Detection of land cover changes in Baluchistan (shared between Iran, Pakistan, and Afghanistan) using the MODIS Land Cover Product

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ORIGINAL PAPER

Detection of land cover changes in Baluchistan (shared between Iran, Pakistan, and Afghanistan) using the MODIS Land Cover Product

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Abstract

Land use and land cover (LULC) changes have been one of the most important and persistent factors recently causing changes in the Earth's land. The present study aimed to detect land use and land cover (LULC) changes in Baluchistan, in Southwestern Asia, which is shared by the three countries of Iran, Pakistan, and Afghanistan, using satellite remote-sensing products. To this end, the global land cover classification provided for a period of 13 years from 2001 to 2013 by the MODIS Land Cover Type product (MCD12Q1) was used. The changes and dynamics of different land cover classes were investigated using net change analysis and cross-tabulating matrix analysis methods. The net change analysis showed that the most area of Baluchistan is covered by the barren or sparsely vegetated land cover (about 82%) and the shrubland (about 16%) classes. The dynamics analysis of different land cover classes also indicated that there were almost mutually inverse relationships between the different land cover classes in Baluchistan. Such mutual relationships were most common between the following pair classes: shrublands—bare and non-vegetated lands; grasslands—bare and non-vegetated land classes; croplands—bare and non-vegetated lands classes; and shrublands—grasslands. The most unstable land cover classes in this territory were forests, Savannas, and grassland classes. Also, the analysis of land cover changes in the period 2001–2013 provided no clear and accurate evidence of desertification and land degradation at this spatial scale in Baluchistan.

Keywords Land cover · Land use · Net change · MODIS sensor · Cross-tabulating matrix

Introduction

Land use and land cover (LULC) changes have been one of the most important and persistent factors recently causing changes in Earth's land (Houet et al. 2010). Land use and land cover (LULC) changes can occur due to various factors such as deforestation, flood, soil erosion, and unplanned development in the agricultural sector and unmanaged urban expansion (Muttitanon and Tripathi 2005; Abdullahi et al. 2015). Humans have changed the Earth's surface to gain more food by expanding agricultural activities (Houghton 1994; Squires 2002) and this expansion has accelerated due to the rapid

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growth of the population in recent decades (Houghton 1994; Williams 1994; Hathout 2002).

Baluchistan, as a geographic area, has an arid and semi-arid climate, regardless of the political divisions between Iran, Pakistan, and Afghanistan. Due to this arid and semi-arid climate, there is a very fragile ecosystem in this area. Long-term droughts, excessive use of surface water and groundwater resources, rapid population growth, poverty, inadequate management of land resources, excessive livestock grazing, and deforestation (Ahmed et al. 2016; Ashraf and Routray 2013; Ahmad et al. 2012; Qasim et al. 2011; Shirazi 2006) are the factors exacerbating this fragility. Ashraf and Routray (2013) stated that Baluchistan, as one of the drought-prone provinces in Pakistan, experienced one of the most severe and longest droughts in its history between 1998 and 2002. During this period, crop production declined by up to 50%, and many gardens and springs dried out. Khair et al. (2012) reported a 75 m drop in groundwater levels in the mountainous areas of northeast Baluchistan in the period 1998–2005 due to the excessive use of groundwater resources and believed that this sharp decline in groundwater resources is a great and dangerous threat to local agriculture and the survival of its dependent communities. Moreover, the drying up of the Hamoun International Wetlands and the Jaz Murian Wetland due to hydro-politic problems between Iran and Afghanistan, inadequate management of water resources, and long and severe droughts cause numerous environmental crises such as increased dust storms, movement, and expansion of sand dunes, salinization of croplands, declined crop yields, migration, and so on in the Iranian Baluchistan (Mahmoudi and Rigi Chahi 2019; Dahmardeh et al. 2019; Eskandari Damaneh et al. 2018; Maleki et al. 2018; Askari et al. 2018; Shakeryari et al. 2016).

Today, remote sensing has become a very powerful tool for monitoring land use and land cover (LULC) changes by providing images with high temporal resolution (Yıldırım et al. 1995; Alsharif et al. 2015; Abdullahi and Pradhan 2016; Firoozi et al. 2020a), and the use of it for mapping land use and land cover (LULC(changes has become increasingly important (Pax-Lenney et al. 2001; Watson and Wilcock 2001; Scanlon et al. 2002; Foody 2003; Turner et al. 2003; Paolini et al. 2006). Digital detection of land use and land cover (LULC) changes is a technique to detect and identify changes in the land cover characteristics over time using satellite images (Jensen 2007; Firoozi et al. 2020b). These changes can be categorized into two different categories: (Abdullahi and Pradhan 2016) land cover changes, whose imperceptible changes do not change the land cover class. Changes in this category are often associated with climate variability such as droughts and vegetation fires; (Abdullahi et al. 2015) land cover changes in which one land cover class is completely converted to another (Coppin et al. 2004) such as conversion of a grassland class to a cropland class or conversion of a cropland class to an urban class.

There are various land use and land cover (LULC) change detection methods, which have been reviewed in detail by Attri et al. (2015), Lu and Weng (2007), and Coppin et al. (2004). Arrays of techniques are available to detect land use and land cover (LULC) changes from multi-temporal remote-sensing data sets which can be broadly grouped into two general types (Singh 1989; Jensen 1996; Coppin and Bauer 1996; Ding et al. 1998; Johnson and Kasischke 1998): (Abdullahi and Pradhan 2016) those based on spectral classification of the input data such as post-classification comparison (e.g., Mas 1999) and direct two-date classification (e.g., Li and Yeh 1998) and (Abdullahi et al. 2015) those based on radiometric change between different acquisition dates, including (a) image algebra methods such as band differencing (Weismiller et al. 1977), ratioing (Howarth and Wickware 1981), and vegetation indices (Nelson 1983); (b) regression analysis (Singh 1986; Alsharif and Pradhan 2014); (c) principal component analysis (Byrne et al. 1980; Gong 1993); and (d) change-vector analysis (CVA) (Malila 1980). Based on a mixture of categorical and radiometric change information, hybrid approaches have also been proposed and evaluated (Colwell and Weber 1981; Alsharif and Pradhan 2015). Deer (1998) suggested a three-level categorization system that differentiates these methods by introducing the notion of a pixel, feature, and object-level image processing. The use of a cross-tabulating matrix method has also been extensively used in the detection of land use and land cover (LULC) change in different parts of the world (Zewdie and Csaplorics 2016a; Zewdie and Csaplorics 2016b; Mtibaa and Irie 2016).

