Spatial Distribution of Soil Salinity and Management Aspects in the Northern United Arab Emirates

Mahmoud A. Abdelfattah and Shabbir A. Shahid

Abstract

The United Arab Emirates is situated in the hyper-arid dry land system where the aridity index (P/PET) is less than 0.05, and hence it is a water stress country. To offset the crop water requirements, irrigation is accomplished mainly with saline/brackish ground water, few progressive farmers use desalinated water using small scale reverse osmosis plants. Mismanagement of these resources leads to soil salinization in the agriculture regions, and in the coastal lands through sea water intrusion. Owing to better management of salt-affected soils to optimize agriculture production, it is essential to characterize root zone salinity as spatial distribution. Regular monitoring identifies future spread of the salinity problem and leads to informed decisions. We attempted to assess soil salinity in the Northern Emirates through a soil survey by investigating 10,200 observation sites on a grid basis, and measuring water and root zone salinity of some agricultural farms. We used a combination of techniques, i.e., remote sensing, GIS, grid survey observation at a depth of 50 cm, and laboratory analyses of soil samples. The electrical conductivity "EC" of 1:1 soil:water suspension was measured for all the observation sites and correlated to EC of soil saturation extract (ECe). Based on the USDA salinity classes (0–2, 2–4, 4–8, 8–6, 16–40 & >40 dS m^{-1}), the NE is divided into six salinity zones, revealing large area (83 %) as non-saline, 10 % (very slightly saline), 4 % (slightly saline), and 3 % moderately, strongly, and very strongly saline, the latter two types are confined to the coastal sabkha

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(due to sea water intrusion), and at the edge of the mountain and inter-dunal sabkhas. Salinity is also observed in agricultural farms irrigated with saline waters, where it has been diagnosed that root zone salinity is not managed properly. We have outlined the management aspects for these saline soils which can be used as a guide for future management and land use planning in the study area.

Keywords
Salinity mapping • Sabkha • Hyper-arid conditions • RS • GIS • Northern Emirates • UAE

1 Introduction

The United Arab Emirates (UAE), federation of seven emirates, is situated in the hyper-arid dryland system where the ratio of precipitation (P) and Potential Evapotranspiration (PET), defined as aridity index (P/PET), is less than 0.05, and hence it is a water stress country. Among seven emirates constituting UAE, Abu Dhabi and Dubai emirates have completed soil inventory and salinity mapping [1, 2], but the Northern Emirates (NE) (Ajman, Fujairah, Ras Al Khaimah, Sharjah, and Umm Al Quwain), and hence this has formed the focus of the paper. Soil salinity is the most discussed issue worldwide from agriculture production and ecosystem management perspectives. It is spreading globally over one billion hectares in all continents. However, the level of salinity problem varies trans-country and even within the country at different locations, landforms, and irrigated agriculture regions to farmers' fields [3]. Worldwide, one in five hectares of irrigated land is suffering from soil salinity and vast areas in China, India, Pakistan, Central Asia, and the United States is losing productivity [4]. About 77 million hectares have been salinized as a consequence of human activities, with 58 % of these concentrated in irrigated areas [5]. On average, 20 % of the world's irrigated lands are affected by salts, but this figure increases to more than 30 % in countries such as Egypt, Iran and Argentina. Generally, soil salinity is limiting food production in many countries of the world. Earlier estimate presents 10 % of the total arable land to be affected by salinity and sodicity and extends over more than 100 countries and almost all continents [6]. However, recent estimates of soil salinity worldwide do not occur, and this is the area where future emphasis should be given. The mechanisms of salinization varies based on many factors, it can be developed through poor management of saline water irrigation, water balance between rainfall, stream flow, groundwater level and evapotranspiration, deforestation and subsequent rise of water table and evaporation, water percolation through saline materials; and seawater intrusion [7]. The salinity can be primary (naturally occurring dryland salinity) and human-induced salinity (secondary). Regardless of salinity types, the development of plants and soil organisms on these lands are affected leading to low crop yields [8].

For an efficient management of salt-affected soils, we need to measure and map soil salinity which is spatially variable and dynamic. This variability is the outcome of different pedological factors like water table depth, topography, parent material, etc. [9]. To keep track of spatial and temporal dynamism of soil salinity and to anticipate future spread, mapping, and regular monitoring is of prime importance [10]. Several studies have assessed and monitored salt-affected soils at national and regional scales [11]. Examples are irrigated agriculture in Arab countries [12], India [13], Thailand [14], Iran [15], Egypt [16], China [17], and Sudan [18]. Recently, presented a comprehensive review on the developments in soil salinity, assessment, modeling, monitoring from regional to submicroscopic levels, as well as procedural matters (RS, GIS, geostatistics, modeling, submicroscopic, modern and routine methods) [3]. A full section on high-tech in soil salinity mapping and monitoring including papers from Spain, South Africa, Thailand, Uzbekistan, Russia, Egypt, Iran, Morocco, USA and India, has been dedicated in the recently published book "Developments in soil salinity assessment and reclamation" [19].

Keeping in mind the influence of soil salinity on agriculture production and ecosystem services, we characterize and map soil salinity status in the Northern Emirates to develop salinity zones for informed decisions to manage soil resources. Managing saline soils is highly site specific and depends on factors such as nature of soils, soluble salts, and local hydrological conditions.

1.1 UAE and the Dry Land Systems

Dry land Systems (DLS) refer to land areas where the mean annual precipitation (P) is less than two-third of potential evapotranspiration (PET). Figure 1 shows global dryland systems (DLS), where either there is lack of water or facing water stress to various levels [20]. Four dry land subtypes are widely recognized based on P/PET: dry sub-humid (0.5–0.65), semiarid (0.2–0.5), arid (0.05–0.2) and hyper-arid (<0.05), showing an increasing level of aridity or moisture deficit. Hyper-arid areas are considered as true deserts. The global DLS (hyper-arid, arid, semi-arid, dry sub-humid) presents different agro-climatic conditions. Therefore, it can be genuinely stated that, drylands management options may be very different for one DLS than the others, for example sub-humid dryland system with rainfall between 200 and 800 mm per annum will require different management than the arid and hyper-arid climates, where rainfall is less than 200 mm per annum. Dry lands have less than 8 % of the world's renewable water resources, the water scarcity in addition to other factors (such as soil and water salinity), are the main limitation in sustainable food production in DLS marginal lands. In such countries agriculture is practiced on environmental cost (high water abstraction and low renewable water) due to depletion of water resources and increase in soil and water salinization. The UAE is situated in the hyper-arid DLS (Fig. 1).

1.2 The Study Area

The NE lies between latitude 24° 44′ and 26° 04′ N and longitude 55° 20′ and 56° 22′ E (Fig. 2) and consist of five (Ajman, Fujairah, Ras Al Khaimah, Sharjah, and Umm Al Quwain) of the seven emirates that make up the UAE. Together they make up 8.2 % of the UAE surface area (82,880 km^2). The climate of the NE is generally hot and dry with a sub-tropical arid climate, and is warm in winter with hot and humid conditions in summer. Temperature may reach 48 °C [21] (Table 1). The soil temperature regime is hyperthermic (mean annual soil temperature is 22 °C or higher, and the difference between mean summer and mean winter soil temperature is 6 °C or more either at a depth of 50 cm below the soil surface or at a densic, lithic, or paralithic contact, whichever is sallower) [22]. The average annual rainfall in the coastal area is 120 mm, but in some mountainous areas it often reaches 350 mm. The landscape ranges from small areas of level coastal plains and sabkha (salt scald) to undulating desert sand plains, extensive areas of linear and transverse dunes, an alluvial plain up to 15 km wide, and mountainous rocky outcrops along the Hajar Mountains which rise to 2,980 m. In the western part, there are linear dunes up to 100 m high, interspersed with small areas of almost level deflation plains and flats.

