

Research Article

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Land use/land cover assessment as related to soil and irrigation water salinity over an oasis in arid environment

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Abstract: The land use and land cover (LULC) changes and the implications of soil and irrigation water salinity have adverse effects on crop production and the ecosystems of arid and semiarid regions. In this study, an attempt has been made to analyze and monitor the LULC changes using multitemporal Landsat data for years 1986, 1998, 2007, and 2016 in Al-Ahsa Oasis, Saudi Arabia. In addition, efforts were made to measure the spatial distribution of soil and irrigation water salinity along the oasis. The supervised maximum likelihood classification method was applied to classify the individual images independently. Moreover, soil samples were collected at surface soil depth from the selected LULC types, namely, date palm, croplands, and bare land. Also, groundwater samples were collected from bore wells located in agricultural farms. The spatial distribution of the soil salinity (EC_e) and irrigation water salinity (EC_{iw}) was classified based on the Food and Agriculture Organization guidelines. The results showed that significant changes in LULC patterns have occurred during 1986–2016 in the study area. The EC_e was found higher in date palm compared with cropland and bare land. However, the spatial distribution of the EC_{iw} over the oasis indicated that 94% of irrigation water ranged between moderate and severe salinity risk. The study concludes that salinity management practices need to be developed in the study area aiming to sustain crop yields, improve soil properties, and minimize the environmental impacts of LULC changes on the ecosystem of Al-Ahsa Oasis.

Keywords: land use and land cover (LULC) changes, soil salinity (EC_e), irrigation water salinity (EC_{iw}), Al-Ahsa oasis

1 Introduction

The study of land use and land cover (LULC) changes is essential for land management, environment, and strategy formulation regarding planning activities. Ecosystems are facing change results of human socioeconomic activities that occurred at local, regional, and global scales [1,2].

The LULC changes were assessed using remote sensing in many studies in Saudi Arabia [3–6]. Mallick et al. [2] analyzed the LULC transformation in the Abha region during 2000–2010. They found that the sparse vegetation and water bodies decreased from 48.5 to 39.3 km² and 0.3 to 0.1 km², respectively, whereas the built-up area increased from 17.0 to 36.4 km². Also, in the Al-Baha region, the LULC dynamics were mapped by Mahmoud and Alazba [7] in the period 1975–2010. Their classified maps showed four main classes: bare soil, sparsely vegetated, forest and shrubland, and irrigated cropland. They reported that bare soil increased during 1975–1995 and decline during 1995–2010 due to the construction of rainwater harvesting dams in the region. Also, significant changes were observed in irrigated cropland during the entire study period.

Salty soils and sand dunes dominated in most land covers of Saudi Arabia. Higher soil salinity is one of the main threats of crop production and represents a challenge for sustainable agriculture in Saudi Arabia [8]. Soil salinity was measured based on actual field samples in Al-AhsaOasis, Saudi Arabia, to investigate its extent and relationship with vegetation growth in the oasis [9]. He indicated that soil salinity is the driving force for vegetation health decline in the oasis. Also, in Al-AhsaOasis, high soil salinity was observed to be dominated in most parts of the oasis [10]. Moreover, soil salinity changes during 1985–2013 were studied by Allbed et al. [11] using remote sensing data.

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They found that higher soil salinity increased in the period 2000–2013 compared with 1985–2000, while the vegetation cover declined to 6.3% for the same period.

Groundwater is a vital source of water in arid regions for domestic and irrigation purposes [12,13]. In Saudi Arabia, the vast increase of agricultural lands during 1990–2009 has put pressure on groundwater use [14]. Hence, groundwater wells rapidly depleted due to the heavy abstraction of the reserved water [15]. Groundwater salinity was evaluated in several studies in Saudi Arabia using different methods and techniques. Along the Red Sea and Arabian Gulf coasts of Saudi Arabia, the salinity of the groundwater was determined at different depths in the pumping well and was found to be low in the top 4 m. It sharply increased to reach a ten times salinity value of the top layer indicating groundwater intermixing with the fresh water and saltwater intrusion. However, the change in the salinity during pumping was erratic, but within a range of 2% [16]. The salinity of irrigation water in Al-Ahsa Oasis was investigated by Aldakheel [9]. He pointed out that the high values of the water salinity were found in the southeastern and part of the southern tip of the oasis. In Al-Kharj groundwater, salinity ranged between 1.1 and 10.2 dS/m, and accordingly, most of the groundwater is unsuitable for drinking uses [17].

Like many regions in Saudi Arabia, Al-Ahsa Oasis has experienced rapid urban developments and LULC changes. These shifts in LULC will significantly affect the socio-economic activities of the oasis as a primary agricultural center in Saudi Arabia. The vast irrigated lands of Al-Ahsa Oasis are affected by salinization [9]. Therefore, to mitigate and control this problem, assessing and measuring of soil salinity are required to ensure sustainable agricultural production. Also, the quality of the pumped groundwater used for irrigation is decreasing as a result of depleting aquifers. Consequently, the salinity of the groundwater becomes hazardous even for a salt-tolerant crop like date palms. Accordingly, the objectives of this study are to quantify LULC change over the 30 years, 1986–2016, and analyze temporal and spatial trends in Al-Ahsa Oasis. Also, an attempt was made to measure the spatial distribution of soil and irrigation water salinity along the oasis.

2 Materials and methods

2.1 Study area

The study area is located in the eastern province of Saudi Arabia and lies between the latitude 25.30° N to 25.63° N

and longitude 49.52° E to 49.77° E. It covers an area of 22,000 hectares (ha) approximately (Figure 1), with an average altitude of 149 m above the sea level [18]. The study area consists of Al-Ahsa Oasis, which is one of the main agricultural centers in Saudi Arabia and dominated by date palm plantation [19]. The study area lies about 300 km from the capital Riyadh and 70 km west of the Arabian Gulf. The climate of the area is characterized by six hot, dry months in the summer and relatively six months cold and wet in winter. The air temperature may exceed 45°C during the summer, while it might reach 5°C in winter. The rainfall occurs mainly during the winter, with an annual average of 50 mm [20]. The pedogenesis and characteristics of soils in the Al-Ahsa region determined by the extremely hot, dry climate, which causes soil water evaporation, result in accumulation of the dissolved salts in upper soil layers and create a crust on the soil surface. Therefore, most of the cultivated lands in Al-Ahsa Oasis are covered with saline soils [9]. The dominated soils of the study area are sandy to sandy loam soil that covers some taxonomic classes such as Gypsiorthids, Haplaquepts, Calciorthids, Torripsamments, Salorthids, and Torriorthents [11]. The primary water source of the oasis is the Neogene groundwater aquifer, and this groundwater is used mainly for irrigation and domestic purposes [21].

2.2 Satellite data

Earth observation satellite data are acquired from the Landsat series covering the study area during the last three decades. The data are retrieved from the United States Geological Survey website (<https://earthexplorer.usgs.gov/>). The used imagery was for the years 1986, 1998, 2007, and 2016 (Table 1). The data files downloaded in Tagged Image File (TIF) format and all obtained images had less than 10% cloud cover. The satellite images were acquired in the same season to minimize the influence of seasonal variations on the results.

