	TrS				
Ck2	70–110	D	Mi	Tr	–	–				

Hydraulic conductivity

Surface saturated, 540 mm h^{-1}; surface unsaturated, 54 mm h^{-1}; subsurface (100 cm) saturated, 487 mm h^{-1}; soil strength, *FS* fine sand, *Mi* minor, *Mj* major, *WRD* water retention difference, *Tr* traces, *np* nonplastic, *ESP* exchangeable

M .25–.5	C .5–1	VC 1–2	TPL	LAT	$CaCO_3$	Gypsum		Coarse fraction 2–5	5–20	20–75	>75	>2
								% <75 mm				%of whole soil
13.2	0.7	1.1	21	19	19	0.3	–	1.9	–	–	–	1.9
12.6	0.2	–	5	5	5	0.2	–	–	–	–	–	–
28.2	2.0	–	4	3	4	0.2	–	0.2	–	–	–	0.2
26.9	0.5	0.1	4	4	5	0.2	–	0.4	–	–	–	0.4
25.2	0.4	–	4	4	5	0.1	–	1.2	–	–	–	1.2

Na	K	HCO_3	SO_4	Cl	NO_3	PO_4	SP	SAR unit	ECe	pHs	SAR	OP
							%	(mmoles $L^{-1})^{0.5}$	dS m^{-1}		(mmoles $L^{-1})^{0.5}$	atmos
4	0.7	1.5	16	3	0.4	–	28	–	1.5	8.23	2	0.5
5	0.6	1.4	4	3	0.7	–	28	–	0.9	8.42	3	0.3
8	0.5	3.0	5	10	0.2	–	27	–	1.0	8.94	4	0.4
16	0.7	1.0	10	11	0.1	–	28	–	2.0	8.30	9	0.7
13	0.6	1.7	6	12	–	–	27	–	1.9	8.40	7	0.7

Other data

Water content (<2 mm) 1/10 bar	1/3 bar	15 bar	Bulk density	Particle density	Porosity	WRD	Organic carbon	Organic matter
%			g cm^{-3}	g cm^{-3}	%	cm cm^{-1}	%	%
3.9	1.9	0.9	1.61	2.69	40	0.016	0.09	0.15
3.2	1.8	1.3	1.62	2.66	39	0.008	0.03	0.05
2.5	1.6	1.1	1.63	2.65	39	0.009	0.01	0.03
3.0	1.6	1.1	1.62	2.67	40	0.009	0.03	0.05
3.3	1.5	0.9	1.62	2.66	39	0.009	0.01	0.03

depth at which soil penetration resistance reached 3.8 MPa, 12 cm

sodium percentage

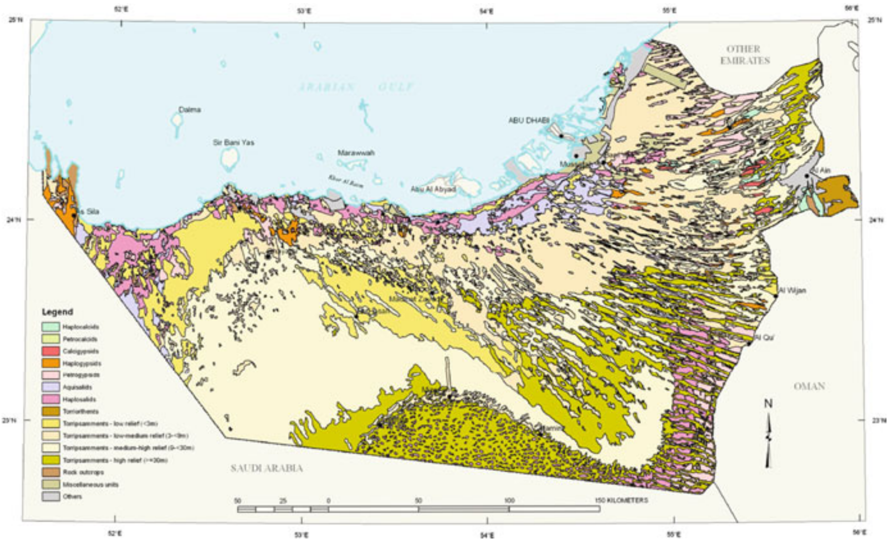

Fig. 1.9 Generalized great group soil map

This unit has some limited use for rangeland grazing. It has little suitability for irrigated agriculture due to high soil gypsum contents.

1.4.4 Haplogypsids

This map unit comprises 1.22% of the Emirate. It consists of deep to very deep well to somewhat excessively drained sandy to loamy soils. Accumulations of gypsum are common and can occur at any depth from the surface down. The unit occurs as almost level to gently undulating deflation plains occasionally with a partial covering of windblown sands. Other soils associated with this map unit include Torripsamments in areas of windblown sand and Petrogypsids where gypsum has accumulated and created an indurated layer. Areas of rock outcrop occur in some areas. This unit is mainly used for grazing of livestock. Some areas are used for forestry, and there are limited areas used for farming, predominantly fodder production.

