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ORIGINAL ARTICLE

Landscape dynamic characteristics using satellite data for a mountainous watershed of Abha, Kingdom of Saudi Arabia

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Abstract The changes in land use/land cover (LULC) play a major role in the study of various aspects of environmental issues. Land use is the results of various socio-economic activities taking place at various urban and regional setups. In this paper, landscape dynamic characteristics are investigated by using remote sensing and geographic information system in mountainous watershed of Abha, Saudi Arabia. Land use classes were mapped and assessed from a time series of maps of year 2000–2010. The LULC transformations were also analyzed according to elevation and slope. Assessment of the data shows that LULC had undergone substantial changes in this semi-arid mountainous watershed from 2000 to 2010. During this period, the sparse vegetation and water bodies decreased from 48.47 to 39.31 km^2 and 0.30 to 0.11 km^2, respectively, whereas build-up area increased from 17.02 to 36.36 km^2. The area under water bodies has reduced due to construction activities, disturbance in drainage network, and sedimentation in the watershed. The areas having high altitudes were exposed to changes in landscape characteristic. In the regions having lower altitude (1,950–2,350), an agricultural land has decreased, whereas build-up land has increased. As a result of rough structure, only small flat areas, located in this sections and valley channels, may be used as build-up land. Slope gradient had also an influence on the distribution of LULC. The assessment of land use and land cover type distribution by slope category provided the baseline for the implementation of the nationwide land conservation policy of conversion of agricultural land to forestland in order to control high soil erosion risk. The changes in land use and land cover in the studied watershed were mainly controlled by human factors (land management, construction, and population pressure) rather than natural factors.

Keywords Land use/land cover · Mountainous watershed · Elevation · Slope · Remote sensing and GIS

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Introduction

Studies have shown that there remain only a few landscapes on Earth, which are currently in their natural state (Mark and Kudakwashe 2011). Man's presence on the Earth and use of land have had a profound effect upon the natural environment (Wilkie and Finn 1996; Briney 2008), thus resulting into change in the land use/land cover (LULC) pattern over different time (Tiwari and Saxena 2011). This human/natural interference has largely resulted in deforestation, loss in actual and potential primary productivity, loss in soil quality, high runoff, high sedimentation rate, and driving forces of global and regional climate change. (Mas et al. 2004; Dwivedi et al. 2005; Ren et al. 2011; Yang et al. 2012). Natural landscapes, i.e., those unaffected or hardly affected by human activities, are being transformed into cultural landscapes throughout the world (Ló pez and Sierra 2010; Feranec et al. 2010). The characteristics of LULC have important impacts on climate; hydrology and land cover change have emerged as one of the most concerns for research and for the development of strategies for sustainable development of urban areas (Turner et al. 1993; Vitousek 1994). In recent years, attention is being given to land use changes dry land degradation (Reynolds et al. 2007) and watershed management. The dynamics of land cover change focusing on the dynamics of natural vegetation cover is as a result of land use pressure, particularly expansion of mainly cropland and pasture (Schulz et al. 2010). The expansion of agricultural land at the cost of loss of forestland is a common geographic phenomenon in the mountain zones of developing countries (Bahadur 2009; Bhattarai and Conway 2008; Gautam et al. 2004). Bahadur (2011) studied the changes in spatial patterns of agricultural land use and their consequences for watershed degradation along an altitudinal gradient in watershed, and it is found that soil loss was characterized by 88 % of total soil losses being from upland agricultural areas. Therefore, the sustainability of the watershed is dependent on forest covers. Zheng (2006) studied the effect of vegetation changes on soil erosion on the Loess Plateau, China, and reported that accelerated erosion caused by vegetation destruction played an important role in land degradation and eco-environmental deterioration.

In order to assess and understand these landscape dynamics, viewing the Earth from space is now crucial particularly in terms of understanding of the man's activities on his natural resource base over a period of time (Lillesand and Kiefer 1999). In the situation of rapid and often unrecorded land use change, observations of the earth from space provide objective information of human utilization of the landscape pattern. Over the past two decades, data from remote sensing (RS) satellites have become vital in mapping the Earth's surface features and infrastructures, managing natural resources, and studying environmental changes that are taking place (Ren et al. 2011; Mallick et al. 2013a). In this extent, the combination of new tools, i.e., RS and geographic information system (GIS) are powerful technology to derive accurate and timely information on the spatial distribution of landscape pattern (Carlson and Azofeifa 1999; Guerschman et al. 2003; Rogana and Chen 2004). Due to urbanization, watershed LULC has also been changed significantly. The watershed is relatively independent natural complex of the earth's surface, and it is also a relatively complete ecological process unit (Hu et al. 2012).

