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Decadal National Land Cover Database for Jordan at 30 m resolution

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Abstract Availability of national land cover database plays a fundamental role in understanding environmental and socio-ecological issues under a constant state of changing climate and demography. However, systematic, compatible, and open access land use and land cover database at a high spatial resolution is not yet developed for Jordan. The overarching goal of this research is to build a decadal land cover database for Jordan at 30-m spatial resolution called the Jordan National Land Cover Database (JNLCD). This database encompasses four wall-to-wall land cover maps for the years 1980s, 1990s, 2000s, and 2015s. A total of 44 Landsat pathfinder satellite scenes were used to develop this database along with multiple ancillaries and field observation data sources. An unsupervised classification method along with accurate ancillary data was used to build a representative land use/cover timeline. The thematic accuracies of JNLCD were assessed using ground reference points at randomly stratified pixels. The overall mapping accuracies achieved were between 90 and 94%. The results show that nearly 5.3% of the pixels changed from one cover type to another at least once while 94% of the pixels did not change between dates. The most remarkable land cover changes were from rainfed agriculture to urban and from rainfed to open rangelands, indicating a progressive decrease in land productivity and high variation in rainfall distribution, most pursuant in the recent decades. In 35 years, Jordan's land surface had been transformed into a human-induced landscape and lost a vast area of its pristine landscape of ecological and sustainable significance. The JNLCD product will help in designing proper monitoring and management regimes at local to national levels. This offers a baseline for substantial advancement of landscape-based research for development in the country.

Keywords Jordan · Landsat · JNLCD · Decadal dynamics · Land degradation · Unsupervised classification · Confused clusters separability

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Introduction

Dryland ecosystems represent nearly 41% of the Earth's land surface, encompassing rangelands, agricultural lands, and major urban centers (Lambin and Ehrlich 1997; Diouf and Lambin 2001). Over 80% of the Mediterranean region falls under these ecosystems, 23% of which has experienced land degradation and desertification, particularly within the arable lands and grasslands (Abahussain et al. 2002; Ibanez et al. 2007; Haddad et al. 2011; Moridenejad et al. 2015). In Jordan, the arid environment dominates nearly 90% with only 1.6 and 5% of it accounting for grasslands and arable land, respectively (FAO 2005; Karadsheh et al. 2012). Such limited natural resource base provides life support to major farming and pastoralist communities in the country. The increasing demand for food and forage resources along with climate change and poor land management regulations have all resulted in a more vulnerable and degrading dryland ecosystems in Jordan (Karadsheh et al. 2012; Jawarneh 2008).

Understanding land use/cover dynamics represents a valuable key when assessing and managing land resources as it provides information on the physiographical characteristics of the surface environment and so as indicators on the status of ecosystem services and natural resource base (Coppin et al. 2004). The recent advances in earth observation systems and improved mapping capacity have encouraged adopting practical frameworks to tackle human-environment interactions at both national and sub-national levels (Vogelmann et al. 1998; Cihlar 2000; Coppin et al., 2004). In addition, the reduction in data cost, increased open accessibility, spatial coverage, enhanced spatio-temporal resolutions, and improved computational processing all have created enormous opportunities to utilize remote sensing-derived information in understanding the biophysical characteristics of agro-ecosystems and landscape dynamics (DeFries et al. 2004; Biradar and Xiao 2011; Gilani et al. 2015).

Among a large number of satellite missions and sensors, the Landsat pathfinder multispectral sensor stands as one of the best sources of satellite imagery due to its continuity, medium-resolution, large swath, and freely available datasets (Dube and Mutanga 2015). Regardless of its coarse spectral resolution and noise, the launch of the Landsat Multispectral Scanner System (MSS) in 1972 provided the first opportunity for researchers to utilize remote sensing data at regional scales. Later, the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) acquired at higher spatial resolution, at their times, introduced greater precision, thematic-demand investigations (Rogan and Chen 2004).The newly launched Landsat 8 operational land imager (OLI) continued the legacy of land imaging with further refined spectral bands, radiometry, and processing chain that are critical for improved application potential (Dube and Mutanga 2015; Loveland and Irons 2016).

Although Landsat datasets have been widely used in many land remote sensing applications, such as vegetation monitoring (Yan and de Beurs 2016), surface conditions (Boegh et al. 2002), water resources, and other key landscape features (Viedma et al. 1997; Kerr and Ostrovsky 2003), land cover mapping is considered the milestone application of Landsat pathfinder (Hansen and Loveland 2012; Thenkabail et al. 2009).

Many initiatives worldwide used Landsat data to produce semi-detailed national land cover databases for sustainable land resource management. The best example is the US National Land Cover Database (NLCD) which consists of decadal land cover maps for the conterminous USA for the years 1992, 2001, 2006, and 2011(Vogelmann et al. 2001; Homer et al. 2007; Fry et al. 2011; Homer et al. 2015). Similarly, the Netherlands produced a national land cover database (LNG) that was updated three times (LNG1, 2, and 3) (Thunnissen and de Wit 2000). In Bhutan (South Asia), Gilani et al. (2015) produced the first decadal national land cover database.

In Jordan, the first land cover mapping effort was undertaken by the Royal Jordanian Geographic Center (RJGC) in 1980 and was based on aerial photos and ground surveys. Between 1989 and1995, the National Soil Map and Land Use Project (NSMLUP) was jointly carried out by the Ministry of Agriculture (MoA), RJGC, and Hunting Technical Serviced (UK) to only map areas located within rainfall zones of 200 mm and above. The primary objective of the project, however, was to map soil across the country and the final land use/cover maps and soils are not readily available to the public (MoA 1995).

Thereafter in 2006, the RJGC built the first nationwide land use/cover map based on supervised classification where the initial training samples were obtained from visual interpretations at a scale of 1:250,000 (Ababsa 2013). The map delineated 18 land cover types to mimic the European Environmental Agency (EEA) CORINE land cover classification system (EEA 1995). In 2013, Al-Bakri et al. (2013a, b) built a 2010 land use/cover map from ASTER and Landsat TM images and which was based on supervised classification and manual digitizing techniques (i.e., urban and agricultural covers were manually digitized and inserted into the final map). The two aforementioned land use/cover mapping efforts lack consistency in terms of classification legend, methodology, inputs, scales, and temporal domains.