1.4.5 Petrogypsids

This unit comprises 2.88% of the Emirate. It consists of shallow to moderately deep sandy or loamy soils with an indurated horizon cemented by gypsum within the top 100 cm. Other soils found in this map unit include Haplogypsids (no hardpan), Torripsamments where windblown sands have accumulated, and Haplosalids where soils have accumulated salt and many of which also have an indurated gypsic hardpan. This unit is used as rangeland grazing for livestock. It has little potential for irrigated agriculture due to limited depth of soil to hardpan and soil gypsum content.

1.4.6 Aquisalids

This map unit comprises 3.07% of the Emirate. It consists of poorly and somewhat poorly drained soils with water tables within 100 cm of the surface for much of the year. The soils are strongly saline, sandy to loamy, and frequently have a substantial surface salt crust. Often, soils contain an accumulation of gypsum. The unit occurs in coastal and inland sabkha flats. Other soils associated with this map unit include Haplosalids on slightly higher flats, some of which may include horizons strongly indurated by gypsum.

This unit is not used for any productive purpose and is considered permanently unsuitable for irrigated agriculture due to near-surface saline groundwater, high salt content, and gypsum content.

1.4.7 Haplosalids

This map unit comprises 6.53% of the Emirate. It consists of imperfectly to somewhat poorly drained, deep to very deep sandy to loamy soils. Water tables are occasionally within 100–200 cm of the surface. Many soils contain an accumulation of gypsum that is often cemented into a hard impenetrable layer. The unit occurs in coastal and inland sabkha flats across the Emirate. Other soils associated with this map unit include the Aquisalids with a saline water table within 100 cm, Torripsamments where sabkha are overlain by windblown sands, and Torriorthents that often contain high amounts of gravel. In some coastal flats, tertiary rock outcrop has been exposed through deflation. This map unit has little productive use. Small areas of forestry are occasionally developed on better soils found within the unit, but rock outcrop, salinity, and gypsum content all limit agriculture land uses.

1.4.8 Torriorthents

This map unit has limited extent and comprises only 0.59% of the Emirate. It consists of well-drained shallow to moderately deep sandy or loamy soils frequently containing large amounts of gravel or seashells. Some components have a lithic contact at less than 50 cm. They occur as deflation plains and flats. Other soils associated with this unit include Haplosalids, with or without gypsum, which typically occur in lower landscape positions, and Torripsamments that reflect accumulations of eolian sand. This unit is used for grazing of livestock and some limited farming and forestry activities. It has limited suitability for irrigated agriculture due to the gravel content of the soils.

1.4.9 Torripsamments

This is the most dominant and widespread unit in the survey area, comprising 81.09% of the Emirate. It consists of deep to very deep excessively well-drained sandy soils that occasionally overlie miliolite within 200 cm. They occur as extensive dune systems and sand sheets across the Emirate. Other soils associated with this map unit include most of the other great groups described above with the exception of Petrocalcids and Torriorthents. This map unit is used for rangeland grazing, farming, and forestry activities. It has a range of suitability for irrigated agriculture depending on the nature of the landform. Low dunes, sand plain, and sand sheet are considered moderately suitable, and suitability typically declines as the dune height and frequency increase. Because of the widespread nature of this unit, it has been subdivided in the generalized soil map on the basis of dominant relief within the map unit. In addition to the nine units described above, a number of other map units have been defined within which the dominant component is not a natural soil. These include rock outcrops, miscellaneous units, and others.

1.4.10 Rock Outcrops

This unit comprises 0.57% of the Emirate. It consists of outcrops of limestone, miliolite (lithified sand dunes), or tertiary sedimentary rocks. The unit occurs in coastal flats where it is often associated with coastal limestone and sedimentary rocks and as the massive rock outlier from the Hajar Mountains at Jabal Hafit. Other soils associated with this map unit include the Haplosalids and Aquisalids associated with coastal areas and the Haplogypsids in some deflation flats. This unit typically has little current use. It is generally unsuitable for irrigated agriculture due to the extensive areas of rock outcrop, steep gradients, and high salt levels of some soils.

1.4.11 Miscellaneous Units

A variety of units have been recorded and defined as miscellaneous units. They include refilled and leveled land, earthworks, rubbish tips, and quarries and amount to 0.97% of the Emirate. These units are not considered suitable for irrigated agriculture.