The Abha semi-arid mountainous watershed is situated in south western part of Aseer province of the Kingdom of Saudi Arabia, an area susceptible to the severe soil erosion (Mallick et al. 2013b), and is also of importance as one of the important regions for Eastern Afromontane biodiversity hotspot (David 2011). In this, Abha and Khamish Mushayet cities are two important locations situated in this watershed area and they are also new economic development place. According to the recent development, the level of urban modernization and urbanization was improved significantly in these cities. Considering the watershed as comprehensive research is the best way to coordinate natural resource development and environmental protection. The objective of this study was (a) to assess the spatio-temporal landscape characteristics in Abha semi-arid mountainous watershed using RS and GIS; (b) to examine the distribution of different LULC types according to topography; and (c) to discuss the driving forces of the landscape dynamics characteristics. This could provide baseline information for the regional use of land resources in the mountainous watershed.

Study area

The Abha mountainous watershed is situated in Aseer province of the Kingdom of Saudi Arabia, covering an area of 370 km^2. The boundary lies between the latitude 18°10′12.39″N and 18°23′33.05″N and longitude 42°21′41.58″E and 42°39′36.09″E (Fig. 1). The topography of the watershed area is undulating, and its elevation ranges from 1,950 to 2,982 m above mean sea level. The average annual rainfall is 355 mm. The precipitation is mainly occurring between June and October every year. Average minimum and maximum temperatures are of 19.3° and 29.70 °C, respectively. The study area embraces one of the richest and the most variable floristic regions of the Aseer Mountains. Jabal Al-Sooda, one of the most famous mountains in the area, located in the north western part of the watershed area, 2,982 m high, and has also a rich flora. The variation in climate and topography in the study area (Aseer Province) has led to the formation of diverse plant community (Abulfatih 1984). It has severe problem of land degradation due to anthropogenic activities, high slope, weak geology, and rain and thus affecting the ecological imbalances.

Materials and methods

Data processing

The watershed boundary was determined using digital elevation model (DEM) with the spatial resolution of 25 m. The process of DEM creation begins with digitization of contour line from the geo-referenced Toposheet of 1:50,000. The grid-based DEM was generated from the extracted digital contour vector data. The DEM was

