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ORIGINAL PAPER

Monitoring desertification by remote sensing using the Tasselled Cap transform for long-term change detection

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Abstract Sensitive areas like oases are threatened by climatic variations and human activities that can catalyze desertification processes. Remote sensing the Earth surface from satellites is a good tool to monitor such types of change through several techniques. In this paper a remote sensing method that has been widely used for vegetated areas is adapted to study dry regions. The method consists of a combination of the Change Vector Analysis and the Tasselled Cap (TC) transform. To adapt it to dryland conditions a new set of parameters for the TC transform is hereby calculated for the Landsat 8 OLI system. The new TC parameters are tested in the analysis of the surface change in Azraq Oasis, Jordan, over a time span of 30 years (1984–2013) for Landsat satellites images. Azraq is considered a good testing site since in the early 1990s it has been subject to a complete drying up of the superficial springs, mainly due to over-exploitation of the groundwater basin. Results show that the chosen technique is able to detect the expected change on the surface, consistent with photo-interpretation and historical information available.

Keywords Tasselled Cap transform · Change Vector Analysis · Desertification · Change detection · Azraq Oasis · Landsat 8 OLI

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1 Introduction

Azraq Oasis, in Jordan, owes its name to the particularly light blue color of its water. The presence of pools of freshwater made Azraq a highly relevant spot in the Jordan Eastern desert: the first settlements in the area date back to the Middle Paleolithic era and are testified by the presence of an ancient Castle, a thirteenth-century Ayyubid dynasty fortress built on some Roman ruins (Ramsar Convention 1998; Cordova et al. 2013). Besides the human colonization, Azraq represents a strategically important area for local fauna and migratory birds, stopping on their way from East Asia, Africa and Europe.

The existence of this historically important site is now at high risk, since in the 1990s the Oasis went through a drastic drying up of the natural springs that were then releasing up to 16 million cubic meters (MCM) of water a year (Dottridge and Abu Jaber 1999; UN-ESCWA and BGR 2013).

The main reason for the depletion of the water level in the Oasis is connected with human abstraction from the groundwater basin for domestic and rural use, especially after the so-called green revolution carried out by the Jordanian Government in the 1980s (National Research Council 1999; Demilecamps 2010; IUCN 2010). The springs that supported the Oasis in fact were the natural discharge of the Azraq–Dhuleil Basin, which today is one of the biggest sources of potable water for the capital Amman (25 %, in a country where groundwater resources make up 57 % of total supply) (Mesnil and Habjoka 2012). The easily reachable water bed, in some points just a few meters under the soil level, allowed the exploitation of water resources by farmers that found in Azraq an easy and fast way of moneymaking, especially since at first the digging was not regulated or monitored. Subsequently and still currently the illegal digging is flourishing and not completely under control. Besides the rural use, which accounts for up to two-thirds of the total abstraction, the drawing of water for domestic purpose by the Water Authority of Jordan (WAJ) constitutes the second source of water exploitation (Demilecamps 2010). Figure 1 shows how the estimated yearly abstraction grew from few MCM in the 1980s up to the current 60 MCM (IUCN 2010), from a basin for which the calculated safe yield is between 20 and 25 MCM (Ramsar Convention 1987; Al-Kharabsheh 2000).

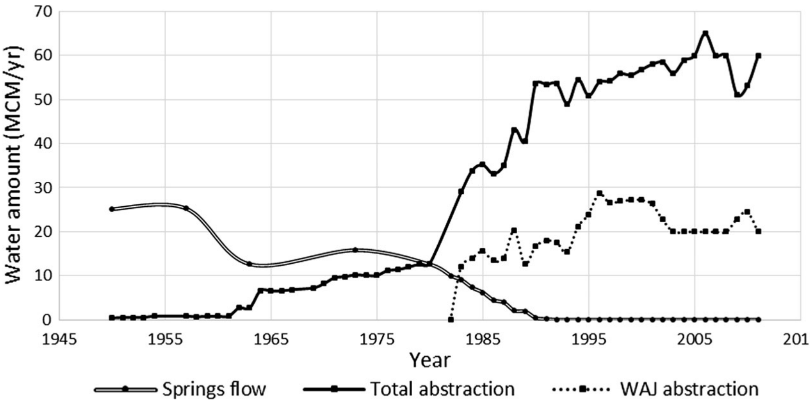

Fig. 1 Springs flow and water abstraction from the Azraq–Dhuleil Basin since 1950, adapted from Dottridge and Abu Jaber (1999) and implemented. *Source*: based on data from the WAJ and Bajjali and Al-Hadidi (2005), El-Naqa et al. (2007), IUCN 2010, Mesnil and Habjoka (2012)

Besides the lowering of the water bed, the groundwater conditions are also experiencing a general deterioration, mainly alteration in the groundwater salinity as shown by recent studies (El-Naqa et al. 2007; Goode et al. 2013). The persistence of the present conditions will unlikely allow reversing the direction of the change, with a big loss in terms of desert biodiversity and cultural and esthetic values (Dottridge and Abu Jaber 1999; National Research Council 1999).

The situation at Azraq Oasis is a good example of how human behavior can pose a huge threat to the existence of an oasis, adding to the naturally imposed hazard of desertification. Oases' characteristics in fact make them particularly vulnerable to desertification, a process defined as 'land degradation in arid, semiarid and dry sub-humid areas resulting from various factors, including climatic variations and human activities' (UNCCD 1994). Understanding the evolution of desertification processes has a huge relevance in a country like Jordan, with a water supply of 145 m^3/person/year putting it high in the list of worldwide water scarcity countries (Edwards et al. 1999; Al Eisawi 2005; WAJ 2007; Al-Bakri et al. 2013; UNICEF 2014; WHO 2015), and poses a question on the sustainability of a society in a growing demand regime. The amount of water available per capita is in fact predicted to diminish down to 90 m^3/person/year in 2025 (personal communication), and this prediction would probably worsen if the number of refugees arriving from neighboring Arab countries keeps on increasing (UNHCR 2015).