1.4.12 Others

Several other map unit types have been defined in areas that have not been surveyed during either this or the coastal survey project. They include areas identified specifically as "not surveyed areas," farms /forestry, urban areas, tidal flats, and highland. They amount to 2.40% of the Emirate. These areas are either already designated for an alternative land use or are unsuitable for irrigated agricultural use.

1.5 Uses and Management of the Soils

Evaluation of the land of Abu Dhabi for a variety of uses has been undertaken to provide a resource for land use planning. Land evaluation is used to match the requirements of each potential land use with the characteristics of each kind of land. Such information can help address soil-related problems and hence encourage better management. A major objective of the extensive soil survey was to develop irrigation suitability map. This assessment, plus others of generalized land uses including forestry, rangelands, wildlife habitats, sources of construction material, and sanitary landfill, has been undertaken. Land evaluation information is of value for many individuals and groups. The reader is referred to EAD (2009a), should he/she wishes to learn about the interpretation of survey results for other uses, to include all these results is beyond the scope of this chapter. However, as a guideline, the other map series published during extensive survey are presented as Table 1.3.

1.5.1 Soil Suitability Classes for Irrigated Agriculture (FAO 1976)

Soil interpretation for "irrigated agriculture" evaluated the soil's suitability for development of irrigated agriculture in the Emirate. The evaluation used follows the land suitability classification concepts developed by the FAO in its *Framework for Land Evaluation* (FAO 1976). The FAO system is generally considered as 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 (Klingbiel and Montgomery 1961), the FAO Framework does not contain predefined judgments about qualities of land in relation to specific land uses nor any proposed hierarchy of those land uses. An outline of the FAO land suitability classes is given below:

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 at currently acceptable costs
N2 *Permanently unsuitable* land with severe limitations which cannot be corrected

Important factors (Table 1.6) to consider in selecting land for irrigated agriculture in Abu Dhabi include the following: emphasis should be placed on profile depth and deep drainage because of the brackish nature of much of the irrigation water available. Areas having a limited capacity to dispose of excess irrigation water should be avoided. It is likely that the quality of water used will require a leaching fraction of between 20 and 25%. Therefore, suitable soils should be permeable in the surface and have deep, free draining subsoil material. 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. Sodicity is not considered critical as many soils contain sufficient amounts of gypsum or free calcium carbonate. Highly gypsic soils (>10% gypsum) should be avoided as, under irrigation, they may subside as the gypsum is dissolved from the soil. Sandy soils require careful water management because of low water-holding capacity. The sandy surface may be susceptible to wind erosion; therefore, wind breaks, mulches, and vegetative ground covers should be encouraged. Water-efficient irrigation systems should also be encouraged. These include drip irrigation, which is widely practiced in the Emirate, and subsurface irrigation may be a good option. Percent distribution of land suitability classes for irrigated agriculture in the Emirate is shown in Fig. 1.10.

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 (Table 1.7). Subclasses and their inherent limitations are originally defined in Part 620.04, National Soil Survey Handbook (USDA 2005). They are intended to assist users in identifying soil features important for use and provide some initial guidelines for their management. This information is intended as a guide to land users. The information presented, in its own right, does not restrict or control the development or use of land. It is intended as an input to the land use planning process and therefore can contribute to decisions on zoning and land use policy that lead to legislation on land use. Although the soil being assessed may have severe limitations or be poorly suited to a particular land use, this does not necessarily mean that it cannot successfully be put to that use. The restrictive features may be overcome by costly and difficult corrective measures such as engineering design or intensive maintenance. These interpretations

Table 1.6 Land suitability rating criteria for irrigated agriculture and summary of areas identified for each category in Abu Dhabi Emirate

Soil characteristic	Subclass code	Rating categories (see text for details)					Restrictive feature	Definition
		S1	S2	S3	N1	N2		
Hardpan 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^{-1}) weighted average for 0 to 50 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
Salinity (ECe dS m^{-1}) weighted average for 50 to 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 layer	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 layer	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 recontour the area
Area ('000 ha)		2	309	1,550	1,753	2,108		Total: 5,723

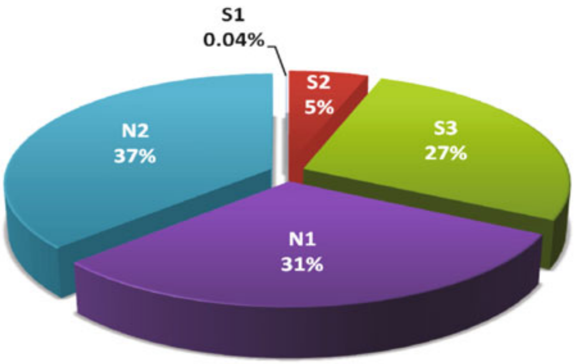

Fig. 1.10 Percent distribution of irrigated agriculture suitability classes in the Emirate

are useful for regional assessment and planning. They provide a regional perspective on restrictions or suitability for the particular land uses. They are by no means site-specific and do not eliminate the need for detailed onsite investigation.