The Landsat files were imported from TIF into Raster format using import tool of the ERDAS IMAGINE 9.2 software. The same software was used to perform a simple haze correction to give the images more contrast. All images had the same projection system; therefore, an image-to-image registration was made using the most recent image of the year 2016. The recertified images resampled to a 30 × 30 m ground resolution.

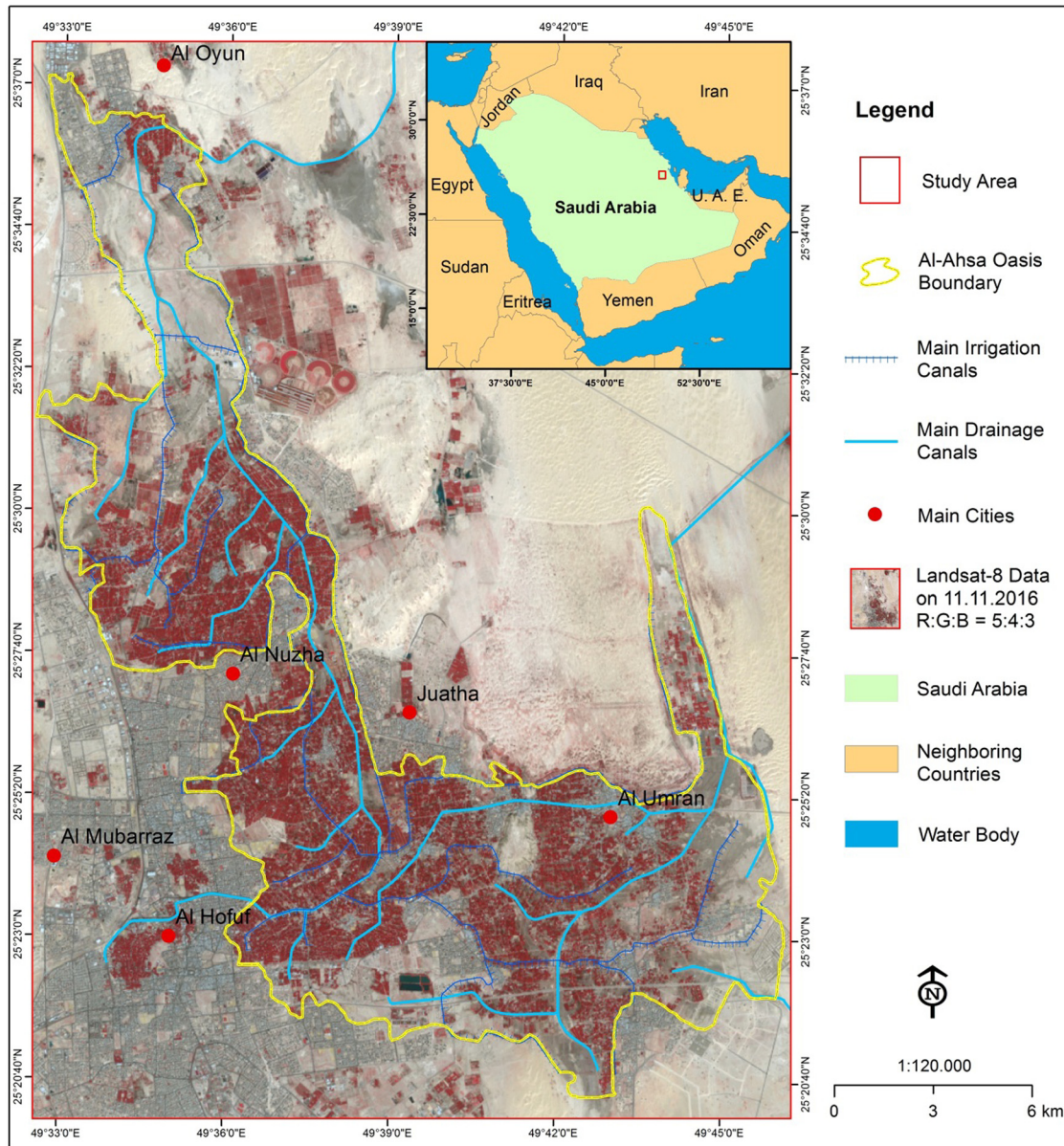


Figure 1: Location of the study area.

Due to an instrument malfunction onboard for Landsat-7 in May 2003, there were some gaps in images downloaded after this date. Thus, all images acquired after

May 2003 needed further processing for gap filling. Gap filling processing was done for the image of 2007 using the IDL 7.0 software (<https://glovis.usgs.gov/>). For that

Table 1: Characteristics of Landsat data used in the study

Satellite	Acquisition date	Spectral bands	Ground resolution (m)
Landsat-5 TM	09.11.1986	1–6	30
Landsat-5 TM	10.11.1998	1–6	30
Landsat-7 ETM+	11.11.2007	1–6	30
Landsat-8	11.11.2016	1–9	30

three additional images were needed: (1) the image to be filled in (anchor), (2) one image acquired before May 2003, and (3) one image acquired after the anchor. For the gap filling of the 2007 image, the following images were used: (1) Landsat-7 SLC-off acquired on 11 November 2007 (Table 1) as the anchor, (2) Landsat-7 SLC acquired on 31 December 2002 as the filling scenes 1, and (3) L7-SLC-off acquired on 13 December 2007 as the filling scene 2.

2.3 Image classification and accuracy assessment

A classification scheme was developed during a field survey conducted between October and November 2016 to define the LULC classes in the study area (Table 2). A total of 220 training areas were selected based on image interpretation keys during field investigations. A supervised maximum likelihood classification (MLC) method was employed to classify the individual images independently. Based on the study objectives, the supervised classification applied in this study does not imply a comparison between different classifiers. Therefore, the MLC was adopted to be the only classification method for this study. MLC has been widely used for image classification [6,22,23].

The accuracy assessment for the image of the year 2016 was made by using 82 points out of the total training points collected during the ground truth (i.e., field reference data). On-screen visual evaluation supported by historical information obtained from the local inhabitant was used to measure the accuracy assessment of the years 1986, 1998, and 2007. Google Earth images were also used as an additional validation method for historical images. Consequently, error matrices based on the stratified random sampling of reference field data were used to assess the classification accuracy [24]. Hence, the overall accuracy, user's and producer's

accuracies, and the Kappa coefficient were used to validate the LULC classification [25,26].

2.4 Soil and water sampling

A total of 60 and 63 random samples of soil and irrigation water were collected, respectively, from Al-Ahsa Oasis during December 2016.

Soil samples were collected from three different LULC types, namely, date palm, cropland, and bare land (Table 2). A composite soil sample was collected from 20 sites for each of the LULC types at a depth of 0–30 cm (Figure 2a). Soil salinity (EC_e) was determined in the laboratory by measuring the EC from the soil saturation extracts based on the study by Klute [27].

The groundwater samples were collected from bore wells located in agricultural farms within the oasis (Figure 2b). The irrigation water salinity (EC_{iw}) was measured *in situ* using a portable EC-meter (470 Jenway Manufacturer) [28].