In this research, efforts to develop a freely available consistent long-term land use/cover database for Jordan was carried out, hereafter referred to as Jordan National Land Cover Database (JNLCD). Multiple-time series Landsat imageries from the 1980s to the 2015s at 30-m spatial resolution in combination with multiple spatial ancillary database and field observations were used. The JNLCD database represents the first of its kind database at the national level with constant and continuous seamless decadal land use/cover maps circa the 1980s, 1990s, 2000s, and 2015s. A web-GIS system (http://geoagro.icarda.org/jnlcd/) was designed to publish the readily available JNLCD thematic maps.

Methods and data

Study area

Jordan is located in the northwest part of the Arabian Peninsula with an area of about 89,000 km^2 representing less than 1% of the Middle East's area (Anderson 2000). It is bordered by Syria to the North, by Iraq and Saudi Arabia to the East and Southeast, and by Palestine to the West. Jordan's relief varies from east to west resulting in a distinct east-west environmental gradient and unique physiographic zones (Fig. 1). The Jordan Valley in the West forms a narrow flat strip that runs linearly to the Lake Dead Sea (the lowest point on Earth with elevation 420 m below sea level). Most of this zone is developed for intensive irrigated agricultural land uses due to its suitable year-round climate, fertile soils, and availability of water resources.

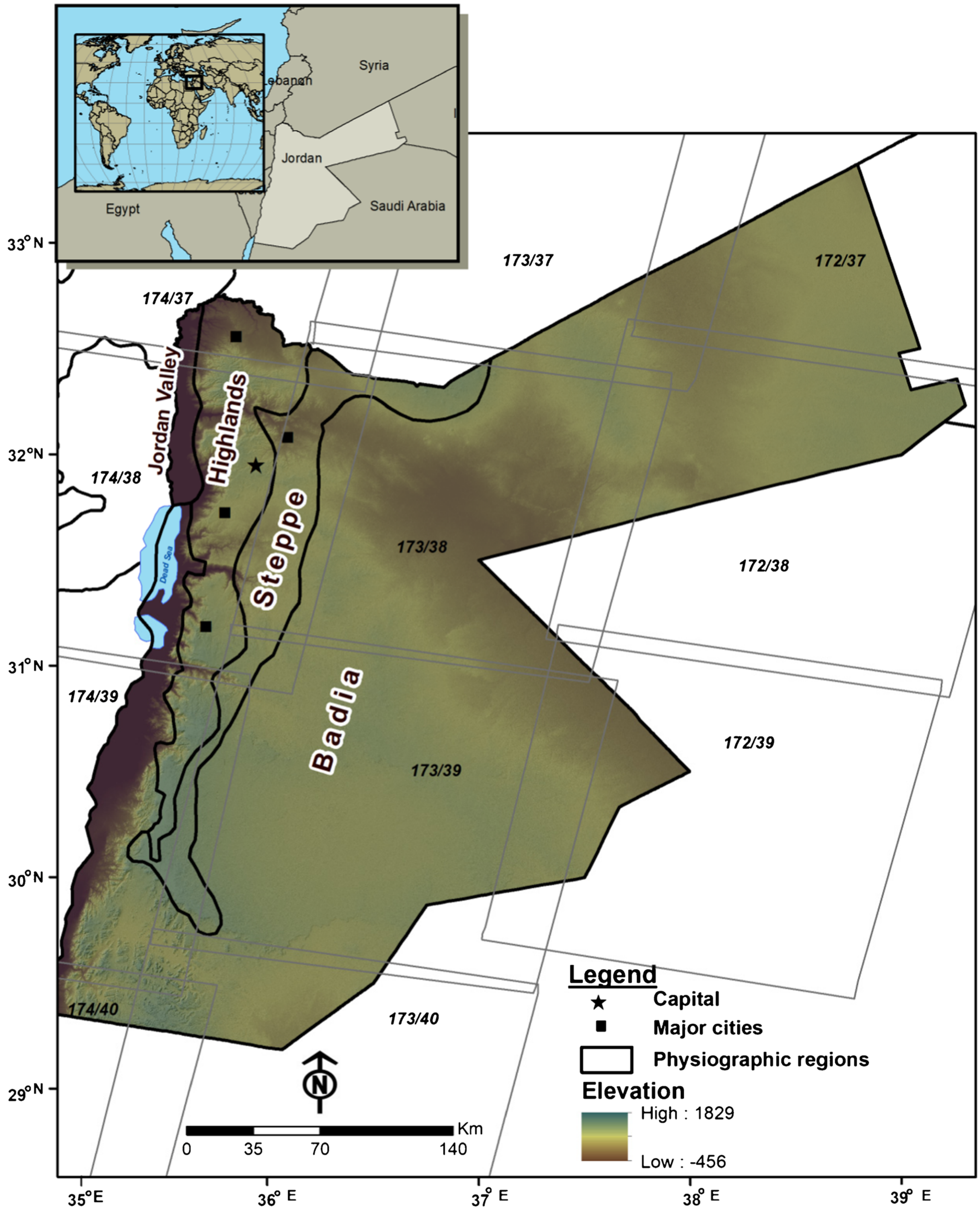

Fig. 1 Location of the study area, Jordan, with base map of ASTER 30-m digital elevation map overlaid with four major physiographic ecoregions and Landsat Path/Row tile reference map of the Jordan

The highlands zone to the east is composed of irregular ridges broken by a number of cultivated plains, small fragmented forested areas, and vast tracts of degraded grasslands (MacDonald 2000; Al-Bilbisi 2013). The semi-arid Mediterranean climate in the north and northwest is characterized by dry summers (average temperature 35 °C) and mild to cold winters (minimum temperature of 5 °C) with moderate rainfall (annual average above 400 mm) (Bender 1974; MacDonald 2000). In this zone, large urban centers and rainfed croplands are found (Finlay 1993; Al-Bakri et al. 2013a).The semi-arid plain region lays to the east with hot summers (average maximum 40 °C), and mild to warm winters. The infertile soil and low precipitation promote mixed agricultural use with barley cultivation and grazing activities.

The *Badia* region, which is composed of arid and semi-arid plains receiving less than 200 mm annual rainfall, is characterized by hot to extremely hot summers (average temperature 45 °C) and dry winters with less than 50 mm annual rainfall (Harris 1958; Al-Bakri et al. 2001). The region is sparsely vegetated and contains a few major ground water reservoirs.