Several attempts have been proposed to choose valuable indicators of desertification, including soil erosion and sedimentation, perennial plant cover and biomass (Dawelbait and Morari 2011). In particular on a long-term temporal scale, remote sensing is a proper tool to monitor such type of change, using Land-Use–Land-Cover Change (LULCC) detection techniques, an effective device also for the investigation of desert environments (Mouat et al. 1997; Palmer and van Rooyen 1998; Lin et al. 2011). The changes to Azraq Oasis in recent history make it an exceptional case to test techniques for monitoring the desertification in drylands: by knowing a priori the change to terrestrial surface between two dates it is possible to look for indicators proving it, and thus check whether the technique is able to detect the change and to which extent. The technique chosen in this study is Change Vector Analysis (CVA) applied to the output of a Tasselled Cap (TC) transform, usually fit to perform LULCC detection in vegetated areas (Malila and Lafayette 1980). CVA gives as an output the direction of change between two dates for each pixel of an image, having the advantage, differently from canonical supervised or unsupervised classifications, of not needing a land-cover classification to be performed in advance. The use of this technique in desert areas bears some doubts, since the TC transform is intrinsically intended to be used in vegetated areas; the aim of this paper is therefore to resolve this issue, using for this purpose a new set of parameters for the TC transform, calculated for Landsat 8 OLI system specifically for desert conditions.

2 Case study

Azraq Oasis is located in Jordan, 80 km east of the capital Amman approximately at coordinates 32°N and 37°S. It lies at the bottom of a relatively shallow natural depression at around 500 m of altitude, which constitutes the northern part of Wadi Sirhan

Depression, a huge hydrological system covering great part of central Northern Saudi Arabia desert (Ramsar Convention 1990a; UN-ESCWA and BGR 2013).

The groundwater system is rather complex and is part of a greater aquifer system that extends from southwestern Syria to Saudi Arabia, consisting mainly of three aquifers, one on top of the other. The upper one, called Basalt Aquifer, has been the most exploited one and is also the aquifer from which the Oasis' springs originated. The superficial catchment area of this aquifer is a huge basin called the Azraq–Dhuleil Basin, that extends almost longitudinally, from the southeastern side of Jebel Al-Arab (or Jebel Al-Druze, 1800 m high) mountain in Syria to the northeastern desert of Jordan (Dottridge and Abu Jaber 1999; El-Naqa et al. 2007; Cordova et al. 2013). The Basin area is considered predominantly arid, with annual precipitation ranging from less than 50 mm in the southeastern depression to more than 300 mm in the northern part, in proximity of the most elevated point of the Basin (Al-Kharabsheh 2000; UN-ESCWA and BGR 2013).

Before drying up in the 1990s, the Oasis was made up of two main groups of springs surrounded by marshes: the Aura and Moustadhema springs surrounded by the Druze Marsh in the northern part, and the Souda and Qaisiyah Springs surrounded by the Shishan Marsh in the south (Ramsar Convention 1990a). The springs and the marshes created a seasonal cycle with the nearby *Qa'* or *Sebkha*, the Arabic terms to refer to a *mudflat*, also called *salt flat* or *playa lake* (Alvarez Cobelas et al. 2005). The mudflat consists of a depressed area that is flooded during the winter season by the drainages from incoming streams (*wadies*) and then dries up due to the dry climate, creating temporary salty water ponds and swamps until the water evaporates (Cordova et al. 2013).

Figure 2 shows the position of Azraq in Jordan with the Azraq–Dhuleil Basin border and a Landsat look-like image of February 25, 2015, centered in the study area (in yellow), where the mudflat area and the RSCN Reserve are also shown.

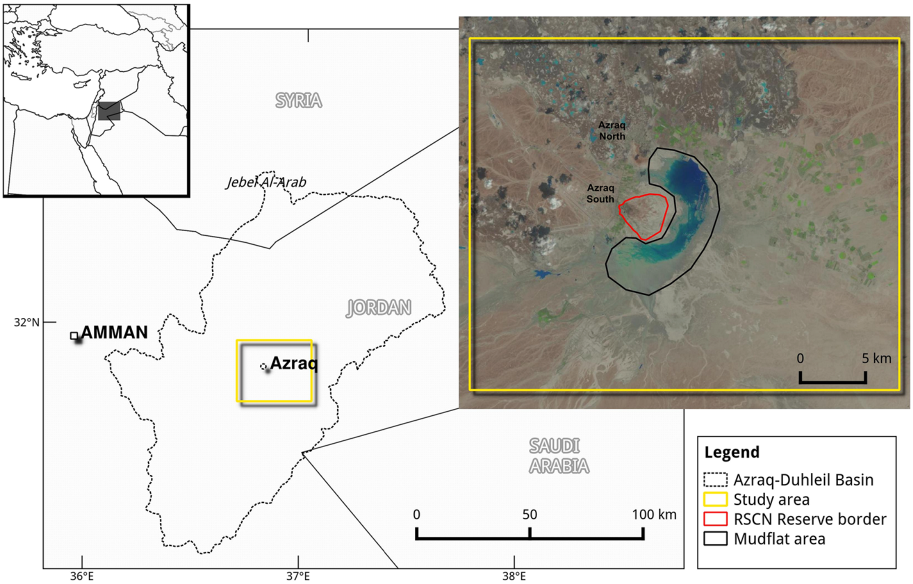

Fig. 2 Location of Azraq in the Middle East region and of Azraq–Dhuleil Basin in Jordan, with zoom on the study area (*yellow border*) showing the RSCN Reserve and the mudflat area (February 25, 2015, Landsat 8 look-like image)

Object in the 1960s of several study campaigns, mainly by ornithologists and desert researchers (Mountfort 1965; Scates 1968; Nelson 1973; Green 1995), Azraq Oasis starts to gain attention far before the complete drying up of the sources in the 1990s: a first draft of the Natural Reserve was drawn as early as 1965. Later, in 1977 Jordan designated the Azraq wetland for the List of Wetlands of International Importance under the Ramsar Convention, an international agreement established in 1971. The Member States of the Convention commit to protect and preserve the wetlands that are enlisted in the agreement (the 'Ramsar Sites' across the world are more than 2000 for 160 Contracting Parties). Also thanks to the Ramsar Recommendations, which are periodically provided during the Ramsar Meetings, the Natural Reserve was finally instituted in 1978, under the jurisdiction of Royal Society for Conservation of Nature (RSCN) which got the mandate from the Ministry of Agriculture.