The coordinates of the soil and water samples were recorded using a high accuracy differential GPS instrument (Trimble ProXR GPS). The Inverse Distance Weighted (IDW) tool of Geostatistical Analyst in the ArcGIS 10.2 software was used to perform data interpolation for EC_e and EC_{iw} . The IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. The measured values closest to the prediction location have more influence on the predicted value than those farther away. IDW assumes that each measured point has a local influence that diminishes with distance [29]. The method properties and weights assigned to EC_e data points are shown in Figure 3. The interpolation output of the EC_e was classified based on Food and Agriculture Organization (FAO) [30]. However, the spatial distribution of the EC_{iw} is classified according to the FAO guidelines for irrigation water quality [30].

Table 2: Description of LULU classes identified in the study area

Classes	Description
Date palm	All date palm areas with (60–100 trees/ha)
Cropland	Areas currently under crop or land being prepared for raising crops
Bare land	Nonvegetated areas such as bare rocks, desert, and special desert features
Urban land	Area with permanent concentration of man-made structures, people, and activities such as towns and industrial areas
Water	Ponds and water surfaces

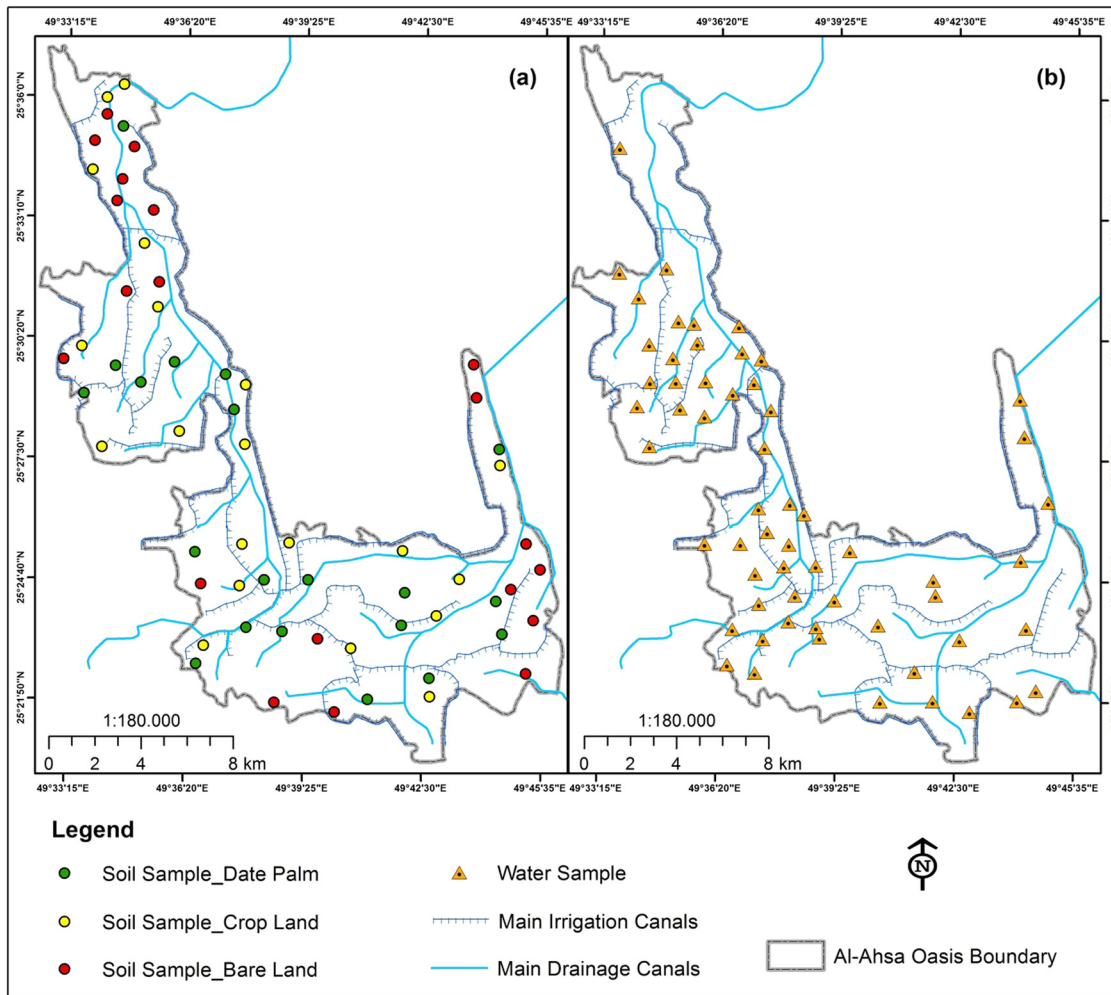


Figure 2: Location of sampling sites: (a) soil samples and (b) irrigation water samples.

2.5 Statistical analysis

The change in LULC throughout the study period was quantified using the descriptive statistics of the Microsoft Excel 2010 software [31]. The second-order polynomial regression was used to describe the trends of LULC changes over time. Using the Statistica (StatSoft) software package [32], the Whisker Plot Box of the factor analysis was used to measure the ECe for different LULC types.

3 Results and discussion

3.1 LULC mapping and accuracy assessment

Based on the produced LULC maps (Figure 4), it was found that date palm and bare land were the dominant

LULC types during 1986–2016. Computed percentages of LULC classes showed that in the year 1986, date palm, cropland, and bare land had occupied 56%, 10.5%, and 32.5% of the study area, respectively, whereas urban land occupied only 0.7% of the study area (Figure 5). However, the significant spatial expansion in bare land and the large decrease in date palm were observed in the LULC map of the year 1998. Consequently, the area of bare land increased to 53%, whereas the date palm and cropland area was reduced to 39.5% and 6.1%, respectively. A slight increase of 1.2% in the spatial extent of urban land was also observed. Spatial analysis of the year 2007 LULC map revealed that there is a slight increment of urban land, which occupied 1.5% of the study area, whereas cultivated area decreased to 5% and no change was observed for date palm and bare land. Nevertheless, a considerable amount of spatial expansion of the urban land and a slight decrease in the date palm were observed in the year 2016 LULC map. The area of urban land and