In most of these methods, only two or more images, usually Landsat images (Liberti et al. 2009; Asis and Omasa 2007; Vrieling 2006; King et al. 2005; Hill and Schütt 2000; Alsharif and Pradhan 2016), are used to detect changes. These images are used to detect changes by comparing them. Using these methods, limited case studies have been carried out on Baluchistan to detect land use and land cover (LULC) changes in it (Khan and Qasim 2017; Khan et al. 2016; Ahmad et al. 2012). Most of these studies have also confirmed land use and land cover (LULC) changes. Reviewing the literature showed that it is difficult to correctly and accurately detect changes in digital images. Spatial, spectral, and subjective limitations can affect the results of change detection. Even in identical environments, different methods may produce different maps and results (Muttitanon and Tripathi 2005). For this reason, it is important to select the appropriate method for land use and land cover (LULC) studies.

Consequently, based on the existing research background, many of which are mentioned above, it was observed that many studies have considered land use-land cover (LULC) changes in Baluchistan. But there are very few or no studies that specifically address land use-land cover (LULC) change in the whole of Baluchistan as an independent geographical unit, regardless of the existing political divisions between Iran, Pakistan, and Afghanistan. Then, due to the lack of up-to-date spatial information in the field of land degradation and reconstruction in Baluchistan (due to its severe geographical isolation) and due to the availability of 13 years of the MODIS Land Cover Type products of Terra Satellite, the main aim of this study was to investigate land use and land cover (LULC) using the method of cross-tabulating matrix to reveal the potential of desertification and land degradation in Baluchistan.

Study area

Baluchistan is a vast territory situated in the southeast of the Iranian plateau and shared by the three countries of Iran, Pakistan, and Afghanistan. The Persian part of this area is now part of Sistan and Baluchestan province and its Pakistani part is also the largest state in Pakistan, which is called Baluchistan. The exact border of this vast region is not clear (Frye and Elfenbein 2019). Its area is about 769,824 km^2, of which about 361,738 km^2 are in Pakistan, 302,845 km^2 in Iran, and 105,241 km^2 in Afghanistan (Fig. 1). Baluchistan is geographically divided into four areas of upper high lands, lower high lands, plains, and deserts (Ahmad et al. 2014). Upper high lands with an elevation of 1500 m above sea level are located in the northeast of Baluchistan and lower high lands with elevations between 600 and 1200 m are located above sea level in the southeast of Baluchistan. The plains are mostly in central and western Baluchistan and the deserts are located in the north, northwest, south, and southwest of Baluchistan (Government of Balochistan 2019). The area has a population of about 15.7 million people, 78.5% of which is in the Baluchistan State of Pakistan, 17.7% in the Sistan and Baluchestan province of Iran, and the remaining 3.8% in Afghanistan. Baluchistan has different climates due to its complex topography and vast area. According to De Martonne climate classification (De Martonne 1909), there are seven different climate classes in this territory. But since Baluchistan is located in the desert belt of the Northern Hemisphere, much of it is dominated by subtropical high-pressure cells. Thus, much of it, except for its northeastern part, which is mountainous, has an arid and semi-arid climate. In Baluchistan, the average annual temperature varies between 15 and 40 °C, with the lowest average annual temperature in its northeast part and the highest on the south coast. In Baluchistan, its central and northeastern parts experience the lowest (ranging 50–100 mm) and highest (ranging 600–650 mm) average annual precipitation.

Data and methodology

In this study, the global land cover classifications provided by the MODIS land cover type product (MCD12Q1) for a period

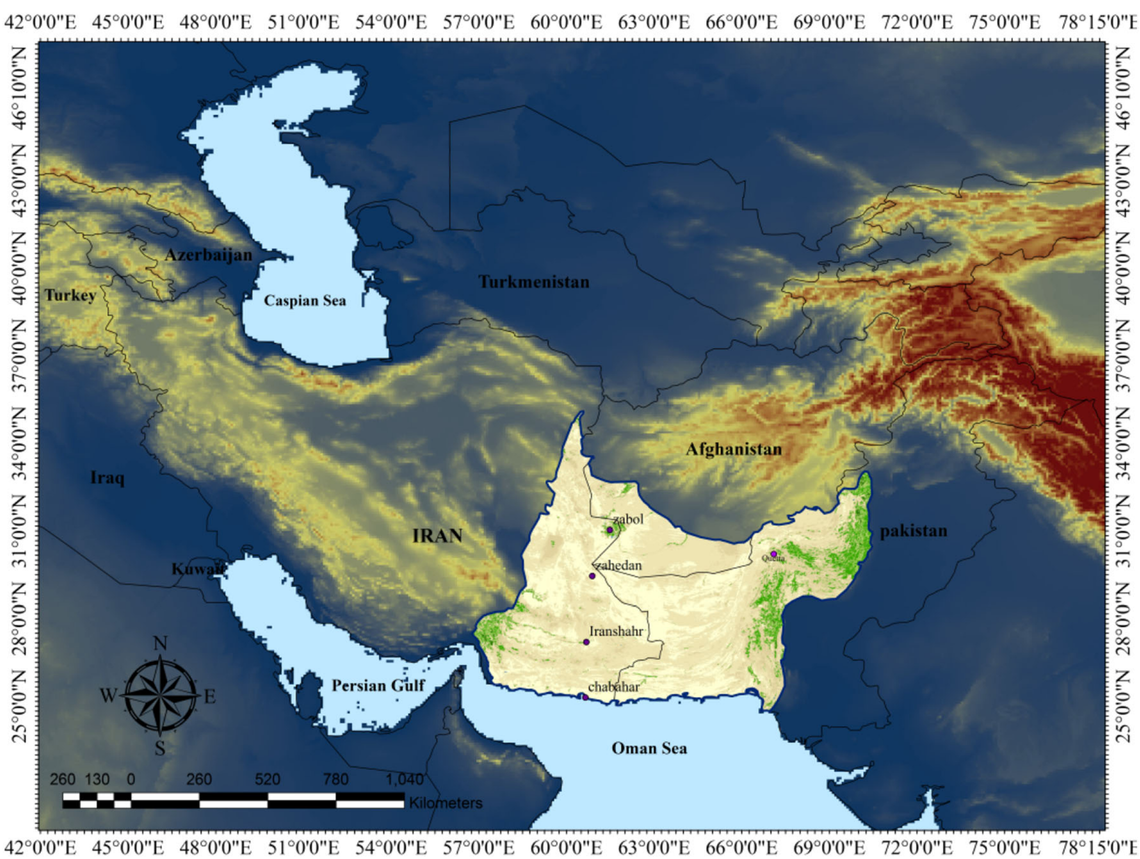

Fig. 1 Geographic location of Baluchistan in Southwest Asia, shared by Iran, Pakistan, and Afghanistan

of 13 years from 2001 to 2013 were used to detect land cover changes in Baluchistan, Southwest Asia. The MODIS land cover type product contains various classification schemes describing the land cover characteristics yearly derived from the observations of the Terra and Aqua data (NASA 2012). Different types of MODIS products were used as inputs for this type of product:

- MOD44W–EOS Land/Water Mask
- MOD42B4–Nadir BRDF Adjusted Reflectance (NBAR)
- MODAGTEX–Spatial Texture derived from Band 1, red, 250 m
- MOD43B1–Directional Reflectance Information
- MOD13Q1–MODIS Enhanced Vegetation Index (EVI)
- MOD10–Snow Cover
- MOD11–Land Surface Temperature (LST)
- MOD03–Terrain Elevation Information

This data set was prepared over a 1-month time period to produce a globally consistent, multi-temporal database on a 1-km grid as input to classification and change characterization algorithms (Strahler et al. 1999). In this study, the new data of the refined Collection 6 MODIS Global Land Cover Type product were used to improve and correct spatial resolution using annual EVI, LST, and NBAR metrics (Sulla-Menashe and Friedl 2018). Table 1 summarizes the important information of this set. Land cover classes are generated by processing a 32-day database and using supervised classifications, decision trees, and artificial neural network classification algorithms, based on training data (Strahler et al. 1999; Friedl et al. 2010). The training data for the collection 6 product include 1860 points distributed across the Earth's lands that are validated using Landsat data or higher spatial resolution data (Friedl et al. 2010).

The MODIS land cover type product was developed to support scientific research as well as to study the dynamics of global land cover characteristics at seasonal to decadal time scales (Friedl et al. 2010). This product consists of six main layers that map the land cover using different classification systems:

- 17-class International Geosphere-Biosphere Programme classification (IGBP(
- 14-class University of Maryland classification (UMD(
- 10-class system used by the MODIS LAI/FPAR algorithm
- 8-biome classification
- 12-class plant functional type classification
- FAO-Land Cover Classification System land cover (LCCS1) legend

In this study, among different land cover classification systems, only the UMD land cover classification system was analyzed. This classification system was chosen due to its greater agreement with the realities of land cover in Baluchistan compared with other classification systems. This agreement was also confirmed by land-based surveys using GPS. The UMD land cover classification system was first introduced on AVHRR data in 2000 at the University of Maryland. In this land cover classification system, a hierarchical tree structure was used to classify the data into 14 classes based on the minimum annual red reflectance, peak annual NDVI, and minimum blue band brightness (Hansen et al. 2000). These 14 classes have been listed in Table 2.

Knowing the geographical and climatic conditions in Baluchistan as well as the share and importance of different

Table 1 Main characteristics of MODIS land cover type product

Product name	MODIS land cover type
Product name code	MCD12Q1
Version number = 9	6
Spatial resolution	500 m (463.312 m)
Temporal resolution	Yearly
Availability	2001–present
Tile size (km)	approx. 1200 × 1200
Tile size (pixel)	2400 × 2400
Projection	Sinusoidal grid projection

Table 2 Reclassification of UMD land cover classes

New codes	Reclassified land cover	Old codes	UMD land cover classes
1	Water	0	Water bodies
		11	Permanent wetlands
2	Forest	1	Evergreen needleleaf forests
		2	Evergreen broadleaf forests
		3	Deciduous needleleaf forests
		4	Deciduous broadleaf forests
		5	Mixed forests
3	Shrublands	6	Closed shrublands
		7	Open shrublands
4	Savannas	8	Woody savannas
		9	Savannas
5	Grasslands	10	Grasslands
		12	Croplands
6	Croplands	14	Cropland/natural vegetation mosaics
7	Urban	13	Urban and built-up lands
8	Non-vegetated lands	15	Non-vegetated lands
		255	Unclassified

Table 3 An example of a cross-tabulating matrix

	Time 2					Total time 1	Loss
	Category 1	Category 2	Category 3	…	Category *n*		
Time 1							
Category 1	$P_{1,1}$	$P_{1,2}$	$P_{1,3}$	…	$P_{1,n}$	$P_{1,+}$	$P_{1+} - P_{1,1}$
Category 2	$P_{2,1}$	$P_{2,2}$	$P_{2,3}$	…	$P_{2,n}$	$P_{2,+}$	$P_{2+} - P_{2,2}$
Category 3	$P_{3,1}$	$P_{3,2}$	$P_{3,3}$	…	$P_{3,n}$	$P_{3,+}$	$P_{3+} - P_{3,3}$
…	…	…	…	…	…	…	…
Category *n*	$P_{n,1}$	$P_{n,2}$	$P_{n,3}$	…	$P_{n,n}$	$P_{n,+}$	$P_{n+} - P_{n,n}$
Total time 2	P_{+1}	P_{+2}	P_{+3}	…	P_{+n}	1	
Gain	$P_{+1} - P_{1,1}$	$P_{+2} - P_{2,2}$	$P_{+3} - P_{3,3}$	…	$P_{+n} - P_{n,n}$		

land cover classes in this area, first, the UMD classification system was reclassified to reduce the number of classes. This reclassification attempted to reduce classes by integrating unnecessary and marginal classes into the main classes. The reclassification allowed researchers to focus on those classes of land cover types and their positions that play the most roles in desertification and land degradation. The results of the integration of unnecessary and marginal classes into the main classes have been listed in Table 2.

Investigating the net change of different land cover types and analyzing their trends over time, some useful primary information about land cover systems may be obtained, although it is obvious that it does not provide specific knowledge about the conversion of one class to another. In other words, it is not possible to determine which land cover class was converted to another or which class caused fundamental changes in other land cover types (Pontius et al. 2004). Thus, in order to meet this weakness, it was necessary to use other methods that could provide more information in this regard. One of these methods was cross-tabulating matrix (Pontius and Cheuk 2006). An example of this cross-tabulating matrix has been illustrated in Table 3 to know its