The irrigated suitability map thus prepared for the Emirate is presented in Fig. 1.11; various soil suitability units in relation to general soil types and area occupied by suitability classes in the Emirate are briefly described below.

1.5.1.1 S1: Land That Is Highly Suitable for Irrigated Agriculture (2,000 ha = 0.04 %)

The soil is capable of producing sustained high yields for a wide variety of climatically adapted crops. The soils are nearly level and well drained. They are deep, fine sandy textured or finer, single grained thereby allowing for 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. Soils selected in this category in Abu Dhabi are lighter textured and contain more gravel and carbonate than might be considered highly suitable in other locations; however, these criteria are appropriate for the range of soils available in the Emirate.

1.5.1.2 S2: Land of Moderate Suitability for Irrigated Agriculture (309,000 ha)

The soils are inherently lower in productive capacity than soils ranked S1. Soil and land qualities may impose restrictions on irrigation; however, these restrictions may be relatively easily corrected or compensated for. S2 soils in Abu Dhabi have sandy texture and are single grain or massive. They are deep and somewhat excessively or well drained. The soils are typically very slightly saline, non-sodic,

Table 1.7 Limitations to land use for irrigated agriculture, management options, and corrective measures

Limitation class	Limitation	Management options/corrective measures
Depth to rock or hardpan	Efficient irrigation requires sufficient soil depth for plants to grow their roots without restriction as well as additional depth for leaching and drainage of salts. If a root-restricting horizon occurs close to the surface, there is only a limited volume of soil from which plants can extract water and nutrients. Low permeability of such a horizon may lead to periodic waterlogging and prevent the leaching of salts	Root-restricting layers such as hardpan can be broken down by deep ripping with a tined implement. However, the pans may reform. Consideration should be given to planting shallow rooting crops (e.g., onions) where root-restricting layer occurs within a meter of the surface. It will be necessary to determine if sufficient percolation to leach salts which accumulate in the soil as a result of irrigation can occur in these soils Irrigation scheduling and monitoring of soil-water to ensure sufficient water was continually available to plant roots while avoiding waterlogging due to ponding above the hardpan should also be undertaken. Appropriate drainage system to be installed at a suitable soil depth to remove drainage water The use of mulches and soil ameliorants may also be useful management tools Shallow soils require monitoring of soil salinity and water in conjunction with irrigation scheduling to ensure sufficient water is available to offset plant water requirements and to control salt buildup. To avoid ponding, these soils require suitable irrigation scheduling or artificial costly drainage systems
Water table depth	Below the water table, the soil is saturated and will restrict root growth. There may be not enough volume of soil from which plants can extract water and nutrients Efficient irrigation requires the leaching of salts and removal of excess water from the root zone. If the water table level is within this zone, then salt and water will build up	Water table levels can be lowered by building drains to remove excess water and salt. Careful irrigation scheduling will be required to ensure sufficient water is available to the plant roots and to avoid the water table rising so saturating the soil

(continued)

Table 1.7 (continued)

Limitation class	Limitation	Management options/corrective measures
Salinity (EC)	The potential and sustainability of irrigated agriculture are reduced by the presence of salts in the soil. High salinity adversely affects the growth of salt-sensitive plants. The high salinity restricts water intake by plants and cause physiological drought in plants	Flushing of saline soil with freshwater will leach salts from the root zone. However, care should be taken to monitor where the salts are flushed to, as a new salt problem may be generated. The risk of induced waterlogging must also be managed
	Excess salts also add impurities into other mineral resources such as gypsum and anhydrite and affect commercial value	Salt-tolerant crops/plants (biosaline agriculture) are the only options for exploiting highly saline conditions. On slightly saline soils, highly sensitive crops such as lettuce, onion, and pepper should be avoided
		Salts are to be removed to improve commercial value using appropriate technology
	Excess salts such as gypsum can corrode underground concrete and other metallic pipelines	Coating with suitable sealant around concrete pipes can control corrosion
Gypsum	Gypsum is partially soluble in water. Soils with >10 % gypsum may collapse if gypsum is removed by percolating water. This problem is exacerbated by irrigation practices. Small quantities of gypsum have positive effects in offsetting sodicity hazard of irrigation water. High gypsum also affects nutrient availability to plants	If subsidence is a problem, flushing of the soil with freshwater to dissolve and remove gypsum from the profile may be attempted prior to establishment of irrigation
		To be effective, this solution is likely to require considerable time and large volumes of freshwater. If gypsum is flushed from one area to another, the problem may merely be moved. Highly gypsic soils should be avoided
Relief	High areas, primarily dune height, will make cultivation and water management difficult for field crops as well as reducing the efficiency of farming operations	Leveling of dunes is used to overcome this problem. The practicality of leveling a dune becomes more difficult the higher the dune
Slope	Areas with steep slopes make cultivation and water management difficult for field crops as well as reducing the efficiency of farming operations	Slope is only prohibitive to flood irrigation practices. Leveling of dunes is used to overcome this problem. Sprinkler irrigation may be considered on sloping ground

