Chapter 3

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Chapter 3
Reconnaissance Soil Survey for the State of Kuwait

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Abstract In 1999, the government of Kuwait in collaboration with international consultant (AACM) completed a soil survey project at two levels: reconnaissance at scale 1:100,000 and a semi-detailed at scale 1:25,000. The survey followed the latest USDA-NRCS norms and standards for the fourth-order extensive soil survey, called as reconnaissance survey. Field mapping was completed by describing one point per 200 ha making a total of 8,400 observation points in the entire state, covering an area of 16,800 km^2. To support field mapping, 105 typical soil profiles representing different soil taxa were described, and 570 horizons were sampled and analyzed for their physical, chemical, engineering, and mineralogical characteristics. Eight diagnostic horizons and eight soil great groups (Haplocalcids, Petrocalcids, Haplogypsids, Calcigypsids, Petrogypsids, Aquisalids, Torriorthents, and Torripsamments) were mapped. Of 12 soil orders distributed worldwide, only two Aridisols and Entisols were mapped. Aridisols occupy 70.8% and Entisols 29.2% of the surveyed area. A total of 23 soil taxa at the family level of USDA soil taxonomy hierarchy were mapped and included as major and minor components of 71 soil map units. The survey results were interpreted for several uses and translated to a number of thematic maps such as sand and gravel sources and uses for shallow excavations, septic tanks, sewage lagoons, sanitary landfills (area and trench), seedling mortality, and herbaceous desert plants. The major outcome was the delineation of 207,309 ha area with highest potential for irrigated agriculture, this area was surveyed at the second-order (semi-detailed) level of USDA-NRCS standards, and suitability map

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for irrigated agriculture was prepared. The reconnaissance survey results are valuable source to base future land-use planning and will serve as a guide for decision makers and land-use planners. The reader is referred to (KISR, Soil survey for the State of Kuwait – vol II Reconnaissance survey. AACM International, Adelaide, 1999) for details of these interpretations.

Keywords Reconnaissance survey • Semi-detailed soil survey • Soil analysis • Soil characteristics • Soil mapping • GIS

3.1 Introduction

National soil surveys are essential to understand distribution and extent of soils of varying land-use capabilities particularly for designating potential agricultural areas. In any country, good soils and sufficient water are taken as granted for successful agriculture and food security. However, due to hyperarid condition and general water scarcity in Kuwait, both resources are not enough to meet national requirement. It is, therefore, necessary to find ways for efficient utilization of these resources; this is only possible if soils are characterized by using internationally recognized standards. Acknowledging these needs, the Public Authority for Agriculture and Fish Resources (PAAFR) and Kuwait Institute for Scientific Research (KISR) jointly implemented "Soil Survey for the State of Kuwait" through an International Australian Contractor AACM International. The project was completed in 1999 (KISR 1999).

Prior to this comprehensive survey, several soil surveys had previously been completed in Kuwait at scales ranging from reconnaissance (1:500,000) to detailed (1:5,000) levels (Ergun 1969). Soil classification was based on the FAO system as outlined in USDA (1938) and modified in 1949 (Ergun 1969), which classified the soils into great groups. Ergun (1969) reported two soil great groups, 10 soil associations, and 18 detailed soil series descriptions. Mapping units comprised of soil associations and soil series. In 1970, the Societe Centrale pour I'Equipement du Territoire Cooperation (SCET) was contracted to map the soils of 264,000 ha that were delineated by Ergun (1969) as having the highest potential for horticulture. Mapping was based on a grid survey for both scales (1:40,000) and (1:5,000). However, details of map production and spatial accuracy were not reported in SCET (1970).

Apart from the above-mentioned surveys, no other formal soil surveys have been carried out at the national scale. However, some soil-related investigations in Kuwait were conducted, such as survey of area for wildlife habitats (Omar et al. 1986), area vulnerable to sand encroachment (Omar et al. 1988), first-order soil survey of demonstration sites and proposed management (Shahid and Omar 1999), and soil survey for farm planning in northern Kuwait (Shahid et al. 2004).

To maintain and upgrade soil information in Kuwait, the present soil survey was carried out between 1996 and 1999, using the sixth edition of the Keys to

Soil Taxonomy (USDA-NRCS 1994) available at the commencement for soil classification in Kuwait. This survey updates the previous surveys (Ergun 1969; SCET 1970) by providing additional information, a wider coverage of the state, and a large database of spatial, site, and soil information, as well as an opportunity for their international correlation (Abdelfattah and Shahid 2007) and its use in the vegetation mapping in Kuwait (Omar et al. 2001). The rigor in using the USDA-NRCS specifications is that the USDA soil taxonomy has been used by over 75 countries in the world including Kingdom of Saudi Arabia (MAW 1985), Sultanate of Oman (MAF 1990), State of Qatar (MMAA 2005), and recently in Abu Dhabi Emirate (ERWDA 2004; EAD 2009).

The main objective of the soil survey was to provide basic information for broad land-use planning and irrigated agriculture development in Kuwait. The surveys conducted at different scales serve as guideline for sustainable farming (SFRI 1995), as agriculture is the most related and the widest field of soil survey data use. Among many deliverables, soil suitability map for irrigated agriculture for the State of Kuwait was the major outcome for future informed planning for irrigated agriculture.

3.1.1 Description of the Study Area

The State of Kuwait is situated at the northwestern corner of the Arabian Gulf between latitudes 28°30 and 30°05 N and longitudes 46°33 and 48°35 E. The total land area is about 17,818 km^2. The study area includes the entire State of Kuwait, excluding all military areas; oil areas in the vicinity of infrastructure; urban areas; industrial areas; minefields; and areas not cleared of ordinance. Collectively, the nonsurvey area is considered as miscellaneous unit.

Kuwait experiences extremely high temperatures during summer, short mild winters, strong sunshine, low humidity, and generally dry conditions. The daily maximum temperature averages 45°C in July, but temperatures as high as 51°C are not uncommon at this time and 18°C in January. The daily minimum temperature fluctuates between 29°C in July and 8°C in January. Rainfall is light, averaging 110 mm per annum and mainly falling between November and April. Annual rainfalls vary widely and have ranged from 20 mm in 1964 to 242 mm in 1976. The average evaporation rate ranges from 21 mm per day for July to 3 mm per day for January. The prevailing winds blow from the northwest and the southeast. In the summer months between June and September, northwesterlies are most common.

Most surface and near-surface formations of Kuwait belong to the Miocene and Pliocene Epochs and Quaternary Period. They consist of clastic deposits with subordinate carbonates and evaporites, locally known as the Kuwait Group. The dominant rock types are calcareous sandstone, fine-grained limestone, and muddy sand with minor quantities of granules and scattered pebbles. Calcrete is widely spread in the thick sand sequence of the undifferentiated Ghar and Fars Formations in the south. Gypcrete is mostly confined to the upper member of the Dibdibah Formation in the north (Al-Sulaimi and El-Rabaa 1994; Al-Sulaimi and Pitty 1995).

Most land outside the metropolitan area is owned by the state. Rangeland grazing by livestock is the predominant land use, covering almost three-quarters of the country (KISR 1999). Some 24,000 ha of privately owned or controlled farms are used for agriculture (of which 5,000 ha is cultivated). Kuwait City, surrounding towns, and industrial areas occupy about 60,000 ha. Oil wells, pipelines, and collection and processing areas also occupy localized areas.