Not only did this physiographic gradient affect the distribution of land resources but also the population distribution in Jordan was significantly impacted. It was estimated that nearly one third of Jordan's population lives in cities (Amman, Zarqa, and Irbid) located within the highlands region. Population growth in Jordan is highly impacted by the waves of refugees from the neighboring countries, mainly because of political instability and conflicts (Müller et al. 2016). Between 1948 and 1967, as hundreds of thousands of Palestinians fled their homes to Jordan and with the outbreak of the Gulf War II in 1990, nearly 300,000 of Palestinians fled the Gulf countries to Jordan (Troquer and Al-Oudah 1999). The ongoing Arab Spring, especially in Syria, has caused more than half million of Syrians to leave the country to Jordan (Müller et al. 2016). Over the past 10 years, Jordan's population nearly doubled from 5.29 million in 2004 to 9.53 million in 2015 (World Bank 2017).

Materials and methods

Satellite remote sensing data

The open-source, multi-temporal satellite imageries for the nominal periods of the 1980s, 1990s, 2000s, and 2015s from the Landsat pathfinder TM and OLI were used. Eleven tiles were downloaded from the Landsat data portal (https://landsat.usgs.gov/) to fully cover the country (Fig. 1) with a total of 44 scenes over the study period. These scenes were mostly cloud-free and were obtained during the peak of vegetation growing periods (Table 1). For the year path/rows of 174/39 and 174/40 in the 1990s, no scenes were available during the vegetation growing period. Scenes obtained during the summer of 1990 cover barren areas with no significant vegetation cover. The Landsat scenes were geo-registered to the Jordan Transverse Mercator projection with a root mean square error of less than one pixel and radiometrically (surface reflectance) corrected using the methodology described in Masek et al. (2006).

Ancillary and derived spatial data

In addition to Landsat bands, a variety of ancillary datasets from various resources were used to help develop the JNLCD. These datasets included (1) 2015 ASTER Global Digital Elevation Model (GDEM, version2) and derivative GDEM product (slope); (2) potential land use map, which was developed from the combination of soil types, rainfall, and biogeography attributes of Jordan to present the potential land use across Jordan (Taimeh 1990); (3) rainfall map; and (4) derived NDVI values from the Landsat images using the NDVI function in *Image Analysis* tool in ArcGIS 10.3 (ESRI 2016). Other datasets were used for validation and cluster labeling purposes and included fine-scale (1:50,000) topographic maps produced in the 1980s in high-resolution GeoTIFF format (The Digital Archaeological Atlas of the Holy Land 2016), and ground visits along with Google Earth® high-resolution satellite images to validate the 2015 land use/cover map.

Field observations

In 2014/2015, data on major crop categories were collected during several field visits throughout Jordan. The pure random scheme that was initially foreseen had to be adjusted due to limited field access caused by accessibility, road conditions, and limited availability of resources. Other reference samples were also extracted from existing georeferenced field photo libraries at the University of Oklahoma Earth Observation and Modeling Facility (http://www.eomf.ou.edu/photos/) and at the ICARDA's Geoinformatics Solutions for Integrated Agro-ecosystems library http://geoagro.icarda.org/en/default/visualization/gt). Additionally, intensive information on vegetated land cover types was collected in the northwestern region of the country, which exhibits the most complex pattern and dynamic land cover types in Jordan, during late April and early May of 2014. These observations were geotagged and available online at http://geoagro.icarda.org/en/default/visualization/gmap/kml/3 (Table 2).

JNLCD classification scheme

The JNLCD classification system (Table 3) provides a consistent, compatible, and harmonized legend to defining major land use/cover classes across Jordan. The system is a revised Anderson Level I that was modified by aggregating the existing general legends used in prior national land cover maps including the RJGC system and Al-Bakri et al. (2013a, b) (Anderson et al. 1976). This system has a semi-detailed legend suitable for the mapping framework developed in this research to produce the JNLCD products that are fully derived based on spectral information and ancillary data. The detailed classification legends of the RJGC and Al-Bakri et al.'s maps were supported by a manual digitizing technique which is time- and effort-intensive to adopt when building multi-temporal LC maps as in the case of JNLCD products. The intent of this integrated classification system is to prepare a national legend to resemble major land use/cover types in Jordan and facilitate future cross-regional studies in the

Table 1 Landsat Thematic Mapper and Operational Land Imager Datasets used to develop Jordan National Land Cover Database. Source: www.earthexplorer.usgs.gov

Path/row	Landsat sensor	Acquisition date	Cloud coverage (%)
172/37	TM5 and OLI	June 1984; March 1991; April 1998; April 2014	0.0; 0.0; 0.0; 0.0
172/38	TM5 and OLI	April 1984; February 1991; March 1998; April 2014	0.0; 0.0; 0.0; 0.0
172/39	TM5 and OLI	June 1984; March, 1991; April 1998; April 2014	0.0; 0.0; 0.0; 0.1
173/37	TM5 and OLI	April 1984, February 1991; March 1998; April 2014	10; 10; 20; 0.0
173/38	TM5 and OLI	August 1984; March 1991; May 1998; April 2014	0.0; 0.0; 0.0; 0.0
173/39	TM5 and OLI	April 1989; February 1991; March 1998; April 2014	0.0; 0.0; 0.0; 0.0
173/40	TM5 and OLI	April 1984; February 1991; March 1998; April 2014	0.0; 0.0; 0.0; 0.0
174/37	TM5 and OLI	April 1984; March 1991; April 1998; April 2014	60[a]; 10; 0.0; 0.8
174/38	TM5 and OLI	April 1984; March 1991; April 1998; April 2014	40[a]; 30[a]; 0.0; 0.2
174/39	TM5 and OLI	April 1984; February 1991; April 1998; April 2014	10; 0.0; 0.0; 0.0
174/40	TM5 and OLI	April 1984; February 1991; April 1998; April 2014	10; 0.0; 0.0; 0.0

[a] The high cloud coverage was over the Mediterranean Sea, Lebanon, and Palestine parts of the scenes

Mediterranean region by enabling comparison among different global sources of land cover information.

JNLCD classification methods

The primary step in building the JNLCD was to cluster spectrally similar classes using an unsupervised classification algorithm because of its capability to iterate more clusters to produce better results than a supervised classification in dry heterogeneous areas (Al-Tamimi and Al-Bakri 2005). A total of 1650 spectral clusters (150 clusters per Landsat scene/partial scene) for each period were initially classified and labeled to one of the nine LC classes in the classification system. However, and due to multi-scene mosaics, the separability of numerous clusters was relatively low, especially for the spatially disconnected ones. To resolve this, a set of rules based on spectral and ancillary data was defined (Fig. 2). Although defining and implementing the appropriate thresholds for complex confused clusters is a challenging task, spectral responses of selected bands (B 1, B, 5, and B 7) and derived NDVI were the most helpful data in assigning the appropriate LC class. The final JNLCD maps were visually checked and edited for modification. A post-classification comparison to correct misclassified errors and edge-matching of the adjacent mosaics were performed for a seamless dataset.