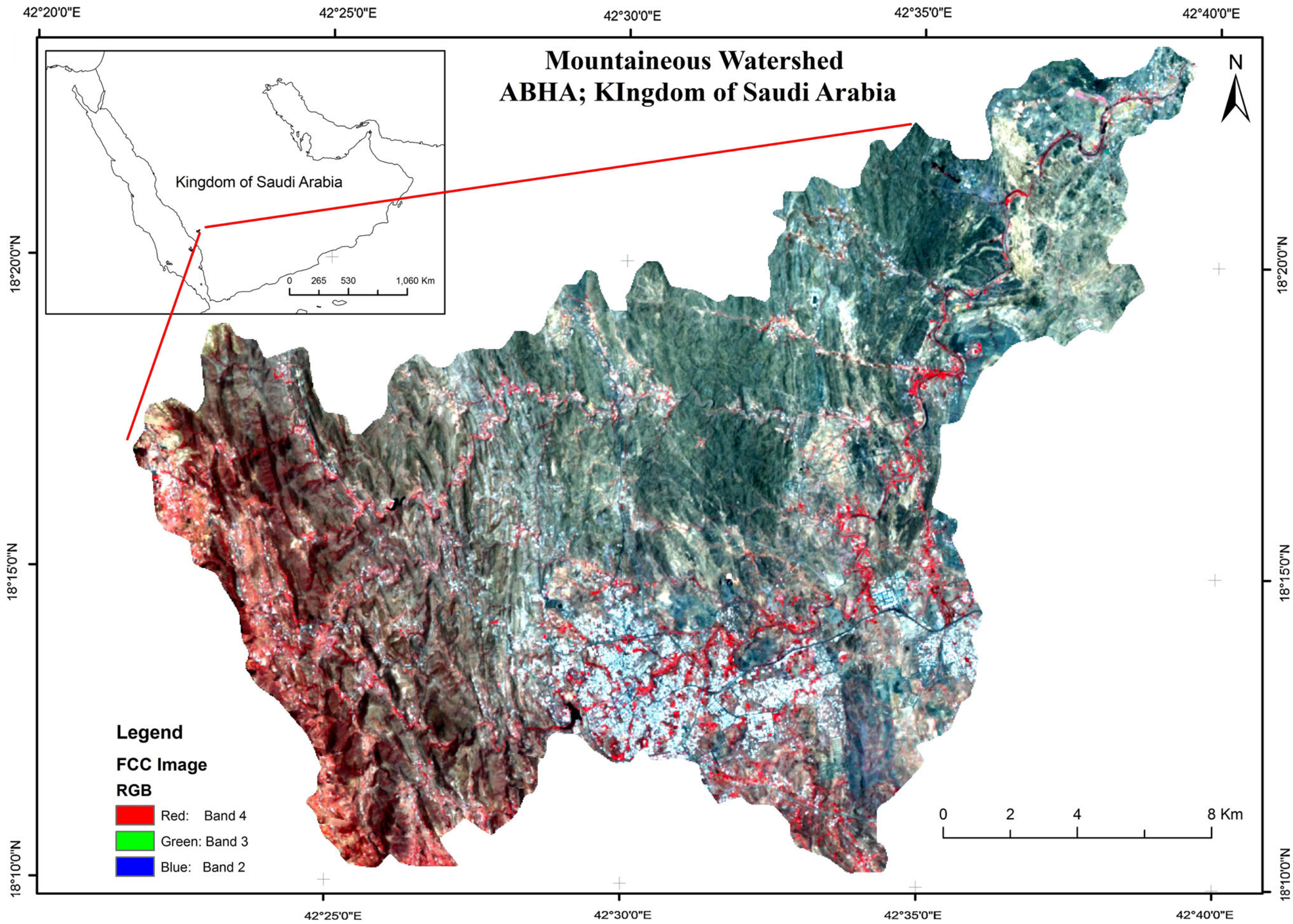


Fig. 1 Mountainous watershed, Abha Kingdom of Saudi Arabia (locational aspect)

produced with the 'Topo to Raster' interpolation techniques in 3D Analyst tool of ArcGIS 10.1. 'Topo to Raster' is an interpolation technique, specially designed for the creation of hydrologically corrected DEM. Slope and elevation maps were generated from DEM. After that, watershed was delineated from DEM by computing the flow direction and flow accumulation using ArcHydro tools of ArcGIS 10.1. The total area of watershed calculated from watershed layer is about 375 km^2. Table 1 shows the details of morphometric parameters of the watershed.

The ASTER satellite dataset of 2000 and 2010, i.e., optical bands 1–3 (0.52–0.86 µm), was used to evaluate the landscape dynamics in the Abha mountainous watershed. ASTER has 14 bands of which bands 1–3 (0.52–0.86 µm) have spatial resolution of 15 m, bands 4–9 (1.60–2.43 µm) have spatial resolution of 30 m, and five thermal bands from bands 10 to 14 (8.125–11.65 µm) have 90 m resolution. All datasets have been converted into raster at 15 m cell size, so that spatial analysis can be done in the same cell size and map projection. Layer stacking and mosaicing were carried out on the data using ILWIS 3.3 image processing software, to obtain multi-band composite images.

Table 1 Morphometric parameters of the study area

Sl. No.	Morphometric parameters	Analysis	Results
1	Watershed area	GIS software analysis	375 km^2
2	Length of the watershed (Schumm 1956)	GIS software analysis	39.54 km
3	Mean watershed width (Horton 1932)	GIS software analysis	9.48 km
4	Average height	GIS software analysis	2,314 m
5	Average slope in degree	GIS software analysis	4.54
6	Average rainfall (2001–2011) in mm	GIS software analysis	355
7	Mean soil erosion (Mallick et al. 2013a)	RUSLE	16.10 ton/ha/year
8	Dominant soil type (Mallick et al. 2013b)	Laboratory experiments	Loamy sand; sandy loam and loam

Georeferenced toposheet 1:50,000 scale map of studied area was used as a reference to perform geometric correction on the images using ArcGIS 10.1 software. Approximately, 30 ground control points (GCPs) were collected to register the satellite images to the universal transverse mercator (UTM) WGS 84 coordinate system and were resampled to its spatial resolution using the nearest-neighborhood algorithm. All the GCPs were collected in a dispersed manner throughout the images. The RMSE is found in acceptable range between the two images, i.e., <0.321 pixels (Jensen 2007). Finally, by means of the GIS watershed boundaries layer, the territory of watershed was extracted from the satellite images.