1.3 Agriculture and Farms in the NE

Most of the farms in the NE are in the three emirates of Sharjah, Ras Al Khaimah, and Fujairah, with smaller numbers in the other two emirates. Sharjah and Ras Al Khaimah have much larger areas in farms than the other three

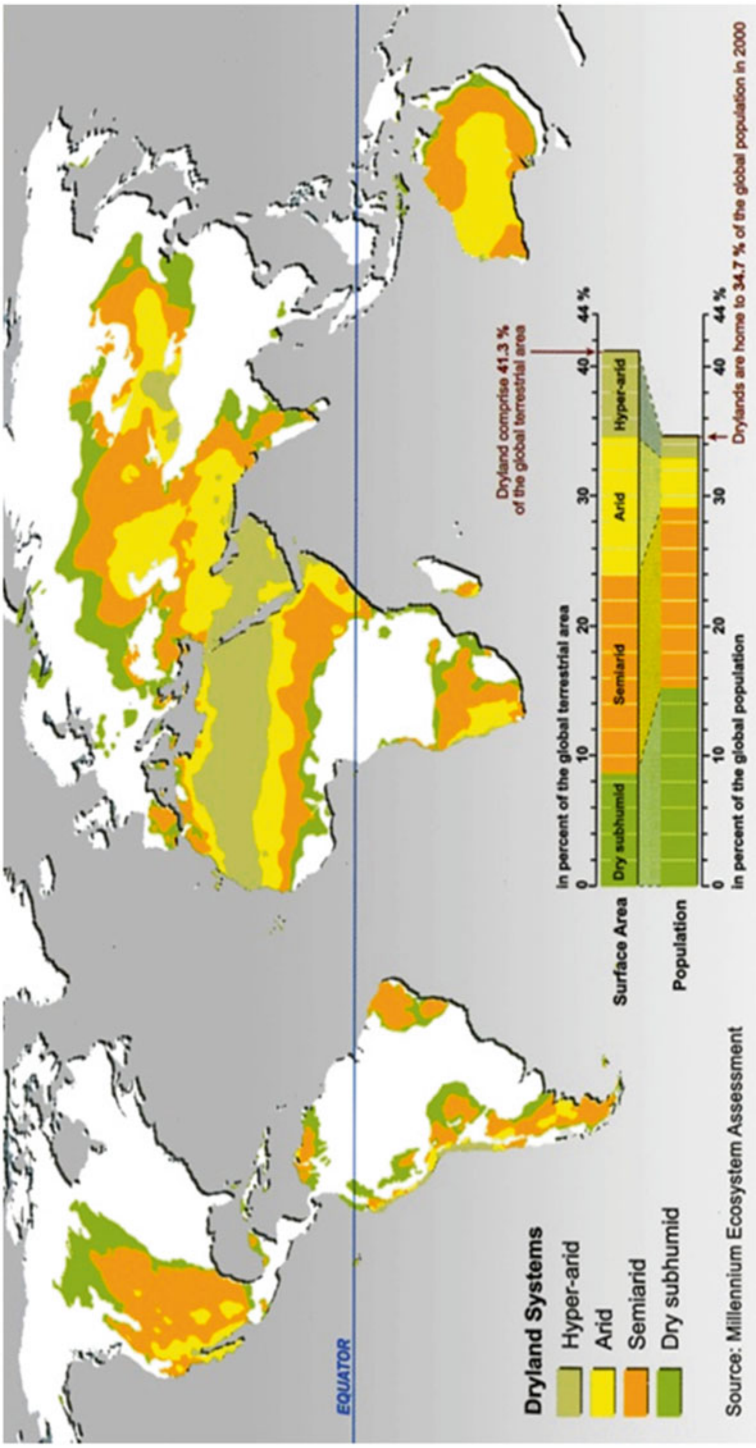

Fig. 1 Dryland systems (Source: MEA [20])

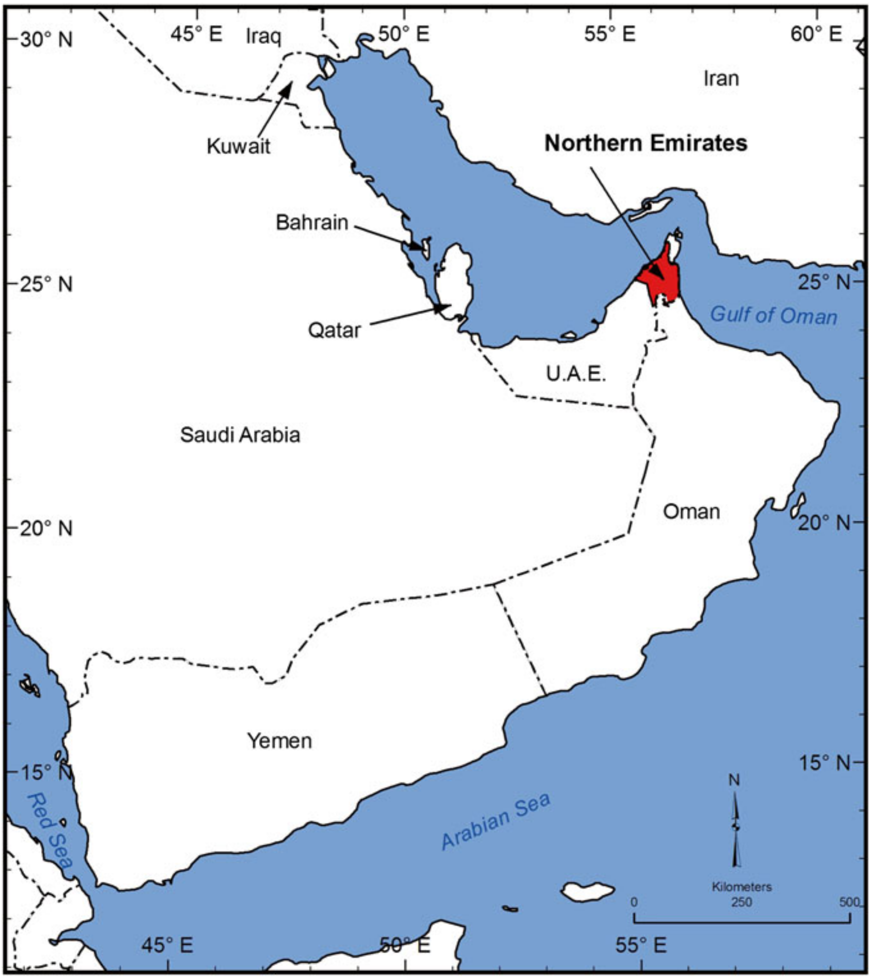

Fig. 2 Location map for the Northern Emirates

Table 1 Climatic data for the Northern Emirates

	Air temperature (°C)			Soil temperature (°C)			Relative humidity (%)			Rainfall (mm)	Evaporation (mm/day)	Wind speed (km/h)	
Month	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Mean	Mean	Mean	Max.
Jan	31.7	18.3	09.0	33.8	21.7	12.8	100	60	2	18.3	9.2	10	66
Feb	34.1	20.7	07.7	39.8	25.0	13.0	100	53	1	15.1	11.5	9	47
Mar	38.1	24.2	12.4	46.1	30.1	16.9	100	43	1	3.7	9.7	10	52
Apr	43.2	29.0	15.4	52.5	35.7	21.6	100	33	2	8	11.1	10	54
May	46.5	33.5	19.8	55.2	41.2	28.4	100	27	2	0	15.0	10	50
Jun	48.6	35.7	23.7	57.3	43.7	32.0	100	33	2	0	15.8	10	41
Jul	47.8	36.3	26.6	56.8	44.4	34.2	91	40	2	0	14.9	12	49
Aug	47.7	36.3	28.2	57.4	44.2	32.3	96	41	4	1.6	14.6	11	49
Sep	45.5	33.7	22.9	55.4	40.9	29.2	98	42	2	3.8	14.0	10	51
Oct	43.0	30.1	18.9	50.2	36.3	25.3	100	45	4	0	13.9	8	47
Nov	38.0	25.2	13.5	44.1	30.3	19.5	100	54	7	0.8	11.5	8	35
Dec	31.4	20.2	08.8	35.9	24.2	12.4	100	63	7	14.1	10.0	8	40
Mean/ (total)	41.3	28.6	17.2	48.7	34.8	23.1	98	44.4	3.0	(65.4)	12.6	09.8	48.4