Accuracy assessment

Thematic accuracy assessment was performed by analyzing 1300 random pixels on the 1980s and 2015s maps. A pixel base was adopted as the spatial unit of our accuracy assessment following the protocols employed in the accuracy assessment of NLCDs (Wickham et al. 2013). A stratified random method was chosen to ensure representative sample sizes in each land cover class (Stehman and Czaplewski 1998).

The validation of the 1980s land cover map was based on visual interpretation of the 1980s fine-scale topographic maps of Jordan while the 2015s land cover map was validated mainly by visual interpretation of high-resolution Google Earth® satellite images and ground data collected in 2014/2015.

Table 2 Ancillary and derived datasets used in vegetation delineation

Name	Description
ASTER GDEM V2	Stereo-pair images collected by the Advanced Spaceborne Thermal Emission and Reflection Radiometer with 30-m resolution and 1 × 1° tiles. Retrieved from: http://earthexplorer.usgs.gov/
Slope	Derived from ASTER DEM with pixel value in degree.
Jordan potential land use map	Ecoregionally based land use map that was produced based on soil types, rainfall, and biogeography of Jordan. Retrieved from: http://books.openedition.org/ifpo/5074?lang=en
Rainfall distribution map	Rainfall lines of mean annual precipitation map that shows precipitation patterns across Jordan under current climatic conditions and based on historical data from 1970 to 2000. Retrieved from: http://geoagro.icarda.org/eatlas/
NDVI	Derived vegetation index using Landsat NIR and Red Bands.

Table 3 Land use/cover classes used for the JNLCD maps. Classification was based on modified Anderson Level I. Inclusive land cover classes from previous national land cover maps are noted

JNLCD land cover	Definition	Inclusive land cover classes	
		RJGC	Al-Bakri et al.'s*
Urban	High-, medium-, low-intensity developed areas with a mixture of constructed materials and vegetation. Generally, impervious surfaces account for 20 to 100% of the total cover.	Urban fabric	Urban area
Sparsely vegetated/-barren	Open rangelands, non-cultivated areas, dwarf shrubs, bare soils, sands, quarries, mud flat, and wadi deposits. Generally, areas with vegetation accounts for less than 10% of total cover.	Pastures, bare soil, sands, dry mudflat, wet mudflat (except Al-Azraq wetland), quarries, wadi deposits.	Bare soil (rangelands/non-cultivated areas), quarries, mudflat (Qa'a), Wadi.
Exposed rocks	Areas of bedrock, desert pavement, volcanic material and chert plains.	Bare rocks, chert plains, basaltic rocks, granitic rocks	Bare rock, chert plain, basalt plain
Rainfed cereals	Rainfed areas cultivated with field crops (wheat and barley), fallow lands.	Field crops	Rainfed cereal
Rainfed woody crops	Rainfed trees (mainly olive trees and fruit trees).	Tree crops	Rainfed trees
Irrigated agriculture	Vegetables crops, orchards grown under permanent irrigation infrastructure and greenhouses.	Vegetables.	Irrigated area
Forest	Evergreen oak, coniferous, and mixed forest, sparse woodland and dense shrubs, and forest plantations.	Open forest, closed forest	Forest
Wetlands	Wet mudflat areas with herbaceous vegetation and the soil periodically saturated with water.	Wet mudflat in Al-Azraq	Wet mudflat in Al-Azraq
Dams	Dams, reservoirs, and ponds generally with less than 25% cover of vegetation or soil.	Dams	Water body

Thematic accuracies for the 1990s and 2000s products were not measured due to the absence of high-resolution reference data for some regions in the 2000s and the high cost of available wall-to-wall aerial photography in the 1990s.

Results and discussion

JNLCD products and decadal land cover changes

The JNLCD classification product (Fig. 3) represents the first consistent multi-temporal land use/cover data set for Jordan. The product provides a continuous overview of major land use/cover information and transitions at the national level. Analysis of land use/cover changes over the past 35 years reflected the spatial distribution of land resources as dictated by rainfall and soil resources. Table 4 denotes the relative estimates of major JNLCD land use/cover classes showing that open rangelands (sparsely vegetated/barren, exposed crops) made up about 95% of the surface area of Jordan and urban accounted for less than 1.5% of the surface area for all periods. Mixed rainfed areas (cereals and woody crops) made up about 5% of the surface area during the first two decades. Following the 2000s, rainfed agriculture declined to less than 3% while irrigated agriculture continued to slightly increase to make up 1.2% of the surface area in 2015s. Dam areas did not change much, likely because major reservoirs in Jordan were constructed in the 1960s and 1970s. Wetland areas declined

