# Land Degradation Indicators and Management Options in the Desert Environment of Abu Dhabi, United Arab Emirates

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**abstract**

The land resources of Abu Dhabi Emirate, United Arab Emirates (UAE) are being subjected to various land degradation stresses such as wind erosion, salinization, waterlogging, landfilling, and overgrazing. It is essential to characterize land degradation indicators in the Abu Dhabi Emirate's desert environment and to develop better conservation and management options for these precious resources. To accomplish this characterization, representative samples from degraded soils were analyzed for selected parameters relevant to specific indicators. The study found that, among natural forces of land degradation, wind has a major role in drifting soil from loose surfaces and mainly from dune areas. Nebkha dunes, formed from sediment accumulations around shrubs, have been considered a reliable indicator of rapid dryland degradation. Soil salinity is also becoming a threat to agricultural farms and coastal areas. The results show that about 90% of the agricultural farms in Al Ain area are affected by salinity. Only 11% of farms have salinity below 4 dS/m and, hence, are classified as non-saline or normal. Waterlogging has also become a serious problem in many of the agricultural farms. Water erosion is also evident in uplands. Overgrazing in general has reduced the biodiversity in many areas. Landfilling for urban development and construction purposes is another unique land degradation feature in the Emirate. This study suggests management options for each land degradation type.

Throughout history humans have used the environment to gain great economic rewards; however, many of the methods are now being seen as unsustainable. Johnson and Lewis (1995) defined land degradation as the substantial decrease in either biological productivity and/or usefulness of an area due to human interference. Chemical or physical land degradation is the result of a number of interrelated factors. It is often accelerated by persistent droughts in many developing arid and semiarid countries. Land degradation is often attributed to human causes (Gray, 1999; Misak et al., 2002). Worldwide, it is estimated that nearly two billion hectares of biologically productive land have been rendered unproductive due to irreversible degradation (Vilanculos, 1994). The present rate of land degradation is estimated at 5 to 7 million hectares per year, suggesting that 0.3 to 0.5% of the world's arable land is lost annually due to soil degradation (Dudal, 1975; FAO, 1983; Vilanculos, 1994). The world is losing 10 ha of arable land each minute—5 ha to soil erosion, 3 ha from salinity, and 2 ha by other degradation processes.

Land and soil are important components of Abu Dhabi Emirate desert ecosystems and of the wider environment in which all plants and animals live. Degradation produces pressures that result in the current state of land resources, with a negative impact on society and the environment (Shahid and Abdelfattah, 2008). Societal cooperation is a sensible approach to tackle land degradation problems, especially when the cause is not confined to a single landowner's property. Human-induced land degradation in the Emirate of Abu Dhabi is of many kinds, including salinization in agricultural farms, soil compaction by off-road vehicles, loss of vegetation through uncontrolled overgrazing and land clearing. Anthropogenic activities ultimately lead to very poor wildlife habitat and ecosystem destruction. Natural causes of land degradation in the Emirate are drought (evaporation exceeds rainfall), wind erosion, and sand encroachment.

To sustain the land resources of Abu Dhabi Emirate, land degradation is a matter of urgency and must be accorded greater significance on the environmental agenda. A legal framework should be created to protect these environmental assets. The present study aimed to characterize the major land degradation indicators in Abu Dhabi Emirate and suggest better conservation strategies and management options.

## The Study Area

The United Arab Emirates is located between 22°50′ and 26° N latitude and 51° and 56°25′ E longitude at the southeastern tip of the Arabian Pennisula. Abu Dhabi is the largest Emirate of the United Arab Emirates, occupying 84% (77,000 km$^2$) of the country's land area. Abu Dhabi's major ecosystems comprise the coast, numerous islands, mountainous areas, gravel plains, and sand desert (Boer, 1998). Nearly 80% of the Abu Dhabi Emirate area is desert; to the north and west is

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an extensive area of coastal salt flats, locally known as *sabkha*. Isolated interdunal sabkhas exist in the desert inland from the coast. The sandy desert begins behind the coastal sabkha, with small white dune ripples, eventually forming an expanse of large orange-red dunes in the southwest. About 100 km inland, towering dunes rising to 200 m (*mega dunes*) are common. These form part of the Empty Quarter or "Rub Al-Khali," a vast desert which stretches beyond the UAE's southern border (UAE Yearbook, 2008). Gravelly plains also cover wide areas in both the far west and east of the Emirate. Mountains are absent, a notable exception being the impressive Jebel Hafit near Al Ain, an outlier of the Hajar mountain range (Brown, 2008). Abu Dhabi Emirate experiences extremely high temperatures (Table 1) during summers (45–50°C) and short mild winters (as low as 3°C), with mean temperature being 28°C (Alsharhan and Kendall, 2002). Humidity is the highest along the coastal fringes and decreases inland. The mean annual rainfall is about 111 mm.