Source: NCMS [51] and Raafat [21]

Table 2 Cultivated areas and number of farms by Emirate in 2009

	Emirates					
	Sharjah	Ajman	Umm Al Quwain	Ras Al Khaimah	Fujairah	Total
Palm tree	4,824	502	385	3,762	2,258	11,731
Other permanent crops	1,551	357	182	1,066	978	4,134
Crop and fodder	1,599	248	289	2,419	359	4,914
Vegetables	1,667	184	176	2,446	721	5,194
Greenhouses	23	2	2	55	19	101
Shifting area	3,244	682	334	3,498	860	8,618
Cultivated area (ha)	12,908	1,975	1,368	13,246	5,195	34,692
Number of farms	4,392	691	343	4,465	5,324	
Average farm size (ha)	3.02	3.04	4.94	3.04	1.23	

Source: Ministry of Environment and Water [52]

emirates. Farms range from 1 to 5 ha in size (Table 2). Crops grown include dates, vegetables, and fodder. The area south of Ras Al Khaimah in the north is an important farming center because of the high suitability and low salinity of the soils in the area.

2 Materials and Methods

In recent years new techniques have been developed for salinity mapping including remote sensing (RS), geophysical methods, determining the electrical conductivity of a soil 'saturation extract' (ECe) or at different soil:water ratios [19, 23]. The choice of the technique ultimately depends upon the purpose of the study, size of the area, frequency of measurement, and accuracy required. To have a clear view of the current status of soil salinity in the NE, we have used a set of techniques for soil salinity assessment and mapping. This has involved an interpretation of RS imagery (Indian Remote Sensing "IRS", Landsat ETM, ASTER, and SRTM DEM) supported by ground truthing of over 10,200 sites at 0–50 cm depth where EC of 1:1 soil:water suspensions was measured. This was later correlated to ECe using a relationship (ECe = EC 1:1 × 3.35) developed on UAE soils [3]. GIS was used for data entry, management, processing, interpretations, and production of maps as detailed below.

2.1 Processing of Remote Sensing Imagery

Remote sensing (RS) coupled with conventional ground truthing data [24], and the integration between RS, GIS, and spatial statistics provide useful tools for modeling variability to diagnose pattern of characteristics [25]. Delineation of saline soils using these techniques has been proven efficient in different studies [26–31]. In this study IRS imagery, Landsat ETM satellite data, ASTER-derived digital elevation, Shuttle Radar Terrain Mission (SRTM) and Digital Elevation Model (DEM) were used. Orthorectified Landsat imagery from 'NASA's Global Orthorectified Landsat Data Set' [32] was used as the survey control for the IRS imagery. Although the spatial resolution of the Landsat imagery is too coarse to be used as a backdrop to the field maps, it is nevertheless very useful for spectral analysis of the soils. In addition to the six-band calibrated mosaic, enhanced Landsat 742 RGB GeoTIFF combinations were prepared so that the use of an image processing system was not required to view the data. Figure 3 depicts unsupervised classification of the alluvial plain, adjacent to Hajar Mountain, draped over the SRTM digital elevation model (DEM). Comparing locations on this image against the corresponding soil map indicates that some of the differences in this image correlate with differences in soil and landscape features. The resulted map was used as guide prior to fieldwork activities.

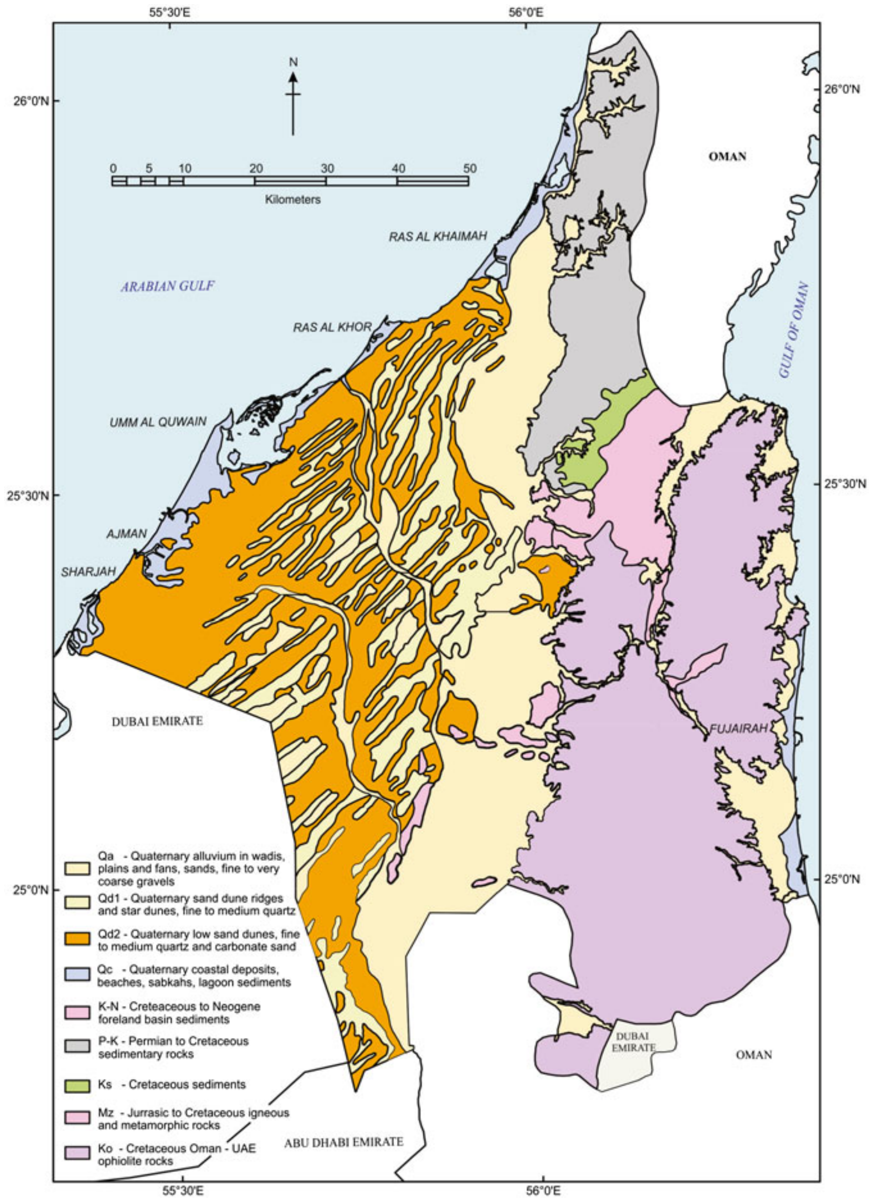

Fig. 3 Unsupervised classification for the western alluvial plain draped over the SRTM digital elevation model

2.2 Fieldwork and Data Collection

Soil salinity mapping is a part of a larger soil inventory study in the NE [33]. Fieldwork at a scale of 1:50,000 was undertaken during 2010–2012. A total of 10,200 observation sites (Fig. 4) at a grid of 550×550m to a depth of 200 cm across the study area were investigated. Each site was described for morphological description (i.e., slope, landscape, landform, erosion, land use and cover, drainage class, surface condition) and in-depth soil horizons