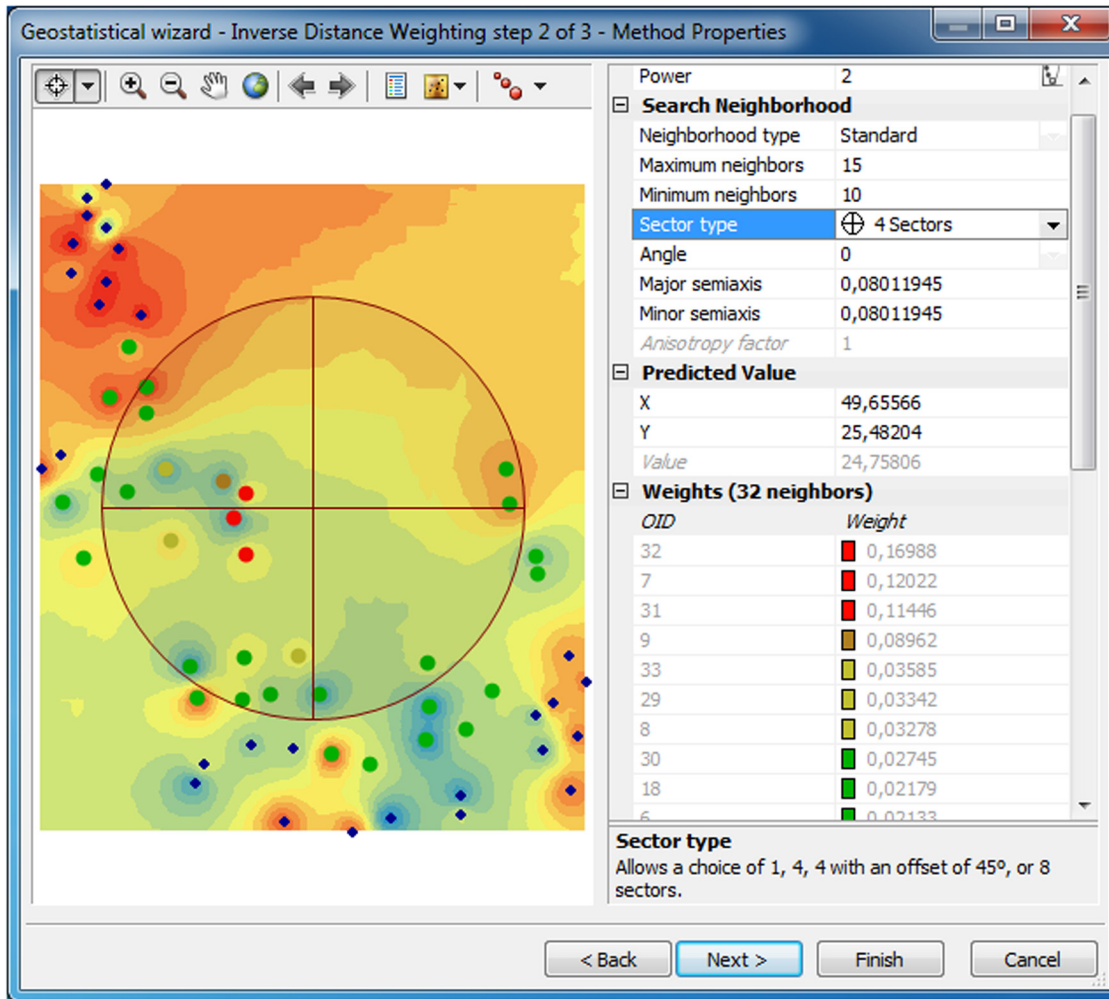


Figure 3: The weight window contains the list of weights assigned to each data point of the soil samples that are used to generate a predicted value at the location marked by the crosshair.

cropland increased to 4.1% and 6.4%, respectively, whereas the date palm decreased to 36.8%.

The general patterns of the LULC maps identified for the study area showed a variable rate of change among different LULC classes. The significant decrease in date palm areas indicated the expansion of the bare land due to desertification. Aldakheel and Al-Hussaini [33] reported that desertification widely documented as one of the major drivers of LULC changes in Al-Ahsa Oasis over the period 1987–1998. Also, in the eastern province of Saudi Arabia, the size of the dune fields was observed to be doubled in 15 months [34]. Although date palm trees are the most dominated vegetation cover in the study area, the rate of its change indicated more capability of declining during the coming years. Based on the FAOSTAT data [35], the date palm areas in Saudi Arabia were reduced from 1,56,901 ha in 2013 to 1,08,133 ha in 2017, with an annual decline rate of 14%. The profits of date palm production become low

due to urbanization and development in the study area. As a result, quite a number of date palm farms shifted to residential areas. Also, the cost of constructing and operating new wells at the date palm farms increased due to the high price of electricity and labor wigs.

The decline of the cropland shown during the first and second parts of the study period was mainly attributed to the aridity conditions and the high cost of agricultural inputs due to the increase of salinity in the soil [9]. However, the increase of cropland during the end of the study period is most likely due to the expansion of rice and vegetable farms in the southern part of the study area. These farms occurred as a result of urban agricultural activities, which are used for providing the local markets in the city centers with some products.

The expansion trend of the urban land was at the expense of date palm. Urban lands were increased significantly during the study period as a result of

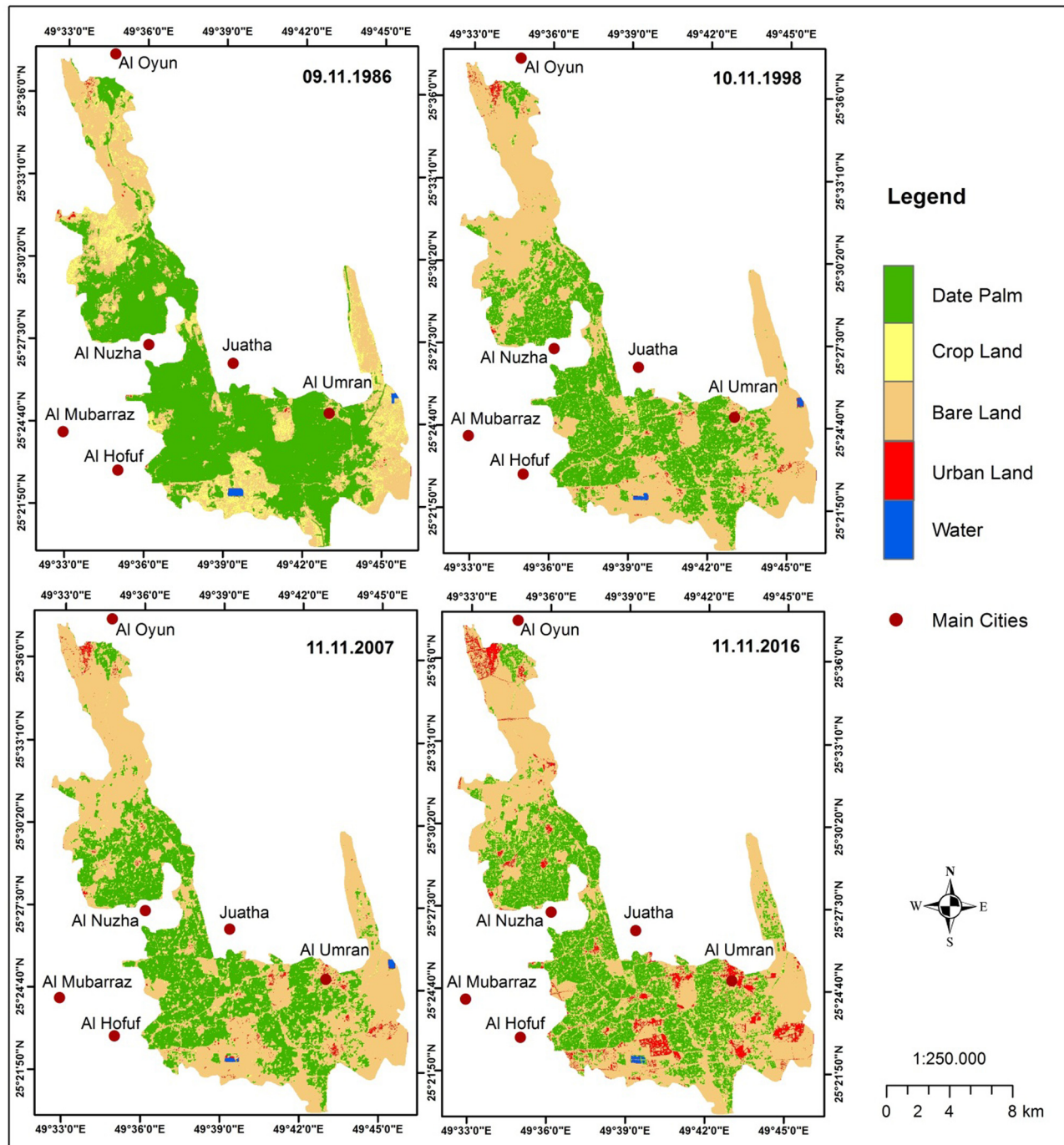


Figure 4: LULC maps of the study area during 1986–2016.

population increase and the extensive development of the study area. In Dammam city located in the same region of the study area, built-up lands found to be increased by 29% between 1990 and 2014 [36]. The rapid expansion of the urban lands was mainly due to the socioeconomic processes, which were closely associated with the agricultural activities in the study area. Urban agriculture can be broadly defined as the production, processing, and

distribution of foodstuffs from crop and animal production within and around urban areas [37].