## Materials and Methods

Representative soil profiles were selected for soils from each land degradation type for this study. The selection was based mainly on areas subjected to wind erosion, salinization, waterlogging, and other degradation types. Soil samples were collected at sites to quantify the extent of degradation via analysis of selected characteristics, such as salinity and organic matter. Bulk density and infiltration rate were also performed. The results are then compared with those sites where degradation indicators were not shown (control sites). Soil information was recorded at each site, and a full morphological description for the soil profiles was completed.

Representative soil samples were air-dried and sieved (<2 mm sieve). Standard laboratory analyses including physical and chemical analyses were performed (Soil Survey Staff, 2004). The soils were analyzed for the following parameters: saturation extract analyses (cations and anions), particle size distribution (texture), salinity, gypsum, organic matter, P, saturation percentage, soil reaction, exchangeable Na percentage, carbonates equivalents, and cation exchange capacity. The sampling was complemented by photographing landscape features showing land degradation indicators throughout the Emirate of Abu Dhabi.

## Results and Discussion

The major land degradation indicators identified in the arid environment of Abu Dhabi Emirate are wind erosion, salinization, waterlogging, loss of vegetation, compaction, water erosion, and land filling. The following explores in depth each of these indicators based on its significance occurrence over the study area.

**Table 1. Monthly climatic characteristics of Abu Dhabi Emirate (DWRS, 2002).**

| Month | Temperature: Avg. daily max. | Temperature: Avg. daily min. | Temperature: Avg. daily | Total rainfall | Max. daily relative humidity | Min. daily relative humidity | Avg. daily relative humidity | Avg. daily wind speed |
|---|---|---|---|---|---|---|---|---|
| | °C | | | mm | % | | | m/s |
| January | 28.63 | 14.03 | 21.02 | 0.9 | 88.9 | 31.2 | 62.01 | 4.6 |
| February | 33.74 | 12.34 | 20.64 | 0.1 | 95.4 | 18.5 | 63.17 | 4.32 |
| March | 33.03 | 17.5 | 24.01 | 14.6 | 93.6 | 0 | 66.77 | 5.04 |
| April | 40.05 | 20.6 | 26.69 | 1.2 | 94.3 | 12.8 | 61.35 | 4.26 |
| May | 43.32 | 25.09 | 31.5 | 16.4 | 93.2 | 6.5 | 60.82 | 3.74 |
| June | 45.37 | 27.87 | 33.16 | 0 | 88.9 | 13.5 | 62.1 | 3.98 |
| July | 43.91 | 29.6 | 34.38 | 0 | 90.2 | 12.1 | 64.77 | 3.71 |
| August | 43.14 | 30.07 | 34.35 | 0 | 90.8 | 21 | 67.82 | 3.69 |
| September | 41.58 | 27.86 | 32.99 | 0 | 86.7 | 8.1 | 66.99 | 3.39 |
| October | 39.57 | 25.06 | 30.72 | 0 | 93 | 19.9 | 65.23 | 3.16 |
| November | 32.07 | 19.17 | 26.36 | 0 | 86.8 | 31.1 | 60.14 | 3.93 |
| December | 29.66 | 15.89 | 22.63 | 0.4 | 87.8 | 28.1 | 62.7 | 3.91 |

**Table 2. Average particle size analyses of sand dunes in Abu Dhabi Emirate.**

| USDA size ranges | 0–40 cm | 40–75 cm | 75–200 cm |
|---|---|---|---|
| | | % | |
| Very coarse sand (1–2mm) | 1.0 | 1.0 | 0.0 |
| Coarse sand (0.5–1mm) | 3.5 | 8.5 | 7.5 |
| Medium sand (0.5–0.25mm) | 14.5 | 20.0 | 21.5 |
| Fine sand (0.25–0.1mm) | 46.0 | 44.5 | 44.5 |
| Very fine sand (0.05–0.1mm) | 30.0 | 23.5 | 23.5 |
| Coarse silt (0.05–0.02mm) | 1.0 | 0.0 | 0.0 |
| Fine silt (0.02–0.002mm) | 0.0 | 0.0 | 0.0 |
| Clay (<0.002mm) | 4.0 | 2.5 | 3.0 |
| Total sand (2–0.05mm) | 95.0 | 97.5 | 97.0 |
| Total silt (0.05–0.002mm) | 1.0 | 0.0 | 0.0 |
| Textural class | Fine sand | Sand | Sand |