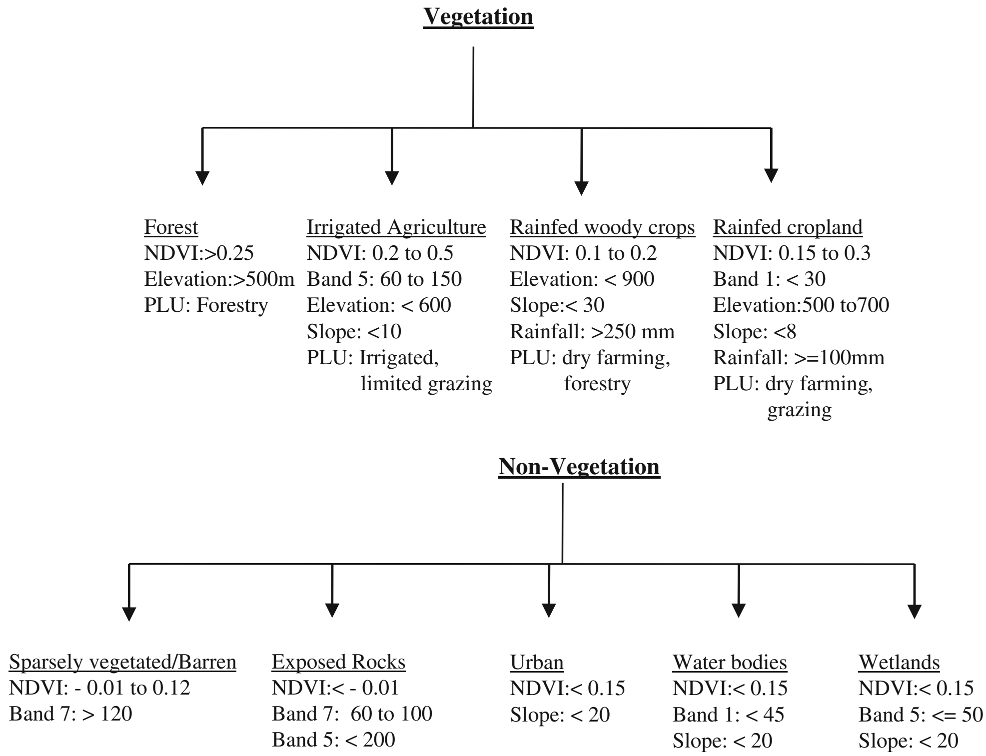

Fig. 2 Rules and their thresholds for confused clusters separability derived from appropriate spectral and ancillary data

dramatically as a result of the expansion of irrigated areas around the Azraq area. Forested land slightly declined, mainly due to conversion to either open rangelands or rainfed woody crops as was also noted by Khresat et al. (2008).

To evaluate the performance of the JNLCD maps, estimates of JNLCD classes were compared with the governmental agricultural census by the Department of Statistics (DOS) and with the 2010 land cover map by Al-Bakri et al. (2013a, b). It was noted that the JNLCD irrigated areas highly agreed with the census estimates. Nonetheless, the JNLCD mixed rainfed areas showed an overestimation compared to the DOS records (Table 4). This overestimation of remotely sensed rainfed agriculture areas, especially woody crops, was also reported by AlRababah and AlHamad (2006). This disagreement is not necessarily attributed to deficiencies in mapping techniques taking into account the advancement in classification methods and incorporating accurate ancillary data. It may have resulted from inaccurate governmental estimates that are based on fact-to-face interviews with farms' owners or employees rather than ground measurements.

The 2015 JNLCD map estimates were compared with the 2010 land cover map built by Al-Bakri et al. (2013a, b). Regardless of the 5-year differences between the two maps, consistent and close estimates were noted for all classes, except for a slight difference in estimating urban areas (Table 4). While the 2010 estimated urban areas were 1.7%, the 2015 estimated urban areas were 1.3%. This difference is attributed to variation in mapping techniques in both maps. While all JNLCD classes were automatically derived, urban and agricultural areas in the 2010 map were manually digitized. This could result in an overestimation of those built-up areas located at the periphery.

Analysis of long-term land change transitions revealed two remarkable changes: urban growth and recession of rainfed agriculture. Urban expansion was evident around the Amman-Zarqa area, where more than three million people are living. The JNLCD timeline on this site showed a rapidly growing urban agglomeration area of Amman-Zarqa (Fig. 4). Statistics showed that urban areas accounted for 6.2% of the land area of the site in 1980. The area nearly doubled in the 1990s and reached nearly 36% of the study site in 2015.

This dramatic increase in urbanization on the site has begun after the outbreak of the Gulf War in 1991(Troquer and Al-Oudah 1999). At that time, the population of Jordan grew from 3.2 million in 1990 to four million in 1992 (Van Hear 1995). With the outbreak of the 2003 Iraqi War, nearly two million refugees were displaced, more than half a million of whom fled to Jordan (Harper 2008) and settled in Amman. Since then, mixed rainfed areas around the Amman-Zarqa metropolitan area were lost to urbanization and in some cases for open rangelands.

The results of "from-to" change detection analysis between the 1980 and 2015 JNLCD land use/cover maps to further