Texture	Soil texture influences the ability of the soil to retain and release water and nutrients to the plant roots. The surface texture will also impact on how the soil is tilled for use. Seepage of water through the soil may be associated with sandy soils	For sandy soils minimize the tillage and maintain a surface vegetative cover or other covering to reduce erosion potential. Windbreaks are other options. Uses of organic matter and organic fertilizers can improve soil physical health and nutrient and water-holding capacity
	A sandy soil will be susceptible to erosion, and a clayey soil may be too sticky when wet; ideal textures are loamy soils	Clay, organic materials, and soil polymers can be used as soil ameliorants to improve the water- and nutrient-holding capacity of the sandy soils found in Abu Dhabi
		Careful nutrient management will be required to reduce nutrient losses through leaching as sandy soils have very high leaching capacity. Application of nitrogen fertilizers containing NO_3–N should be avoided. Fertilizer requirement can be split into small. Foliar application of micronutrients can be used for field crops
	If sandy soils are to be used as waste landfill sites (trench), the walls of the excavation can cave in or slough (cut banks cave), and for landfill (area) the excessive leaching of soluble materials can contaminate groundwater	Measures such as construction of compacted or hard layer, clay liners, or suitable geotextile layers can be used to avoid contamination at lower depths
		A trench can be excavated in “steps” or the sides of the trench angled out from the base near to the angle of repose of the soil
Flooding	Soil flooded by moving water from stream overflow, runoff, or high tides	Locate land use above high tide level and off active flood plains. Alternatively, for restricted areas, use protective structures such as levees and bunds to protect high-value infrastructure from flooding
Coarse fragments	These can range in size from gravel (2–75 mm) to rock fragments 75 mm or more across that adversely affect the specified use of the soil through a number of mechanisms	Where stones are present in the topsoil, crops requiring mechanical harvesting (e.g., potatoes) should be avoided as the stones may interfere with the harvesting machinery. Where localized patches of stones occur on the surface, they can be removed by raking or scraping with machinery. For forestry plantation (in pits), gravelly soil material is to be replaced with a suitable mixture of soil and organic material based on plant selection. For some tree crops, a surface gravel cover may prove an advantage by reducing soil evaporation.

(continued)

Table 1.7 (continued)

Limitation class	Limitation	Management options/corrective measures
	High quantities of gravels in potential resource deposits (e.g., gypsum, sand, clay) are a restriction to their use as resource material for soil improvement, cement factories, or construction material	Gravels can be removed through grinding and sieving at large scale to improve gypsum purity. Similarly, gravels can be separated through sieving to improve the quality of other materials such as sand, clay, sweet soil, and carbonates sources
Percs slowly	The slow movement of water through the soil adversely affects the specified use	Deep ripping with a tined instrument and application of gypsum and organic materials on selected soils can improve soil structure and water movement in the soil profile
Ponding	Standing water on soils in closed depressions that is removed only by percolation or evapotranspiration	Remove ponded water with shallow drains and other earthwork solutions. Alternatively plant vegetation suited to anaerobic environments in an effort to increase transpiration from the ponded area
Calcareousness	High levels of carbonates (most commonly calcium carbonate – $CaCO_3$) cause high pH and high buffering capacity and low nutrient availability to plants, particularly P, B, Fe, Cu, Mn, and Zn	Band placement of phosphorous fertilizers can be used to reduce reaction with soil material. Foliar sprays of micronutrients can be used
Mined material has low quality	The mined material has lower commercial value to be cost-effective, and the mining has impact on the environment	Prior to commercial mining of materials such as gypsum, gravels, anhydrite, and carbonates, a pilot-scale mining on a small area is recommended. Once it is proved that the material at a certain location has passed the criteria for commercial exploitation, it is only then large-scale mining is to be performed. In parallel to mining, impact of such practice on the environment is to be evaluated and suitable rehabilitation measures adopted