Digital image classification technique

The digital image classification procedure is to automatically categorize all pixels in an image into LULC classes, and supervised classification is much more accurate for mapping classes, but depends on the quality of the training sets (Nicholas 2005). Training sites are areas representing each known land cover category that appear fairly homogeneous on the image. All the supervised classifications usually have a sequence of steps that must be followed (1) defining training sites, (2) extraction of spectral signatures, and (3) classification of image. The training sites are done with digitized features (i.e., polygon). Generally, two or three training sites are selected. The more training site is selected, the better results can be achieved. This process assures both the accuracy and true interpretation of the image class results. Thereafter, the statistical characterizations of the information (mean values and variances of DNs for each band) are created. These are called spectral signatures. Finally, the digital image classification methods are applied.

Maximum likelihood classification (MLC) is based on Bayesian probability theory. The MLC technique is because it is the most powerful classification method when accurate training data/site is provided. Also, it is one of the most popular supervised classification methods and uses the training data by means of estimating means and DNs variance of the classes, which are used to estimate probabilities, and it also consider the variability of brightness values in each class (Jensen 2007).

In the present exercise, MLC was run with original bands, producing two final LULC maps of 2000 and 2010, and later on these two maps were compared. A cross-classification procedure is a fundamental pairwise comparison technique used to compare two images of qualitative data (Eastman 1995). By using the attribute table classified map, the change in LULC can be observed. To achieve this, the first task was to develop a table showing the area in sq. km. and the percentage change for each year of the dataset that measured against each LULC categories. The trend of change was then calculated by dividing observed change by sum of changes multiplied by 100 using the Eq. 1. To get annual rate of change, the percentage change is divided by 100 and multiplied by the number of study year.

$$\text{(Trend) percentage change} = \frac{\text{Observed change}}{\text{sum of change}} \times 100. \quad (1)$$

Accuracy assessment was critical for a land cover map generated from any satellite data. To validate the classified LULC map, field survey was conducted. The sample points were selected, in such a way that all major LULC classes can be covered and also wherever there were some doubt about a particular LULC classes for improving the accuracy of classified (LULC). The cover type information of these locations (i.e., GCPs) was compared with classified maps. The field sample locations were overlaid on classified maps to assess corresponding classes. Statistically valid sampling strategy was adopted to assess commission, omission, and overall accuracy (Rosenfield and Fitzpatrick-Lins 1986; Stehman 1996). The error of commission is a measure of the ability to discriminate within a class particularly and occurs when the classifier incorrectly commits, i.e., pixels of a class get added of another class, whereas the error of omission is a measure between class discrimination and results when a particular class on the ground is misidentified and goes to another classes. Traditionally, the total number of correct pixels in a category is divided by the total number of pixels of that category as derived from the reference data, i.e., the column total. This accuracy measure indicates the probability of a reference pixel being correctly classified and is really a measure of omission error and is often called 'producer's accuracy' because the producer of the classification is interested in how well a certain area can be classified (Congalton 1991). On the other hand, if the total number of correct pixels in a category is divided by the total number of pixels that were classified in that category, then this result is a measure of error of commission and this measure is called as 'user's accuracy' or reliability, which is indicative of the probability that a pixel classified on the map/image actually represents that category on the ground, whereas the overall classification accuracy shows how good the classified map is obtained. It is computed by dividing the total correct (i.e., the sum of the major diagonal) by the total number of pixels in the error matrix (Congalton 1991). Finally, the contingency table was tested using Kappa statistics (or Kappa coefficient) (Lillesand and Kiefer 1999). This test determines whether the results presented in the error matrix are significantly better than a random result (i.e., the null hypothesis: KHAT = 0). This test is based on the standard normal deviate and the fact that, although remotely sensed data are discrete, the KHAT statistic is asymptotically normally distributed (Congalton 1991).