In 1980, a special cabinet committee created to establish a plan of action, assessed the safe yield at 20 MCM; in the meantime the Amman Water and Sewage Authority (AWSA) set up a governmental wellfield for domestic use abstraction, and during the 1980s the pumping from the Oasis kept on growing, despite the calls from Ramsar Recommendations to reduce it at least by 50 % (Ramsar Convention 1987, 1990b, personal communication). Eventually the sources dried up completely in 1992 and this led to a Global Environment Facility (GEF) funding of a three-year project aimed to restore and manage Azraq Wetlands Reserve. This resulted in a variety of management activities during 1994–1999, including the opening of a Visitors Center (active from 2000) and a guided natural trail through the Reserve, together with the return of a supply of water to the Shishan Marshes from June 1994, following lack of water for 2 years. In 1998 the artificial water supply started to be pumped bypassing the former springs (Souda and Quasiya), where a large amount of water was being lost through infiltration, and transported directly to the central marsh (Ramsar Convention 1999).

3 Materials and methods

3.1 Landsat data

For the present research five images centered on Azraq Oasis were chosen, namely from path/row 173/38 of the Landsat database available at http://glovis.usgs.gov/. Cloudless images taken in summer season dates were chosen, this in order to avoid the climatic seasonal fluctuation and to have the most similar conditions on the terrestrial surface. Given the desert and arid conditions, we can assume that no big climatic variation occurs in summer in the analyzed area and that the atmospheric correction is negligible. The earliest available image respecting the above-described criterion, and considering also the availability of TC transform for that type of sensor, is from the summer of 1984. Images taken around the 30th of August have been chosen over a span of 30 years, in order to detect the long-term change but also the shorter-scale variation. Tables 1 and 2 give the list of

Table 1 Selected dates for Landsat 5 and Landsat 8 satellites for the multitemporal change detection

Landsat 5	1984/08/30, 1990/08/31, 1998/08/21, 2003/08/19
Landsat 8	2013/08/30

Table 2 Technical data of selected spectral bands used in the TC transform for the Landsat 5 satellite TM (Thematic Mapper) and Landsat 8 satellite OLI (Operational Land Imager) sensors, with resolution of 30 m

Denomination	Landsat 5		Landsat 8	
	Band n.	Range (μm)	Band n.	Range (μm)
Coastal aerosol			1	0.43–0.45
Blue	1	0.45–0.51	2	0.45–0.52
Green	2	0.52–0.60	3	0.53–0.59
Red	3	0.63–0.69	4	0.64–0.67
Near infrared—NIR	4	0.76–0.90	5	0.85–0.88
Shortwave infrared—SWIR1	5	1.55–1.75	6	1.57–1.65
Shortwave infrared—SWIR2	7	2.08–2.35	7	2.11–2.29

selected dates for the analysis and the characteristics of the involved Landsat satellites. Later in this article the images will be denoted just by the year (i.e., 1984 for August 30, 1984).

3.2 Tasselled Cap (TC) transform

The Tasselled Cap (TC) transform was introduced by a work of Kauth and Thomas (sometimes it is also called KT transform) in 1976 (Kauth and Thomas 1976) and consists of a linear transformation of the pixels' values of a satellite image of terrestrial surface, in order to convert the originally highly correlated bands (in the Infrared and Visible region, see Table 2) to a new set of uncorrelated axes. The new axes, also called TC features, bear a physical meaning in terms of the characteristics of the surface: Brightness, Greenness and Wetness. As a linear transform, the TC consists of a set of parameters (frequently referred to as *coefficients*) that weigh the original spectral bands' values and sum up to give as an output a new value for that pixel in the new set of axes, therefore literally transforming the coordinates reference system passing from the satellite bands space to a new TC features space. Unlike other transformations, Principal Component Analysis (PCA) as one example, TC transform is not image dependent; therefore once a set of parameters for the transformation is given, it can be used to convert any image with the same characteristics (type of satellite, data and region) (Ivits et al. 2008; Yarbrough et al. 2012; Zanchetta et al. 2015). In particular when dealing with desert conditions, special attention should be paid when applying the existing coefficients, noticing whether the original studies were carried out specifically for vegetated areas.

The coefficients present in the literature for Landsat 8 were calculated for vegetated conditions (Baig et al. 2014; Liu et al. 2015); therefore a new set of parameters have been calculated for desert conditions, using Top Of Atmosphere Reflectance (TOAR) images (Table 3). The method chosen to calculate the coefficients uses the Gram–Schmidt orthogonalization as extensively illustrated by Jackson (1983), as well as the original study by Kauth and Thomas and in other sources (Chang 1992; Ivits et al. 2008). Another common way of calculating the coefficients is through PCA followed by a rotation, to match some preferential directions given by the position on the bands space of selected categories of the surface cover (Crist and Cicone 1984; Huang et al. 2002; Yarbrough et al. 2012). In the present paper the first method was chosen following the considerations made by Zanchetta et al. (2015), source from which are also taken the coefficients used in the

Table 3 TC coefficients for Landsat 8 TOAR data for desert conditions

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
Brightness	0.185	0.206	0.316	0.403	0.478	0.491	0.418
Greenness	0.075	0.080	0.020	−0.180	0.771	−0.349	−0.425
Wetness	0.250	0.264	0.400	0.529	−0.289	−0.433	−0.246

present study for Landsat 5 images. The Gram–Schmidt orthogonalization is performed on selected pixels that belong to three categories of surface cover (indicative of soil, vegetated and wet surfaces) and on a range of images from different seasons and selected geographic locations in the Middle East (Jordan and Egypt), in order to overcome the dependency of the TC calculation on temporal conditions and location. These criteria allow the use of the new Landsat 8 coefficients to perform a LULCC detection against products of older Landsat systems.