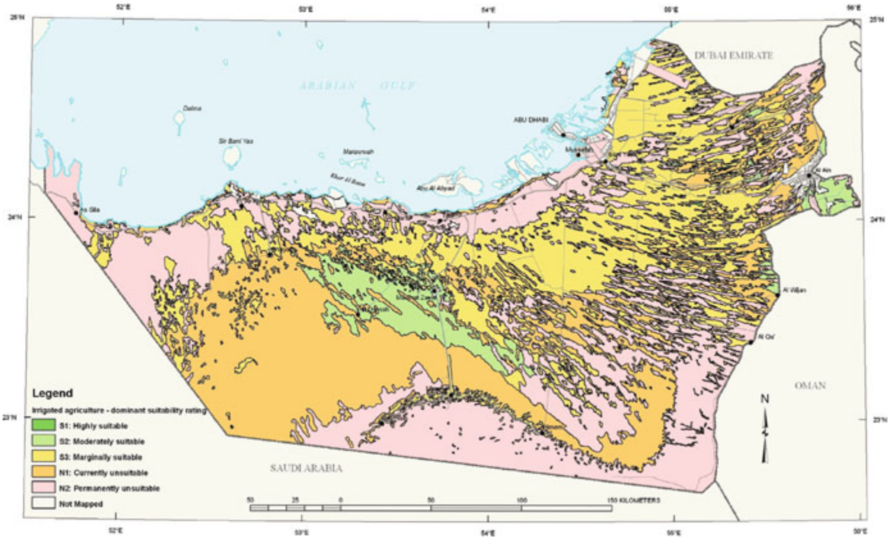

Fig. 1.11 Suitability for irrigated agriculture – map

have low gypsum content, and can have a hummocky microrelief. These moderate restrictions may be overcome with appropriate management strategies.

1.5.1.3 S3: Land of Marginal Suitability for Irrigated Agriculture (1,550,000 ha)

The productive capacity of S3 is less than S1 and S2 soils. The soils have severe limitations that may be corrected with appropriate management strategies. S3 soils in Abu Dhabi 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 may have moderately steep gradient (up to 32 %) with moderately high relief (up to 9 m).

1.5.1.4 N1: Land That Is Currently Unsuitable for Irrigated Agriculture (1,753,000 ha)

Such soils in Abu Dhabi 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%).

1.5.1.5 N2: Land Considered to Be Permanently Unsuitable for Irrigated Agriculture (2,108,000 ha)

The N2 category includes soils which are very shallow, occur with rock outcrops, are on very steeply sloping land (over 56%), have a very high relief (over 30 m), are very poorly drained and strongly saline, or have shallow depth to gypsum. Under conventional economic conditions, these soils do not warrant further investigation for irrigation purposes.

The results of this evaluation indicated that 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, but again 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 eolian sands at a shallow depth, there is a danger that rising saline water tables may develop rapidly. The scale and frequency of sand dunes are a further constraint to the utilization of these otherwise suitable soils. High dunes generate long, moderately steep slopes, and frequent dunes create an irregular topography and are difficult to manage for agricultural purposes. However, perhaps with the exception of the bigger dunes, dune leveling is a feasible, though expensive, management option in these areas. Other soils are generally 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 Figs. 1.10; 1.11. The most suitable areas for irrigated agriculture 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 indicated to the east of Jabal Hafit. Other much smaller areas lie near Al Ain and Al Wijan. Extensive areas of marginally suitable land occur inland from the coastal plains from the northeast of the Emirate, westward to Sabkhat Matti.

1.5.2 Limitations to Irrigated Agriculture and Management Options

A number of limitations and limitation classes to irrigated agriculture have been identified during the extensive survey. Management options to overcome these restrictions are addressed in Table 1.7.

1.5.3 Delineation of Area Having Potential for Irrigated Agriculture for Intensive Survey at 1:25,000 Scale

As stated earlier, one of the objectives of extensive survey was to delineate 400,000 ha area having potential for irrigated agriculture in the Emirate for fur-

Table 1.8 Extent of subareas for intensive survey

Subarea	Mapped area (ha)
Al Ain	198,596
Madinat Zayed	116,146
Ghayathi	105,355
As Sila’	27,809
Total	447,906

ther survey at 1:25,000 scale using norms and standards of second-order USDA protocols, modified to fit Abu Dhabi conditions. Using the extensive survey results and the irrigated suitability map (Fig. 1.11), 1 million ha area was delineated (Fig. 1.12), from which an area of 447,906 ha divided into four subareas was selected based on four broad criteria: (1) availability of suitable soil/landscape map units, (2) availability of suitable water resources, (3) access to infrastructure and workforce to support any development, and (4) strategic issues. The first two criteria were given in the highest weighting, while the third was used to corroborate the selection. The relative size of the four areas surveyed is shown in Table 1.8. The area mapped includes map units interpolated between or extrapolated away from survey sites.

The area (having the potential for irrigated agriculture) delineated was over 400,000 ha as described earlier, it was surveyed at intensive survey level, and results can be consulted elsewhere (EAD 2009b).

1.6 Future Opportunities to Use Emirates Terrestrial Resources and Policy Development

The extensive survey identified a number of issues facing the Emirate and further work that needs to be undertaken to build on this foundation. Such future work may include policy, research and development, and education and extension related to soil management.