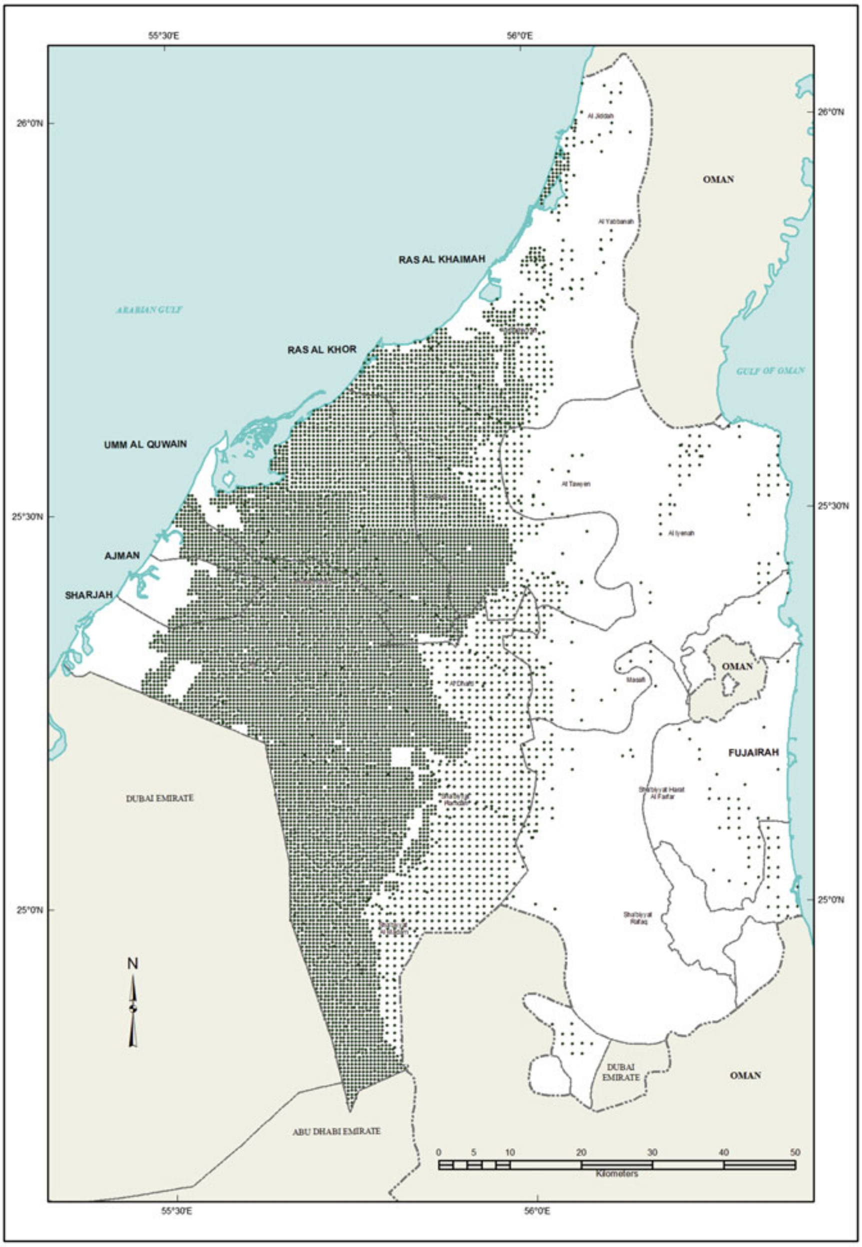

Fig. 4 Location of observation points in the study area

description (colour, texture, structure, consistence, concretions, gravels, excavation difficulty, and effervescence). Soil samples from different horizons (2–5 at least) of each investigated sites were analysed in the field for salinity measurement using 1:1 soil water suspension. Representative samples were analysed using soil paste extract for ECe for correlation. Relationships between the EC and ions were established from 1:1 and saturated paste extracts using regression equations [34]. They found that these soil properties are highly correlated but the correlation depends on ionic charge and soil texture (fine texture with less than 60 % of sand as opposed to coarse texture). Based on these relationships and the analysed samples from the same area in the laboratory, the EC of the 1:1 soil water suspension were converted into ECe by multiplying them by a factor of 3.35. This was based on a comparison of field (EC 1:1 soil water suspension) and laboratory (ECe soil paste extract) measured results from UAE soils. The EC values were used to calculate an average EC value (weighted for horizon thickness) for the first 50 cm layers of soil at each site. This ECe value was used to calculate the average salinity of each soil type and subsequently soil map unit, which was later used to develop the overall salinity map. The data in Table 3 demonstrate soil classes, their extent, and the overall soil salinity value for each.

2.3 Converting Point Data into a Generalized Map

The salinity map was generated as an attribute of the soil map. The soil map is composed of number of map units; each of them consists of number of component soils in different proportions. For each soil component, a representative ECe value was assigned, and then an overall ECe value was calculated for the map unit based on a weighted average of the components making up the map unit (Table 3). Each map unit was then placed into one of six salinity zones. The ECe 0–1.99 dS m^{-1} is rated as 1 (non-saline), ECe 2–3.99 dS m^{-1} is rated as 2 (very slightly saline), ECe 4–7.99 dS m^{-1} is rated as 3 (slightly saline), ECe 8–15.99 dS m^{-1} is rated as 4 (moderately saline), ECe 16–39.99 dS m^{-1} is rated as 5 (strongly saline), and ECe >40 dS m^{-1} is rated as 6 (very strongly saline) (Table 4) [35] and the appropriate rating allocated to the map unit. This procedure has been repeated for each map unit to generate the salinity map for the whole area at a scale of 1:50,000. Table 4 shows the ECe rating categories for salinity in the 0–50 cm layer and summary of areas identified for each emirate. A map illustrating the distribution of salinity in the 0–50 cm soil layer is presented in Fig. 5.

3 Results and Discussion

3.1 Delineation of Surface Salinity

The landscape salinity zones can guide for informed decisions on land use planning, such as designing experiments [36–39], sampling strategy [40, 41], and soil reclamation [42]. In the present study a depth of 0–50 cm was chosen to represent plant root zone depth. The high electrolyte concentrations reduce water absorption by plants due to increase in osmotic pressure in the soil solution. Salts may also interfere with the exchange capacity of nutrient ions, thereby resulting in nutritional imbalances in plants. Field investigation revealed high saline zones in the sea coast developed through sea water intrusion. The coastal area was either devoid of vegetation or only highly salt tolerant (halophytes) vegetation was recorded such as in Um Al Quwain (Fig. 6). Figure 7 presents typical salt crust in the coastal sabkha of the NE. Soil salinity has also been recorded in agricultural farms, but to a much lower level compared with sabkha area (Fig. 8).