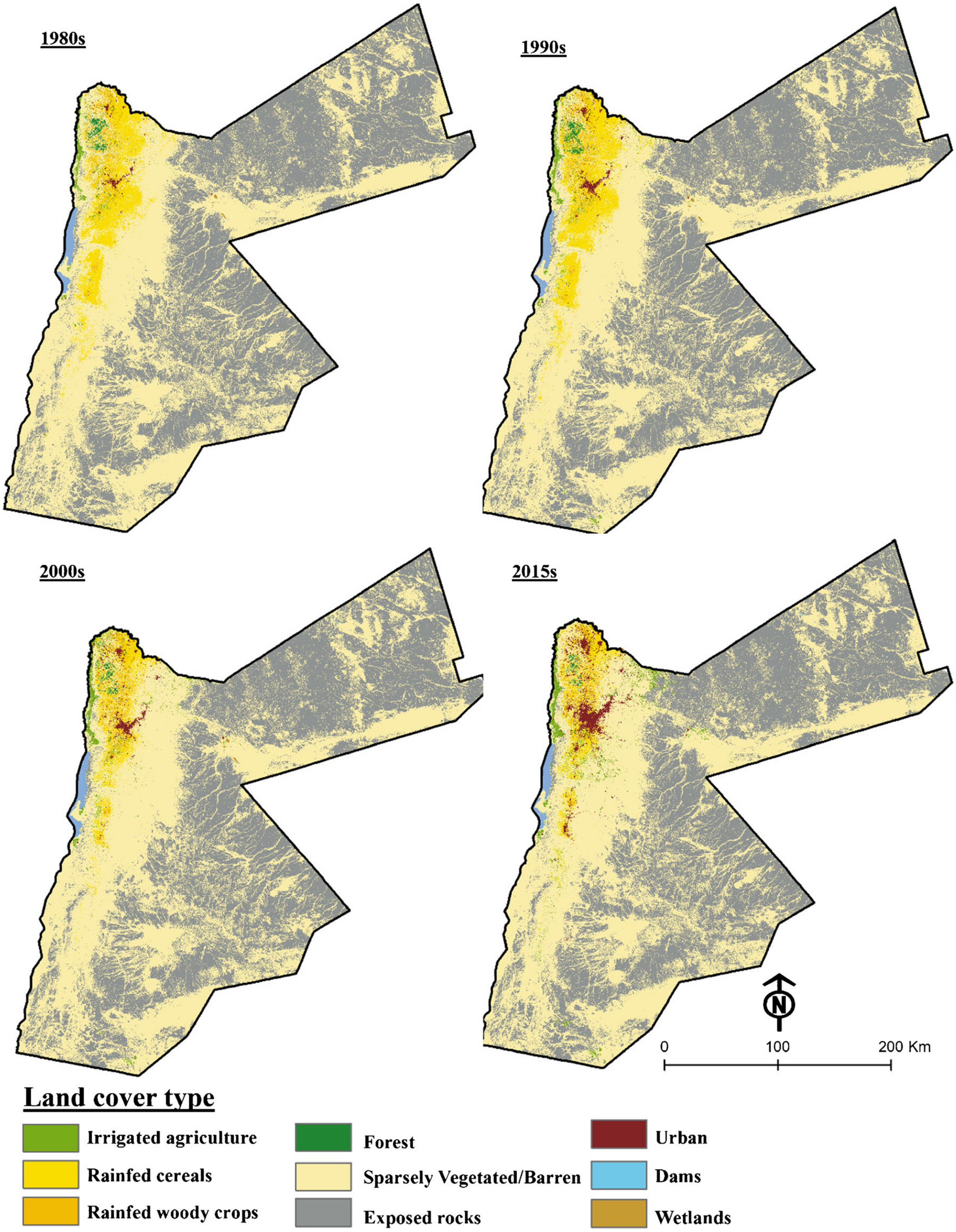

Fig. 3 The JNLCD land use/cover maps in four decades at 30-m resolution

measure the intensity of mixed rainfed agriculture conversion showed a total of 283 km^2 of mixed rainfed areas which were converted to urban while 286 km^2 of mixed rainfed areas were converted to open rangelands. These results also support the findings of Al-Bakri et al. (2013a, b), who investigated the growing urbanization trend in the Amman-Zarqa area, mainly at the expense of mixed rainfed agriculture. Besides consuming mixed rainfed agricultural areas by urbanization, frequent droughts and soil degradation have led to abandoning agricultural fields, especially in the areas cultivated with cereals (Khresat et al. 2008). In addition, the land tenure system, by which the number of fragmented small lots (less than 0.005 km^2) increased by

Table 4 Summary of JNLCD major land use/cover changes in comparison with prior LC map and governmental censuses estimates

Class	JNLCD (%)				2010 land cover map[a] (%)	DOS agriculture census estimates (%)		
	1980s	1990s	2000s	2015s	2010	1994	1998	2014
Urban	0.2	0.3	0.5	1.3	1.7	NA	NA	NA
Mixed rainfed areas	5.1	5.5	3.0	2.5	3.8	1.7	2.4	1.9
Irrigated areas	0.4	0.6	0.8	1.2	1.1	0.7	0.8	1.2
Rangelands and non-cultivated areas	94.0	93.3	95.4	94.8	93	NA	NA	NA
Forest	0.3	0.3	0.2	0.1	0.3	NA	NA	NA
Dams	< 0.1	< 0.1	< 0.1	0.1	< 0.1	NA	NA	NA

[a] Al-Bakri et al. (2013a, b)

195%, contributed to a decline in mixed rainfed areas as farmers are not encouraged to cultivate small landholdings (NCARE 2017).

JNLCD data accuracy and quality

The results of thematic accuracy assessment for the 1980s and 2015 maps are denoted in Tables 5 and 6. Overall, thematic accuracies were 94 and 90% for the 1980s and 2015s maps, respectively. In both dates, the highest accuracy was for dams, sparsely vegetated/barren, and exposed rock classes. High commission errors, however, occurred for the rainfed woody crop (58% in 1980 and 40% in 2015), irrigated agriculture (26% in 1980 and 37% in 2015), and rainfed cereal (21% in the 1980s and 20% in 2015) classes. In both error matrices, primary sources of disagreements were between rainfed

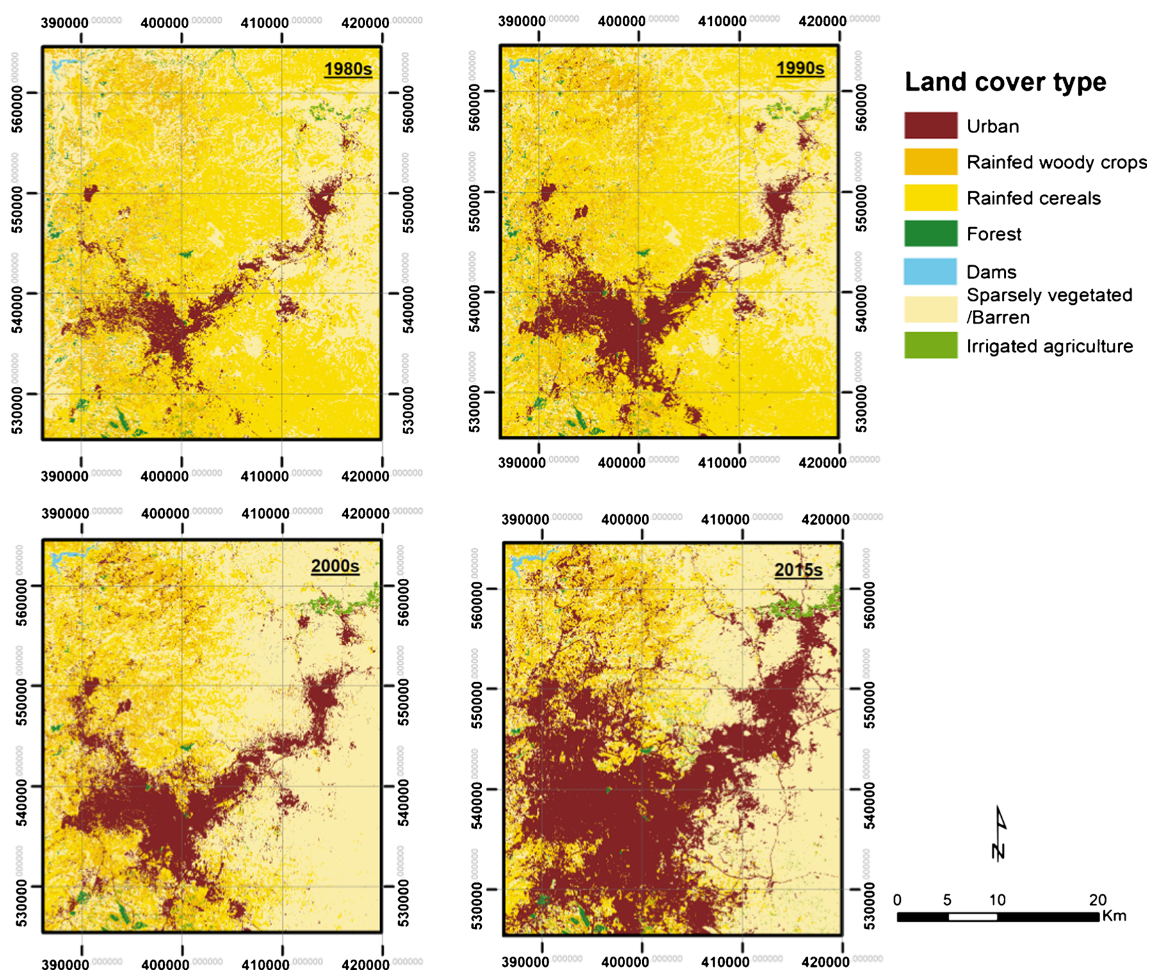

Fig. 4 Decadal land cover changes in the Amman-Zarqa metropolitan area

Table 5 Accuracy assessment for the 1980s JNLCD map, using 1300 pixels distributed across Jordan using stratified-random sampling scheme