### 1. Wind Erosion and Aeolian Deposits

Wind erosion is considered the major cause of irreversible land degradation in the arid environment of Abu Dhabi Emirate where dry, noncohesive sandy soils, poor vegetation cover, strong wind, and hyper-arid conditions prevail. The dunes are not static but constantly moving. The wind erosion indicators are formation of fall dunes, blocking of highways, dust storms (Fig. 1), nebkha features, reduction of waterways capacity due to fallen sand, exposure of a hardpan at the surface, and gravel lag. Nebkha dunes (Fig. 2) are considered a reliable indicator for dryland degradation (Dougill and Thomas, 2002). Understanding the particle size distribution of typical desert soils assists in the identification of mechanisms of particles movement and in formulating necessary measures to reduce aeolian movement.

Particle size for selected soils (Table 2) indicate that 70 to 92% of the sand particles move by saltation, 5 to 24% in the creep mode, and 2 to 8% in suspension mode. These data confirm initial findings of Shahid and Abdelfattah (2008) and are similar to results that have been reported in Kuwait (Shahid and Omar, 2001; Shahid et al., 2003) and by Chepil (1945).

### Nebkha Dunes as an Indicator of Land Degradation

Nebkha dunes have been proposed as a reliable indicator of dryland degradation (Dougill and Thomas, 2002). *Nebkha dunes*, also referred to as *nebkhas* (Nickling and Wolfe, 1994; Khalaf et al., 1995) or *coppice dunes* (Gile, 1966; Thomas and Tsoar, 1990), are plant-obstacle dunes and form by the trapping of sand around the body of a plant (Cooke et al., 1993). Rather than the vegetation simply acting as an obstacle, shrubs become an integral part of the dune, growing as the sediment accumulates. Rain splash and overland flow erosion may lower intershrub areas (e.g., Parsons et al., 1992), and high rooting densities and termite activity under bushes may lead to plant mounds (e.g., Biot, 1990). However, it is apparent from the growing number of detailed morphological and sedimentological studies in semiarid localities bordering the Sahel and in the Middle East that nebkhas

**Fig. 1. Dust storms show the effect of wind erosion on drifting the soil surface (saltation).**

**Fig. 2. Nabkha dune, a dominant feature due to wind erosion.**

are good indicators of wind erosion and deposition (e.g., Gunatilaka and Mwango, 1987; Nickling and Wolfe, 1994; Tengburg, 1994, 1995; Khalaf et al., 1995; Tengburg and Chen, 1998). In the desert environment of Abu Dhabi Emirate, nebkha dunes are very common in different sizes, heights, and shapes (Fig. 2). They also halt degradation through catching drifted soil particles and reducing wind speed, thus protecting some area around them. Tables 3a and 3b present a complete morphological and analytical characterization of two sandy soils nebkha dunes, one is characterized as carbonatic mineralogy class (carbonatic, hyperthermic, Typic Torripsamments) and another as mixed mineralogy class (mixed, hyperthermic, Typic Torripsamments).

Stabilization of these soils is accomplished by reducing saltation. This reduction may involve binding surface soil particles through organic amendments, green manures, mulching material, or synthetic polymers to increase size of the aggregates above saltation range or stabilize the sand surface. Agricultural areas can also be protected by introduction of shelter belts and sand dunes stabilization through afforestation.

Afforestation has been practiced on about 330,000 ha in Abu Dhabi Emirate. In addition, many green belts in urban areas and along roadsides have been established. The implementation of afforestation was considered a preventive measure for some of the desert lands that are not yet degraded or are only slightly degraded. Forestry plantations are playing a great role in combating wind erosion and are presenting multiple benefits, such as hydrological balance, enhancement of environmental quality, improvement habitat restoration, and increasing aesthetic value.