3.2 Materials and Methods

3.2.1 Field Soil Mapping

The reconnaissance field survey was conducted at 8,400 sites. Each site was investigated to a depth of 100 cm using shovel and hand augers. Sites were located accurately with global positioning system (GPS) equipment attached to each vehicle and marked on field maps and aerial photographs. During the survey, pedologists recorded the key characteristics of each investigated site. At the sites, auger holes were dug, and the sequence of natural layers or horizons is described (Soil Survey Division Staff 1993). The descriptions included color, texture, structure, rock fragments, segregation, and other features as appropriate that enabled identification, classification, and mapping of the soils. To support field mapping, 105 typical soil profiles representing different soil taxa were described, and 570 horizons were sampled and analyzed for their physical, chemical, engineering, and mineralogical characteristics. The soils were described at the family and phases of soil family level using fourth-order level of soil survey.

In addition to routine soil mapping, 12 transacts were established throughout the country to test the previous studies to provide an overview of the soil variation. Soil descriptions were recorded on field cards and information transferred into the Soil Information System (SIS).

Soil taxonomy is based on soil properties observed or inferred during the field survey and confirmed by laboratory assessments of soil samples. Soil taxonomy takes into account the soil's morphology, physical and chemical characteristics, soil temperature, and soil moisture status.

3.2.2 Soil Information System and Development of Soil Map

Information from preliminary mapping and routine soil mapping was used to compile the final soil map and reports of the reconnaissance survey. Compilation of the map line work was then transcribed onto a base map provided by 1:100,000 scale Satellite Pour l' Observation de la Terre (SPOT) and Landsat Thematic Mapper (TM) satellite imagery rectified to remove distortions. These were used because they allowed map line work to be placed accurately in relation to observed features, then efficiently digitized and captured in the GIS. Map boundaries were defined using field data, photo interpretation, and existing information. This enabled preparation of a map legend, definition of map units, and characterization of the main soils and production of a soil map.

Data collected was stored and managed in a Soil Information System (SIS) that integrates a textural database and GIS. Soil maps were prepared at scale of 1:250,000, nine A1 size map sheets at scale 1:100,000, and an atlas (A3 size) at scale 1:100,000. Although, the soil survey was carried out according to the protocols of the fourth order (Soil Survey Division Staff 1993) at the family level, in this chapter, the soil distribution at soil great groups levels are generalized. The reader is referred to KISR (1999) for further information.

3.2.3 Laboratory Soil Analyses and Sampling Archive

Soil samples were collected from shovel/auger holes and typical soil profiles, air-dried and stored in the soil sampling archive at Kuwait Institute for Scientific Research (KISR). A total of 105 profiles (570 horizons) were analyzed to confirm the soil classification made during the field survey. The soil samples were analyzed at the State Chemistry Laboratory of Victoria, Australia, having ISO 9000 accreditation and familiar with USDA methods and standards (USDA-NRCS 1996). Soil samples were analyzed for their physical, chemical, engineering, and mineralogical characteristics. Soil-saturated paste was analyzed for pH, soil saturation extract for EC, and soluble Ca, Mg, Na, and K using atomic absorption spectroscopy, HCO_3 by acid titration, chlorides by chloride analyzer, and SO_4 by ICP (USDA-NRCS 1996). CO_3 was undetectable in all samples. Sodium adsorption ratio (SAR) was calculated using standard calculation procedure (Richards 1954). Calcium carbonate equivalents were measured by a standard calcimeter and gypsum by loss on hydration (Page et al. 1982) and acetone precipitation procedures (USDA-NRCS 1996). Particle size distribution analyses were made by plummet balance method (Ross 1996) after the removal of soluble salts and gypsum (USDA-NRCS 1996).

3.2.4 Land-Use Assessment for Irrigated Agriculture

Several land evaluations of both agricultural and nonagricultural land uses have been undertaken for the 1:100,000 reconnaissance scale map data. One major outcome was the delineation of 207,309 ha area having the highest potential for irrigated agriculture (Fig. 3.1, Table 3.1), later examined at semi-detailed scale 1:25,000 level. The results can be found in Volume IV (KISR 1999). The FAO land evaluation system of (FAO 1976) and important soil characteristics were considered in selecting land for irrigated agriculture. Criterion was developed, which considered rooting depth, site drainage, profile coarse fragments, slope, microrelief, surface stone, salinity, sodicity, soil reaction, gypsum, and $CaCO_3$ percentage.

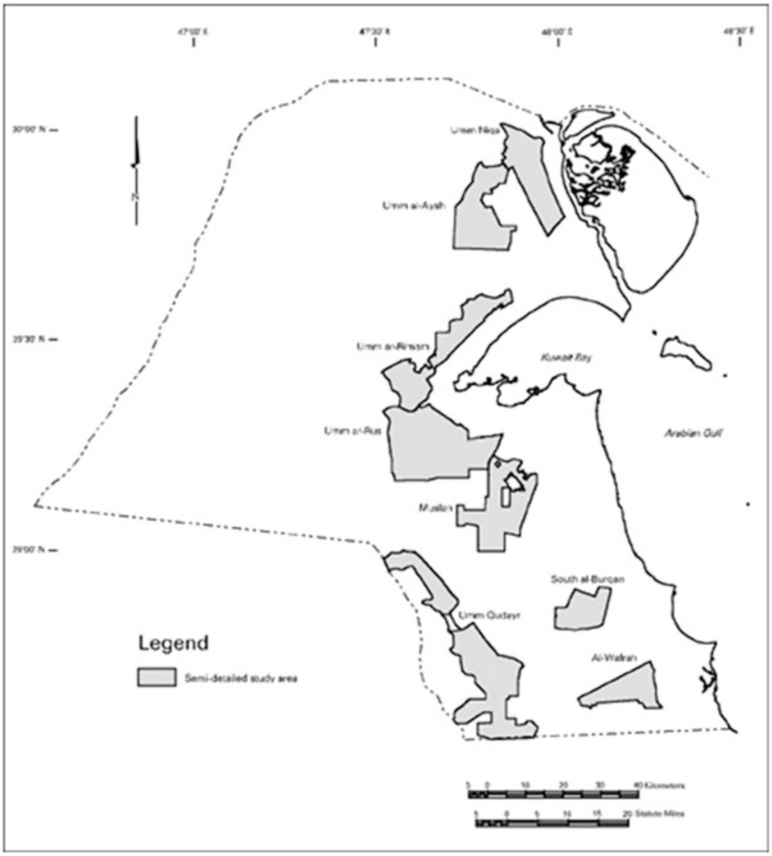

Fig. 3.1 Delineation of area having highest potential for irrigated agriculture

Table 3.1 Extent of areas studied in the semi-detailed survey

Subarea	Area (ha)
Umm al-Aish	23,121
Umm Niqa	21,430
Umm ar-Rimam	24,894
Umm ar-Rus	41,808
Muslan	25,571
South al-Burqan	11,838
Al-Wafrah	13,538
Umm Qudayr	45,109
Total area	207,309

3.3 Results and Discussion

The soils of Kuwait are generalized into great group map units using the USDA-NRCS specifications (USDA-NRCS 1994; Soil Survey Division Staff 1993).