3.2 Classification of Saline Soils in the Coastal Sabkha of the NE

In the USDA Soil Taxonomy [22] hierarchy (order, suborder, great group and sub group), true saline soils are identified in the order "Aridisols" and suborder "Salids" divided into Aquisalids and Haplosalids (great groups). At the subgroup levels various Aquisalids (gypsic, calcic, anhydritic, typic) and Haplosalids (duric, petrogypsic, gypsic, calcic, typic) are reported. The Salids are equivalent to Solonchaks (saline soils in Russian classification system). In the Northern Emirates, only Salids have been mapped. The Salids have a salic horizon within 100 cm of the surface. Salic horizon has accumulation of salts more soluble than gypsum in cold water. It is characterized by the followings: (1) 15 cm or more thick and has, 90 consecutive days or more in normal years; an electrical

Table 3 Soil classes, their extent, and the overall soil salinity value

Soil class	Extent (ha)	Salinity 0–50 cm (ECe dS m^{-1})	Soil class	Extent (ha)	Salinity 0–50 cm (ECe dS m^{-1})
Oxyaquic Torriorthents, sandy, carbonatic, hyperthermic	1,336	4	Typic Haplocalcids, sandy-skeletal, mixed, hyperthermic	6,066	0.9
Typic Torriorthents, fragmental, mixed, hyperthermic	9,259	1	Typic Haplocalcids, sandy, mixed, hyperthermic	7,875	0.5
Typic Torriorthents, sandy-skeletal, mixed, hyperthermic	36,996	1.5	Typic Haplocalcids, sandy, carbonatic, hyperthermic	5,403	0.5
Typic Torriorthents, sandy-skeletal, mixed, hyperthermic	10,581	1	Sodic Haplocambids, coarse-loamy, mixed, active, hyperthermic	3,372	3.7
Typic Torriorthents, sandy-skeletal, mixed, hyperthermic	5,327	8.5	Typic Haplocambids, coarse-silty, carbonatic, hyperthermic	4,390	2.3
Typic Torriorthents, sandy, mixed, hyperthermic	8,152	2	Typic Haplocambids, sandy over loamy, carbonatic, hyperthermic	250	1.5
Typic Torriorthents, sandy, mixed, hyperthermic	3,558	0.3	Leptic Haplogypsids, coarse-loamy over sandy or sandy-skeletal, carbonatic, hyperthermic	1,077	15
Typic Torriorthents, coarse-loamy, carbonatic, hyperthermic	5,064	3	Typic Haplogypsids, loamy-skeletal, mixed, superactive, hyperthermic	9,204	7
Typic Torriorthents, coarse-loamy, carbonatic, hyperthermic	23,204	2.5	Typic Calcigypsids, coarse-loamy, carbonatic, hyperthermic	5,224	4
Typic Torriorthents, coarse-loamy, carbonatic, hyperthermic	988	3	Gypsic Aquisalids, sandy, carbonatic, hyperthermic	1,023	75
Typic Torripsamments, carbonatic, hyperthermic	200,157	0.15	Gypsic Aquisalids, coarse-loamy, carbonatic, hyperthermic	1,476	40
Typic Torripsamments, carbonatic, hyperthermic	21,914	0.25	Typic Aquisalids, sandy, carbonatic, hyperthermic, shallow	378	28
Sodic Haplocalcids, coarse-loamy, carbonatic, hyperthermic	1,509	3.6	Gypsic Haplosalids, sandy, carbonatic, hyperthermic	1,508	55
Typic Haplocalcids, sandy-skeletal, mixed, hyperthermic	22,175	0.9	Gypsic Haplosalids, coarse-silty, gypsic, hyperthermic	346	5.5

conductivity (EC) ≥30 dS m^{-1} in the water extracted from a saturated paste; and (2) A product of ECe (dS m^{-1}) and thickness (cm), equal to 900 or more [22]. Salids have been mapped in the coastal salt flat above the high-tide level (coastal sabkha). These soils are strongly to very strongly saline (ECe exceeds 50 dS m^{-1}), due to the capillary rise of saline water and subsequent evaporation from a subsurface water table that lies within 200 cm of the surface. Salids are further classified at Great Group level into Aquisalids and Haplosalids.

Table 4 Salinity ratings in the 0–50 cm layer and summary of areas identified for each emirate

			Area (ha)						
Rating category	Electrical conductivity (ECe dS/m)	Yield restriction	Ajman	Fujairah	RAK[a]	Sharjah	UAQ[a]	Total	%
Non saline	0 to <2	Salinity effects mostly negligible	6,398	25,603	65,594	190,786	46,265	334,646	83.39
Very slightly saline	2 to <4	Yields of very sensitive crops may be restricted	2,537	131	15,330	11,585	10,830	40,412	10.07
Slightly saline	4 to <8	Yield of many crops restricted	0	3,826	5,248	10,422	0	19,495	4.86
Moderately saline	8 to <16	Only tolerant crops yield satisfactory	0	0	0	32	459	491	0.12
Strongly saline	16 to <40	Only a few very tolerant crops yield satisfactory	0	0	380	1,617	1,923	3,920	0.98
Very strongly saline	≥40	Halophytes are the only option	0	218	1,414	0	687	2,319	0.58
Total area (ha)			8,935	29,777	87,966	214,441	60,164	401,283	
Total area (%)			2.23	7.42	22.92	53.44	14.99		

[a]*RAK* Ras Al Khaimah, *UAQ* Umm Al Quwain

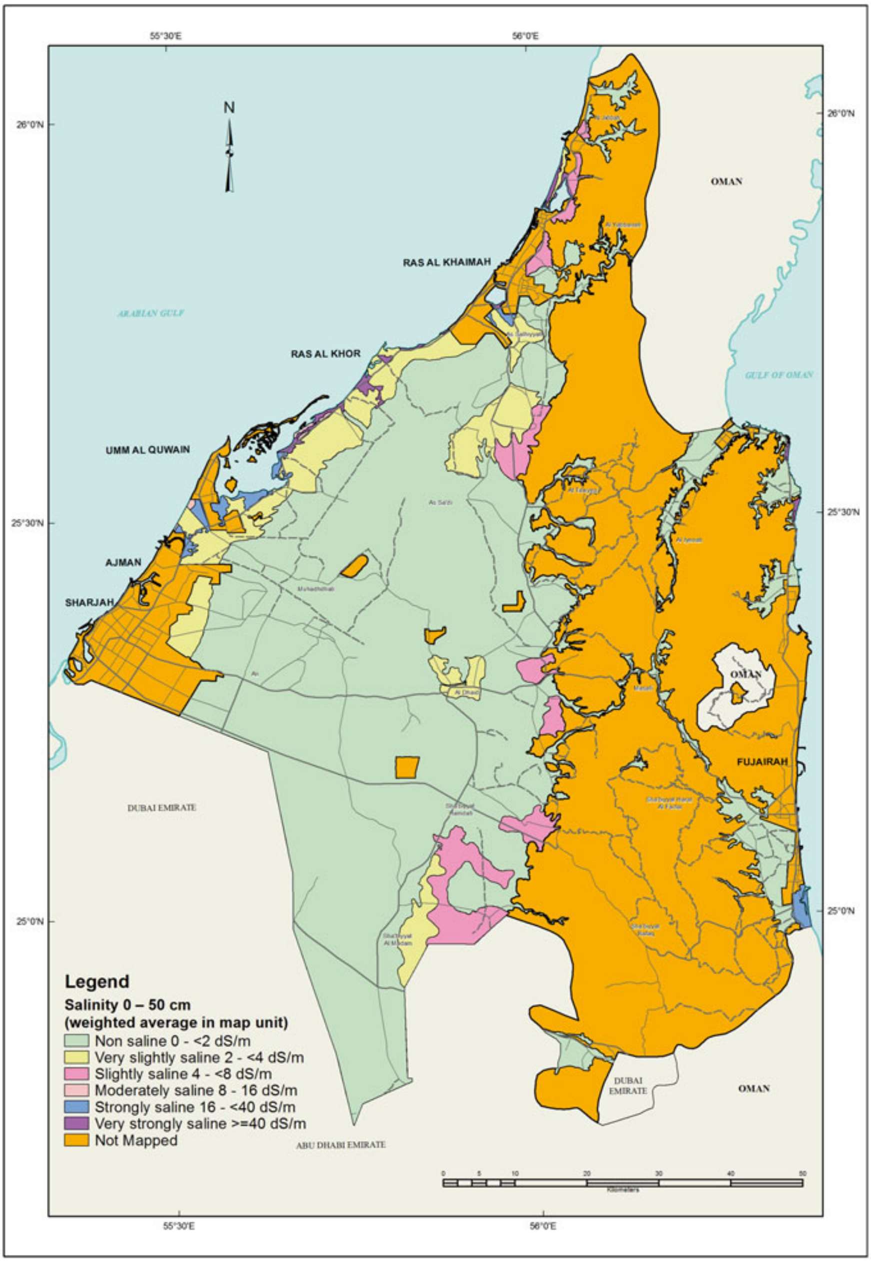

Fig. 5 Soil salinity map of the Northern Emirates

3.2.1 Aquisalids

Aquisalids are saturated with water in one or more layers within 100 cm of the surface. These are highly saline soils in wet areas where capillary rise and evaporation concentrate salts near the surface. These soils have redoximorphic features in the layers normally saturated with water (Fig. 9). Vegetation on Aquisalids is limited to salt-tolerant species and halophytes. Two subgroups of Aquisalids have been identified; (a) Gypsic Aquisalids (Aquisalids that, in addition to having a salt-rich salic horizon), also have an