## 2. Soil Salinization

Soil salinization, the process of soluble salt accumulation, is of great concern on farms because it directly influences plant growth and yield reduction by increasing osmotic pressure of soil moisture causing physiological drought, and indirectly by causing deterioration of soil medium. Due to the prevailing hyper-arid conditions in Abu Dhabi Emirate, the soil receives inadequate and irregular precipitation to effectively leach the salts from the soil profile. A soil salinity study of the agricultural farms in Al Ain area of southeast Abu Dhabi Emirate

**Table 3a. Morphological and analytical properties of mixed, hyperthermic, Typic Torripsamments and carbonatic, hyperthermic, Typic Torripsamments.†**

| Horizon | Lower depth | Munsell color | | Sand | Silt | Clay | Texture class | Gravels | Structure | Consistence (dry) | Stickiness | Effervescence | Boundary |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dry | Moist | | | | | | | | | | |
| | cm | | | ——— | % | ——— | | % | | | | | |
| Mixed, hyperthermic, Typic Torripsamments | | | | | | | | | | | | | |
| $C_k$ | 15 | 10YR7/3 | 10YR3/4 | 97 | 2 | 1 | Sand | 0 | SG | S | NS | Strong | CS |
| $2C_{bik}$ | 65 | 7.5YR7/5 | 7.5YR5/5 | 96 | 3 | 1 | Sand | 0 | SG | S | NS | Strong | CS |
| $2C_{bk1}$ | 100 | 7.5YR5/6 | 7.5YR4/3 | 96.5 | 1.5 | 2 | Sand | 0 | SG | S | NS | Strong | CS |
| $2C_{bk2}$ | 150 | 7.5YR5/5 | 7.5YR4/3 | 96 | 1 | 3 | Sand | 0 | SG | S | NS | Strong | CS |
| $2C_{bk3}$ | 200 | 7.5YR5/5 | 7.5YR4/4 | 97 | 2 | 1 | Sand | 0 | SG | S | NS | Strong | |
| Carbonatic, hyperthermic, Typic Torripsamments | | | | | | | | | | | | | |
| $A_k$ | 25 | 2.5Y7/2 | 2.5Y6/3 | 92.5 | 4.5 | 3 | Sand | 0 | SG | S | NS | V | CS |
| $B_k$ | 70 | 2.5Y7/2 | 2.5Y7/2 | 93 | 3 | 4 | Sand | 0 | SG | S | NS | V | DS |
| $C_{k1}$ | 110 | 2.5Y7/3 | 2.5Y7/4 | 93 | 4 | 3 | Sand | 0 | SG | S | NS | V | GS |
| $C_{k2}$ | 150 | 2.5Y7/3 | 2.5Y7/4 | 95.5 | 1.5 | 3 | Sand | 0 | SG | S | NS | V | |

† SG = single grain; S = soft; NS = nonsticky; DS = abrupt smooth; CS = clear smooth; GS = gradual smooth.

**Table 3b. Analytical properties of mixed, hyperthermic, Typic Torripsamments and carbonatic, hyperthermic, Typic Torripsamments.†**

| Horizon | Lower depth | pHs | ECe | ESP | Carbonates eq. <2 mm | Gypsum | Olsen P | Organic matter | Water retention (15 bar) | Saturation percentage | Bulk density | CEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | | dS/m | ——— | % | ——— | mg/kg | % | | % | g/cm$^3$ | cmol/kg |
| Mixed, hyperthermic, Typic Torripsamments | | | | | | | | | | | | |
| $C_k$ | 15 | 8.3 | 1.1 | 3 | 22.8 | 0.0 | 0.151 | 0.38 | 3.7 | 25 | 1.30 | 3.12 |
| $2C_{bik}$ | 65 | 8.2 | 0.4 | 3 | 23.3 | 0.0 | 0.090 | 0.03 | 3.9 | 26 | 1.60 | 2.18 |
| $2C_{bk1}$ | 100 | 8.1 | 0.3 | 3 | 18.8 | 0.0 | 0.060 | 0.01 | 3.3 | 24 | 1.60 | 2.9 |
| $2C_{bk2}$ | 150 | 8.3 | 0.5 | 1 | 18.7 | 0.0 | 0.044 | 0.07 | 3.6 | 26 | 1.60 | 1.86 |
| $2C_{bk3}$ | 200 | 8.0 | 0.8 | 7 | 21.8 | 0.0 | 0.060 | 0.04 | 3.5 | 25 | 1.61 | 1.19 |
| Carbonatic, hyperthermic, Typic Torripsamments | | | | | | | | | | | | |
| $A_k$ | 25 | 8.18 | 1.74 | 2.3 | 78.3 | 0.0 | 0.110 | 0.09 | 4.5 | 21 | 1.45 | 2.35 |
| $B_k$ | 70 | 8.23 | 2.89 | 3.72 | 76.5 | 0.0 | 0.060 | 0.45 | 3.7 | 20 | 1.62 | 1.38 |
| $C_{k1}$ | 110 | 8.02 | 9.26 | 11.4 | 71.4 | 0.0 | 0.70 | 0.29 | 3.8 | 22 | 1.54 | 1.56 |
| $C_{k2}$ | 150 | 8.18 | 11.3 | 14.0 | 73.5 | 0.4 | 0.50 | 0.37 | 3.4 | 19 | 1.56 | 1.81 |