3.3.1 Diagnostic Horizons Identified in Kuwait

Eight diagnostic soil horizons (1 surface and 7 subsurface) were recognized in Kuwait. The surface horizon (ochric) is light colored with little organic matter. Subsurface horizons are argillic, with accumulation of clay; calcic, rich in calcium carbonate; cambic, with loam texture and/or structural development; gypsic, rich in gypsum; petrocalcic, characterized by cemented calcium carbonate; petrogypsic, characterized by cemented gypsum; and salic, that is extremely salty. The presence/absence or combination of these diagnostic horizons in the pedon identifies the soil great group in Kuwait.

3.4 Soil Taxonomy Hierarchy (Reconnaissance Survey)

Soil taxonomy hierarchy from reconnaissance soil survey of Kuwait is presented as Fig. 3.2 and is briefly described below.

3.4.1 Aridisols

Aridisols are dry and do not have moisture available for plants for long periods. They have one or more of the subsurface diagnostic horizons. The Calcids and Gypsids are the major suborders identified in Kuwait; however, in the coastal area, Salids and Orthents in minor quantities are also mapped. All soils in Kuwait have an aridic soil moisture regime except for those in low-lying areas such as sabkhas where shallow groundwater sits within the soil profile. These soils are classified as the great group Aquisalids.

Gypsids cover 39.6% area of Kuwait. In many investigation sites, Gypsids have a calcic horizon above the gypsic or petrogypsic horizon. Gypsids are recognized as Haplogypsids, Petrogypsids, and Calcigypsids. Haplogypsids are minor and are included in Calcigypsids mapping unit. The Typic Haplogypsids (Fig. 3.3a) are soils with illuvial accumulations of gypsum (gypsic horizon), and the illuvial gypsic layer is not cemented sufficiently to give a petrogypsic horizon. When the gypsic horizon extends to within 18 cm of the surface, the soils are a Leptic Haplogypsid (Fig. 3.3d). If there was a calcic horizon, then the soil is Typic Calcigypsid (Fig. 3.3g).

Order	Suborder	Great Group	Subgroup	Family
Aridisols	Salids	Aquisalids	Gypsic Aquisalids	sandy, mixed, hyperthermic
			Typic Aquisalids	sandy, mixed, hyperthermic
	Gypsids	Petrogypsids	Petrocalcic Petrogypsids	sandy, mixed, hyperthermic
				sandy, mixed, hyperthermic, shallow
				coarse-loamy, mixed, hyperthermic
			Calcic Petrogypsids	sandy, mixed, hyperthermic
			Typic Petrogypsids	sandy, gypsic, hyperthermic
				sandy, gypsic, hyperthermic, shallow
		Calcigypsids	Typic Calcigypsids	sandy, mixed, hyperthermic
				sandy, gypsic, hyperthermic
				coarse-loamy, mixed, hyperthermic
		Haplogypsids	Leptic Haplogypsids	sandy, gypsic, hyperthermic
			Typic Haplogypsids	sandy, mixed, hyperthermic
				sandy, gypsic, hyperthermic
				coarse-loamy, mixed, hyperthermic
	Calcids	Petrocalcids	Calcic Petrocalcids	sandy, mixed, hyperthermic
				sandy, mixed, hyperthermic, shallow
				coarse-loamy, mixed, hyperthermic
			Typic Petrocalcids	sandy, mixed, hyperthermic
				sandy, mixed, hyperthermic, shallow
		Haplocalcids	Typic Haplocalcids	sandy, mixed, hyperthermic
				coarse-loamy, mixed, hyperthermic
Entisols	Psamments	Torripsamments	Typic Torripsamments	mixed, hyperthermic
	Orthents	Torriorthents	Typic Torriorthents	sandy-skeletal, carbonatic, hyperthermic

Fig. 3.2 Soil taxonomy hierarchy from reconnaissance soil survey of Kuwait

In gypsic horizon, the gypsum translocates from overlying horizons so that in gypsiferous material, the absence or relatively lower gypsum in A horizon and its presence and enrichment in B horizon are strong evidences of a gypsic horizon, particularly in Calcigypsids identified in Kuwait. It is visualized that gypsic horizon due to looser gypsum crystals remained soft, except where they were identified as Petrogypsid (Fig. 3.3f). Van Alphen and Romero (1971) noted that gypsum is redistributed in the soil and frequently forms cemented and indurated layers. It is believed that in Petrogypsids, the gypsic horizon like argillic and calcic horizons and duripans form by feedback process (Torrent and Nettleton 1978). Petrogypsic horizon may have some amount of gypsum as in a normal gypsic horizon; however, the gypsum is indurated rather than being soft. They become hard due to continuous interlocking crystals of gypsum. Dissolution of gypsum can cause subsidence, particularly in irrigated farming, where leveling becomes necessary. Cracked building foundations and uneven roadbeds can be other victims of subsidence. Gypsum is also present in some soil parent materials, particularly those of the Dibdibah Formation in Kuwait. The soil depth ranges from very shallow, when a restrictive layer is present, to very deep. Textures are sandy or loamy, rarely sandy-skeletal. They are extensive throughout the west and north of Kuwait.