Table 2 Confusion matrix for accuracy assessment of year 2000 LULC images

LULC	BT	WB	AGC	DV	SV	FWL	BSW	BS	RCEXP	Total
BT	310	8	0	0	0	3	4	2	3	330
WB	4	122	0	0	0	0	0	0	3	129
AGC	0	0	612	13	21	0	0	14	0	660
DV	0	0	15	1,027	82	0	0	2	0	1,126
SV	2	0	41	52	1,121	0	0	1	0	1,217
FWL	0	0	52	0	0	912	14	21	4	1,003
BSW	32	0	32	0	0	0	802	84	41	991
BS	0	0	8	0	32	3	12	805	21	881
RCEXP	62	0	0	0	4	5	13	21	1,021	1,126
Total	410	130	760	1,092	1,260	923	845	950	1,093	7,463

BT built-up, *WB* water bodies, *AGC* agricultural cropland, DV dense vegetation, *SV* sparse vegetation, *FWL* fallow land, *BSW* bare soil/waste land, *BS* bushes and scrubland, *RCEXP* rocks exposed

Table 3 Confusion matrix for accuracy assessment of year 2010 LULC images

LULC	BT	WB	AGC	DV	SV	FWL	BSW	BS	RCEXP	Total
BT	345	8	0	0	0	5	4	5	18	385
WB	6	141	0	2	0	0	0	0	5	154
AGC	0	0	648	8	16	0	0	8	0	680
DV	0	3	34	408	26	0	0	2	0	473
SV	2	0	42	24	469	0	9	6	0	552
FWL	22	0	36	0	0	617	23	31	6	735
BSW	36	0	16	0	3	6	908	61	42	1,072
BS	0	0	9	0	29	3	16	802	29	888
RCEXP	21	3	0	0	10	16	9	31	903	993
Total	432	155	785	442	553	647	969	946	1,003	5,932

Accuracy assessment

Accuracy assessment is an important step in the digital image classification process. The LULC types derived from digital image classification require validation with data obtained from ground verification. To assess the classification accuracy, independent ground samples collected (i.e., GCPs) during the field survey, finer resolution images (Worldview-2), and derived LULC maps have been used. A total of 78 sample GCPs were collected, so as to cover all the major classes in the study area. A set of land cover information collected during the fieldwork of present exercise was also kept separate for accuracy assessment. The cover type information of these locations (GCPs) was compared with classified maps. The field sample locations were overlaid on classified maps to assess corresponding classes. Statistically, the confusion matrix, derived from LULC maps and field data (signature file), as described by Stehman (1996) and Jensen (1996), was generated for the accuracy assessment. Additionally, a coefficient of agreement between classified data and ground reference data was calculated using Kappa and its variance. The importance of overall accuracy, producer's accuracy, user's accuracy, and kappa coefficient indicates the classification accuracy.

Table 4 User and producer accuracy of year 2000 and 2010 LULC images

LULC	2000		2010	
	User accuracy (%)	Producer accuracy (%)	User Accuracy (%)	Producer Accuracy (%)
BT	93.94	75.61	89.61	79.86
WB	94.57	93.85	91.56	90.97
AGC	92.73	80.53	95.29	82.55
DV	91.21	94.05	86.26	92.31
SV	92.11	88.97	84.96	84.81
FWL	90.93	98.81	83.95	95.36
BSW	80.93	94.91	84.70	93.70
BS	87.87	86.79	90.32	84.78
RCEXP	92.06	94.12	90.94	90.03

Tables 2 and 3 show the confusion matrix for quantitative analysis of LULC classification accuracy of 2000 and 2010, respectively. In this study, overall accuracy of LULC map of 2000 was 90.21 % and Kappa coefficient was 0.887, whereas in 2010, overall accuracy was 88.35 and Kappa coefficient was 0.866. The producer's accuracy in some of the classes viz., built-up (75.61 %) and

Table 5 Statistics of land use/land cover of 2000 and 2010 images

Sl. no	LULC classes	Surfaces 2000		Surfaces 2010	
		Area in km^2	%	Area in km^2	%
1	Urban build-up land	17.02	4.54	36.36	9.70
2	Water bodies	0.30	0.08	0.11	0.03
3	Agricultural crop land	26.13	6.97	16.12	4.30
4	Dense vegetation	2.52	0.67	2.06	0.55
5	Sparse vegetation	48.47	12.92	39.31	10.48
6	Fallow land	30.41	8.11	32.24	8.60
7	Bare soil/waste land	19.05	5.08	15.09	4.02
8	Bushes and scrub land	32.20	8.59	41.15	10.97
9	Rock exposed	198.91	53.04	192.57	51.35
	Total	375.00	100.00	375.00	100.00

agricultural cropland (80.53 %) classes etc., is found relatively low in Table 4. This is attributed to intermixing in the classes in different altitudinal zones, uncertainly in spectral reflectance in features class. Some of the classes viz., water bodies, fallow land, and rock exposed showed a very good agreement.