3.3 Change Vector Analysis (CVA)

Change Vector Analysis (CVA) was first implemented by Malila and Lafayette (1980) for detecting forest changes and then widely adopted for LULCC detection by several authors also for desert areas (Lorena et al. 2002; Bayarjargal et al. 2006), sometimes further developed and variated (Lambin and Strahlers 1994; Chen et al. 2003; Flores and Yool 2007; Dawelbait and Morari 2011; Dubovyk et al. 2013; Singh and Talwar 2014). The technique uses two (or more) spectral variables, like spectral bands or surface features or spectral indices, to produce in output a map of the *magnitude* and a map of the *direction* of the change between two dates. For each date, the pixel's values in the two bands are plotted on the bands space, generating a vector of the change in time. The vector's length and *angle* give, respectively, the *magnitude* and *direction* of the change. Once a threshold is chosen, the significant change is given as those pixels that exceed that value in the map of the *direction*.

As spectral variables, some biophysical indicators connected with surface characteristics are chosen. In this way, the combined variation can have a meaning in terms of surface change. In general (considering the two bands space) an indicator of the soil reflectance and an indicator of the vegetation vigor are used, like Albedo and NDVI (Normalized Difference Vegetation Index) (Karnieli et al. 2014) or the Tasselled Cap features Brightness and Greenness (Malila and Lafayette 1980).

3.4 CVA interpretation

The determination of the threshold and the interpretation of the direction of the change are critical points when applying the CVA technique and have been faced in several ways by different authors. The threshold in particular can be set with the use of empirical values, or through interactive trial-and-error procedures, or semi-automated approaches (He et al. 2013). For this work, the threshold given by the average plus the standard deviation of the *magnitude* values was chosen; therefore it is not a fixed value and it changes for each pair of images taken into consideration. This choice respects a statistical requirement and does not require human supervision, but in the same time it bears some uncertainty connected with different statistical distributions of the values of *magnitude* when used for multi-temporal analysis, meaning when, like in our case, the change is investigated in more than one time interval. To address this issue, the CVA was carried out on a vast area surrounding the Oasis (891 km^2), and not only the actual area of interest around the Shishan marsh (see Fig. 2, yellow border).

Once the angle of the change vector is mathematically determined, the meaning of the CVA *direction* is not straightforward. Generally a simplified interpretation of the quadrants of the bands space is given: the first quadrant in fact represents a positive change for both variables, the third quadrant a negative change for both, and so on. In line with the interpretation given by other authors for desert conditions (Lorena et al. 2002; Karnieli et al. 2014), we defined the four change *directions* as follows. The first quadrant, which is characterized by an increase in both Greenness and Brightness, indicates moisture reduction and drying up of salty surfaces (Karnieli et al. 2014); the second quadrant, with increase in Brightness, is indicative of chlorophyll increase and of regrowth and regeneration of vegetated features in general; the third quadrant, where both spectral features have a decrease, indicates burning or water and in general a change toward higher moisture land; the fourth quadrant, with increasing Brightness, is strongly related to great losses of vegetation biomass and to bare soil expansion (Fig. 3).

4 Discussion and results

Before performing CVA on the selected dates, a visual interpretation of images was carried out in order to visualize the expected change between the pre-drying up conditions and the present conditions. As a reference for the pre-event situation, a map from 1979 was

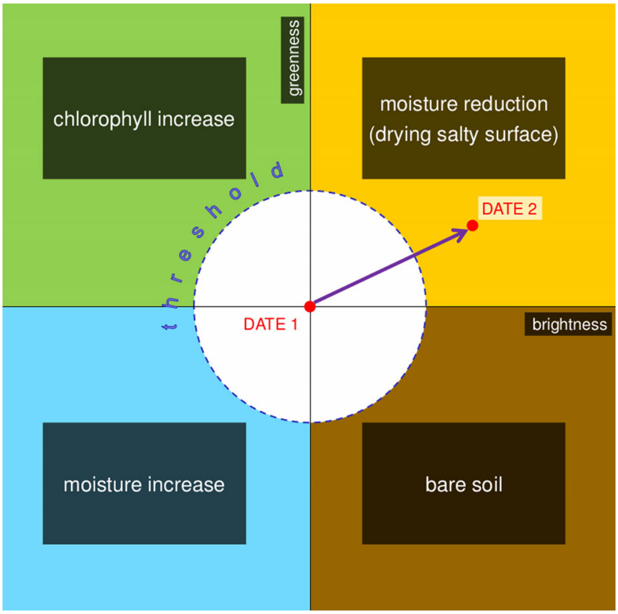

Fig. 3 CVA explanation and physical meaning of the quadrants

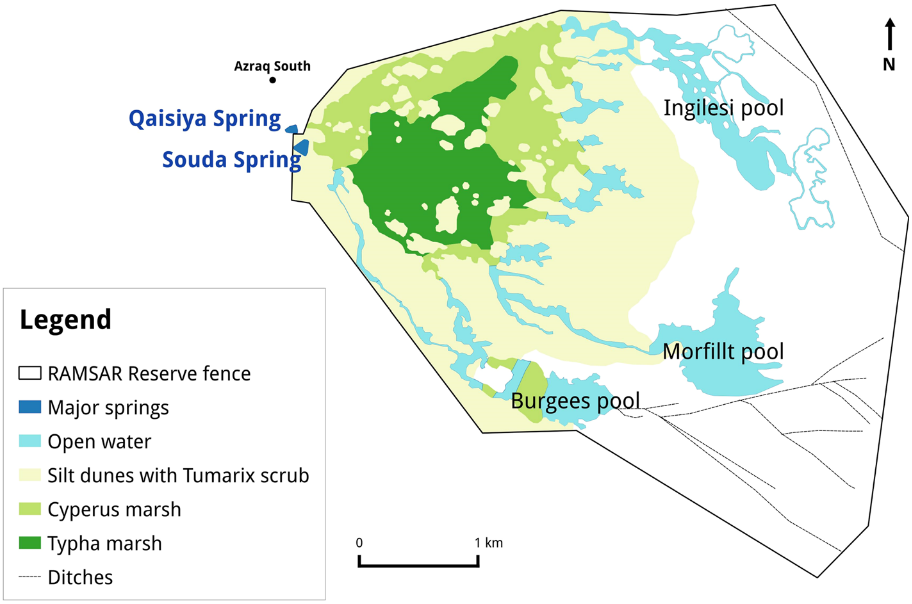

Fig. 4 Major habitats/vegetation communities in Azraq Wetland Reserve, digitization of a 1979 map. (*Source*: Ramsar Convention 1990a)