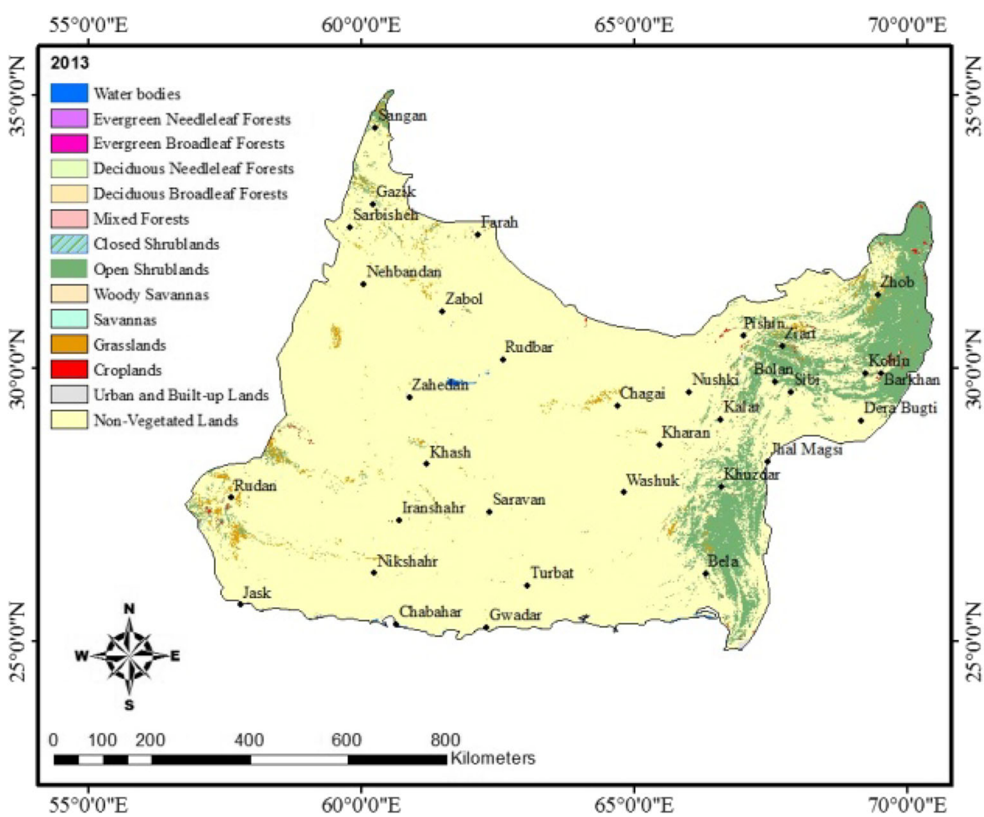

Fig. 2 Spatial distribution map of different land cover classes in Baluchistan, Southwest Asia, in 2013

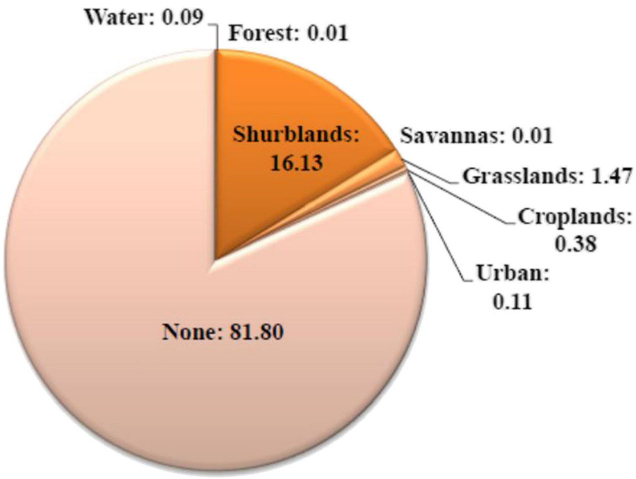

Fig. 3 Share of different land cover classes in Baluchistan, in Southwest Asia, in 2013 (in percent)

basic principles. In this matrix, the percentage of each land cover was placed at time t in rows and at time $t+1$ in columns. Elements of the diagonal of the matrix represented stable land cover classes and the remaining elements represented land cover changes from one class to another at the time interval from t to $t+1$. For any given class, the net change was estimated by calculating the difference between P_{+n} and P_{n+}.

Cross-tabulating matrices were calculated based on raster data with a spatial component. Thus, the cross-tabulating matrix can be seen as a summary of the underlying data containing spatial information. The simplified basic formula used for calculating the cross-tabulating raster was as follows:

$$\text{cross-tabulating-raster} = ([\text{LCT raster }(t)] \times 100) + [\text{LCT raster }(t+1)] \quad (1)$$

This formula was used for all land cover classes from 2001 to 2013; 8×8 cross-tabulation matrices were prepared. Comparing the two distinct points in these cross-tabulating tables over time indicated the locations where specific geographic changes occurred.

Results

Primary evaluation of land cover changes

Spatial distribution of different land cover classes over the whole studied period, obtained from the UMD land cover classification system, were presented in 13 maps. For example, Fig. 2 shows the spatial distribution map of the land cover classes in 2013. Bare and non-vegetated lands in the center and west, shrublands in the east, and a combination of croplands and grasslands in the southwest also had the highest spatial concentration in Baluchistan (Fig. 2). Considering the share of each land cover class in 2013, it was found that the bare and non-vegetated lands (81.8%) and shrublands (16.13%) had the largest shares of the area of Baluchistan (Fig. 3). These two classes, especially the shrubland class, can play a key role in Baluchistan's environmental systems, followed by grasslands, croplands, and urban classes, with 1.47%, 0.38%, and, 0.11% share, respectively. Savannas, forests, and waterbody classes had the smallest shares of the area of Baluchistan (Fig. 3).

Figure 4 shows the evolution of the share of each land cover class in the period 2001–2013. The largest growth was observed in the shrubland class between 2001 and 2009. Over the 2 years, a 6.52% rise was observed in the shrubland class. In 2001, this class accounted for 10.71% of the total area of Baluchistan and 17.23% in 2009. On the other hand, between 2001 and 2009, a 6.38% decline was observed in the bare and non-vegetated land cover class. In 2001, this class accounted for 87.64% of the total area of Baluchistan and 81.26% in 2009. Grasslands, forests, and waterbody classes also experienced 0.32%, 0.1%, and 0.04% decline, respectively. But from 2009 to 2013, the share of the shrubland class has decreased while the share of the class of bare and non-vegetated lands has increased. However, the increase has not been significant at all.

The grassland class has also experienced many changes in its share over the studied 13 years. The lowest percentage of this class was observed in 2003 (0.55%) and the highest in 2011 (1.69%). The cropland class has also varied from 0.11% (2004)

Fig. 4 Evolution of the share of each land cover class obtained from the UMD land cover classification system in Baluchistan, in Southwest Asia, in the period 2001–2013

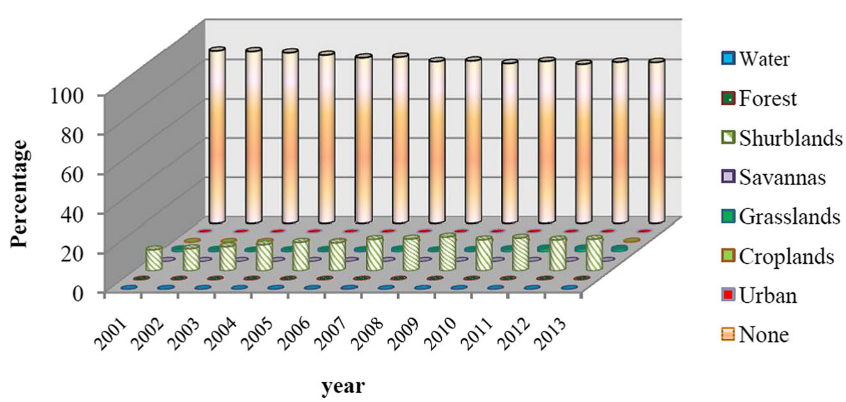

Table 4 All land cover classes' shares of the total area of Baluchistan, in Southwest Asia, based on the UMD land cover classification system in the period 2001–2013 (in percent)