1.6.1 Policy

The best management of the Emirate’s soils will result from a planned, well-implemented approach based on policies that oversee research, development, education, regulation, and enforcement. Establishing and implementing the required policies must take account of these other objectives. This means that in addition to ensuring that adequate ongoing support is given to soil specialists with local knowledge, the activities of those specialists must be linked to the people and groups who are managing

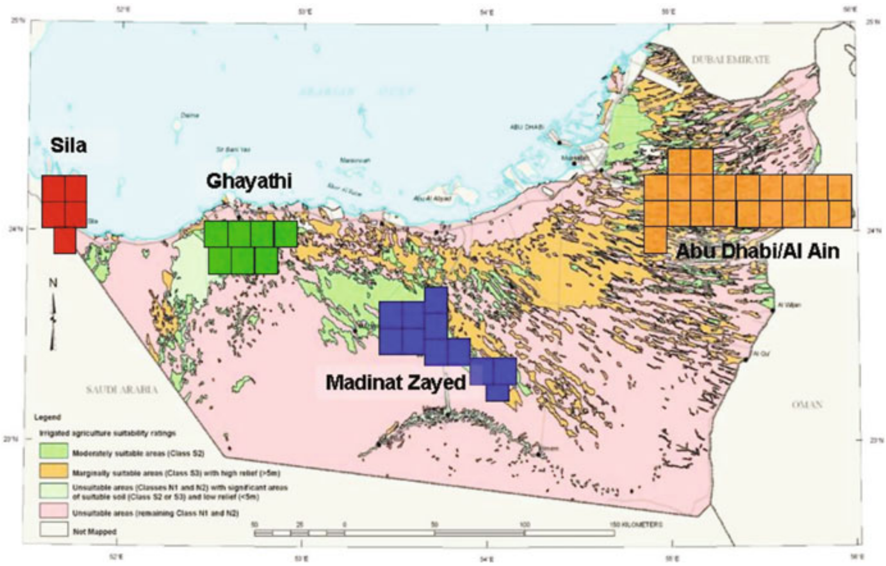

Fig. 1.12 Location of subareas in relation to 1 million ha of land identified in the extensive soil survey as the most suitable for irrigated agriculture (*green color* area)

the larger, integrated activities. Failing to provide the former (support for the specialists) will result in uninformed decisions being taken about soil management.

1.6.2 Establish a Soil Monitoring Program

The monitoring of soil quality is likely to be linked to monitoring of other environmental conditions (e.g., rangeland condition, wildlife status). In addition, soil monitoring by itself may not provide enough benefit in its own right to justify a single-focus monitoring program. However, it is an important part of an overall environmental monitoring program. This can be separated into at least two elements: monitoring of commercially used soil (primarily farmland), which has an impact on medium- to long-term economics, and monitoring of public lands (rangeland and nature reserves), which can impact on the ability of the land to support land uses of public benefit and avoid negative impacts on the community (e.g., excessive dust storms).

1.6.3 Establish a Soil Research, Development, Education, and Extension Program

In order to develop and implement an appropriate set of activities, it is recommended that the Emirate appoints a small group to oversee the establishment and management of a program of research, development, and education. This group should include a core of people with expertise in soil science, policy development, research implementation, public education, and contract management. Integration of soil data with other natural resource and cultural and political datasets allows it to be used for decision making, anticipating questions regarding land use that will arise, and using experienced soil people to correctly interpret the data to assist with providing answers. The group should work with other agencies and the private sector to maintain a technical knowledge base on the soils for the Emirate; recommend activities for partner organizations to undertake; implement research, development, and education activities, probably through subcontracts; and recommend policy settings for regulators to enforce in relation to activities that have significant impact on soils. Such a group will necessarily be part of a bigger organization because soil management objectives cannot be achieved in isolation from the real-world economy.

1.6.3.1 Integrated Soil Salinity Management

The huge amounts of salt in the soils and waters of the Emirate are one of the key features that impact on the management of land. The many factors that are impacted by the presence of salt mean that an integrated approach must be taken to its management.

1.6.3.2 Amelioration of Saline Soil

Options for saline soil management which could be explored as parts of an integrated management approach are physical (soil structure improvement and breaking hardpan), chemical (using soil ameliorants such as gypsum), hydraulic (understanding the leaching requirements of particular soils, drainage system), and biological (biosaline agriculture, where appropriate).