Fig. 5 Google Earth image of the Azraq Reserve in 2015, 1979 RAMSAR fence (*in black*) is shown

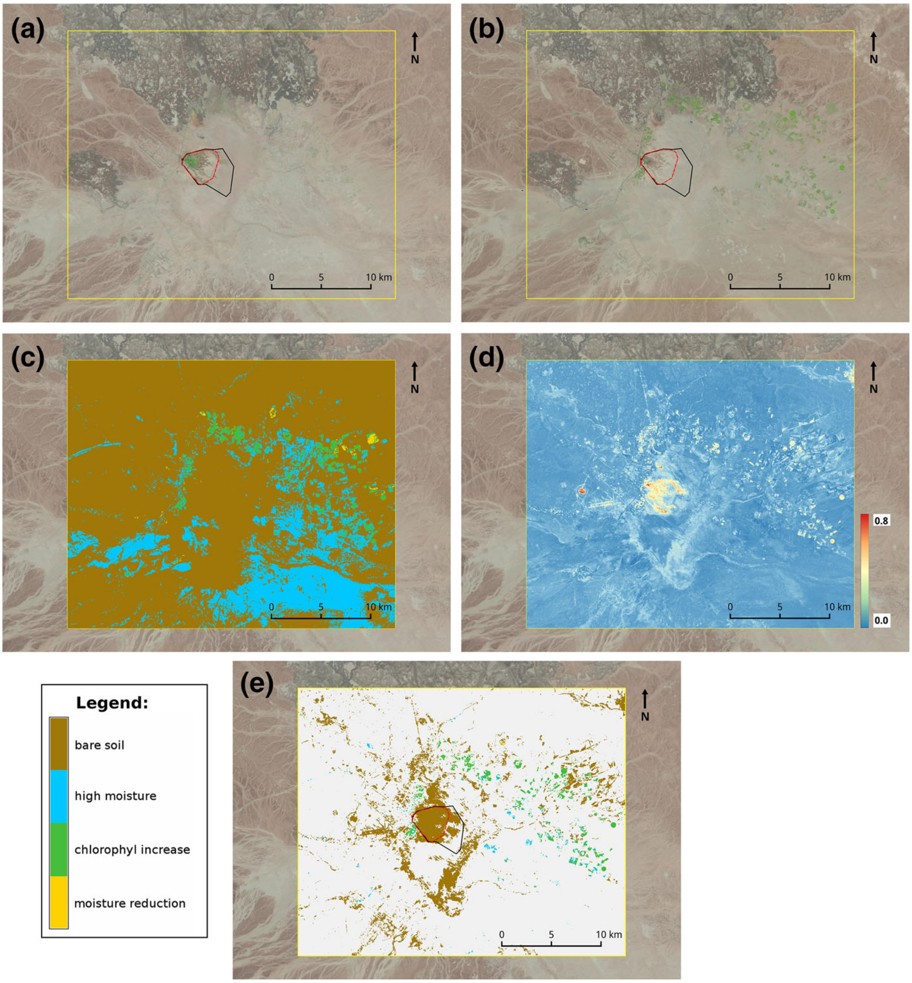

Fig. 6 Landsat look-like image for August 30, 1984 (**a**) and August 30, 2013 (**b**) and results of the CVA between the two images for the study area: directions (**c**) and magnitude (**d**) images before applying the threshold, final change detection analysis (**e**); RSCN Reserve border (*in red*) and the 1979 RAMSAR fence (*in black*) are shown

digitized and georeferenced (see Fig. 4). The map is available from the 1990s RAMSAR Report, and it contains also some updates from an expedition organized by the RAMSAR committee in March 1990 (Ramsar Convention 1990a). The annotations describe a general deterioration of the Oasis: stressed or tainted vegetation in the central area of the marsh (on dunes and water) and low water level in the pools, with the Ingilesi pool almost dry and the ditches totally dry. As a reference for the present conditions, missing ground truth data, a comparison with updated base maps available online (OpenStreetMap, Google) was taken in consideration (Fig. 5). Further help in interpreting the intermediate dates comes from aerial pictures available from the APAAME online catalog (Aerial Photographic Archive for Archaeology in the Middle East) that dates from 1998 to present.

Table 4 CVA results for the studied time periods in km^2 and % on the total study area (for the meaning of the categories refer to Fig. 3)

Categories	1984–2013		1984–1990		1990–1998		1998–2003		2003–2013	
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Moisture reduction	0.2	0.02	26.34	2.96	26.65	2.99	26.54	2.98	0.02	0.00
Chlorophyll increase	10.2	1.14	28.43	3.19	29.00	3.25	34.67	3.89	4.58	0.51
Moisture increase	3.1	0.35	11.76	1.32	19.46	2.18	13.67	1.53	1.93	0.22
Bare soil expansion	76.8	8.62	30.81	3.46	21.83	2.45	11.21	1.26	83.71	9.39
No-change	800.7	89.86	793.67	89.08	794.07	89.12	804.91	90.34	800.77	89.87
Area changed	90.3	10.13	97.33	10.93	96.93	10.87	86.09	9.66	90.23	10.12

The visual comparison over the entire time span shows indeed a deterioration of the general status of the Oasis area, while rural areas on the north east part of the plateau seem to flourish. These impressions were confirmed during a field visit in June 2014.

The CVA image resulting from the comparison between 1984 and 2013 is given in Fig. 6, where Landsat look-like images are also shown. The highest change occurs in the 'bare soil expansion' category, which accounts for more than 80 % of the total changed pixels (see Table 4). A bare soil expansion was detected in and around the Reserve area, while 'generation/increase in chlorophyll' and 'moisture increase' were detected in the eastern side and around the mudflat area, with clear identification of agricultural fields (Fig. 6).