Year	Water	Forest	Shrublands	Savannas	Grasslands	Croplands	Urban	Non-vegetated lands
2001	0.14	0.01	10.71	0.01	1.20	0.19	0.11	87.64
2002	0.12	0.00	11.31	0.00	0.95	0.14	0.11	87.36
2003	0.13	0.00	12.34	0.00	0.55	0.16	0.10	86.72
2004	0.11	0.01	13.34	0.00	0.79	0.11	0.11	85.54
2005	0.15	0.01	14.56	0.00	0.89	0.14	0.11	84.14
2006	0.09	0.01	14.27	0.00	0.84	0.18	0.11	84.50
2007	0.15	0.00	16.06	0.01	1.14	0.31	0.11	82.23
2008	0.09	0.00	16.21	0.00	0.68	0.30	0.11	82.60
2009	0.10	0.00	17.23	0.01	0.88	0.42	0.11	81.26
2010	0.08	0.00	15.86	0.01	1.27	0.33	0.11	82.34
2011	0.09	0.00	16.75	0.01	1.69	0.52	0.11	80.83
2012	0.09	0.01	15.78	0.01	1.64	0.40	0.11	81.97
2013	0.09	0.01	16.13	0.01	1.47	0.38	0.11	81.80

to 0.52% (2011). The waterbody class, which also accounted for a very small percentage of the total area of Baluchistan, has changed yearly. In 2005 and 2007, it reached its maximum value of 0.15%, and in 2010, its minimum value of 0.08%. Other classes, such as forests, savannas, and urban classes, have either been unchanged or experienced little change during the 13 years. Table 4 shows each land cover class's share of the total area of Baluchistan, presented in Fig. 4.

As Table 4 shows the shares of all land cover classes in percent, Table 5 shows the absolute changes in the area of each of the eight land cover classes in square kilometers. In this table (Table 5), the negative values in red indicate the decrease in area and the positive values in black indicate the increase in the area of each land cover class from year to year. As shown in Table 5, except for the urban class that has not experienced any changes during the 13 years studied, the remaining classes have experienced an increase or decrease in area. The savannas class covering a very small area of Baluchistan was the only land cover class, which has experienced an ascending trend for 7 years from 2004 to 2011. This variation trend has been the longest continuous variation trend among all the studied eight classes. The shrubland class, as the most important and major land cover, especially in eastern Baluchistan, has experienced both incremental and decremental changes. But its incremental changes were more than decremental ones. Its maximum incremental change was observed during 2006–2007 (13837.7 km^2) and its maximum decremental was observed during 2011–2012 (7550.2 km^2). As noted earlier, and shown in Table 5, it is obvious that the increase in the shrubland class has been accompanied by a decrease in the bare and non-vegetated land class, and then other classes, especially grasslands and croplands classes. But such a relationship between the shrubland class and the bare and non-vegetated land class has not been the case all year, and many exceptions can be observed (Table 5).

Figure 5 shows the net changes of the eight land cover classes between 2001 and 2013, as presented in Table 5 as decreasing or increasing values. In this diagram (Fig. 5), the decreasing or increasing variations of the different land cover classes are visible. According to the diagram, most land cover changes occurred in the periods of 2003–2004 and 2006–2007. During 2003–2004, there was a tremendous increase in the absolute area of grasslands (244,427.7 km^2), followed by the shrublands (7771.5 km^2). The increase in the area of grassland class was the largest incremental change among all the classes in the first studied period. During 2006–2007, the second largest change in land cover classes in Baluchistan is observed. During this period, the increases in the areas of shrublands (13,837.7 km^2), grasslands (3333.7 km^2), croplands (1046 km^2), and water bodies (408 km^2) are visible. In contrast to this development, the greatest reduction is observed in the area of bare and non-vegetated lands (17,627 km^2).

The inverse incremental-decremental relationship between the grassland and cropland classes with the bare and not-vegetated land's class that has been visible for most of the studied years can be explained by the geographic conditions of the transition zones (ecotones). In these transition zones (ecotones), the shares of different land cover classes may change several times over the studied time. This may be due to the sensitivity of the classification algorithm or as a result of seasonal variability of the climate affecting the growth of plants in transition zones.

Cross-tabulating matrices

To detect the dynamics of different land cover classes obtained from the UMD land cover classification system, four cross-tabulating matrices were prepared for the years of 2001–2004, 2004–2007, 2007–2010, and 2010–2013. Here, for example,

Table 5 Net change of land cover type obtained from the UMD classification system for Baluchistan, in Southwest Asia, in the period 2001–2013 (in km^2). Italicized values indicate the decrease in land cover class and bold values indicate the increase in land cover class

Year	2001–2002	2002–2003	2003–2004	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013
Land cover												
Water	*− 85.5*	*− 34.7*	*− 180.2*	**7052.2**	*− 422.5*	**408**	*− 418.5*	**54.2**	**98.5**	*− 69.5*	**32.7**	*− 30*
Forest	*− 12.7*	*− 13*	**48.7**	**− 22.2**	**10**	*− 25.5*	*− 2.2*	*− 4.7*	*− 3.7*	**6.2**	**27**	**40.2**
Shrublands	*− 4654.5*	**8007.7**	**7771.5**	**9463.7**	*− 2224.5*	**13837.7**	**1230**	*− 2751.7*	**10642.5**	*− 3730.5*	*− 7550.2*	**2739.5**
Savannas	*− 25.7*	*− 15*	*− 11*	**8.5**	**23.2**	**23.5**	**16.7**	**19.2**	**12**	**22**	*− 15.2*	**25.2**
Grasslands	*− 1937*	*− 3175.7*	**24427.7**	**761.2**	*− 390.5*	**2337.2**	*− 3564.2*	**4586**	*− 3064.5*	**6302.2**	*− 355.5*	*− 1317.7*
Croplands	*− 389.5*	**132.2**	*− 369*	**265**	**263.5**	**1046**	*− 82.2*	**239**	**674**	**778.7**	*− 969*	*− 148*
Urban	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Non-Vegetated Lands	**2181.7**	**4971**	*− 8403*	*− 8405.5*	*− 10828.2*	*− 17627*	**2583.2**	*− 2033.5*	*− 8358.7*	*− 3309.25*	**8839.2**	**1318.2**

and also, as a basis for discussion of variations in land cover classes and their dynamics over time, the cross-tabulating matrix related to 2 years of 2001 and 2004 (the first 3 years of the studied period) has been presented. The diameters of the matrices, shown in Italics, actually represent stable areas. The values in red represent the largest transitions between different land cover classes. Bold cells also indicate changes. Although these cells are not as important as the values in Bold and Italics, they should not be ignored in any case.