During the first stage of the study period, bare lands showed a significant increase in taking parts of the date palm and cropland areas. However, during the second and last stages of the study period, bare lands keep no change due to the difficulty associated with the utilization of lands resulted from desertification.

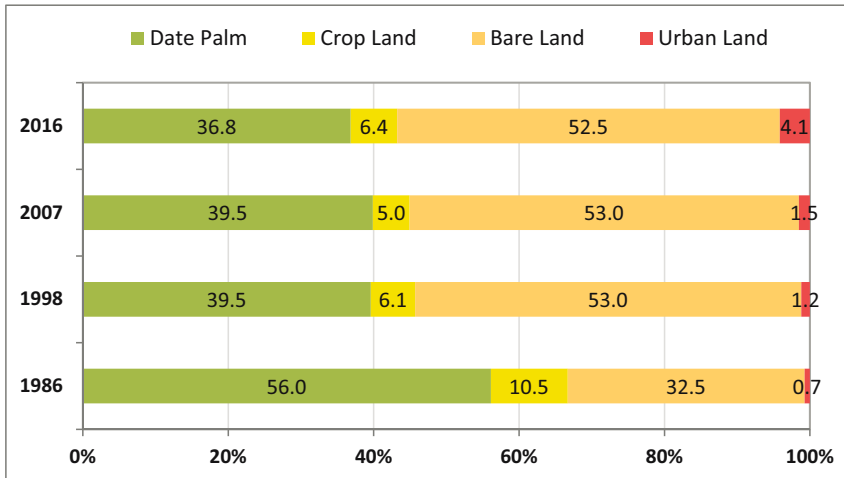


Figure 5: Changes in LULC areas (%) for the period 1986–2016.

The overall LULC classification accuracy levels for four dates of Landsat satellite images ranged from 84% to 91%, with Kappa indices of agreement ranging from 78% to 87% (Table 3), which is satisfactory for the study area based on the validation measures applied to the classified LULC maps.

The achieved classification accuracy is satisfactory for the study area considering the multitemporal analysis of Landsat data and the visual interpretation adapted to image classification.

Also, the data in Table 3 showed that the producer's and user's accuracies for crop and urban lands were lower compared with the other LULC types. This is mainly due to the misclassification of some cropland pixels that have been classified as date palm, while the urban land ones were classified as bare lands.

3.2 Soil salinity measurements

The spatial distribution of soil salinity along Al-Ahsa Oasis is shown in Figure 6. Based on the FAO soil salinity

classification, it can be seen that the EC_e values ranged from nonsaline (0–2 dS/m) to very strong saline (>16 dS/m). However, the strong saline (8–16 dS/m) is the most dominated class along the oasis. EC_e was higher in date palm with an average value of 18.97 dS/m compared to cropland and bare land that show mean values of 10.25 and 5.20 dS/m, respectively (Figure 7).

Soil salinity is likely to be higher in cultivated lands (i.e., date palm and croplands); this might be due to the accumulation of salts as a result of saline water flow from the water table and also due to using saline irrigation water. Over-irrigation in the cultivated areas can result in the rising of the water table and hence accumulation of salinization at the root zone. Therefore, salinization problems can be more severe when the salinity of groundwater is high, as is usually the case in arid regions [30]. High level of salinity might restrict the growth of some crops in the area. However, date palm considered as a salt tolerance crop [38], and this indicates its domination within the study area compared with the other field crops.

Table 3: Accuracy assessment (%) of LULC maps

LULC classes	1986		1998		2007		2016	
	Producer's	User's	Producer's	User's	Producer's	User's	Producer's	User's
Date Palm	81	82	88	86	85	87	92	88
Cropland	70	72	72	78	77	78	82	84
Bare Land	93	94	95	92	98	97	94	97
Urban Land	74	71	71	76	83	76	84	79
Water	86	75	83	88	88	100	100	100
Overall accuracy	84		86		89		91	
Kappa statistic	78		81		85		87	