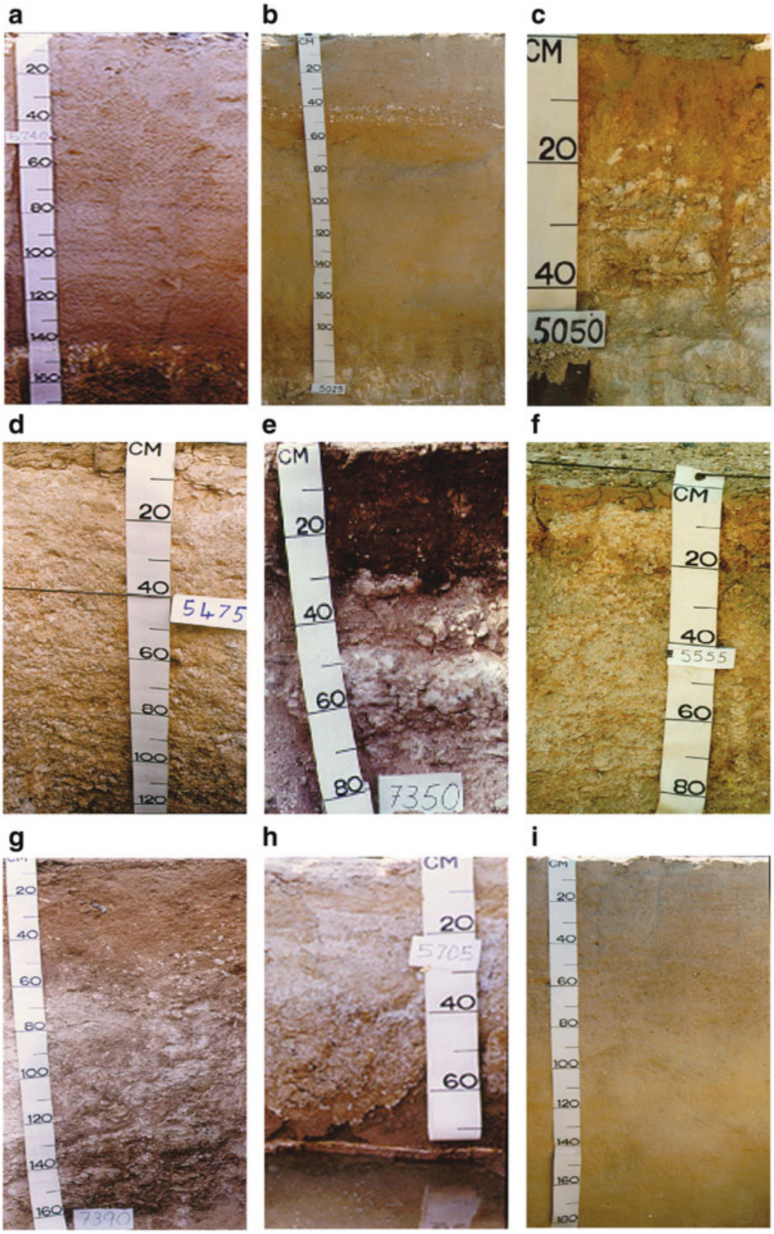

Fig. 3.3 Typical soil profiles of major soil families identified in Kuwait. (**a**) Typic Haplogypsids, (**b**) Typic Haplocalcids, (**c**) Calcic Petrogypsids Hardpan 40 cm, (**d**) Leptic Haplogypsids, (**e**) Petrocalcic Petrogypsids, (**f**) Typic Petrogypsids, (**g**) Typic Calcigypsids, (**h**) Gypsic Aquisalids, (**i**) Typic Torripsamments

Petrocalcic Petrogypsid (Fig. 3.3e) soils contain a petrogypsic horizon and in addition have a carbonate-cemented horizon (petrocalcic horizon) that does not overlie the gypsic or petrogypsic horizon. Sometimes, the petrogypsic and petrocalcic horizons are separated within the profile, but more commonly, they overlap or coincide to give a very hard layer that is cemented by both carbonate and gypsum. Such a layer has a slow permeability and presents a physical barrier to root penetration. If carbonate cementation is not a feature, but a calcic horizon is still present, the soils are identified as Calcic Petrogypsids (Fig. 3.3c). When the carbonates were even less evident, then the soils are identified as Typic Petrogypsids (Fig. 3.3f).

Argids were encountered during routine field survey, but they are of minor extent and therefore are not described in this survey as a separate suborder. They occurred on the sand plains in the south of Kuwait where they were found as a minor soil in association with the Typic Haplocalcids.

Calcids occupy 18.77% area of the landscape. In Calcids, secondary carbonates have accumulated to form a calcic or petrocalcic diagnostic horizon that has its upper boundary within 100 cm of the soil surface. Only two great groups, Petrocalcids and Haplocalcids, were mapped; they occupy 11.05 and 7.72% of the Kuwaiti landscape, respectively. It is visualized that in Kuwait the rainfall has not been sufficient to leach carbonates from the upper part of the soil. As a result, these soils are usually calcareous from the surface down to, and below, the calcic horizon. Calcids have sandy and loamy textures and range from very shallow, when a restricting layer is present, to very deep. They occur throughout Kuwait but are more common on the sand sheets in the south and center of the country, and in other areas, they may occur in depressions.

Petrocalcids and Haplocalcids are the recognized great groups. In the soils where the carbonate accumulation and cementation occur in the upper part of a hard substrate, it was difficult to distinguish a petrocalcic horizon from a hard calcareous substrate (a petrocalcic horizon rather than a lithic contact). However, if there is clear evidence of carbonate illuviation in the soil above the cemented layer, then it is highly likely that it will be a petrocalcic horizon. A one-centimeter laminar capping on the hard substrate material is all that is required for defining a petrocalcic horizon. If the level of carbonate accumulation above the petrocalcic horizon is too low for a calcic horizon, the soil was identified as Typic Petrocalcids.

Typic Haplocalcids (Fig. 3.3b) are soils that have accumulated sufficient carbonates to form a calcic horizon. It is recognized that in Kuwait many of the Typic Haplocalcids occurring in the south of the country are very similar to the Typic Torripsamments (Fig. 3.3i). There is only a small difference in the quantity of carbonate in the top 100 cm of the profile between calcareous Typic Torripsamments and Typic Haplocalcids. The soil survey of Kuwait project visualized that in Kuwait probably the Typic Haplocalcids soils are the best for agricultural purposes (USDA 1998).

Salids occur in landscape positions that receive saline or brackish groundwater through lateral flow or through seawater intrusion in the coastal area. In these areas, the water evaporates from the soil surface leaving behind the soluble salts. The water extract (1:1 soil:water) from a salic horizon is more saltier than seawater.

Soils are strongly saline, sometimes wet, occurring in basins, such as playas and coastal flats above the high tide level locally named “sabkha.” In most places, the surface layers when dry has a salt crust of varying thicknesses. They are deep soils with textures that range from sand to clay. The Aquisalid is the only great group recognized in Kuwait. At the subgroup level, they are identified as Typic Aquisalids and Gypsic Aquisalids (Fig. 3.3h). When the water table remains below 100 cm, the soils are Haplosalids. The Haplosalids were encountered during fieldwork, but they are of relatively minor extent and are not mapped separately. The Salids are mainly confined to coastal and associated depression areas (sabkhas) and show significant salinity development (Shahid et al. 1998).

3.4.2 Entisols

Entisols occupy 29.2% of the surveyed area; it comprises soils that show little or no evidence of soil development. They are loose calcareous sandy material. They may have an ochric epipedon but have none of the other diagnostic horizons. The Entisols are found in recent eolian sand deposits on level to gently undulating plains in the south of Kuwait, as well as on steep actively eroding slopes, and in drainage depressions that have been filled with sand (Khalaf and Al Ajmi 1993). The Psamments (dominant) and Orthents (minor) are the suborders recognized in Kuwait.

Psamments (suborder) are formed in poorly graded (well-sorted) sands on dunes and in other sandy deposits on plains and wadi floors. They occur throughout Kuwait but are more extensive in the south of the country on the sand sheets. The soils are deep and have a texture of sand or loamy sand throughout the top 100 cm of the profile or to a lithic contact at a depth of 50–100 cm.

Typic Torripsamments are usually deep and have a texture of sand or loamy sand throughout the top 100 cm of the profile. They are mostly nonsaline and calcareous, but carbonates have not been accumulated enough to form a calcic horizon (Table 3.2). Areas of shallow Torripsamments have also been recognized in places where there is a thin sand cover (<50 cm) over bedrock. These soils are Lithic Torripsamments; these are very minor soils and are not described in this survey as a separate map unit.

Orthents (suborder) are soils that have a rock fragment content exceeding 35% (by volume) or a texture of loamy fine sand or finer (and there is no cambic horizon) in any horizon within the top 100 cm of the soil surface. Torriorthents is the only recognized great group in Kuwait. This is an Orthent that has a torric moisture regime (dry and does not have moisture available for plants for long periods). Typic Torriorthents have formed mostly in deposits on coastal dunes and beach ridges or in colluvium on actively eroding slopes. Some have formed in alluvium on wadi floors. They occur throughout Kuwait but are more extensive on the coast, islands, Jal Az Zur scrap, and in wadis in the northeast. They range from nonsaline to strongly saline.