The total areas of all land cover classes are summarized in the "Total" column. In addition, the absolute loss and gain, as well as their percentages, were calculated and listed in the related columns. To derive net changes from cross-tabulating matrices, the difference between loss and gain of each land cover class must be calculated. Finally, to ensure the correctness of the analysis, the obtained areas should be equal to the areas calculated in the actual assessments.

According to Table 6, showing the net changes of the eight land cover classes over the 3-year periods, it is observed that the shrubland class had a gain of 20,433.7 km^2 in Baluchistan between 2001 and 2004. In the cross-tabulating matrix produced for this period, it is observed that this net change was the result of a gain of 29,874.5 km^2 and a loss of 9440.7 km^2 in the studied area (Table 7). The matrix also shows that a total 20,433.7 km^2, which was the difference between the two

Fig. 5 Evolution of temporal changes in the area of each land cover class in the period 2001–2013, in km^2

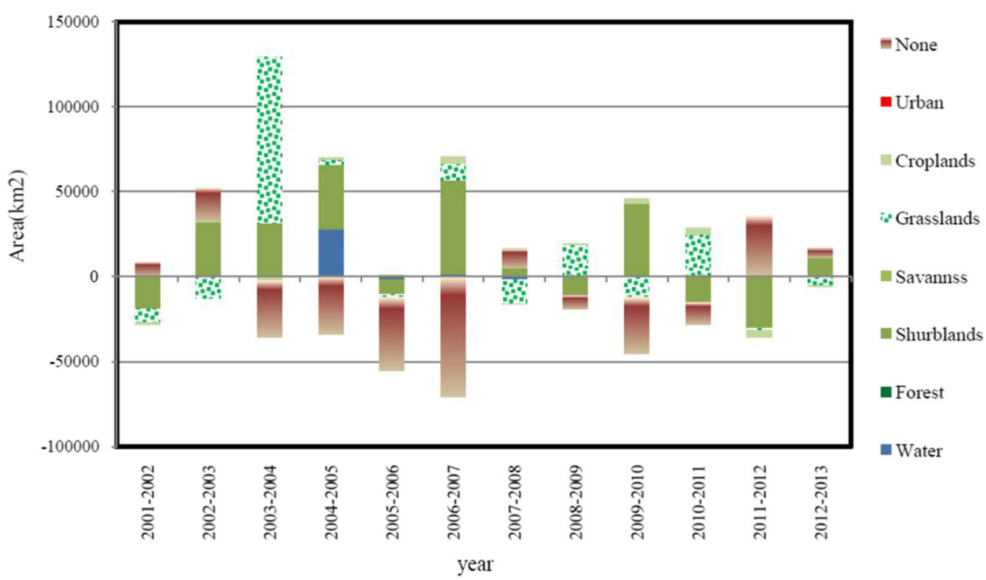

Table 6 Net changes of the eight land cover classes in the 3-year periods, in km^2

Land cover type	2001–2004	2004–2007	2007–2010	2010–2013
Water	− 231	305.2	− 473	31.7
Forest	23	− 37.7	− 7	69.7
Shrublands	20433.7	21077	− 1521.7	2101.2
Savannas	− 52.5	33.5	2.5	43.7
Grasslands	− 3185	2708	1021.7	1564.5
Croplands	− 626.2	1574.5	157.5	335.7
Urban	0	0	0	0
Non-vegetated lands	− 16330.5	− 25692	819.7	− 4147

Table 8 Loss, gain, and stability in the area of each eight land cover classes obtained from the UMD land cover classification system in the period 2001–2004, in percent

Land cover type	Loss in %	Gain in %	Stability in %
WAT	25.7	4.9	69.4
FOR	76.5	70.1	0
SHU	11.3	28.8	59.9
SAV	94.1	65.9	0
GRL	29.3	70.7	0
CRL	63.2	36.4	0.4
UBU	0	0	100
BAR	4.4	2.01	93.59

values of 2987.55 (sum of increased areas) and 9440.7 (sum of decreased areas), was affected by the dynamics of these mutual changes (Table 7). But, about the bare and non-vegetated lands, the net changes showed a loss of 16,330.5 km^2 between the period 2001 and 2004 (Table 6). According to the cross-tabulating matrix, this loss was the difference between the two values of 30,123 (sum of increased areas) and 13,793.2 (sum of decreased areas) (Table 7). It is therefore observed that the area affected by these changes was several times larger than the value obtained from the net change analyses.

The net change of grassland class was about + 1609 km^2, resulting from a gain of 4348 km^2 and a loss of 2739 km^2. This value was not only very different from the one obtained from the net change analysis but was precisely the opposite. The net change analysis showed a loss of 3185 km^2 in the area of the grassland class.

Table 8 shows the loss, gain, and stability in the area of each eight land cover classes in the period 2001–2004. According to Table 8, it can be seen that the urban class was the only class with no changes in its area and its value remained constant. But the forests, savannas, and grassland classes were completely unstable and no stability was observed during this period (2001–2004) (it should be noted that in any case where the sum of loss and gain values exceed 100%, that land cover class is completely unstable). The instability of these classes must be analyzed with their absolute values. As shown in Table 4, it can be seen that the share of each of these classes is negligible. About 40% of the area of the shrubland class, which accounted for the largest area after the bare and non-vegetated land class, has changed dynamically in the period 2001–2004.

By examining the percentage of loss, gain, and stability in the area of each eight land cover classes in Baluchistan, it was observed that the forests, savannas, and grassland classes were

Table 7 Cross-tabulating matrix of the eight land cover classes obtained from the UMD land cover classification system for the period 2001–2004, in km^2

	2004									2001		
		WAT	FOR	SHU	SAV	GRL	CRL	UBU	BAR	Total 2001	Loss	%Loss
2001	WAT	*782.5*	6.2	1.5	0	3	1.7	0	**258.7**	1053.7	271.2	25.7
	FOR	17.2	*9.5*	1.5	1.7	1.5	1.2	0	**7.7**	40.5	31	76.5
	SHU	1.7	0.2	*73,774.2*	3.2	**402**	212.2	0	***8821.2***	83,215	9440.7	11.3
	SAV	3.5	3	18.5	*3.7*	5.5	7.5	0	**22.2**	64	60.2	94.1
	GRL	8.2	8.7	***2927.5***	0.7	*1082.2*	26.2	0	***4561.5***	9335.2	2739	29.3
	CRL	0.5	0	798	1.5	17	*545.7*	0	121.7	1484.5	938.7	63.2
	UBU	0	0	0	0	0	0	*826*	0	826	0	0
	BAR	9	4	***26,127.5***	0	***3919***	63.5	0	*650,704.7*	680,827.7	30,123.7	4.4
2004	Total 2004	822.7	31.7	103,648.7	11	6150.2	858.2	826	664,498			
	Gain	40.2	22.2	29,874.5	7.2	4348	312.5	0	13,793.2			
	%Gain	4.9	70.1	28.8	65.9	70.7	36.4	0	2.01			

the most unstable land cover classes in Baluchistan due to their very small areas. Shrublands and water zone classes were also the most dynamic land cover classes. Bare and non-vegetated lands and cropland classes were the two land cover classes with little changes. However, they still reflect the fact of inverse development.