The long-term trend is replicated in the shorter-term periods, where the highest change occurs in the 'bare soil expansion' category with a maximum in the 2003–2013 period (9.39 %). The intermediate periods show in general a more varied picture, with change occurring homogeneously in all the categories. The whole area study includes also the north east side of the image, where a high rural activity developed in the period taken into account; therefore a closer view on the Oasis area, centered on the RSCN Reserve, for shorter temporal scales is also analyzed (Fig. 7).

The centered CVA image for 1984–2013 (Fig. 7j) detects a high change toward 'bare soil expansion' in the Reserve area, and this is affirmed by the base maps. The CVA image for 1984–1990 (Fig. 7f) detects 'bare soil expansion' and 'moisture reduction' all along the Reserve area and the mudflat. This trend continues in the 1990–1998 CVA image (Fig. 7g), where the drying up of the major pools adjacent to the mudflat is evident. This trend is partly halted in the following CVA image for 1998–2003 (Fig. 7h) likely as a result of the restoration project completed in 1998 through the GEF fund, and in fact a replenishment of green areas is detected in the central part of the marsh. The following CVA image for 2003–2013 (Fig. 7i) shows again a change toward 'bare soil expansion,' and this is attributable to the fire that broke out in October 2010, after which the Reserve was temporarily closed and could open again just in April 2011: the fire's consequences on the vegetation were still evident during the field visit in June 2014.

A closer analysis of the CVA results on the area of the pools surrounding the former Shishan springs was also considered (not shown here). The results show a main change toward drier conditions between 1990 and 1998, as expected, and a partial recovery

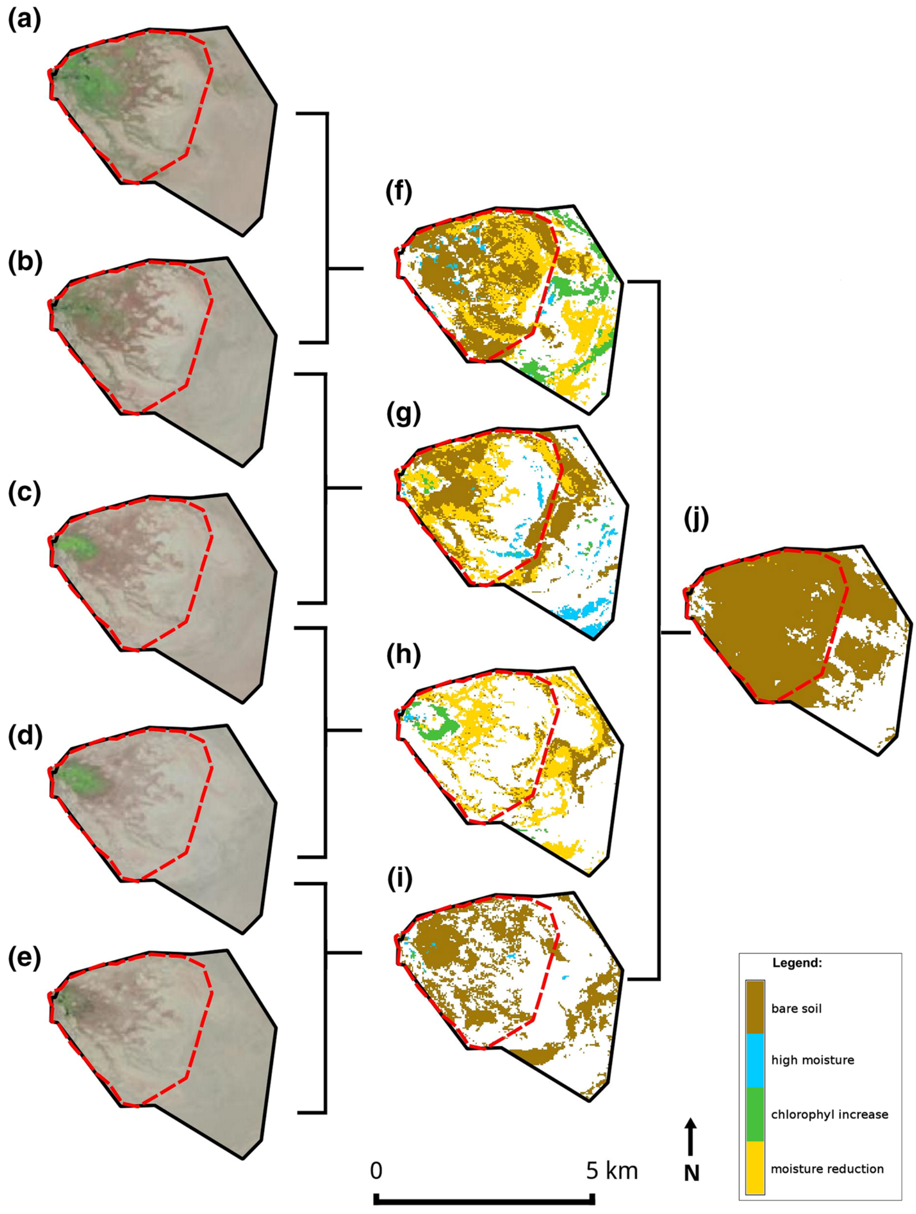

Fig. 7 Look-like Landsat images (**a** 1984, **b** 1990, **c** 1998, **d** 2003, **e** 2013) and CVA results images (**f** 1984–1990, **g** 1990–1998, **h** 1998–2003, **i** 2003–2013, **j** 1984–2013) for the Reserve area from 1984 to 2013 (for the dates specification see Table 1)

between 1998 and 2003. Finally between 2003 and 2013 the Oasis achieves its present conditions, with the former springs' pools left empty and a partial recovery of the marsh and of the stream that flows toward the former Burgees pool (Fig. 5).