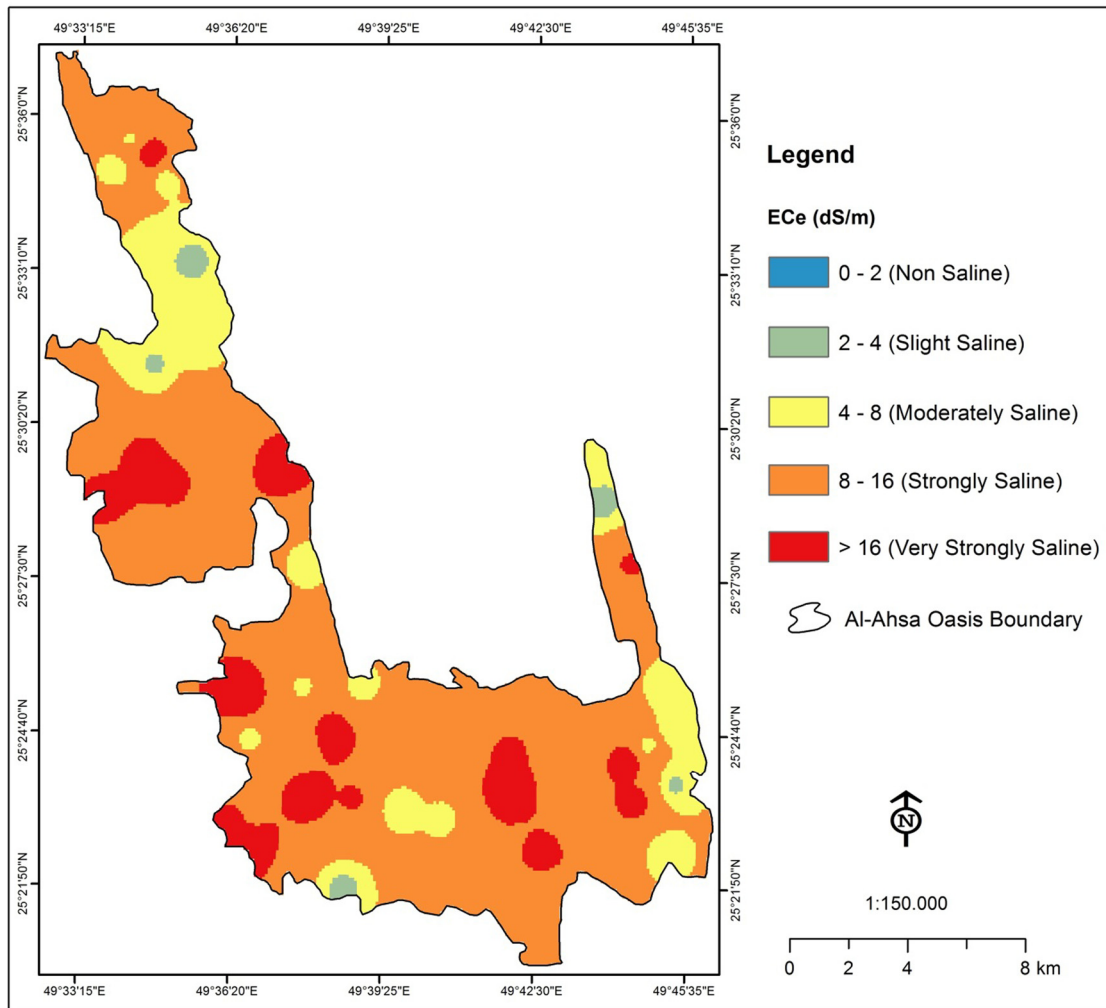


Figure 6: Spatial distribution of soil salinity (EC_e) over Al-Ahsa Oasis.

Moderate soil salinity level is found to be associated with the bare land since most of the bare lands are covered by sandy soils and sand dunes, which are in dynamics due to desertification. Nevertheless, some parts of the bare lands showed extreme salinity level and these types of lands covered by inland saline flat areas are known locally as “Sabkha”. Rain and the rising groundwater can flood the Sabkha lands during the winter season and then turns dry during the summertime, these lands are converted to salt soils that are covered with thin crust surfaces of salts [10].

3.3 Irrigation water salinity measurements

The classified range of water salinity across Al-Ahsa Oasis is displayed in Figure 8. The EC_{iw} have values of nonsaline (<0.7 dS/m), slight to moderate saline ($0.7-3.0$ dS/m), and

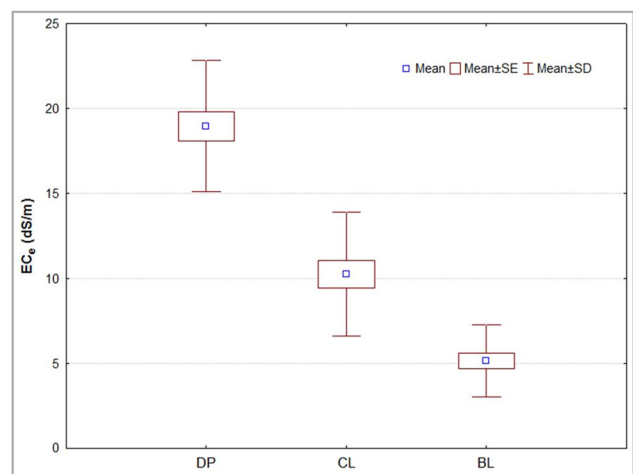


Figure 7: Soil salinity (EC_e) for the different LULC types in Al-Ahsa Oasis. DP = date palm; CL = crop land; BL = bare land.

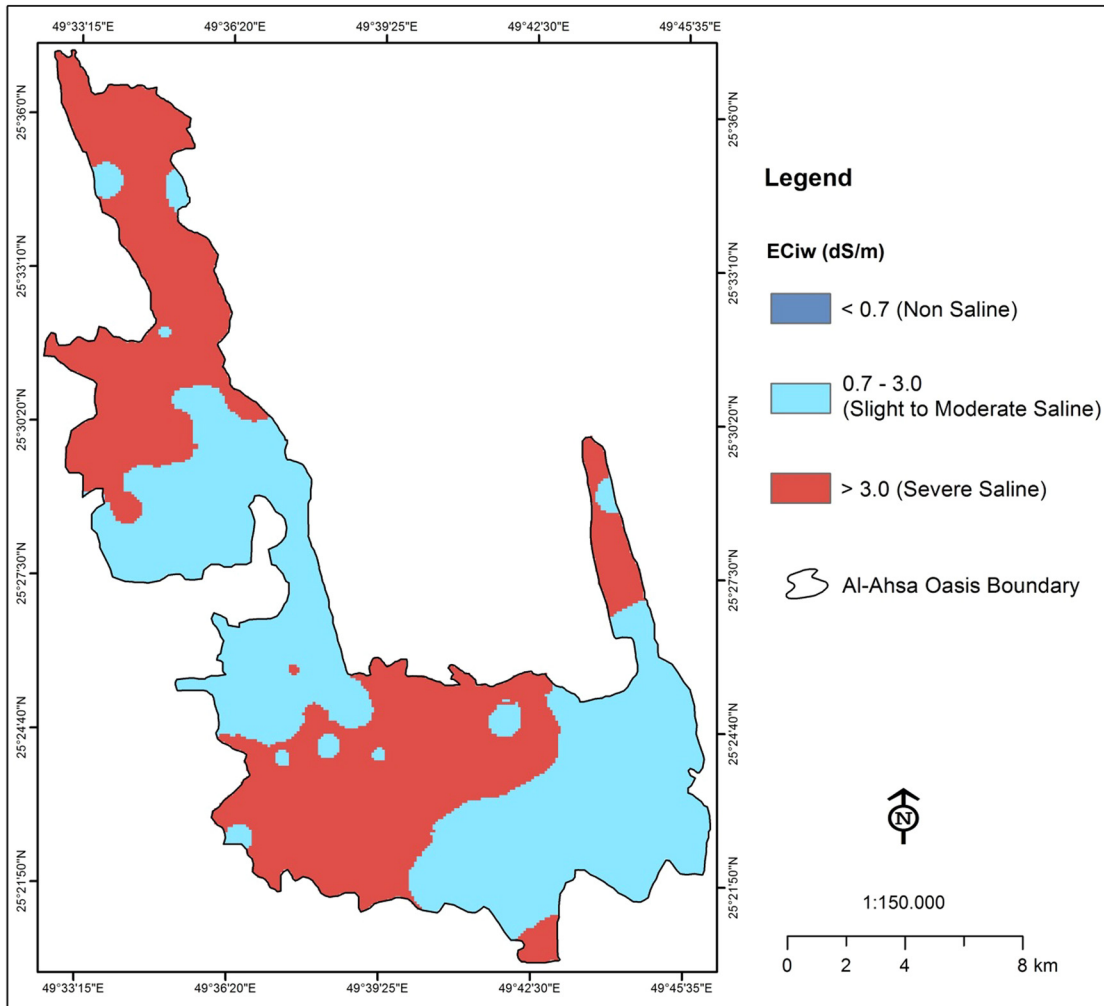


Figure 8: Spatial distribution of irrigation water salinity (EC_{iw}) over Al-Ahsa Oasis.

severe saline (>3.0 dS/m) according to the FAO guidelines for irrigation water. The spatial distribution of the EC_{iw} over the oasis indicated that 94% of irrigation water ranged between moderate and severe saline, while only 6% was under none to moderate saline conditions (Figure 9).