Dynamic development of land cover changes

In general, the major land cover changes in Baluchistan have been mutual changes or often, between the following pair classes: shrublands—bare and non-vegetated lands; grasslands—bare and non-vegetated lands; croplands—bare and non-vegetated lands; and shrublands—grasslands. In most of the studied years, the areas affected by the mutual changes for the shrublands and the bare and non-vegetated land classes were more than 7500 km^2, and in some periods, such as 2001–2004, it reached above 31,750 km^2, which means about 4% of the total area of Baluchistan. Clearly, this was the largest change among the different land cover classes in Baluchistan, since these two land cover classes covered the largest area of Baluchistan and the largest sensitive transition area. Figure 6 shows the dynamic development of these two land cover classes. According to Fig. 6, it is clear that the two classes were significantly related to each other and affected each other dynamically and perhaps even cyclically. But this requires more investigations, data prepared in a longer period, and more advanced statistical methods. In addition, the dynamics have declined from the early years to the late years.

The dynamics between the grassland and bare and non-vegetated land classes is illustrated in Fig. 7. As seen in Fig. 7, the dynamics of the class of bare and non-vegetated lands to the grassland class has increased over the studied 13 years compared with its inverse dynamics, namely conversion of the grassland class to bare and non-vegetated land class. At the beginning of the studied period, it was approximately 3750 km^2, while at the end of the period, it increased to more than 5250 km^2. As discussed earlier, the grassland class has been one of the most unstable land cover classes in Baluchistan, due to its very smaller share compared with other land cover classes.

The third land cover change was related to changes between grassland and shrubland classes. Figure 8 shows that the areas of grasslands converted to shrublands and vice versa varied yearly, and no specific regularity was observed. The reason for this irregularity was certainly the very small area of rangeland area and their extreme instability in this part of the world with an arid and semi-arid climate. During 2001–2004, only 402 km^2 of shrublands was converted to grasslands, while in contrast, 2927.5 km^2 of grasslands was converted to shrublands. At the end of the studied period (2001–2013), it is observed that in addition to the fact that the differences between the conversion of these two classes have been reduced, their value has decreased.

In addition to the conversions above mentioned, the mutual conversions of the two croplands and bare and non-vegetated land classes must be considered. There was a mutual relationship between them. About these two classes, croplands-to-bare and non-vegetated land conversion was more than its inverse conversion (Fig. 9).

In addition to the conversions above mentioned, there were almost unilateral conversions for classes such as savannas, forests, and even water bodies. During the studied period, it was observed that the areas of the forests, savannas, and water body classes decreased, increased, and decreased, respectively.

Discussion

Land use and land cover (LULC) changes have been one of the most important and persistent factors recently causing changes in the Earth's land. Thus, the main purpose of this study was to investigate land use/land cover changes in

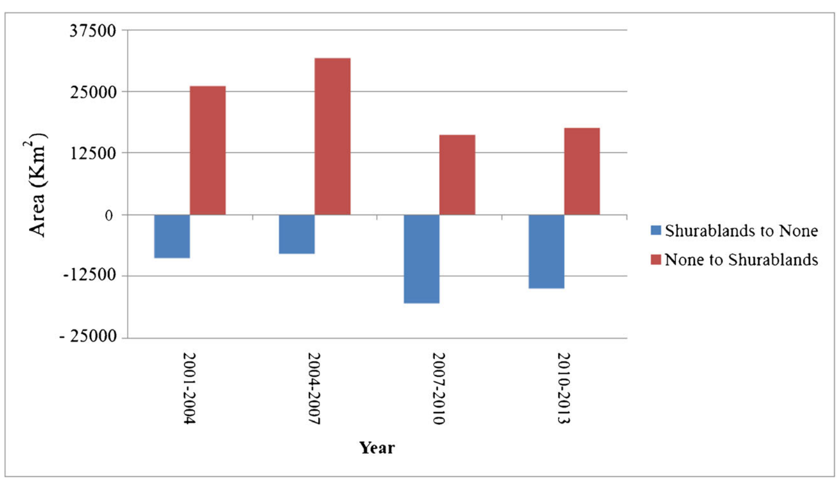

Fig. 6 Development of conversion between shrublands and bare and non-vegetated land classes from 2001 to 2013 at 3-year intervals and in km^2

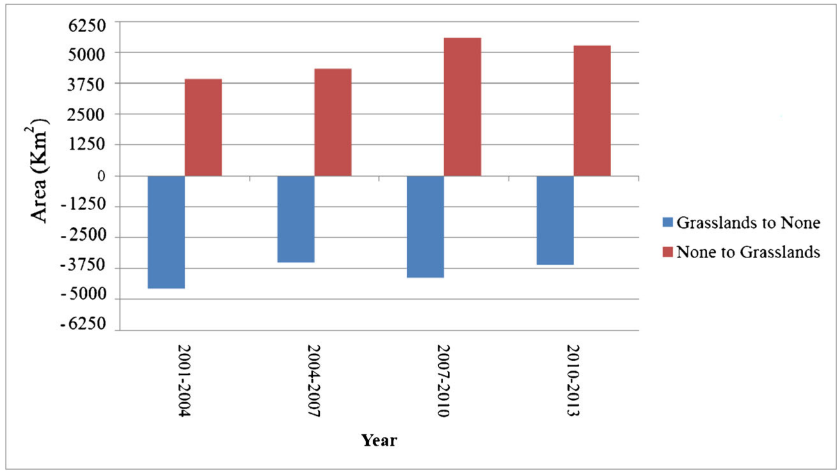

Fig. 7 Development of conversion between grasslands and bare and non-vegetated land classes from 2001 to 2013 at 3-year intervals and in km^2

Baluchestan located in the south-west of Asia to demonstrate desertification and land degradation using land cover world databases. The changes and dynamics of different land cover classes were investigated using net change analysis and cross-tabulating matrix analysis methods. Investigating the spatial distribution maps of different land cover classes and determining their share of the total area of Baluchistan, it was found that the shrublands (about 82%) and bare and non-vegetated lands (about 16%) classes were the most important and dominant land cover in Baluchistan, respectively. The net change analysis of different land cover classes showed that the greatest increase in the area was related to the shrublands, which was about 6.52% in the period 2001–2009. This increase was associated with a 6.38% decrease in the area of the bare and non-vegetated land class and a 0.14% decrease in the area of grasslands, forests, and water bodies' classes. Investigating the dynamics of different land cover classes also showed that there was a mutual relationship between the bare and non-vegetated lands and shrubland classes, that is, an increase in the area of one of them was associated with a decrease in the area of another one. Such a mutual relationship has also been observed between the grasslands and the bare and non-vegetated land classes, the croplands, and the bare and non-vegetated lands, as well as the shrubland and the grassland classes. Regardless of the bare and non-vegetated lands and shrubland classes that are the most stable land cover classes in Baluchistan, other classes, especially croplands, water bodies, and grasslands, experienced extreme instability.