Classified data	Reference data										
Map	Urban	Rainfed woody crops	Rainfed cereals	Irrigated agriculture	Forest	Sparsely vegetated/barren	Exposed rocks	Dams	Wetlands	Total	Commission error (%)
Urban	30	0	0	0	0	7	1	0	0	38	21.1
Rainfed woody crops	3	5	1	1	2	0	0	0	0	12	58.3
Rainfed cereals	0	4	33	0	0	5	0	0	0	42	21.4
Irrigated agriculture	1	0	1	14	2	0	0	0	1	19	26.3
Forest	0	2	0	0	10	1	0	0	0	13	23.1
Sparsely vegetated/-barren	4	3	4	0	0	785	11	0	**0**	807	2.7
Exposed rocks	0	0	1	0	0	17	334	0	2	354	5.6
Dams	0	0	0	0	0	0	0	8	0	8	0.0
Wetlands	0	0	0	1	0	0	1	0	5	7	28.6
Total	38	14	40	16	14	815	347	8	8	1300	
Omission error (%)	21.1	64.3	17.5	12.5	28.6	3.7	3.7	0.0	37.5		
Overall accuracy (%)	94.2										

woody crops and urban classes, between rainfed woody crops and forest classes, and between rainfed cereals and rainfed woody crops classes.

The source of confusion between rainfed woody crop and urban classes is attributed to the inclusion of low-intensity urban areas within the agricultural class. The low-intensity urban areas contain a reasonable portion of vegetation cover knowing that stakeholders tend to build their houses on the orchard farms. The source of confusion between woody crops and forested areas is due to the spectral similarity between the two classes considering the fact that forested land in Jordan is no more than dense shrublands. This source of disagreement encountered Alrababah and Alhamad (2006) when mapping the orchard class in the highlands region of Jordan. The source of confusion between woody crops and rainfed cereals is attributed to the traditional agricultural practices by which

Table 6 Accuracy assessment for the 2015s JNLCD map, using 1300 pixels distributed across Jordan using stratified-random sampling scheme

Classified data	Reference data										
Class	Urban	Rainfed woody crops	Rainfed cereals	Irrigated agriculture	Forest	Sparsely vegetated/barren	Exposed rocks	Dams	Wetlands	Total	Commission error (%)
Urban	47	0	0	0	0	13	1	0	0	61	23.0
Rainfed woody crops	8	19	1	1	2	3	0	0	0	32	40.6
Rainfed cereals	2	3	62	0	0	8	2	0	0	77	19.5
Irrigated agriculture	0	4	4	24	1	3	0	0	0	38	36.8
Forest	0	2	0	0	6	0	0	0	0	8	25.0
Sparsely vegetated/-barren	23	1	4	1	0	736	17	3	0	785	6.2
Exposed rocks	0	0	1	0	0	25	251	0	0	277	9.4
Dams	0	0	0	0	0	0	0	19		19	0.0
Wetlands	0	0	0	1	0	0	0	0	2	3	33.3
Total	80	29	72	26	9	788	271	22	2	1300	
Omission error (%)	41.3	34.5	13.9	7.7	33.3	6.6	7.4	13.6	0.0		
Overall accuracy (%)	89.7										