Ayers and Westcot [39] reported that the critical EC_{iw} level that causes severe salinity problems for most vegetable and field crops is 3 dS/m. Therefore, most of the date palm and cropland areas are facing a water salinity problem, which might lead to a decrease in the quality and quantity of agricultural productions [40]. However, some farmers use desalination plants to overcome the irrigation water salinity [41]; nevertheless, this process is of high cost and not sustainable for long-run crop production.

Moreover, Minhas [42] indicated that crop type, soil characteristics, irrigation methods, cultural practices, and climatic conditions should be studied when the saline groundwater is considered for irrigation purposes. The

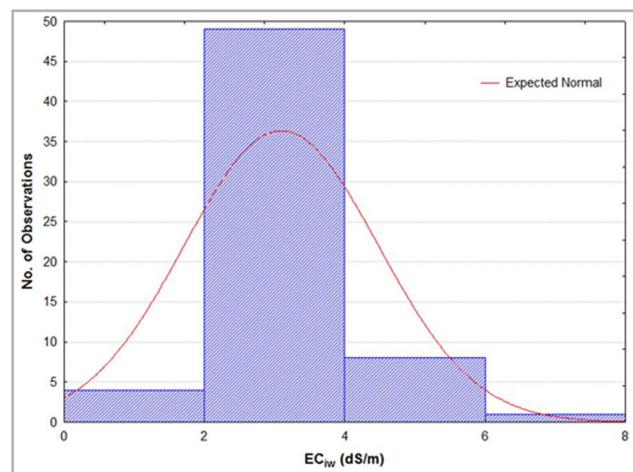


Figure 9: Irrigation water salinity (EC_{iw}) frequency across Al-Ahsa Oasis.

spatial variability in irrigation water salinity levels was observed in Al-Ahsa Oasis, which subjected the irrigation groundwater in the oasis to a process of quality degradation [43]. Along with different aquifers, in Saudi Arabia, the water salinity was found in range 1.56 and 8.24 dS/m, and accordingly, a leaching requirement of 15% to 20% above crop water requirements is suggested for safe use of this water [44]. However, Zaidi et al. [45] argued that the large variation in groundwater salinity (i.e., 1.2–3.4 dS/m) in the northwestern part of Saudi Arabia is probably due to the geochemical evolution of water in an evaporation-dominant environment.

4 Conclusions

The LULC change was investigated in this study based on Landsat data for the years 1986, 1998, 2007, and 2016. LULC change trends varied significantly during the above mentioned periods. The results indicated that a continuous decrease in date palm area with a significant increase of the cropland was observed in the period 1986–2016. Soil and irrigation water salinity are major issues of concern when related to LULC change under the arid ecosystem of the study area. The most dominated soil saline class Al-Ahsa Oasis was the strong saline (8–16 dS/m). However, soil salinity was found to be higher in date palm areas compared to crop and bare lands. Also, 94% of the groundwater in the oasis ranged between moderate and severe saline hazards.

Mapping and analysis of LULC dynamics in Al-Ahsa Oasis provide a basis for strategic planning, management, and conservation decision-making because changes in the LULC will have substantial social and environmental implications within the ecosystem of the study area. However, urbanization and rapid development of infrastructure might continue growth, which might induce human pressure on energy and water resources. Therefore, this study recommends that the local authority in the study area should develop a master plan that considers population growth and future development based on the current land-use system of Al-Ahsa Oasis. Also, strategies for conserving the date palm lands should be adopted and implemented by the local authority in the study area to ensure sustainable production of date palm as cultural heritage and a cash crop for the area.

The risk of soil and irrigation water salinity is increasing among the date palm and cropland areas, and hence, salinity management and amendment are essential to be adopted in the study area. Moreover,

improving the water use efficiency at the farm scale along with applying the suitable rate of salinity leaching will maintain crop production and minimize the salinity hazard within the crop root zone. However, leaching requirement for date palm and crops cultivated in Al-Ahsa Oasis needs to be evaluated. Consequentially, guidelines of salinity management practices need to be developed in the oasis aiming to sustain crop yields, improve soil physical properties, and minimize adverse environmental impacts on the different land-use systems.

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References

- [1] Giri CP. Remote sensing of land use and land Cover: Principles and applications. CRC Press; 2012.
- [2] Mallick J, Al-Wadi H, Rahman A, Ahmed M. Landscape dynamic characteristics using satellite data for a mountainous watershed of Abha, Kingdom of Saudi Arabia. *Environ Earth Sci.* 2014;72:4973–84.
- [3] Weiss E, Marsh SE, Pfirman ES. Application of NOAA-AVHRR NDVI time-series data to assess changes in Saudi Arabia's rangelands. *Int J Remote Sens.* 2001;22(6):1005–27. doi: 10.1080/014311601300074540.
- [4] Alahmadi M, Atkinson P, Martin D. Fine spatial resolution residential land-use data for small-area population mapping: a case study in Riyadh, Saudi Arabia. *Int J Remote Sens.* 2015;36(17):4315–31. doi: 10.1080/01431161.2015.1079666.
- [5] Alqurashi AF, Kumar L. Spatiotemporal patterns of urban change and associated environmental impacts in five Saudi Arabian cities: a case study using remote sensing data. *Habit Int.* 2016;58:75–88.
- [6] Abdallah S, Abd elmohemen M, Hemdan S, Ibrahim K. Assessment of land use/land cover changes induced by Jizan Dam, Saudi Arabia, and their effect on soil organic carbon. *Arabian J Geosci.* 2019;12:350.
- [7] Mahmoud SH, Alazba AA. Land cover change dynamics mapping and predictions using EO data and a GIS-cellular automata model: the case of Al-Baha region, Kingdom of Saudi Arabia. *Arabian J Geosci.* 2016;9:419.
- [8] Elhag M. Evaluation of different soil salinity mapping using remote sensing techniques in arid ecosystems, Saudi Arabia. *J Sens.* 2016;7596175. doi: 10.1155/2016/7596175.
- [9] Al-Dakheel YY. Assessing NDVI spatial pattern as related to irrigation and soil salinity management in Al-Ahsa Oasis, Saudi Arabia. *J Indian Soc Remote Sens.* 2011;39(2):171–80.
- [10] Allbed A, Kumar AL, Aldakheel YY. Assessing soil salinity using soil salinity and vegetation indices derived from IKONOS high-spatial resolution imageries: Applications in a date palm dominated region. *Geoderma.* 2014;230–231:1–8.