Fig. 6 Coastal sabkha with halophytes near Um Al Quwain

Fig. 7 An example of coastal sabkha with surface salt crust in the Northern Emirates

accumulation of gypsum (gypsic horizon) within 100 cm of the surface, and (b) Typic Aquisalids: These Aquisalids only have a salic horizon and do not have a calcic or gypsic horizon within 100 cm of the surface.

3.2.2 Haplosalids

Haplosalids are the Salids that are not saturated with water within 100 cm of the surface. One subgroup is recognized in the NE – Gypsic Haplosalids: These are the Haplosalids that have

Fig. 8 Accumulation of salinity in the root zone of agricultural farms in the Northern Emirates

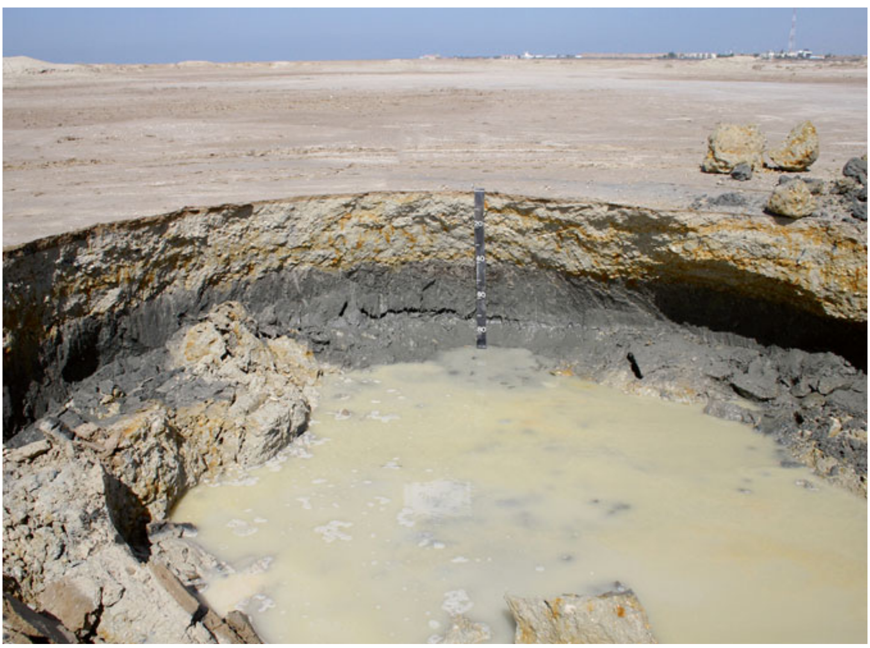

Fig. 9 Redoximorphic features in the Aquisalids of the Northern Emirates

both a salic horizon and a gypsic horizon within 100 cm of the soil surface. Due to their immediate vicinity to the sea, these coastal soils are not suitable for agriculture production. These soils have continuous sea water intrusion, which has been increased in recent years due to high water abstraction, and this has led salids extended slightly inland. These soils present only halophytes. Salt harvesting for commercial purposes (industrial use) could be an ideal choice from such areas.

3.3 Micromorphological Views of Saline Soils in the NE

Study of soil thin sections (25–30 μm thick) under the polarizing microscope allows in-situ views of soil fabric and its components. This is different to soil assessment whereby water is added into the soil (disturbed assessment) and soil extract studied by various equipment, this gives average composition and soil sample loses its recognition. Thin section preserves soil recognition. Recently [3] has published a review on soil micromorphological aspects of salt crusts from arid regions. We attempted to include this important assessment in the NE soil investigation, whereby we studied Gypsic Aquisalids under the polarizing microscope.

The investigation revealed dominance of gypsum crystals and brownish microcrystalline calcite. The b-fabric is granostriad (clay), infillings were not observed, intergrowth of blocky gypsum found, microstructure is mainly vughy. Figure 10a shows an image (plane polarized light) of blocky gypsum crystals (Gyp) with remnants and coatings of clay material, Fig. 10b shows same feature as (10a) but under crossed polarized light, clearly illustrating low order grey interference colors of gypsum. Magnified view of clay coatings (C) and gypsum crystals (gyp) is shown in Fig. 10c (plane polarized light) and 10d (crossed polars). The total view of thin sections under the polarizing microscope through point counting did not show halite (NaCl) and other crystals, perhaps due to high solubility of halite has been dissolved during sample impregnation with crystic resin and thin section preparation.

3.4 Soil Salinity Map

Information about spatial variability and temporal distribution of soil salinity is vital for site-specific management since they are the most important factors influencing soil quality and agricultural production [43]. The effective control of soil salinity and waterlogging requires, among others, the knowledge of the magnitude, the extent, and the distribution of root zone salinity (inventory), the knowledge of the changes and trends of soil salinity over time (monitoring), and the ability to determine the impact of management changes upon saline conditions [44]. In the NE, soil salinity map (to 50 cm depth) was developed as an attribute of soil map that was produced at a scale of 1:50,000 (Fig. 5). The results indicate that most of the soil survey area is shown as non-saline and consists of predominantly native sandy soils (unused) with little or no accumulation of salts within the upper 50 cm of the soil. However, it should be noted that local areas of more saline soils do occur within this area but are too small to map within the scale of the present study. These are often a result of past irrigation of small farms where repeated applications of water containing even small amounts of salt results in an accumulation of salt in the soil profile. The highest levels of salinity are found along the coasts in the sabkha where the soils are moderate, strong or very strongly saline. This is a natural occurrence resulting from the upward movement of salts from a water table toward the soil surface due to evaporation. Intermediate salinity levels (very slightly saline or slightly saline) occur in some soils on the alluvial plain, often associated with soils that are loamy in at least part of the profile.

3.5 Extent and Spatial Distribution of Soil Salinity

As shown in Fig. 5, saline areas are dominant along the coastal areas and minor inland. The non-saline areas (0 to <2 dS m^{-1}) is the most common soils in the NE and covers an area of 334,646 ha (83.39 %), distributed in Sharjah (190,786 ha), Ras Al Khaima (65,594 ha) and