† ECe = electrical conductivity of soil saturation extract; pHs = pH of soil saturated paste; ESP = exchangeable sodium percentage; CEC = cation exchange capacity.

showed that 43% of the farms have soils with salinity >9.4dS/m (>6000 ppm), and 26% of soils have salinity ranging from 6.25 to 9.4 dS/m (4000–6000 ppm) (Fig. 3). The salinity of about 90% of the farms falls into the saline class (Richards, 1954), and about 70% are in the range of salinity where yields of many crops are restricted (4–6 dS/m) or only tolerant crops result in satisfactory yields (8–16 dS/m). Only 11% of farms have salinity levels below 4 dS/m and, hence, are classified as non-saline or normal (El Bershamghy and Al Tamimi, 2003).

In irrigated agriculture, irrigation water is the primary source of salts. Irrigation leads to phenomenal enhancement of land productivity. However, if this important resource is mismanaged, it can cause soil degradation and increase salinization risk. Figure 4 shows the salinity of groundwater wells used for irrigation. The data reveal that the water salinity of 68% farms is very strongly saline (>8000 ppm), indicating that irrigation water is likely a major source of salinity accumulation in the soil profile.

## Coastal and Inland Salinity of Abu Dhabi Emirate

The coastal sabkha of Abu Dhabi Emirate stretches over 400 km. In this area, saline soils are the most common feature (Abdelfattah and Shahid, 2007; Abdelfattah et al., 2008b; Shahid et al., 2004). Locally these saline soils are known as *sabkhas*, a feature that can be found in coastal or inland areas. Coastal sabkhas are developed through sea water intrusion, followed by evaporation (Fig. 5 and 6). The largest area covered by an inland sabkha, Sabkhat Matti, occurs in the western Abu Dhabi. Sabkhat Matti extends inland from the coast for about

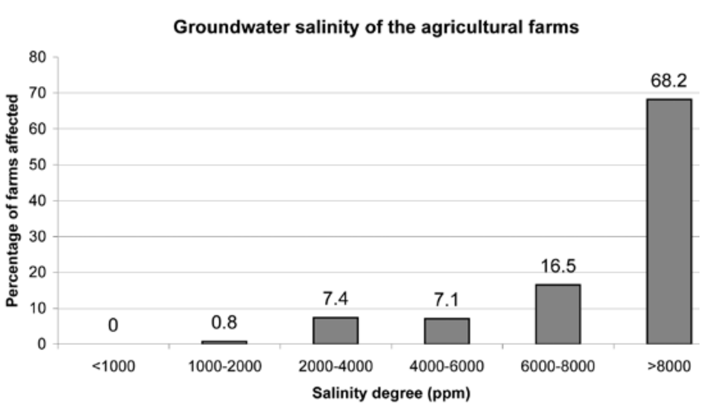


**Fig. 3. Salinity of the agriculture farms in Al Ain area.**

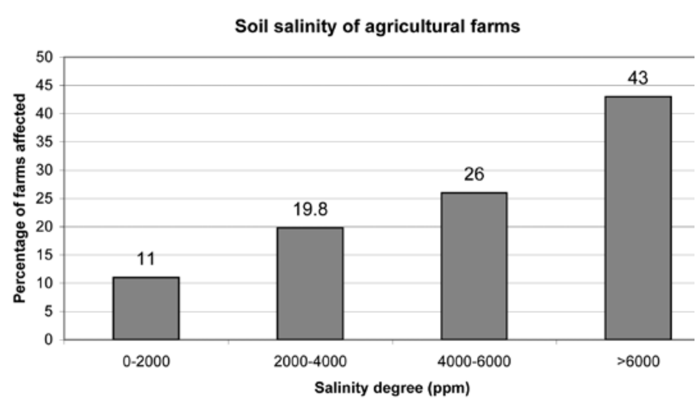


**Fig. 4. Salinity of groundwater wells in Al Ain area.**

Fig. 5. Hexagonal salt crust on the surface, an indication of salinization on the coastal area.