1.6.3.3 Irrigation Using Brackish Water

Water supplies most readily available for irrigation in the Emirate are brackish. This raises several issues that interact with the soil. There is a need to overwater in order to avoid accumulation of salts. Because of issues with shallow water tables and hardpans, it would be valuable to understand the interaction between irrigation strategy and soil properties in their impact on water use and productivity. Better use of saline and freshwater resources could be achieved by investigating when particular plant species can tolerate the existing groundwater resource and designing a farming system that utilizes freshwater during critical growth periods. This may need to be customized for each particular crop and saline water during "maintenance growth" periods. Part of this approach could involve using hydroponic systems for agriculture and using halophyte plants in all aspects of agricultural development (e.g., landscape, production farms, and agro forest).

1.6.3.4 Living with Shallow Saline Water Tables

Research should target this problem through (a) surveying the current extent of elevated water tables under plantings and relating any rise to soil type, longevity of the planting, irrigation methods, and landscape; (b) understanding the impact of rising water tables on productivity of the Emirate's plantings, initially by surveying existing plantings and examining the relationship between water table level, salinity, soil properties, and productivity and then, if required, undertaking controlled experiments to study this impact; and (c) forecasting the future development of problems by extrapolating the principles established in the research using modeling techniques with varying scenarios and so identifying the location, timing, and severity of future problems.

1.6.3.5 Selection of Salt-Tolerant Plants and Dewatering Options

The effect of salinity on plant growth may be magnified many times in the presence of waterlogging. Research should be undertaken into the particular interactions that apply in Abu Dhabi's environment, particularly accounting for shallow water tables and the potential overwatering through inefficient irrigation. If significant occurrence of induced shallow water tables is found, it may be worth considering evaluating efficient methods of drawing them down and ameliorating the salt bulges associated with them. An interesting alternative to plant production systems in addressing the issue of shallow water tables could be through development of artificial lakes for biodiversity or aquaculture (e.g., for brine shrimp or prawns or algae for beta-carotene and stock feed). It would be useful to understand the soil properties that would be best suited to the construction of such artificial lakes.

1.6.3.6 Understanding Shallow Hardpans

As with shallow water tables, Abu Dhabi Emirate has a high proportion of soils with shallow or very shallow hardpans. These vary in depth and in their nature. In some cases, they may be sufficiently fractured to allow water movement and root growth through them; however, hydraulic properties of the Emirate's hardpans and their effects on plant productivity are unknown. The management of areas with hardpans can include deep cultivation to disrupt the hard layer and so improve soil conditions. Whether this technique is effective on the local hardpans is unknown. Undertaking research to better understand these issues would allow a more rational approach to their management.

1.6.3.7 Gypsum and Soil Subsidence

In the extensive soil survey of Abu Dhabi Emirate, the presence of gypsum has been identified as a limitation for irrigated agriculture. Yet many existing farms have been established on soils with enough gypsum to be concerned that subsidence will occur as a result of irrigation water dissolving gypsum and creating voids in the soil profile. Research could focus on identifying the likely distribution of the problem and the high-risk areas, assessing the likely practical impacts and severity of the problem (e.g., by calculating the amount of subsidence if all the gypsum present was to dissolve), and evaluating the cost effectiveness of possible management options (e.g., importing additional topsoil to infill the subsided areas).

1.6.3.8 Managing Nutrients in a Desert Environment

Abu Dhabi's soils have little clay and very low organic matter levels, very high $CaCO_3$, and pH higher than optimum level. This results in soils' low nutrient-holding and availability capacity. Several inorganic nutrients (e.g., NO_3) leach readily in such conditions leading to high costs of fertilizer inputs and high risk of off-site pollution by the outflow of nutrients. Others are fixed in soil due to high $CaCO_3$ and pH (P, Fe, Cu, Mn, Zn). There is a significant body of knowledge in relation to soil-nutrient interactions which the Emirate can capitalize on. In addition to farmland, there is an opportunity to understand the cycling of nutrients in the natural, desert soils of the Emirate to contribute to an understanding of the management of the natural ecosystem and wildlife reserves.

1.6.3.9 Managing Fragile Soils in Grazing Systems

The best way to protect Abu Dhabi's fragile soils, particularly given its extremely harsh climate, is to have controlled grazing. The grazing impact on ecosystem can be minimized through adopting a conservative approach to grazing management. Commercial animal industries should be limited to as small an area as possible, consistent with productivity and animal welfare constraints, and those areas should be restricted to soils that are most resilient under animal grazing; the grazing should be managed carefully to minimize impact, and protective measures such as windbreak plantings should be implemented.

1.6.3.10 Fundamental Soil Research

While the topics suggested above as future opportunities in this section target issues that have clear, practical applications, it is also important to ensure the accuracy and rigor of the fundamental knowledge that underpins those immediately applicable activities. The following recommendations target specific research that is of particular relevance to Abu Dhabi and is not likely to be addressed elsewhere. These topics offer the opportunity for minimal investments that often suit being studied at universities or specialist research organizations, thereby also helping build the capacity of local scientists to work on the Emirate's soils in the future.

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