Table 3.2 Physical, chemical, and morphological characteristics of typical soil taxa from great groups identified in Kuwait

Horizon	Depth (cm)	Munsell color Dry	Munsell color Moist	Sand %	Silt	Clay	Texture	Gravel %	Structure	Consistence	Stickiness	Effervescence	Boundary	$CaCO_3$ % eq.	ECe dS/m	pHs	Gypsum %
Haplocalcids																	
Ak	0–40	2.5Y 6/4	10YR 5/4	92.1	2.9	5.0	S	6.0	SG	LM	–	VE	CS	6.9	0.31	8.3	<0.1
Bk1	40–55	2.5Y 7/3	10YR 6/4	92.0	0.7	7.3	S	29.0	SG	LM	–	VE	CW	10.1	0.87	8.1	<0.1
Bk2	55–190	2.5Y7/3	10YR 6/4	89.9	5.8	4.4	S	2.0	M	FM	–	VE	GS	10.3	1.75	8.2	<0.1
Petrocalcids																	
Ak	0–15	10YR 7/4	10YR 5/3	95.0	3.3	1.7	S	1.0	SG	LD	–	SE	AS	8.6	2.20	7.9	–
Bk1	15–40	10YR 7/4	10YR 6/3	97.3	1.7	1.0	S	35.0	SG	LD	–	SlE	AS	3.4	2.50	7.9	–
Bk2	40–60	10YR 5/4	10YR 5/4	95.7	1.7	2.6	S	48.0	M	LD	–	SE	AS	3.0	1.20	7.9	–
Bkm	60–90	10YR 8/2	10YR 5/6	–	–	–			–	–	–	SE	–	21.5	–	–	–
Calcigypsids																	
Ak	0–10	10YR 6/4	10YR 4/3	78.1	12.1	9.8	SL	26	PS	MHD	–	SE	CS	15.2	0.99	7.9	1.3
Bk1	10–45	10YR 7/3	10YR 5/3	77.8	7.9	14.3	SL	52	M	MHD	–	VE	GW	15.2	0.46	8.1	3.8
Bk2	45–70	10YR 7/3	10YR 5/4	79.1	6.4	14.5	SL	31	SG	LD	–	SE	GW	8.0	2.60	7.8	2.5
By1	70–110	10YR 7/3	10YR 6/4	86.8	4.3	8.9	LS	37	M	HD	–	NE	GW	2.0	4.30	7.9	12.0
By2	110–150	10YR 7/3	10YR 6/3	93.9	1.1	5.0	S	33	M	MHD	–	NE	GW	1.5	4.20	7.8	8.1
By3	150–200	10YR 7/3	10YR 6/3	–	–		–	44	SG	LM	–	NE	–	0.4	–	–	3.5
Haplogypsids																	
Ak	0–10	2.5Y 6/4	10YR 5/4	94.9	1.4	3.7	S	4.0	P	SD	–	SlE	CW	3.9	2.75	8.3	1.1
Bk1	10–30	2.5Y 7/4	2.5Y 6/3	87.9	2.1	10.0	LS	1.0	M	MHD	–	SE	GS	2.5	1.50	7.8	1.3
Bk2	30–70	2.5Y 7/4	2.5YR 6/3	84.7	2.6	12.8	LS	0.0	M	MHD	–	SlE	GS	1.0	0.31	7.9	2.4
By1	70–110	5Y 7/3	5Y 7/3	88.1	1.1	10.8	LS	0.0	M	MHD	–	VSlE	GS	0.1	2.60	7.8	5.8
By2	110–160	5Y 7/3	5Y 7/2	88.7	1.6	9.6	LS	0.0	M	MHD	–	NE	–	0.1	2.50	7.8	5.5
Petrogypsids																	
Ak	0–6	2.5Y 6/3	10YR 7/3	93.1	2.1	4.8	S	7.0	SG	LM	–	VE	CS	13.2	2.60	7.8	1.5
Bky	6–20	10YR 6/3	10YR 5/3	77.6	9.9	12.5	SL	20.0	AB	FM	–	SE	CS	11.2	3.10	7.8	10.7

By	20–40	10YR 7/3	10YR 6/4	86.8	8.0	5.2	LS	24.0	M	FM	–	SE	CI	2.8	3.90	7.9	29.5
Bym	40–140	10YR 8/3	10YR 6/4	88.2	5.9	5.9	S	–	–	–	–	NE	–	0.3	6.00	7.7	49.4
Aquisalids																	
Akz	0–2	2.5Y 6/4	2.5Y 5/3	96.2	2.5	1.3	S	0	M	VFrM	NS	SE	AS	3.5	358.4	7.4	9.5
Bkz	2–30	2.5Y 6/4	2.5Y5/3	95.7	3.8	0.5	S	0	M	VFrM	SS	SE	CS	5.6	64.3	8.0	3.1
Bkyz1	30–60	2.5Y 6/4	2.5Y5/3	94.3	3.1	2.6	S	0	M	VFrM	SS	SE	CW	4.7	46.4	7.9	14.0
Bkyz2	60–90	2.5Y 7/4	2.5Y5/3	92.1	5.9	2.0	S	0	M	VfrM	SS	SE	CW	6.9	30.9	7.9	14.0
Bkyz3	90–120	2.5Y 7/4	10YR 5/4	95.0	3.8	1.2	S	0	M	FM	SS	SE	–	9.0	44.2	7.8	5.0
Torripsamments																	
Ak1	0–10	2.5Y 6/4	10YR 5/3	93.7	2.5	3.8	S	1.0	M	LM	NS	VE	–	8.4	0.31	8.2	0
Ak2	10–60	2.5Y 6/4	10YR 5/3	92.8	2.2	5.0	S	1.0	M	LM	NS	VE	–	7.3	0.29	8.3	0
Ak3	60–120	2.5Y 6/4	10YR 5/3	93.4	2.2	4.4	S	2.0	M	LM	NS	VE	GW	7.5	0.31	8.3	0
Bk1	120–135	2.5Y 6/4	10YR 6/4	91.6	1.0	7.4	S	11.0	SG	FrM	NS	VE	AS	3.8	0.41	8.3	0
Bk2	135–145	2.5Y 6/4	10YR 7/2	83.3	5.9	10.8	LS	65.0	M	VHD	NS	SE	AS	21.6	–	–	0
C	145–190	2.5Y 7/3	10YR 7/3	93.4	0.2	6.4	S	8.0	SG	VFM	NS	VSE	AW	3.6	–	–	0
2Btb	190–215	5YR 4/4	2.5Y 7/3	65.6	9.0	25.4	SCL	0.0	AB	VHD	SS	NE	–	4.1	–	–	0
Torriorthents																	
A	0–20	2.5Y 7/3	2.5Y 5/3	42.1	33.0	24.9	L	11	P	SlHD	–	SE	GW	29.7	8.27	8.2	0
C1	20–40	10YR 5/2	10YR6/2	37.2	42.1	20.7	L	41	M	MHD	–	VE	DW	52.5	29.2	7.4	0
C2	40–70	10YR 6/2	10YR 6/2	73.4	11.8	14.8	SL	52	M	MHD	–	VE	DW	54.7	28.3	7.6	0
C3	70–100	10YR 6/2	10YR 6/2	72.8	15.4	11.8	SL	64	M	MHD	–	VSlE	–	55.9	26.6	7.6	0