Result and discussion

Digital image classification: land use/land cover

Keeping in view of the objectives, ASTER satellite datasets were used for preparation of LULC map for the study area, and nine major classes were made as per Anderson et al. 1976 classification scheme, i.e., urban built-up, water bodies, agricultural cropland, fallow land, dense vegetation, sparse vegetation, bare soil/wasteland, scrubland/bushes, and rock exposed. The total area of each LULC

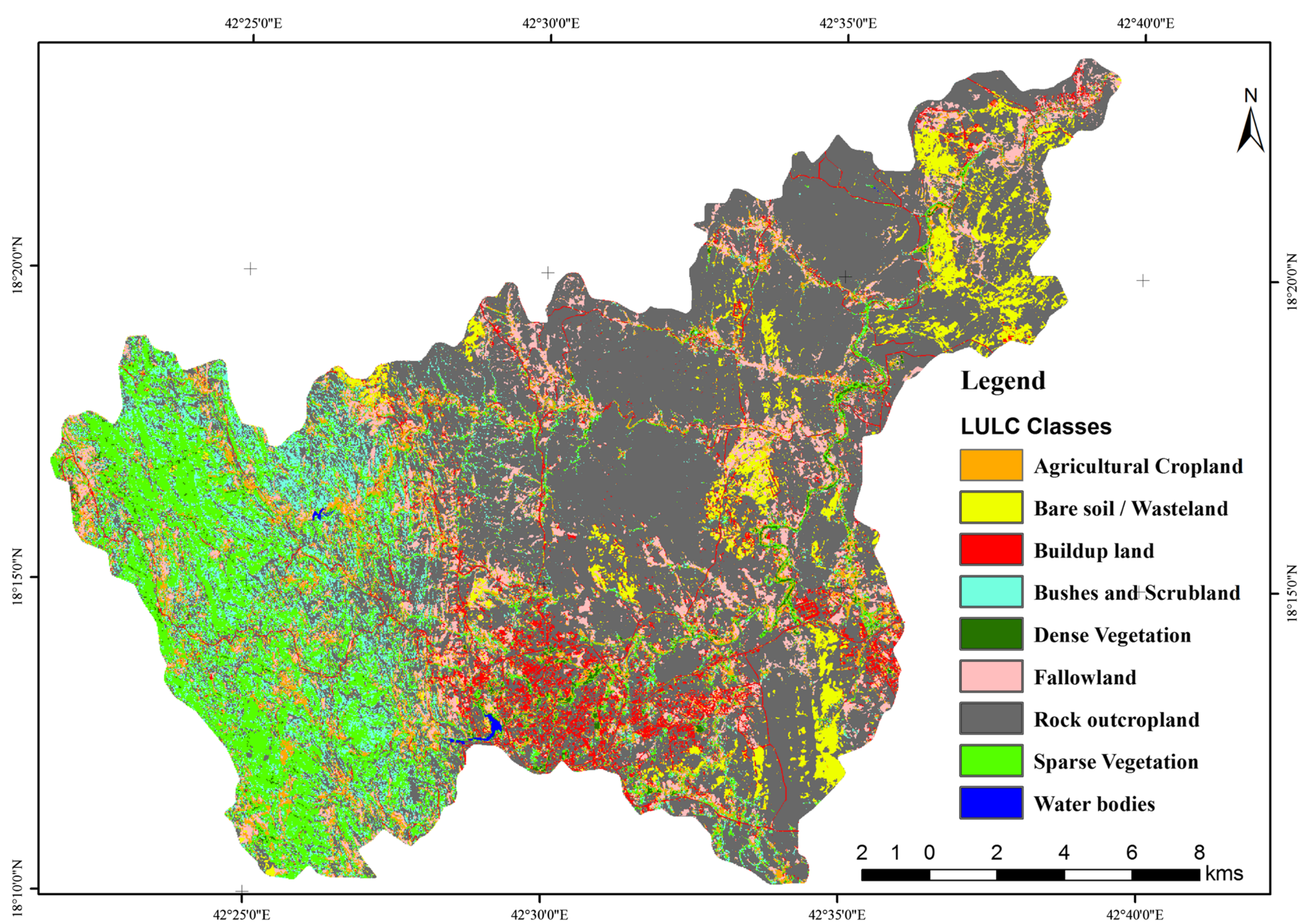


Fig. 2 Land use/land cover map of Abha Mountainous watershed 2000

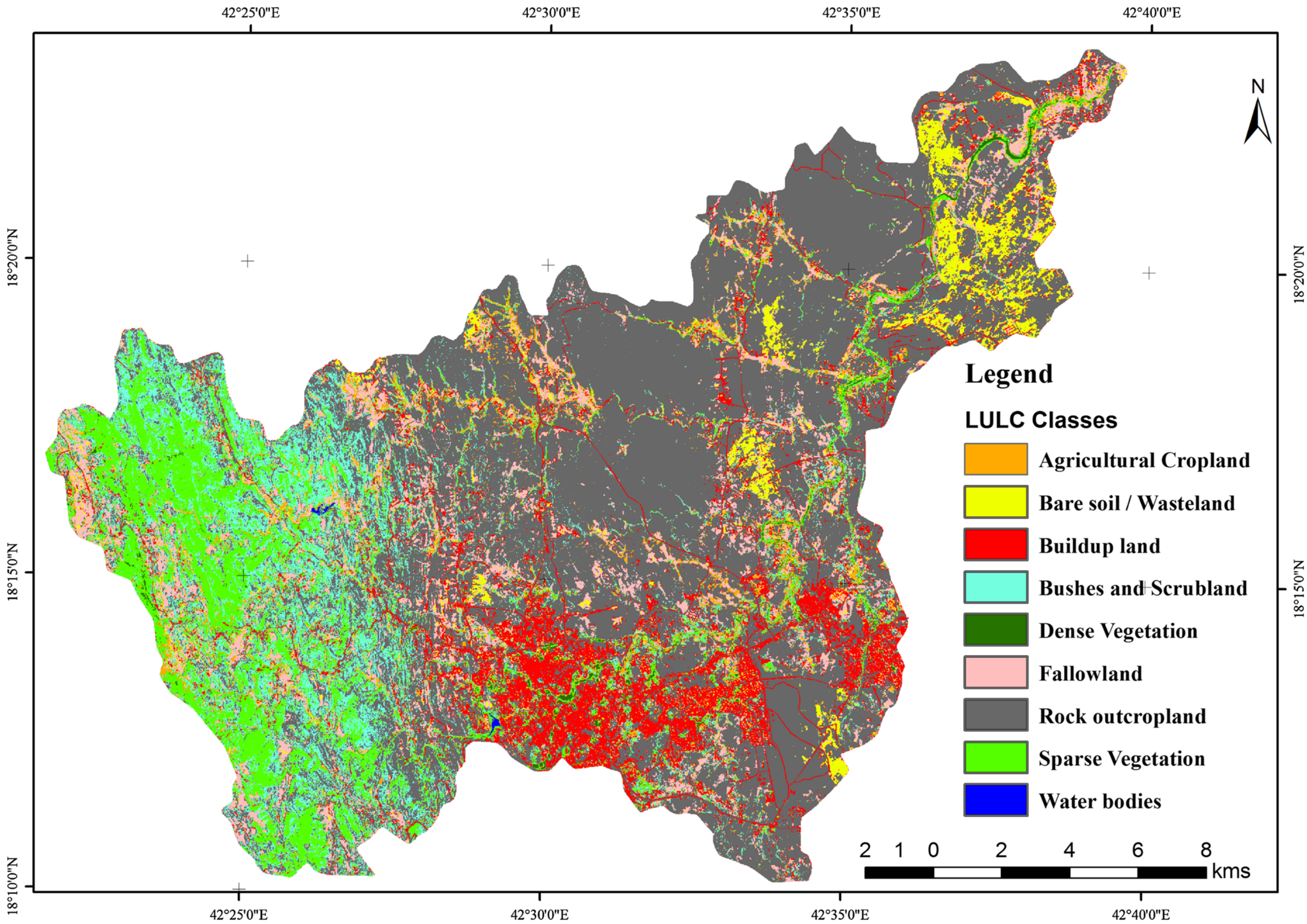


Fig. 3 Land use/land cover map of Abha Mountainous watershed 2010

category and percentage of each class of the study watershed region between 2000 and 2010 were calculated and presented in Table 5. Thereafter, the LULC change using these two classified locations and magnitude of the land use change in the study area has been obtained. Fig. 2 shows the LULC of 2000, and the built-up area is mainly in the central and south eastern part of the study area. The most dominant class in 2000 was the rock exposed land (53.04 %) followed by sparse vegetation (12.92 %), bushes and scrubland (8.59 %), and agricultural cropland (6.97 %) as shown in Table 4, whereas in 2010 scenario (Fig. 3), the major LULC class was also found in rock exposed land (51.35 %) a shown in Table 4, followed by bushes and scrubland (10.97 %), sparse vegetation (10.48 %), and agricultural cropland (4.30 %). The transition is mainly found over the built-up area, located in the central and south eastern part of the study area. This may be related to the change in the economic base of the city from agriculture to secondary activities. The area under agricultural land in 2000 and 2010 was 4.30 and 6.97 %, respectively. This shows that the agricultural land