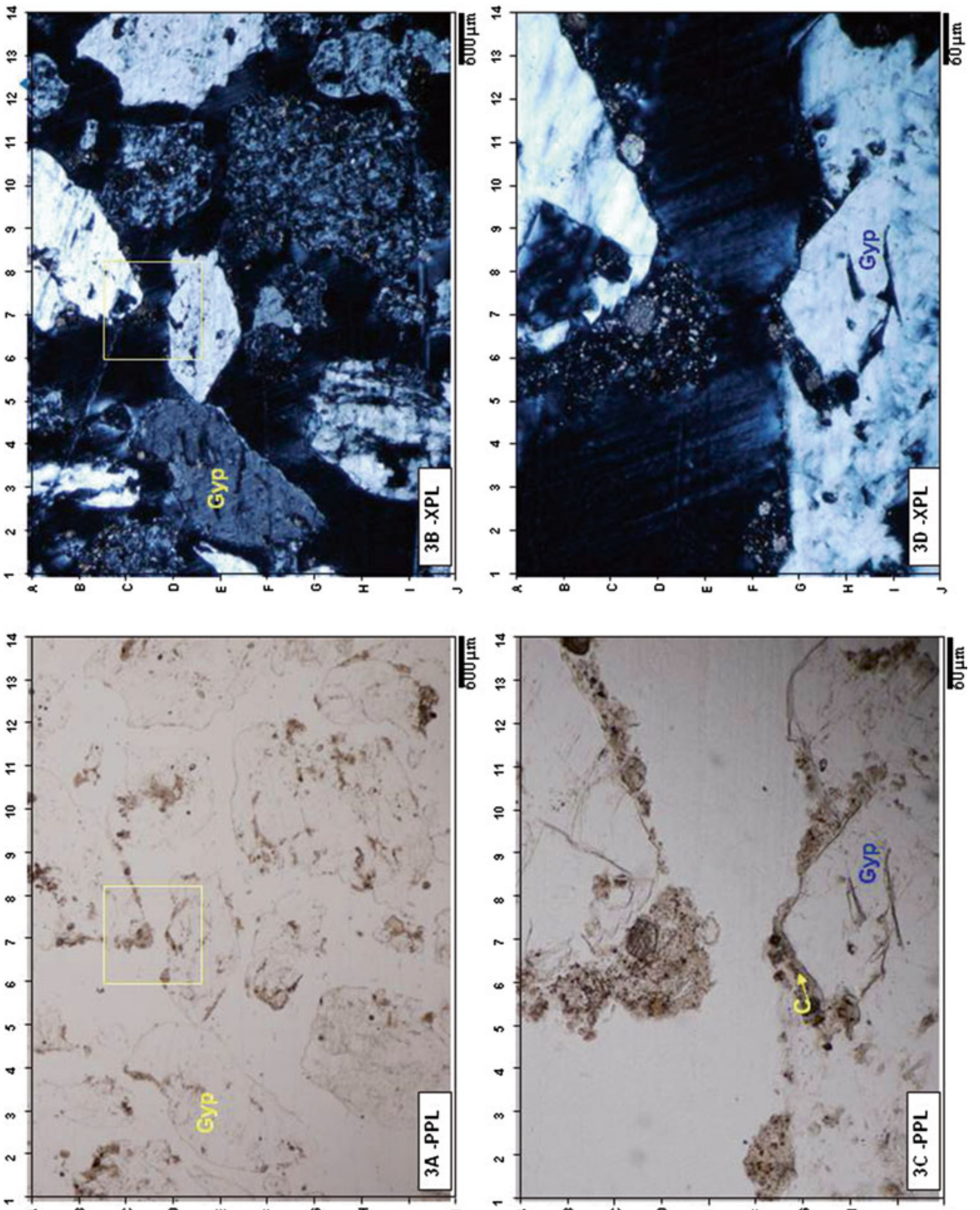

Fig. 10 Micrographs from a Gypsic Aquisalids in the coastal sabkha of the NE

Um Al Quwain (46,265 ha), with lesser extent in Fujairah (25,603 ha) and Ajman (6,398 ha). The very slightly saline soils (2 to <4 dS m^{-1}) represent the second common soils with an area of 40,412 ha (10.07 %) and distributed in Ras Al Khaima (15,330 ha), Sharjah (11,585), and Um Al Quwain (10,830 ha), with lesser areas in Ajman (2,537) and Fujairah (131 ha). The slightly saline soils (4 to <8 dS m^{-1}) covers an area of 19,495 ha (4.86 %) and concentrated mainly in Sharjah (10,422 ha), Ras Al Khaima (5,248), and Fujairah (3,826 ha). The moderately saline soils (8 to <16 dS m^{-1}) are very small elongated stripes along the coastline of the Arabian Gulf and covers an area of 491 ha (0.12 %) concentrated mainly in the coastal areas of Um Al Quwain (459 ha) and Sharjah (32 ha). The strongly saline soils (16 to <40 dS m^{-1}) are represented by a small batches of sabkha distributed along the coastal area of the Arabian Gulf and the Gulf of Oman and cover an area of 3,920 ha (0.98 %), concentrated in Um Al Quwain (1,923 ha), Sharjah (1,617 ha), and Ras Al Khaima (380 ha). The very strongly saline soils (≥40 dS m^{-1}) are represented by a small batches of sabkha distributed along the coastal area of the Arabian Gulf and the Gulf of Oman and cover an area of 2,319 ha (0.58 ha), concentrated in Ras Al Khaima (1,414 ha), Um Al Quwain (687) and Fujairah (218 ha).

It is evident from above that an area of about 6.54 % presents soil salinity (ECe) over 4 dS m^{-1} and mainly confined to the coastal land. This is a good sign that most of the soils are non-saline and have the potential to be converted to agricultural regions, with the condition that these areas have sufficient soil depth (to 200 cm) and devoid of water table (within 200 cm) and have sufficient irrigation water. The land use planners and decision makers can use the salinity map for future land use planning.

3.6 Management of Farm Salinity Through Assessment of Water Salinities

In order to assess water salinity in agricultural farms, many water samples were collected from the water wells. These samples were analyzed for water salinity (EC), and compared with water salinity classes; C1 (Low salinity 0.1–0.25 dS m^{-1}); C2 (medium salinity 0.25–0.75 dS m^{-1}); C3 (high salinity 0.75–2.25 dS m^{-1}); C4 (very high salinity 2.25–10.0 dS m^{-1}); C5 (strong salinity 10.0–25.0 dS m^{-1}); and C6 (very strong salinity 25–45 dS m^{-1}). In order to have better presentation of various salinity classes we have modified the Richards water salinity classification, from four to six classes [45]. The water salinity revealed per cent water samples distributed into various salinity classes C1 (1.0 %), C3 (26.4 %), C4 (44.0 %), C5 (24.2 %) and C6 (4.4 %), no water sample was found in the C2 category. Major concern of water salinity is in the range of above 2.25 dS m^{-1}, where most of the vegetable crops yield is reduced (low salinity threshold values). During field survey, we found few farms have the facilities of small scale reverse osmosis to desalinate water for irrigation purpose, these waters are classified as C1 class((<0.25 dS m^{-1}), where only less than 1.1 % of the farms surveyed represent this type of modern irrigation facilities.

3.7 Prediction of Soil Salinity Management in Agricultural Farms

Root zone salinity monitoring in various agricultural fields (where soil is sandy and sand is over 90 %) revealed root zone soil salinity (ECe) essentially equals to the irrigation water applied (ECw = ECe), however, in other textured soils (fine texture) 50 % greater than the irrigation water salinity (ECe = 1.5 × IW salinity) is reported in the literature (ECe = ECw × 1.5) [3]. Based on this information we evaluated root zone salinity to assess if the farm salinity is well managed or otherwise. We used ratio of (ECe/ECw), if the ratio is less than 1.1 we considered farm salinity is well managed, and if ratio is more than 1.1 we considered farm salinity not managed properly. The results of many farms surveyed showed variable root zone salinities based on the irrigation water salinity and management practices. The percent distribution of samples in different ECe/ECw have been found as, <1.1 (25 %), ≥1.1–≤5.0 (48 %), ≥5.1–<10.0 (12 %), ≥10.0 (15 %). The result shows that in over 75 % farms root zone salinity is not well managed.

It is evident that the farm salinity is not managed properly, and hence, we recommend following management aspects to optimize farm resources uses for better crop production:

- Prior to sowing seeds it is essential to collect soil samples at potential rootzone (0–20 cm) depth and sent to soil and water testing laboratory for salinity analysis.
- The extension worker should translate the root zone salinity to the farmer and help him in the following aspects:
  - What crop to be selected (based on salt-tolerance level).
  - How much, and how frequent irrigation water to be applied keeping in mind the leaching requirement (ET + LR).
  - Guide the farmer to regularly monitor root zone salinity at the farms, or send to government laboratory for testing to assure root zone salinity should not increase above the threshold salinity level.
  - Provide advisory services on other aspects (nutrient management, pest management, post-harvest losses, and marketing).