S sand, SL sandy loam, LS loamy sand, SCL sandy clay loam, L loam, SG single grain, M massive, P platy, AB angular blocky, LM loose moist, FM firm moist, LD loose dry, MHD moderately hard dry, HD hard dry, VFrM very friable moist, FM firm moist, FrM friable moist, SlHD slightly hard dry, NS nonsticky, SS slightly sticky, VE violently effervescent, SE strongly effervescent, VSE very strongly effervescent, SlE slightly effervescent, VSlE very slightly effervescent, NE noneffervescent, CS clear smooth, CW clear wavy, GS gradual smooth, AS abrupt smooth, GW gradual wavy, CI clear irregular, DW diffuse wavy, ECe electrical conductivity of soil saturation extract, pHs pH of saturated soil paste, dS/m deci Siemens per meter, %eq percent equivalents of $CaCO_3$

3.5 Physical and Chemical Characteristics

Some important physical and chemical characteristics of representative soil profiles from each great group are presented in Table 3.2. It is apparent that all the pedons are calcareous to varying degrees of $CaCO_3$ accumulation, the highest being in the Torriorthents due to broken shells in the soil material. Minor to high quantities of gypsum were identified in the pedons based on the soil characteristics (Table 3.2). It is apparent from soil characteristics that the soils in the great groups Haplocalcids, Calcigypsids, and Torripsamments can be exploited for irrigated agricultural activities; however, the variable quantities of $CaCO_3$ may affect the nutrient availability to plants such as P, Mo, Fe, Zn, and Mn. The deficiencies of which are quite common in plants growing in calcareous soils (Tisdale et al. 1993). Calcium carbonate may induce buffering capacity and resist a change in soil pH while managing calcareous soils. Minor quantities of gypsum are related to its presence in the fallen dust through wind erosion and the highest (Petrogypsids) to pedogenically formed gypsic horizon. The primary soil particles are dominant in sand, which give sand a sandy loam and loamy sand texture to different horizon depth; clay is the highest at 0–40 cm in Torriorthent and gives loamy texture.

The Ca and SO_4 ions dominate the solution chemistry of all pedons. In salids and orhents, Na and Cl are dominant ions, this is due to the major influence of seawater intrusion in the coastal areas where these were identified. In these pedons, higher sodium content developed high exchangeable sodium percentage (ESP) compared to other pedons. The native soils of Kuwait are generally nonsaline (Torripsamments); however, where there is influence from seawater in the coastal areas, high levels of salinity are developed (Salids and Orthents); in others, variable quantities of gypsum and calcium carbonate add some electrolytes in the soil solution. The pH is buffered between slightly to moderately alkaline (7.4–8.3) range (Soil Survey Division Staff 1993), which is above the optimum levels (6.7–7.3) where most of the nutrients become available to plants (Tisdale et al. 1993).

3.6 Great Group Level Generalized Soil Map of Kuwait

Of 12 soil orders reported (USDA-NRCS 1998, 1999), only two have been identified in the State of Kuwait; they are Aridisols and Entisols. Excluding the nonsurveyed restricted areas (6.64%), the surveyed area constitutes 70.8% Aridisols and 29.2% Entisols. The area and extent of soil great groups and their component soil subgroups are shown in Table 3.3.

The general distribution of soils in Kuwait (at the great group level) is shown in Fig. 3.4. Seven major (Torripsamments, Haplocalcids, Aquisalids, Calcigypsids, Petrocalcids, Petrogypsids, and Torriorthents) and a minor (Haplogypsids, 0.05%) soil great group are mapped characterizing the soils of Kuwait. Miscellaneous map unit comprises 6.64% of the state area and includes quarries and dumps (2.94%) and urban and industrial areas (3.7%). The distribution of great groups into units is associations and complexes and therefore may contain other great groups in minor quantities.

Table 3.3 Area and extent of soil great groups and their component soil subgroups

Soil great group	Soil subgroup	Hectares	Percent
Haplocalcids		**133,929**	**7.72**
	Typic Haplocalcids	133,929	7.72
Petrocalcids		**191,764**	**11.05**
	Calcic Petrocalcids	166,118	9.58
	Typic Petrocalcids	25,646	1.47
Calcigypsids		**107,255**	**6.18**
	Typic Calcigypsids	107,255	6.18
Haplogypsids		**812**	**0.05**
	Leptic Haplogypsids	812	0.05
Petrogypsids		**578,289**	**33.39**
	Calcic Petrogypsids	81,755	4.72
	Petrocalcic Petrogypsids	202,654	11.70
	Typic Petrogypsids	293,880	16.97
Aquisalids		**122,630**	**7.08**
	Gypsic Aquisalids	104,537	6.03
	Typic Aquisalids	18,093	1.05
Torripsamments		**473,627**	**27.27**
	Typic Torripsamments	473,627	27.27
Torriorthents		**10,769**	**0.62**
	Typic Torriorthents	10,769	0.62
Miscellaneous unit		**115,337**	**6.64**
	Dump and quarries	51,134	2.94
	Urban and industrial	64,203	3.70
Total		**1,734,412**	**100.00**

The soil map units in great group soil map cover broad areas that have a distinctive pattern of soils, relief, and drainage. Each map unit is a unique natural landscape and consists of a number of soil families (component soils) or miscellaneous areas. The generalized soil map can be used to determine the suitability of large areas for broadly determined land uses and provides an overview of the general soil distribution in Kuwait. Because of its small scale, the map is not suitable for detailed on-site planning, and the statements made in the map unit description are generalizations; however, this can be used as a guideline for more detailed investigation for specific purposes. The general soil map units are described below.

3.6.1 Haplocalcids

This map unit consists of well-drained, deep or very deep, sandy to loamy soils, which have a layer of carbonate masses and nodules (calcic horizon) in the profile. The soils occur on level to gently undulating plains and in depressions or basins. This unit makes up 8% of the survey area. Other soils found in this unit are Torripsamments, Calcigypsids, and minor areas of Petrocalcids. The unit is used for rangeland grazing,