- [11] Allbed A, Kumar AL, Sinha P. Soil salinity and vegetation cover change detection from multi-temporal remotely sensed imagery in Al Hassa Oasis in Saudi Arabia. *Geocarto Int.* 2018;33(8):830–46. doi: 10.1080/10106049.2017.1303090.
- [12] Sener E, Davra A. Assessment of groundwater vulnerability based on a modified DRASTIC model, GIS and an analytic hierarchy process (AHP) method: the case of Egridir Lake basin (Isparta, Turkey). *Hydrogeol J.* 2013;21:701–14. doi: 10.1007/s10040-012-0947-y.
- [13] Uyan M, Cay T. Spatial analyses of groundwater level differences using geostatistical modeling. *Environ Ecol Stat.* 2013;20:633–46. doi: 10.1007/s10651-013-0238-3.
- [14] Chowdhury S, Al-Zahrani M. Characterizing water resources and trends of sector wise water consumptions in Saudi Arabia. *J King Saud Univ Eng Sci.* 2015;27:68–82. doi: 10.1016/j.jksues.2013.02.002.
- [15] Elhag M, Bahrawi JA. Soil salinity mapping and hydrological drought indices assessment in arid environments based on remote sensing techniques. *Geosci Instrum Method Data Syst.* 2017;6:149–58. doi: 10.5194/gi-6-149-2017.
- [16] Sabtana AA, Shehata WM. Hydrogeology of Al-Lith Sabkha, Saudi Arabia. *J Asian Earth Sci.* 2003;21:423–9.
- [17] Al-Omran AM, Aly AA, Al-Wabel MI, Al-Shayaa MS, Sallam AS, Nadeem ME. Geostatistical methods in evaluating spatial variability of groundwater quality in Al-Kharj Region, Saudi Arabia. *Appl Water Sci.* 2017;7:4013–23.
- [18] Al-Zarah Al. Elemental composition of groundwater and spring waters in Al-Ahsa Oasis, Eastern Region Saudi Arabia. *Trends Appl Sci Res.* 2011;6(1):1–18.
- [19] Al-Zarah Al. Chemistry of groundwater of Al-Alisa Oasis Eastern Region Saudi Arabia and its predictive effects on soil properties. *Pak J Biol Sci.* 2008;11(3):332–41.
- [20] Al-Taher AA. Estimation of potential evapotranspiration in Al-Ahsa Oasis, Saudi Arabia. *Geo J.* 1992;26(3):371–9.
- [21] Almadini AM, Al-Safarjalani AM, Al-Naeem AA. Spatial variations in chemical properties of irrigation groundwater at Al-Ahsa Oasis, Kingdom of Saudi Arabia. *Arab Gulf J Sci Res.* 2007;25(4):207–18.
- [22] Richards JA, Jia X. Remote sensing digital image analysis, an introduction. 4th ed. Berlin: Springer-Verlag; 2006.
- [23] Ellis EA, Baerenklau KA, Marcos-Martínez R, Chávez E. Land use/land cover change dynamics and drivers in a low-grade marginal coffee growing region of Veracruz, Mexico. *Agroforest Syst.* 2010;80:61–84.
- [24] Congalton RG, Green K. Assessing the accuracy of remotely sensed data, principles and practices. 2nd ed. Boca Raton, FL: CRC Press; 2009.
- [25] Jensen JR. Introductory digital image processing. 3rd ed. Upper Saddle River, NJ: Prentice Hall; 2005, ISBN: 0-13-145361-0.
- [26] Lillesand TM, Kiefer RW, Chipman JW. Remote sensing and Image Interpretation. New York, NY: John Wiley & Sons, Inc.; 2008. p. 213. ISBN: 978-0-470-05245-7.
- [27] Klute A. Water retention: laboratory methods. In: Klute A, editor. *Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods.* Madison: ASA and SSSA; 1986. pp. 635–62.
- [28] Aly AA, Al-Omran AM, Sallam AS, Al-Wabel MI, Al-Shayaa MS. Vegetation cover change detection and assessment in arid environment using multi-temporal remote sensing images and ecosystem management approach. *Solid Earth.* 2016;7:713–25. doi: 10.5194/se-7-713-2016.
- [29] ArcGIS Help Library, 2013, <http://desktop.arcgis.com/en/arcmap/latest/get-started/main/get-started-with-arcmap.htm>.
- [30] FAO. Salt-Affected Soils and their Management. Rome, Italy: FAO Soils Bulletin 39, Food and Agriculture Organization of the United Nations; 1988.
- [31] Baskauf SJ. Introduction to Biological Sciences Lab (BSCI 1510L) Excel Reference and Statistics Manual. Nashville, TN: Vanderbilt University; 2016, <http://researchguides.library.vanderbilt.edu/bsci1510L>.
- [32] Hill T, Lewicki P. STATISTICS: Methods and Applications. Tulsa, OK: StatSoft; 2007.
- [33] Aldakheel Y, Al-Hussaini A, The use of multi-temporal remote sensing imagery to detect land cover/use changes in Al-Hassa, Saudi Arabia. 2nd Conference on Lidar Remote Sensing for Industry and Environment Monitoring Location: San Diego, CA, Date: JUL 30-31, 2001. Proceeding of the Society of Photo-Optical Instrumentation Engineers (SPIE), 2002, Volume, 4484: 244-252, Article Number: UNSP 4484-49.
- [34] Barth H. Desertification in the Eastern Province of Saudi Arabia. *J Arid Environ.* 1999;43:399–410.
- [35] FAOSTAT data, 2019. <http://www.fao.org/faostat/en/#data>.
- [36] Rahman MT, Aldosary AS, Mortoja MdG. Modeling future land cover changes and their effects on the land surface temperatures in the Saudi Arabian Eastern Coastal City of Dammam. *Land.* 2017;6:36. doi: 10.3390/land6020036.
- [37] Drechsel P, Olufunke C, Niang S. Conserving land, protecting water. In: Bossio D, Geheb K. editor. *Sustainability and Resilience of the Urban Agricultural Phenomenon in Africa.* Part II, 8. CAB International; 2008, ISBN: 13-978-1-84593-387-6.
- [38] Yaish MW, Kumar PP. Salt tolerance research in date palm tree (*Phoenix dactylifera* L.), past, present, and future perspectives. *Front Plant Sci.* 2015;6:348. doi: 10.3389/fpls.2015.00348.
- [39] Ayers RS, Westcot DW. Water quality for agriculture. Paper 29FAO Irrigation and Drainage. Rome: FAO; 1976.
- [40] Sappa G, Ergul S, Ferranti F, Sweya LN, Luciani G. Effects of seasonal change and seawater intrusion on water quality for drinking and irrigation purposes, in coastal aquifers of Dar es Salaam, Tanzania. *J Afr Earth Sci.* 2015;105:64–84.
- [41] Al-Omran AM, Aly AA, Al-Wabel IM, Sallam AS, Al-Shayaa MS. Hydrochemical characterization of groundwater under agricultural land in arid environment: a case study of Al-Kharj, Saudi Arabia. *Arab J Geosci.* 2015;9:9–15.
- [42] Minhas PS. Saline water management for irrigation in India. *Agr Water Manage.* 1996;30:1–24.
- [43] Mohamed AA, Mohaldeen AA, Abdulatif AA. Spatial variations in chemical properties of irrigation groundwater at Al-Ahsa Oasis, Kingdom of Saudi Arabia. *Arab Gulf J Sci Res.* 2007;254:207–18.
- [44] Al-Jaloud AA, Hussain G. Water quality of different aquifers in Saudi Arabia and its predictive effects on soil properties. *Arid Soil Res Rehabil.* 1993;7(2):85–101. doi: 10.1080/15324989309381339.
- [45] Zaidi FK, Nazzal Y, Jafri MK, Naeem M, Ahmed I. Reverse ion exchange as a major process controlling the groundwater chemistry in an arid environment: a case study from north-western Saudi Arabia. *Environ Monit Assess.* 2015;187:607. doi: 10.1007/s10661-015-4828-4.