We believe it is necessary to explain in a user friendly manner as how the root zone salinity affects crop production. A saline land with salinity (ECe) 5 dS m^{-1} will not be ideal for vegetable crops such as beans (threshold salinity 1 dS m^{-1}), but suitable resource for forage production such as barley (salinity threshold 8 dS m^{-1}), and sorghum (threshold salinity 6.8 dS m^{-1}). Under such condition, either, the root zone salinity is reduced through leaching or a salt-tolerant crop with high salinity threshold to be used for better crop production.

This suggests that the diagnoses of salinity problem become prime importance for proper crop selection.

It has been experienced that such an important component is mostly missing in crop production as the farmer in general is ignorant due to its inaccessibility to soil and water testing laboratories and poor extension-framers link. The explanation below and the table can be used as a general guide for yield prediction in saline conditions compared to the yield from a non-saline soil.

Crops can tolerate salinity up to certain levels without a measurable loss in yield (this is called threshold level). As a general rule, the more the crops are salt tolerant, the higher the threshold level. At salinity levels greater than the threshold, crop yield reduces linearly as salinity increases. Using the salinity values a salinity/yield model was developed [46], predictions of expected yield loss can be made. Maas and Hoffman expressed salt tolerance of crops by the following relationship:

$$\mathrm{Yr} = 100 - \mathrm{s}\left(\mathrm{ECe} - \mathrm{t}\right)$$

where Yr = percentage of the yield of crop grown in saline conditions relative to that obtained on non-saline conditions; t = threshold salinity level where yield decrease begin; s = percent yield loss per increase of 1 ECe (dS m^{-1}) in excess of t. Table 5 may be used as a guide to predict yield losses.

3.8 Water Quality, Crop Water Requirement and Drainage Water in Saline Production Systems – Serious Concerns

The survey of the agricultural farms in the Northern Emirates and discussions with farm supervisors has reflected that in most of the saline production systems, emphasis has been mainly given to either water salinity or soil salinity, the soil and water sodicity aspects have merely been ignored. This is justified that the soils in the region are sandy in texture, and therefore soil sodicity is not a problem, but soil salinity, over-ruling the effect of water sodicity (high SAR-nutrient imbalance) in crop production in sandy soils. The general consensus, that, the soils are sandy “is not correct” as other soil textural classes have been mapped in the national soil surveys [2, 33, 47] showing potential for irrigated agriculture.

Let us put an examples of two waters, W1 (EC 0.5 dS m^{-1} and SAR 60 $(mmol\ L^{-1})^{0.5}$, W2 (EC

Table 5 General threshold (t) and slope (s) values to calculate crop yield as a function of soil salinity for various crops (Hoffman [50]; cf Shahid and Rahman [23])

Crops	Threshold (t) ECe dS/m	Slope (s) % yield loss per 1 ECe (dS/m) above (t)
Alfalfa (*Medicago sativa*)	2.0	7.3
Barley for grain (*Hordeum vulgare*)	8.0	5.0
Bean (*Phaseolus vulgaris*)	1.0	18.9
Bean, dry edible (*Phaseolus vulgaris*)	1.0	19.0
Cabbage (*Brassica oleracea*)	1.8	9.7
Carrot (*Daucus carota*)	1.0	14.1
Clover (*Trifolium spp.*)	1.5	12.0
Corn for grain (*Zea mays*)	1.7	12.0
Corn for silage (*Zea mays*)	1.8	7.4
Cucumber (*Cucumis sativus*)	2.5	13.0
Date (*Phoenix dactylifera*)	4.0	3.6
Lettuce (*Latuca sativa*)	1.3	13.0
Onion (*Allium cepa*)	1.2	16.1
Pepper (*Capsicum annum*)	1.5	14.1
Potato (*Salanum tuberosum*)	1.7	12.0
Radish (*Raphanus sativus*)	1.2	13.0
Sorghum for grain (*Sorghum bicolor*)	6.8	16.0
Soybean (*Glycine max*)	5.0	20.0
Spinach (*Spinacia oleracea*)	2.0	7.6
Sugar beet (*Beta vulgaris*)	7.0	5.9
Tomato (*Lycopersicum esculentum*)	2.5	9.9
Wheat for grain (*Triticum aestivum*)	6.0	7.1

s = % yield loss per 1 ECe (dS/m) increase above t (ECe) value; t = salinity threshold ECe (dS/m), where yield is optimum

5 dS m^{-1} and SAR 5 (mmol $L^{-1})^{0.5}$. Ignoring the role of sodicity, W1 will be rated as good quality water compared to W2, whereas, soil scientists will consider W1 as bad quality water, because high SAR will affect physical properties of soils, through soil dispersion and plugging of soil pores and ion balance. The adverse effect of sodium on soil structure, clay dispersion, and water infiltration is well documented in the literature. The rectification of water sodicity requires the addition of gypsum ($CaSO_4.2H_2O$), which on dissolution release Ca and lower SAR in the water. Ignoring the gypsum addition, may lead to a soil to highly sodic, which will require higher costs of reclamation.

Irrigation water requirement is usually based on evapotranspiration-ET (water consumed by the crop and lost through soil) and application of water in excess of crop requirements needed to leach salts out of the root zone (leaching requirement) and thus control root zone salinity. The ET is a measure of evaporation data (class A pan) and transpiration from crops in weighing lysimeter experiments conducted on different crops. In such experiments, usually, fresh water is used to offset water requirements of crops and to determine ET. In such water requirements determinations, the concept does not consider the decrease in water uptake (saline water) by plants compared to when fresh water is used for irrigation, and thus increase in leaching that occurs when plant yield decreases. The possibilities to use saline waters at low leaching fractions have been significantly overlooked due to use of current guidelines, such as [48]. The combination of the assumption of fixed crop ET (regardless of salinity of irrigation water) with the salt tolerance calculation from average root zone salinity estimates or measurements results in overestimation of the quantity of water needed for leaching [49]. From these facts, it can be concluded, that in most of the salt-tolerant production systems, irrigation in excess of ET + LR has been practiced, and that has exerted pressure on the drainage system. It is, therefore, essential to consider the use of irrigation water salinity, water uptake by salt-tolerant crops (ET) and variable leaching requirement in determining crop water requirements, this can save precious water resources, decrease pressure on drainage system, and this way water requirements can be optimized and saved water can be used for other crops.

The other major concern in salt-tolerant production systems is the lack of baseline soil information (EC, ESP, nutrients, soil depth etc.). The seed germination requires good soil conditions, moisture at field capacity, highly saline soil will hinder seed germination, shallow depth may not be enough for long rooted crops and also develop water logging, high sodicity will affect plant nutrition and soils physical health, therefore, it is essential to establish baseline soil information and use holistic approach to deal such issues for better agriculture.

4 Conclusion and Recommendations

The paper presents six soil salinity zones in the NE. The saline soils are concentrated along the coastal sabkha and reduced inland. The coastal sabkha is special habitat where halophytes are adapted to these environments. The soils where water table is recognized, unique bio-geochemical processes of oxidation, reduction, and accumulation of salts, gypsum, and other minerals under very high climatic temperatures are observed. The extent of these soils is limited and is progressively decreasing as coastal areas are developed. The study revealed that the root zone salinity in many farms has been poorly managed. It also concludes that soil and water salinity are one of the key features that impact the use and management of land resources in the NE. Hence it is recommended to enhance the links between research-extension-farmers for better technology adoption leading to sustainable management of soils for crop production.

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