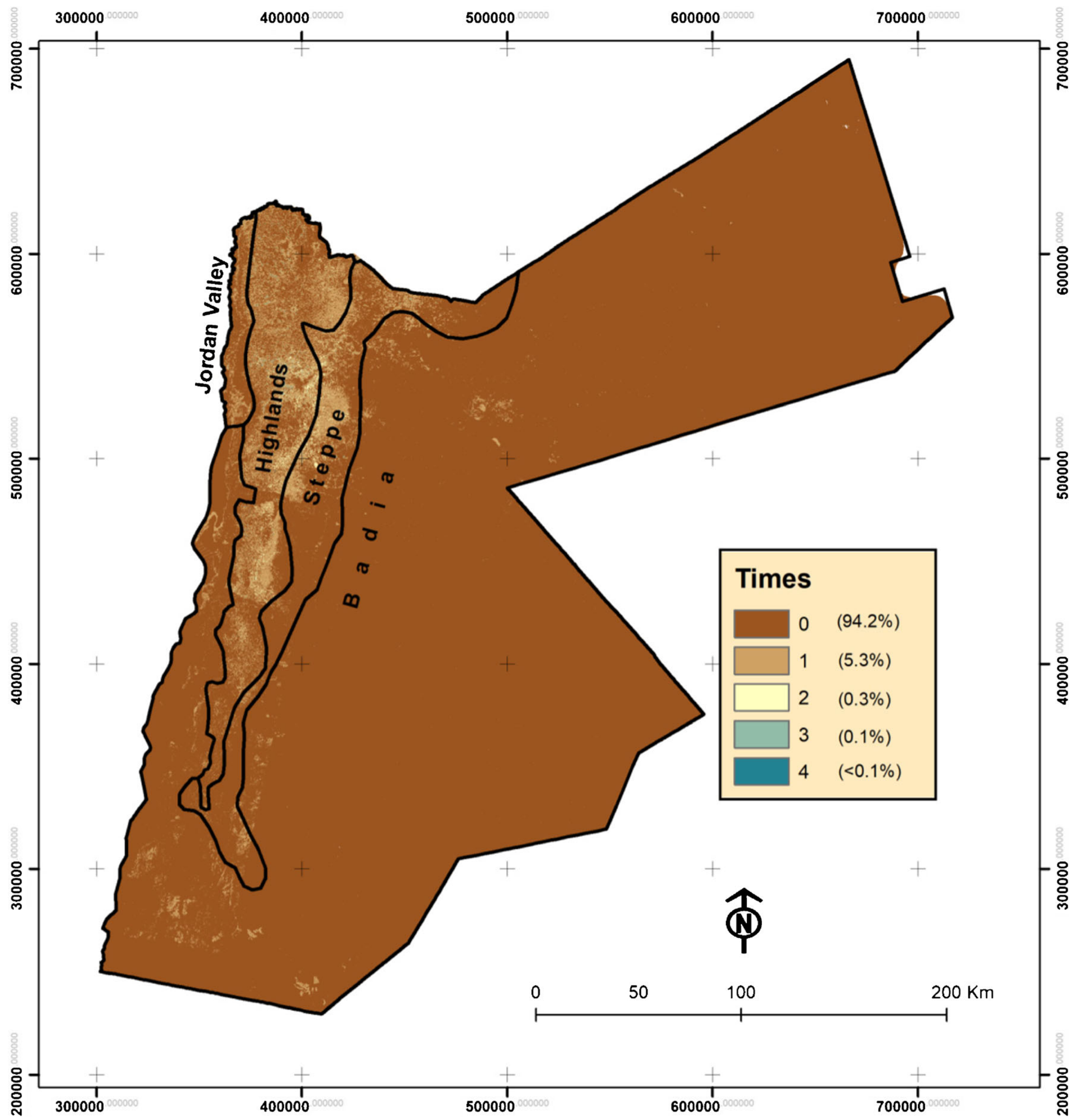

Fig. 5 Number of times pixels changed from one class type to another class for three decadal periods: 1980s–1990s, 1990s–2000s, and 2000s–2015s. 0 indicates no change over the three periods while 4 indicates the highest level of conversion, meaning that the pixel was converted to a new type in every period. Note that the northwestern part of Jordan experienced the highest level of pixel changes

farmers grow strips of annual crops, such as chickpeas and fava beans, in the open spaces among the olive grove orchards. This source of confusion was reported by Al-Tamimi and Al-Bakri (2005) in the Ajloun area, where complex intercropping, mixed pixels, and complex fragmented patterns of mixed rainfed agricultural class reduced its mapping accuracy. Such low accuracy could be improved by obtaining higher spatial and spectral resolution data and to certain limits using the on-screen manual digitizing method.

Despite the relatively low accuracy for agricultural classes, the overall accuracies for the verified JNLCD maps exceeded the accepted level (85%) within the remote sensing community and the accuracy achieved for land use/cover maps built for sub-regions in Jordan (Congalton and Green 2009; Al-Tamimi and Al-Bakri 2005; Alrababah and Alhamad 2006). The JNLCD accuracy level was even similar to the level achieved for well-developed land cover databases (i.e., 2006 NLCD reached 88.57% in Sioux Falls, South Dakota) (Xian et al. 2009). Classification difficulties in agricultural land are widely expected even with using accurate ancillary data. Despite these limitations, JNLCD is a reasonably accurate and efficient product. The accepted level of overall accuracy for the JNLCD product indicates consistent and accurate mapping methods utilized to develop this database. This is reflected by the agreements between JNLCD estimate and governmental census estimates as shown in the previous section.

While mapping LC for 1 year can be carried out easily, multi-temporal LC changes are more challenging and demanding because of the variability in spectral responses from one year to another. To minimize these effects and limitations in the JNLCD product, the unsupervised classification was chosen as the primary classification method because of its suitability for mapping heterogeneous landscapes with high variation in spectral responses and gradient between vegetation types (Al-Tamimi and Al-Bakri 2005). Unsupervised ISODATA clustering is preferable and most successful when a large number of clusters are used. The developed JNLCD maps with a harmonized legend helped to map major land use/cover types and track their transitions on a multi-temporal basis.

The high quality of JNLCD product is also related to the high quality of remote sensing input data from the standpoints of cloud coverage and seasonality. The early spring Landsat data were targeted to map vegetated classes as accurately as possible. Accuracy was improved by incorporating various ancillary data to increase separability of confused clusters and collecting field data.

Eco-regional framework of land cover change in Jordan

Results of quantifying the number of times each pixel changed in each ecoregion to determine the most dynamic ecoregions in Jordan showed that 94% of the pixels did not change between dates and 5.3% changed at least once over the study period (Fig. 5). Less than 0.1% of the pixels changed at least four times. Among the four ecoregions, the highlands ecoregion experienced the highest rate of change with 35% of the pixels changing at least once and 2% at least twice, followed by the steppe ecoregion where 18% of its pixels changed at least once. Around 98% of the Badia region experienced no change, and around 51% of the Jordan Valley also experienced no change. The heterogeneity of the highlands landscape increased and land lots became more fragmented and smaller.

Mapping where most land cover changes occurred among different ecoregions is another vital application of such long-term land cover database. Patterns of land cover change in the Jordan considerably varied among physiographic regions. Irrigated agriculture dominated the Jordan valley, while rainfed agriculture dominated the highlands (mainly cereals and olive trees) and the steppe (mainly winter barley). Urban areas were mostly found on the elevated plains with high rainfall rates while the Badia relatively is dominated by exposed rocks and sparsely vegetated/barren areas.

Conclusions

The robust contribution of this paper is the development of the first historical and current nationwide land cover timeline for Jordan from Landsat images and ancillary spatial data. The 35-year JNLCD timeline represents the first compatible readily available information on land use/cover in Jordan. The JNLCD product will allow researchers to better understand land cover transitions, trajectories, and magnitude of conversions. In spite of the effort and time to retrieve, compile, geo-process, delineate, and validate the variable data sources, this wall-to-wall database at 30-m spatial resolution is a milestone for several studies in the change detection, developmental interventions, and designing sustainable land management practices in the region.

The decadal landscape changes reflected through JNLCD emphasize the state of Jordan's natural resources and to the ongoing deterioration process, mainly due to unplanned use of land and adverse climate changes. This timeline shows the transition stages in land cover from homogenous landscape patterns into fragmented diversified land practices. The very early map of the 1980s highlighted the homogeneous land cover patterns that were mainly dictated by rainfall. The 1990s and the 2000s maps reflected the period in Jordan history when the country experienced difficult economic and political circumstances. The 2015s map shows the current status of land cover arrangements and its degradation status.

The long-term JNLCD database fills a crucial data gap and allows for capturing and assessing past and present land transformations. This data set lays the foundation for future institutional policy assessment and land management regulation enforcements. The LC information from this timeline offers the baseline for many applications to be carried out in the natural resource management and in many other planning fields.

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