deceases due to low agricultural production and people are transferring their primary activity to secondary activities. It is also land decreased due to urban expansion, and agricultural land changed to built-up area. Apart from this, dense vegetation area occupied 0.67 % in 2000, whereas in 2010 it decreases to 0.55 % and sparse vegetation accounted 12.92 % in 2000 and it decreases to 10.48 % in 2010. These losses in vegetation classes are due to decrease in rainfall, increase in construction activities, and lack of practices in vegetation conservation. There is also one remarkable change in water bodies during one decade. In 2000, the area of water bodies is occupied of 0.30 km^2, decline to 0.11 km^2 in 2010. This is due to construction activities, disturbance in drainage network, and sedimentation in the watershed area.

Land use/land cover change characteristics

In order to assess the LULC change characteristics from 2000 to 2010, classified LULC map of these time periods was used to run the change detection model in GIS platform. The outcome is in the form of a map, which shows where all the land transformation has taken place, whereas their attribute tables show the quantitative values of LULC

Table 6 Gains and losses and net change between 2000 and 2010 LULC images

Land use/land cover classes	Gain (Km^2)	Gain (%)	Loss (Km^2)	Loss (%)	Net change (Km^2)
Urban build-up	25.31	16.13	−8.25	5.26	17.06
Water bodies	0.00	0.00	−0.21	0.13	−0.21
Agricultural cropland	12.84	8.19	−22.74	14.49	−9.90
Dense vegetation	1.61	1.03	−2.06	1.31	−0.45
Sparse vegetation	16.17	10.31	−25.32	16.14	−9.15
Fallow land	21.29	13.57	−19.50	12.43	1.79
Bare soil/wasteland	8.41	5.36	−12.19	7.77	−3.78
Bushes/scrubland	29.19	18.61	−20.32	12.95	8.87
Rock exposed	42.05	26.81	−46.31	29.52	−4.26