Fig. 6. Salt fibers in Abu Dhabi coastal area.


Fig. 7. (a) Thick hardpan on a farm affected by waterlogging. (b) Waterlogging in the agricultural farms. (c) Waterlogging affects the surrounding urban community.

Fig. 8. Combined effect of water and wind erosion.

Fig. 9. Excavation for construction materials.

120 km, and within Saudi Arabia it reaches a height of 40 m above sea level at its southern tip. Inland sabkhas occur in deserts where water accumulates in low-lying landscape positions through seepage (i.e., from hydrological flow from surrounding areas) and evaporates, leaving a surface salt crust.

In the coastal area, gypsum and anhydrite are commonly found under the hyper saline conditions (Shahid et al., 2007; Abdelfattah et al., 2008a). These data show that the salinity reaches 28.8 dS/m compared with the inland sandy soils, which are within 4 dS/m (Tables 4 and 5). Saline soils identified in the coastal area of Abu Dhabi (Tables 6a and 6b) classify as Typic Haplosalids and Typic Aquisalids (Soil Survey Staff, 1999, 2003). Salinity and sodicity are extremely high in these coastal area soils, with EC exceeding 200 dS/m, indicating that land use is restricted to salt harvesting.

**Table 4. Average physical and chemical properties of coastal sand dunes.**

| Depth | ECe | pHs | ESP | Saturation percentage | Water retention (15 bar) | CEC | Bulk density | Porosity | Organic matter |
|---|---|---|---|---|---|---|---|---|---|
| cm | dS/m | | | % | | cmol/kg | g/cm³ | % | % |
| 0–30 | 1.74 | 8.8 | 2.3 | 24.0 | 3.8 | 1.26 | 1.609 | 39 | 0.08 |
| 30–60 | 28.8 | 8.63 | 36.2 | 22.4 | 3.5 | 1.34 | 1.644 | 37 | 0.38 |
| 60–110 | 9.26 | 8.02 | 11.4 | 21.2 | 3.3 | 1.65 | 1.532 | 42 | 0.38 |
| 110–140 | 11.3 | 8.18 | 14.0 | 20.8 | 3.3 | 1.75 | 1.451 | 45 | 0.38 |

**Table 5. Average physical and chemical properties of inland sand dunes.**

| Depth | ECe | pHs | ESP | Saturation percentage | Water retention (15 bar) | CEC | Bulk density | Porosity | Organic matter |
|---|---|---|---|---|---|---|---|---|---|
| cm | dS/m | | | % | | cmol/kg | g/cm³ | % | % |
| 0–40 | 2.76 | 8.28 | 1.0 | 23.6 | 3.7 | 1.31 | 1.543 | 41 | 0.78 |
| 40–75 | 2.77 | 8.13 | 1.18 | 22.8 | 3.6 | 1.22 | 1.618 | 38 | 0.787 |
| 75–200 | 4.51 | 8.12 | 1.99 | 22.4 | 3.5 | 1.20 | 1.629 | 38 | 0.24 |

To manage the salinity problem in Abu Dhabi Emirate, an action plan needs to be developed to determine the best practices of soil reclamation and management. Aspects to the plan include the recommendations for most suitable plant species, optimal irrigation requirements, and development of drainage conditions to achieve salinity control. The following are suggested as prerequisite research needed on salt-affected soils in Abu Dhabi Emirate:

- characterization, mapping, and monitoring of salt affected soils
- identification of causes and sources of salts
- source of good quality irrigation water
- investigation and development of proper leaching requirements and efficient drainage systems
- selection of the optimal crops

## 3. Waterlogging

Many agricultural farms in Abu Dhabi Emirate suffer from waterlogging, poor drainage conditions due to the presence of strong and thick hardpan at different depths (Fig. 7a), excessive use of irrigation water, and seawater intrusion. The most affected areas in Abu Dhabi are Al Ajban, Al Samha, Al Rahba, and Al Bahia (Dawoud and Abdelfattah, 2007). In many areas, water reaches the surface and causes suffocation of existing vegetation (Fig. 7b). The waterlogging problem is often coupled with a rise of salinity due to the absence of proper leaching. Also, it is important to note that waterlogging also affects the surrounding urban community around the affected agricultural farms (Fig. 7c).