5 Conclusion

An analysis was performed of the capability of the Tasselled Cap (TC) transform combined with Change Vector Analysis (CVA) to detect surface changes in arid areas, using as a case study the wetland of the Azraq Oasis, Jordan. The analysis was carried out on a 30-year interval (1984–2013) on Landsat satellites images. For the purpose of the research, a new set of TC coefficients was calculated, using several Landsat 8 images of selected dryland locations in the Middle East, and is here presented for the first time.

CVA gives as an output a map of the *magnitude* and a map of the *direction* of the change between two dates, having the advantage of not needing a previous land-use/land-cover classification. There are two difficulties though that are intrinsic to the use of the CVA technique: the first is deciding what the meaningful change is, namely choosing a threshold for the change detection, and the second is the absence of an objective validation method. The first issue was addressed using a statistical criterion for the selection of the threshold (average of the magnitude values plus the standard deviation), allowing for an automatic selection of the value for each couple of dates. The second one was faced with the support of data and material collected in a field visit in June 2014, together with several sources available in the literature.

The results show that the CVA applied to desert-adapted TC transform features is able to detect the expected changes in the studied area and can therefore be considered a valuable technique for change detection studies in areas subject to desertification and deterioration processes in drylands.

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References

Al Eisawi DMH (2005) Water scarcity in relation to food security and sustainable use of biodiversity in Jordan. In Hamdy A, Monti R (eds) Food security under water scarcity in the Middle East: Problems and solutions. CIHEAM Options Méditerranéennes: Série A. Séminaires Méditerranéens, vol 65, pp 239–248

Al-Bakri J, Salahat M, Suleiman A, Suifan M, Hamdan M, Khresat S, Kandakji T (2013) Impact of climate and land use changes on water and food security in Jordan: implications for transcending "the tragedy of the commons". Sustainability 5:724–748. doi:10.3390/su5020724

Al-Kharabsheh A (2000) Ground-water modelling and long-term management of the Azraq basin as an example of arid area conditions (Jordan). J Arid Environ 44:143–153. doi:10.1006/jare.1999.0580

Alvarez Cobelas M, Rojo C, Angeler DG (2005) Mediterranean limnology: current status, gaps and the future. J Limnol 64:13–29. doi:10.4081/jlimnol.2005.13

Baig MHA, Zhang L, Shuai T, Tong Q (2014) Derivation of a tasselled cap transformation based on Landsat 8 at-satellite reflectance. Remote Sens Lett 5:423–431. doi:10.1080/2150704X.2014.915434

Bajjali W, Al-Hadidi K (2005) Hydrochemical evaluation of groundwater in Azraq Basin, Jordan using environmental isotopes and GIS techniques. In: Proceeding of 25th annual ESRI international user conference, San Diego, California, July, pp. 25–29

Bayarjargal Y, Karnieli A, Bayasgalan M, Khudulmur S, Gandush C, Tucker C (2006) A comparative study of NOAA–AVHRR derived drought indices using change vector analysis. Remote Sens Environ 105:9–22. doi:10.1016/j.rse.2006.06.003

Chang YJ (1992) Developing tasselled cap transformation for SPOT HRV reflectance data. In: Fritz LW, Lucas JR (eds) XVIIth ISPRS Congress. Technical commission VII: Interpretation of photographic and remote sensing data, vol XXIX Part B7. Washington, DC, USA, 2–14 August 1992

Chen J, Gong P, He C, Pu R, Shi P (2003) Land-use/land-cover change detection using improved change-vector analysis. Photogramm Eng Remote Sens 69:369–379. doi:10.14358/PERS.69.4.369

Cordova CE, Nowell A, Bisson M, Ames CJH, Pokines J, Chang M, Al-Nahar M (2013) Interglacial and glacial desert refugia and the Middle Paleolithic of the Azraq Oasis, Jordan. Quat Int 300:94–110. doi:10.1016/j.quaint.2012.09.019

Crist EP, Cicone RC (1984) A physically-based transformation of Thematic Mapper data—The TM Tasseled Cap. IEEE Trans Geosci Remote Sens GE-22:256–263. doi:10.1109/TGRS.1984.350619

Dawelbait MAA, Morari F (2011) LANDSAT, spectral mixture analysis and change vector analysis to monitor land cover degradation in a Savanna region in Sudan (1987–1999–2008). Int J Water Resour Arid Environ 1:366–377

Demilecamps C (2010) Farming in the desert, analysis of the agricultural situation in Azraq Basin. German-Jordanian Programme “Management of Water Resources.” Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Amman, Jordan

Dottridge J, Abu Jaber N (1999) Groundwater resources and quality in northeastern Jordan: safe yield and sustainability. Appl Geogr 19:313–323. doi:10.1016/S0143-6228(99)00012-0

Dubovyk O, Menz G, Conrad C, Thonfeld F, Khamzina A (2013) Object-based identification of vegetation cover decline in irrigated agro-ecosystems in Uzbekistan. Quat Int 311:163–174. doi:10.1016/j.quaint.2013.07.043

Edwards MC, Wellens J, Al-Eisawi D (1999) Monitoring the grazing resources of the Badia region, Jordan, using remote sensing. Appl Geogr 19:385–398. doi:10.1016/S0143-6228(99)00007-7

El-Naqa A, Al-Momani M, Kilani S, Hammouri N (2007) Groundwater deterioration of shallow groundwater aquifers due to overexploitation in northeast Jordan. Clean-Soil Air Water 35:156–166. doi:10.1002/clen.200700012

Flores SE, Yool SR (2007) Sensitivity of change vector analysis to land cover change in an arid ecosystem. Int J Remote Sens 28:1069–1088. doi:10.1080/01431160600868482

Goode DJ, Senior LA, Subah A, Jaber A (2013) Groundwater-level trends and forecasts, and salinity trends, in the Azraq, Dead Sea, Hammad, Jordan Side Valleys, Yarmouk, and Zarqa groundwater basins, Jordan. Executive Summary for Open-File Report 2013–1061. US Department of the Interior US Geological Survey

Green J (1995) Groundwater abstraction and plankton in the Druze pool of Azraq Oasis, Jordan. Freshw Forum 5:157–160

He C, Zhao Y, Tian J, Shi P, Huang Q (2013) Improving change vector analysis by cross-correlogram spectral matching for accurate detection of land-cover conversion. Int J Remote Sens 34:1127–1145. doi:10.1080/01431161.2012.718458