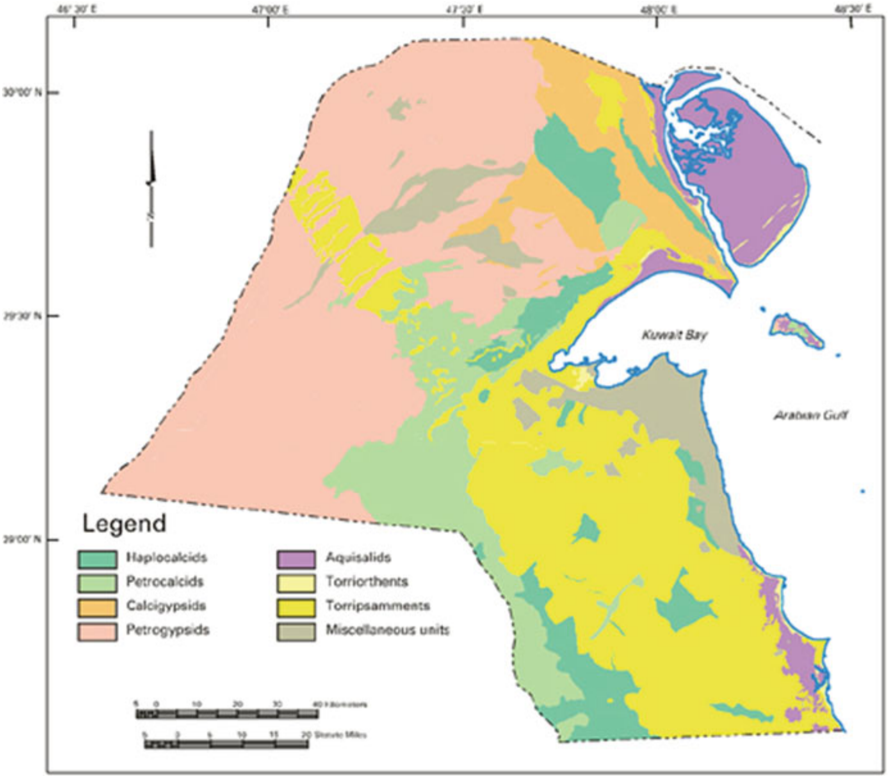

Fig. 3.4 Great group level generalized soil map of Kuwait

and in some areas, there are oil fields. It is moderately suited for irrigated agriculture; the main limitations are areas of other soils that have a shallow rooting depth, impeded drainage, and medium gypsum content.

3.6.2 Petrocalcids

The map unit consists of well-drained or moderately well-drained, shallow or moderately deep, sandy to loamy soils overlying a calcic hardpan (petrocalcic horizon). Within the soil profile, there is usually a layer of carbonate masses and nodules (calcic horizon). The soils occur on elevated plains or along the rim of escarpments. This unit makes up 11% of the survey area. Other soils found in this unit are Torripsamments, Calcigypsids, and Haplocalcids, which tend to occur in shallow depressions, in the lee and on slopes of rises, and as low sand ridges. The unit is used for rangeland grazing, and in some areas, there are oil fields. Most of this unit is marginally suited for irrigated agriculture, but where the soils are shallow, it is currently unsuitable; the main limitations are a shallow rooting depth and impeded drainage.

3.6.3 Haplogypsids

The map unit consists of well-drained, deep or very deep, sandy to loamy soils, which have a layer of gypsum crystals (gypsic horizon) in the profile. The soils generally occur on slopes and ridges. This unit makes up of less than 0.5% of the survey area and therefore not shown in Fig. 3.4. This small area has been included with the Calcigypsids. Other soils found in this unit are Calcigypsids, Petrogypsids, and Torripsamments. The unit is used for rangeland grazing. It is unsuitable for irrigated agriculture; the main limitation is high gypsum content.

3.6.4 Calcigypsids

The map unit consists of well-drained, deep or very deep, sandy to loamy soils containing a layer of carbonate masses and nodules (calcic horizon) and a layer of gypsum crystals (gypsic horizon) within the profile. The soils occur on slopes and ridges within level to gently undulating plains. This unit makes up 6% of the survey area. Other soils found in this unit are Torripsamments and Haplocalcids that occur in drainage depressions or where sand has accumulated and Haplogypsids and Petrogypsids that occur on the crests of rises. The unit is used for rangeland grazing. It is currently unsuitable for irrigated agriculture; the main limitation is a medium to high gypsum content.

3.6.5 Petrogypsids

The map unit consists of moderately well-drained, shallow or moderately deep, sandy to loamy soils overlying a gypsic hardpan (petrogypsic horizon) or a gypsic horizon underlain by a calcic hardpan (petrocalcic horizon). The hardpan is commonly cemented by both gypsum and carbonate. The soils generally occur on a level to gently undulating plain formed on the sand and gravel deposits of the Dibdibah Formation. Within the plain, low rises and shallow drainage depressions are common, and in the central and western areas, there are a number of recognizable gravel ridges and intervening valleys. This unit makes up 33% of the survey area. Other soils found in this unit are Haplocalcids and Petrocalcids which occur in the shallow depressions. The unit is used for rangeland grazing. It is currently unsuitable for irrigated agriculture; the main limitations are a shallow rooting depth, impeded drainage, and high gypsum content.

3.6.6 Aquisalids

The map unit consists of poorly or somewhat poorly drained, deep or very deep, sandy to clayey soils. Within the soil, there is a layer of salt accumulation (salic horizon) that usually occurs near the surface, and often there is a layer of gypsum crystals and water table within upper 1 m. The soils occur on coastal flats and in inland playas. This unit makes up 7% of the survey area. Other soils found in this unit are Torripsamments on sand dunes and Torriorthents. The unit is not used for any form of agricultural production or rangeland grazing. It is permanently unsuitable for irrigated agriculture; the main limitations are the high salt content, poor drainage, and high gypsum content.

3.6.7 Torriorthents

The map unit consists of excessively drained to well-drained, moderately deep or very deep, sandy soils. Within the soil profile, there is a high content of shell fragments and some salt and gypsum accumulations. The soils occur on coastal dunes or beach ridges. This unit makes up 1% of the survey area. Other soils found in this unit are Torripsamments on sand dunes. The unit is not used for any form of agricultural production or rangeland grazing. It is permanently unsuitable for irrigated agriculture; the main limitations are excessive drainage, high salt content, and low water storage capacity (due to the high shell content).

3.6.8 Torripsamments

The map unit consists of well to somewhat excessively drained, deep or very deep, sandy soils. The soils generally occur on an extensive sand sheet in central and southern areas that is aligned in a northwest to southeast direction. They also occur at the base of escarpments where fall dunes have formed, along the coast on dunes, and in the northwest on isolated barchan dunes and sand ridges. This unit makes up 27% of the survey area. Other soils in this unit are Haplocalcids and Calcigypsids that occur in low-lying and deflated areas and Petrocalcids that occur on rises. The unit is used for rangeland grazing, and in some areas, there are oil fields with their associated infrastructure. It is moderately suitable for irrigated agriculture; the main limitations are the rapid permeability and low water storage capacity (somewhat excessive drainage).

3.6.9 Miscellaneous Units

The map unit consists of areas that are not soils, such as areas where the soils have been removed or severely disturbed or covered by urban and industrial activities.

These areas include, in the north, mined areas comprising gravel quarries and overburden and tailing dumps and, in the center of Kuwait, sand quarries, dumps of building rubble, rubbish dumps, and the urban and industrial areas of Kuwait City and associated satellite towns, including vacant land reserved for urban or industrial use. This unit makes up 7% of the survey area. Soils found in this unit include Haplocalcids, Torripsamments, Haplogypsids, and Petrogypsids. The unit is used for mining, refuse disposal, and urban and industrial activities. It is permanently unsuitable for irrigated agriculture. Some areas such as overburden and tailing dumps could be rehabilitated, but the cost would be high.