Urgent corrective action is required to tackle the waterlogging problems on affected farms. Management options are:

- level the area to avoid stagnant water
- avoid areas with hardpan, or break (rip) hardpans if possible
- establish an efficient drainage system
- implement proper water consumption
- implement careful, appropriate reuse of collected drainage water

## 4. Loss of Vegetation

Rapid economic development of Abu Dhabi Emirate in the past decade has inevitably left its scars on the natural environment. In general, vegetatative cover across the emirate is exceedingly sparse and is generally dominated by a few (mainly invader) species that can be found in most of the desert. Together, overgrazing and the harsh climate contribute to low vegetation cover, and large areas of barren land are commonly encountered in the saline coastal flats and the mobile sand dunes (Brown and Sakkir, 2004). El-Keblawy (2003) investigated species diversity and productivity within and outside of enclosures that prevent animal consumption of plants. He reported a greater species diversity and frequency inside the enclosure. These plants were more palatable and important range legumes (e.g., *Crotalaria aegyptiaca* and *Indigofera articulata*) and grasses (e.g., *Pennisetum divisum, Stipagrostis plumosa,* and *Panicum turgidum*). These species were absent outside the enclosure, indicating the plants were not able to tolerate the current grazing intensity in the study area.

## 5. Compaction, Sealing, and Crusting

Surface sealing, crusting, and compaction are the indicators of land degradation in the Emirate desert. These features are common on soils that are calcareous, gypseous, and sandy. The compaction is accelerated during rainy seasons when soils are wet. Soils that are relatively heavy, cohesive, and rich in silt and dispersible clay contents are also vulnerable when leveled. Landfilling and leveling for infrastructure development is a common activity during this time of increasing urban development. The difference between noncompacted and compacted soils was assessed through bulk density and infiltration rate measurement. The control site had a bulk density of 1.15 g/cm³, while bulk density at the compacted site was much higher (1.66 g/cm³). Infiltration was 267 mm/h compared with 52 mm/h at the two sites, respectively.

## 6. Water Erosion

Most of the desert environment of Abu Dhabi Emirate consists of sand dune soils that absorb rainwater. Due to their very high infiltration rate and water storage capacity, no water erosion occurs in these areas. However, the soils that are more stable and cohesive (such as aeolianite and highlands) have shown signs of the combined effect of wind and water erosion (Fig. 8). Water erosion in Abu Dhabi Emirate is active only during the intensive rainy season, causing severe runoff flows in sloping landscapes in the form of rills and gullies. In flat areas, signs of sheet erosion are also noticable. The Ministry of Environment and Water has taken necessary steps to collect the runoff water from highlands in the dams in the northern emirates, a source of irrigation to the agricultural farms.

**Table 6a. Morphological and analytical properties of saline soils: sandy, mixed Typic Aquisalids and sandy, mixed, hyperthermic Typic Haplosalids.†**

| Horizon | Lower depth | Munsell color | | Sand | Silt | Clay | Texture class | Gravels | Structure | Consistence (moist) | Stickiness | Effervescence | Boundary |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dry | Moist | | | | | | | | | | |
| | cm | | | ——— % ——— | | | | % | | | | | |
| Sandy, mixed, hyperthermic Typic Aquisalids | | | | | | | | | | | | | |
| Az | 17 | 5Y 8/1 (Salt crust) | | Salt Crust | | | | | | | | | |
| Akz | 50 | 2.5Y 6/4 | 2.5Y 5/4 | 88 | 3.5 | 8.5 | Sand | 0 | M | Fr | NS | Strong | AS |
| Bz | 80 | 2.5YR 5/6 | 2.5YR 6/4 | 87 | 4.0 | 9.0 | Sand | 0 | M | Fr | NS | None | – |
| Bzw | Sample not collected because water table started at 80 cm | | | | | | | | | | | | |
| Sandy, mixed, hyperthermic Typic Haplosalids | | | | | | | | | | | | | |
| Akz | 15 | 10YR 5/6 | 10YR 4/4 | 88 | 10 | 2 | Sand | 0 | M | Fr | NS | Strong | CS |
| Bkz1 | 50 | 10YR 5/6 | 10YR 4/4 | 97 | 2 | 1 | Sand | 0 | M | Fr | NS | Strong | DS |
| Bkz2 | 100 | 10YR 5/6 | 10YR 4/4 | 96 | 2 | 2 | Sand | 0 | M | F | NS | Strong | DS |
| Ckz | 140 | 10YR 5/6 | 10YR 4/4 | 97 | 2 | 1 | Sand | 0 | M | L | NS | Strong | |