It can be very important to pay attention to the instability of these three classes (croplands, water bodies, and grasslands) in Baluchistan, especially in its land management. What has made this important is the livelihood based on agriculture and animal husbandry of the inhabitants of this land, especially in rural areas. Numerous reasons can be mentioned for the instability of these three classes of land cover in Baluchistan. The occurrence of severe and prolonged droughts (Ashraf and Routray 2013; Ahmed et al. 2016), overgrazing of livestock (Shirazi 2006), improper use of groundwater resources (Khair et al. 2012), improper management of land resources (Ahmad et al. 2012; Eskandari Damaneh et al. 2018), and hydropolitical problems between Iran and Afghanistan (Ettehad 2010) can be the most important of these factors. In general, the effects of these instabilities can be seen in increasing dust storms

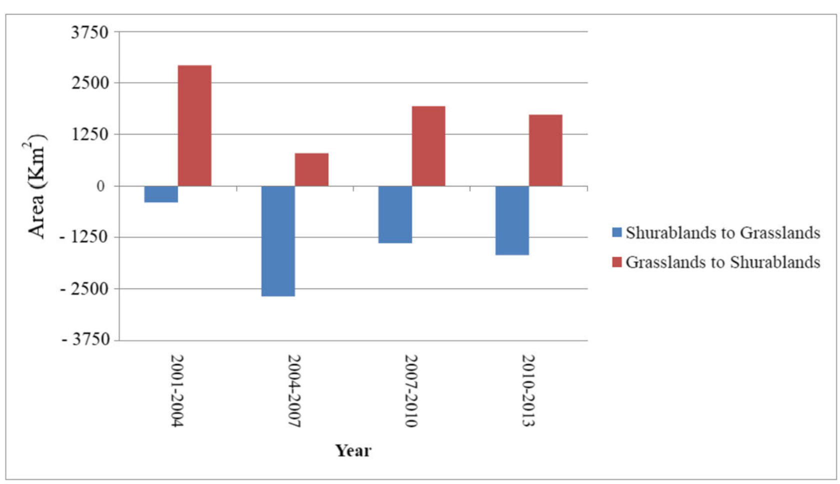

Fig. 8 Development of conversion between grasslands and shrubland classes from 2001 to 2013 at 3-year intervals and in km^2

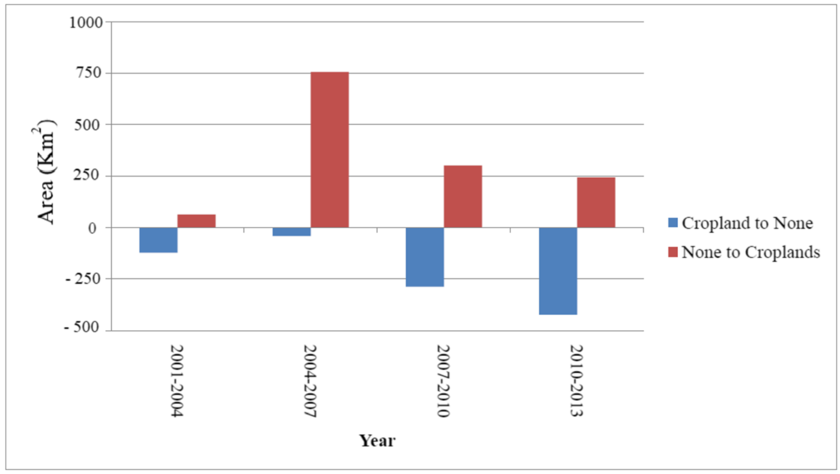

Fig. 9 Development of conversion between croplands and bare and non-vegetated land classes, from 2001 to 2013, at 3-year intervals and in km^2

(Mahmoudi and Rigi Chahi 2019), movement, and expansion of sand dunes (Asgari Lafmejani and Naderianfar 2015), salinization of croplands (Chandio et al. 2017), the reduced yield of agricultural products, and migration. Therefore, considering the arid and semi-arid climate of this area, the instability of cropland and grasslands can be a very serious warning in the field of Baluchistan land management. This instability can also jeopardize the stable rural livelihoods, which is heavily dependent on livestock and agricultural land.

Zewdie and Csaplovics (2016a, b) and Mtibaa and Irie (2016) found the use of a cross-tabulating matrix method to be very appropriate in detecting land use/land cover change (LULC). In these studies, they used the cross-tabulating matrix method for only a few Landsat satellite images and a limited area. Another very important point that has become more apparent in these studies is their non-use of ready-made ground cover products of various satellite sensors. In their studies, they used different supervised and unsupervised classification methods to determine the different land cover/land use classes in their study area. Though it seems that the use of a cross-tabulating matrix method for very large study areas such as Baluchistan and also the use of the MODIS Land Cover Type products of Terra Satellite with medium spatial resolution cannot provide accurate spatial details of land cover/land use changes. This may be due to the nature of the UMD classification system, which is slightly erroneous for arid and semi-arid regions of the world with sparse vegetation.

Conclusion

Using land cover classification at more than two distinct points in time reveals the development of dynamics and therefore exposes additional important information. As it was shown, cross-tabulating is a key method to assess not only net change but more important the dynamics between different land cover type classes. Comparison of the two methods of net change analysis and cross-tabulating matrix analysis showed that it was not adequate and sufficient to compare the distribution and share variation of different land cover classes at two or more specific time points to understand the land cover change processes. The cross-tabulating matrix analysis is, in fact, a method that complements the perceptions obtained from the primary evaluations. Therefore, these methods only provide primary information about the changes and dynamics of land cover in an area for researchers, planners, and policymakers, and it is required to use smaller limits and higher spatial resolution images to obtain more detailed and accurate information. Thus, to obtain more accurate information, it is suggested that in the future, the results of this study be considered by changing the variability of climatic and meteorological variables such as precipitation and temperature to understand the dynamics of land use/land cover (LULC). Furthermore, droughts and their short-term and long-term effects on vegetation degradation are another issue that has not been addressed in this study and could be seriously considered by researchers in the future. It is suggested that with newer classification methods, land use dynamics/land cover (LULC) in Baluchistan be studied and their results be compared with the results of this study. Finally, the analyses of land cover changes in the period 2001–2013 provided no clear and accurate evidence of desertification and land degradation at this spatial scale in Baluchistan.

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