3.7 Spatial Distribution of Gatch-Like Deposits

A common feature of many Kuwaiti soils is a calcic and/or gypsic pan, colloquially named gatch. As discussed above and defined in the soil classification section, a pan formed from precipitated and cemented carbonate or gypsum is called a petrocalcic or petrogypsic horizon where the pan is continuous and provides a barrier to plant

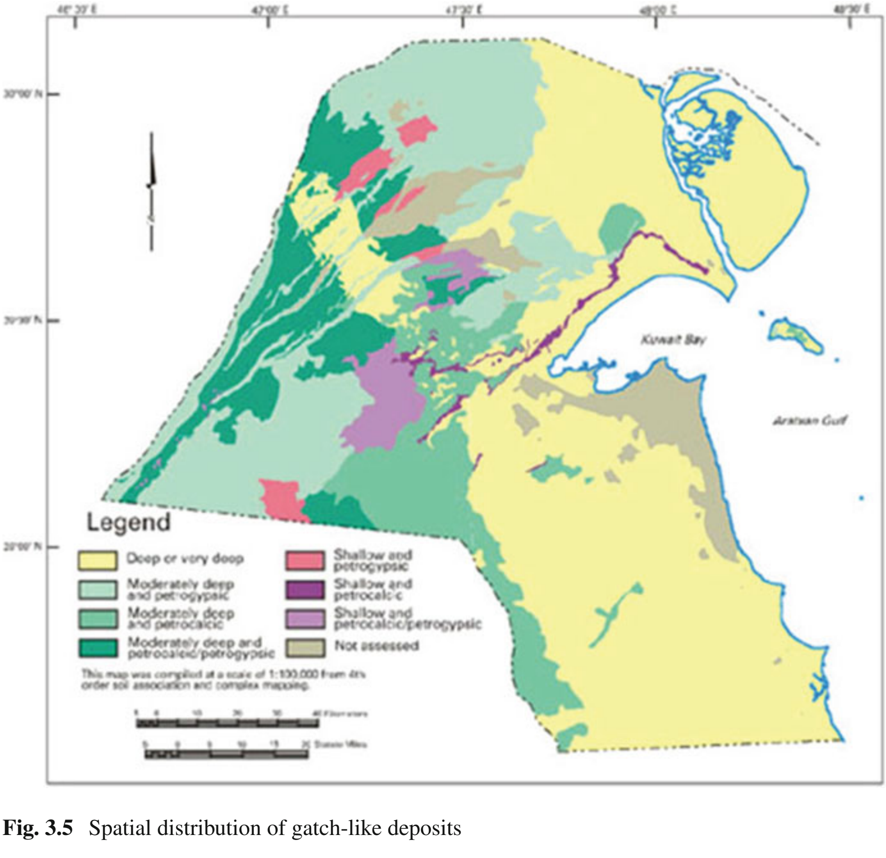

Fig. 3.5 Spatial distribution of gatch-like deposits

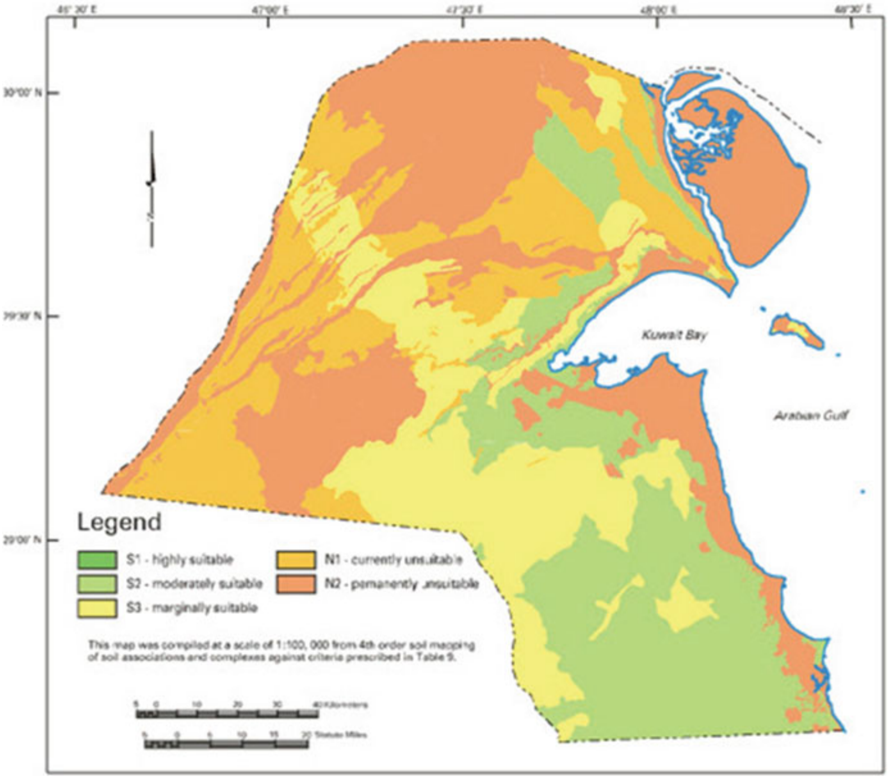

Fig. 3.6 Irrigated suitability map of Kuwait

roots. Figure 3.5 shows the spatial distribution of gatch-like deposits in Kuwait. The gatch layer is more common in the center and northwest of Kuwait. The map identifies where the gatch layer becomes an impediment to land use, namely, within 50 cm of the soil surface (shallow), and where it is within 50–100 cm of the soil surface (moderately deep). The eastern and southern parts of Kuwait comprise deeper soils with the gatch layer below 100 cm if present.

Gatch layers have the effect of hindering water movement in soils, decreasing the soil air proportion in soil pores, and ultimately limiting the growth of plants. If soils with shallow and moderately deep gatch layers are developed for irrigated agriculture, the gatch will increase the likelihood of perched water tables and development of secondary salinization and make irrigation management extremely difficult. Therefore, irrigation development on such soils should be avoided. If development does take place, it may be necessary to deep plow or rip the gatch layer to break the gatch up and install a subsurface drainage system. In soils where gatch occurs, shallow-rooted crops can be grown and proper irrigation scheduling is practiced to minimize the amount of excess water in the soil profile.

3.8 Land-Use Assessment for Irrigated Agriculture

The outcome of evaluating the soils of Kuwait against the criteria developed in the soil survey project (KISR 1999) is presented in Fig. 3.6, which presents the suitability of soils for irrigated agriculture. The results of the evaluation indicated that well-drained Torripsamments and Haplocalcids with good drainage are the preferred soils for irrigated agriculture in Kuwait.

3.9 Conclusions

A number of uses and resources were identified to be part of the soil survey project activities. These were achieved by developing criteria of their assessment and uses through using Soil Information System. The survey results were interpreted for several uses and translated to a number of thematic maps such as sand and gravel sources and uses for shallow excavations, septic tanks, sewage lagoons, sanitary landfills (area and trench), seedling mortality, and herbaceous desert plants. The major outcome of the soil survey for the State of Kuwait was the delineation of more than 207,309 ha area with highest potential for irrigated agriculture; in Kuwait, this area was surveyed at the second-order (semi-detailed) level of USDA-NRCS standards, and suitability map for irrigated agriculture was prepared.

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