† M = massive; SG = single grain; Fr = friable; L = loose; NS = nonsticky; AS = abrupt smooth; CS = clear smooth; DS = diffused smooth.

**Table 6b. Analytical properties of saline soils: sandy, mixed Typic Aquisalids and sandy, mixed, hyperthermic Typic Haplosalids.†**

| Horizon | Lower depth | pHs | ECe | ESP | Carbonates eq. <2 mm | Gypsum | Olsen P | Organic matter | Water retention (15 bar) | Saturation percentage | Bulk density | CEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | | dS/m | | ——— % ——— | | mg/kg | % | | % | g/cm³ | cmol/kg |
| Sandy, mixed, hyperthermic Typic Aquisalids | | | | | | | | | | | | |
| Az | 17 | Salt Crust | | | | | | | | | | |
| Akz | 50 | 7.06 | 212 | 81 | 20 | 0.1 | 0.26 | 0.11 | 3.2 | 20 | 1.42 | 1.49 |
| Bz | 80 | 6.93 | 202 | 71 | 1 | 0 | 0.25 | 0.16 | 4.3 | 27 | 1.03 | 2.95 |
| Bzw | Sample not collected because water table started at 80 cm | | | | | | | | | | | |
| Sandy, mixed, hyperthermic Typic Haplosalids | | | | | | | | | | | | |
| Akz | 15 | 7.67 | 232 | 88 | 6.4 | 2.3 | 0.30 | 0.78 | 3.3 | 21 | 1.35 | 3.10 |
| Bkz1 | 50 | 7.84 | 105 | 67 | 6.4 | 0 | 0.28 | 0.76 | 4.2 | 27 | 1.41 | 4.61 |
| Bkz2 | 100 | 7.57 | 139 | 72 | 8.8 | 0 | 0.26 | 0.76 | 4.6 | 29 | 1.50 | 4.60 |
| Ckz | 140 | 7.49 | 152 | 71 | 9.6 | 0 | – | 0.76 | 4.6 | 29 | 1.57 | 4.48 |

† ECe = Electrical conductivity of soil saturation extract; pHs = pH of soil saturated paste; ESP = Exchangeable sodium percentage.

### 7. Landfilling, Mining, and Other Land Degradation Types

Other land degradation indicators observed in Abu Dhabi Emirate are landfilling, mining and quarrying, and excavation for construction material (Fig. 9). A traditional landfilling practice commonly used in the Abu Dhabi Emirate is to bring material from the desert area and dump it into the saline areas. This practice is being applied for landscaping as well as agricultural purposes and is often performed in areas close to cities, around roads, palaces, farms, gardens, parks, etc. However, this excavation harms the areas from which the soil is removed, sometimes resulting in stagnation of water. In addition, irresponsible gravel quarrying and off-road transport cause environmental damage, such as rupture of the lag cover. This rupturing results in soil displacement, landscape disruption, vegetation deterioration, soil compaction, and dust fallout (Al-Awadhi, 2001). This damage is increasing due to ongoing rapid and large developmental projects.

From management perspective, a strategy needs to be developed to control, manage, and rehabilitate the huge excavation activities. This should be science-based, identifying other suitable areas through the use of the soil inventory of Abu Dhabi.

## Conclusions and Recommendations

Land degradation is of great concern in the desert environment of Abu Dhabi Emirate. Among natural forces of land degradation, wind has a major role in drifting soil from loose surfaces and mainly from dune areas. Nebkha dunes, formed from sediment accumulations around shrubs, have been considered a reliable indicator of rapid, dryland degradation. Soil salinity is becoming a threat to agricultural farms. The study also reveals that waterlogging has become a serious problem on many agricultural farms. An emirate-wide action plan needs to be developed and implemented to manage and combat all types of degradation.

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