Huang C, Wylie B, Yang L, Homer C, Zylstra G (2002) Derivation of a tasselled cap transformation based on Landsat 7 at-satellite reflectance. Int J Remote Sens 23:1741–1748. doi:10.1080/01431160110106113

IUCN (2010) Azraq Oasis Restoration Project, Final report—study of salt fresh water intrusion in Azraq Basin, Jordan

Ivits E, Lamb A, Langar F, Hemphill S, Koch B (2008) Orthogonal transformation of segmented SPOT5 images: seasonal and geographical dependence of the tasselled cap parameters. Photogramm Eng Remote Sens 74:1351–1364

Jackson RD (1983) Spectral indices in N-space. Remote Sens Environ 13:409–421. doi:10.1016/0034-4257(83)90010-X

Karnieli A, Qin Z, Wu B, Panov N, Yan F (2014) Spatio-temporal dynamics of land-use and land-cover in the Mu Us sandy land, China, using the change vector analysis technique. Remote Sens 6:9316–9339. doi:10.3390/rs6109316

Kauth RJ, Thomas GS (1976) The Tasselled Cap—a graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. In: Proceedings of symposium on machine processing of remotely sensed data, West Lafayette, Indiana, USA, 29 June–1 July 1976, pp. 41–51

Lambin EF, Strahlers AH (1994) Change-vector analysis in multitemporal space: a tool to detect and categorize land-cover change processes using high temporal-resolution satellite data. Remote Sens Environ 48:231–244. doi:10.1016/0034-4257(94)90144-9

Lin ML, Chu CM, Tsai BW (2011) Drought risk assessment in western inner-mongolia. Int J Environ Res 5:139–148

Liu Q, Liu G, Huang C, Xie C (2015) Comparison of tasselled cap transformations based on the selective bands of Landsat 8 OLI TOA reflectance images. Int J Remote Sens 36:417–441. doi:10.1080/01431161.2014.995274

Lorena RB, dos Santos JR, Shimabukuro YE, Brown IF, Kux HJH (2002) A change vector analysis technique to monitor land use/land cover in sw Brazilian amazon: acre state. ISPRS Arch XXXIV:8

Malila WA, Lafayette W (1980) Change vector analysis: An approach for detecting forest changes with Landsat. In: LARS symposia, pp. 326–335

Mesnil A, Habjoka N (2012) The Azraq dilemma, past, present and future groundwater management. German-Jordanian Programme "Management of Water Resources." Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Amman, Jordan

Mouat D, Lancaster J, Wade T, Wickham J, Fox C, Kepner W, Ball T (1997) Desertification evaluated using an integrated environmental assessment model. Environ Monit Assess 48:139–156. doi:10.1023/A:1005748402798

Mountfort G (1965) Portrait of a desert, the story of an expedition to Jordan. Collins, St James's Palace, London

National Research Council (1999) Water for the future. National Academies Press, Washington, DC

Nelson B (1973) Azraq Desert Oasis. Allen Lane - Penguin Books, 21 John Street, London

Palmer AR, van Rooyen AF (1998) Detecting vegetation change in the southern Kalahari using Landsat TM data. J Arid Environ 39:143–153. doi:10.1006/jare.1998.0399

Ramsar Convention (1987) RAMSAR recommendation 3.8: conservation of Azraq Ramsar site, convention on wetlands In: (Ramsar, Iran, 1971) 3rd meeting of the conference of the contracting parties, Regina, Canada

Ramsar Convention (1990a) Ramsar advisory missions: Report No. 17, Azraq Oasis, Jordan

Ramsar Convention (1990b) RAMSAR Recommendation 4.9.3: Azraq Oasis, Jordan, Convention on wetlands. In: (Ramsar, Iran, 1971), 4th meeting of the conference of the contracting parties, Montreux, Switzerland

Ramsar Convention (1998) Ramsar information sheet (RIS) on Ramsar wetlands

Ramsar Convention (1999) Jordan National Report. In: 7th meeting of the conference of the contracting parties to the convention on wetlands (Ramsar, Iran, 1971), San José, Costa Rica

Scates MD (1968) Notes on the hydrobiology of Azraq Oasis Jordan. Hydrobiologia 31:73–80. doi:10.1007/BF00170136

Singh S, Talwar R (2014) A comparative study on change vector analysis based change detection techniques. Sadhana 39(6):1311–1331. doi:10.1007/s12046-014-0286-x

UNCCD (1994) United nations convention to combat desertification in those countries experiencing serious drought and/or desertification, particularly in Africa. Paris

UN-ESCWA and BGR (United Nations Economic and Social Commission for Western Asia; Bundesanstalt für Geowissenschaften und Rohstoffe) (2013) Inventory of shared water resources in Western Asia, Beirut

UNHCR (2015) 2015 UNHCR country operations profile—Jordan. http://www.unhcr.org/cgi-bin/texis/vtx/page?page=49e486566. Accessed 27 Nov 2015

UNICEF (2014) Annual report 2014 Jordan executive summary. http://www.unicef.org/jordan/wash.html. Accessed 27 Nov 2015

WAJ (2007) Water for life Jordan's water strategy 2008–2022. http://www.mwi.gov.jo/sites/en-us/Documents/Jordan_Water_Strategy_English.pdf

WHO (2015) Jordan: water is life. http://www.who.int/heli/pilots/jordan/en/. Accessed 27 Nov 2015

Yarbrough LD, Easson G, Kuszmaul JS (2012) Proposed workflow for improved Kauth–Thomas transform derivations. Remote Sens Environ 124:810–818. doi:10.1016/j.rse.2012.05.003

Zanchetta A, Bitelli G, Karnieli A (2015) Tasselled Cap transform for change detection in the drylands: findings for SPOT and Landsat satellites with FOSS tools. In: Hadjimitsis DG, Themistocleous K, Michaelides S, Papadavid G (eds) Proceedings of SPIE 9535, third international conference on remote sensing and geoinformation of the environment (RSCy2015). doi:10.1117/12.2192597