changes. The result demonstrates that there have been significant changes in all LULC classes between 2000 and 2010. Any increase in the area of a particular class from other classes has been termed as gain, which has been shown both in Table 6 and in Fig. 4. The maximum gains are found over rock exposed and built-up area. Gains in rock exposed due to excavation of construction activities (basement, deep foundation construction) at construction materials extraction sites often involve major changes to allow extraction activities and also often including clearing of preexisting vegetation. Quarrying activities were also increased the rocky exposed area due to removal of topsoil and rock waste. The maximum net change 17.06 km^2 has been recorded in the built-up area (Table 6; Fig. 5). This transformation is due to increase in urban population of the study area. While the area of agricultural cropland decreased from 26.13 km^2 in 2000 to 16.12 km^2 in 2010 and fallow land increased from 30.41 km^2 in 2000 to 32.24 km^2 in 2010, the urban build-up land increased from 17.02 km^2 in 2000 to 36.36 km^2 in 2010. This transformation may be due to shift in agricultural activities to commercial, industrial activities, and housing units.

Nature and location of change in land use/land cover

An important aspect of LULC change detection is to determine landscape transformation interchanging, i.e., LULC class is changing to which one and where. This information will show both the desirable and undesirable changes and LULC classes stability. Table 6 and Fig. 6 show the category-wise change that has been taken place between 2000 and 2010. Rock exposed (−46.31 km^2) and agricultural cropland (−22.74 km^2) shows major losses as shown in Table 6 urban built-up shows major increase (17.06 km^2), bare soil/wasteland moderate decrease; whereas in all other LULC classes,

Fig. 4 Gains and losses of LULC during 2000–2010

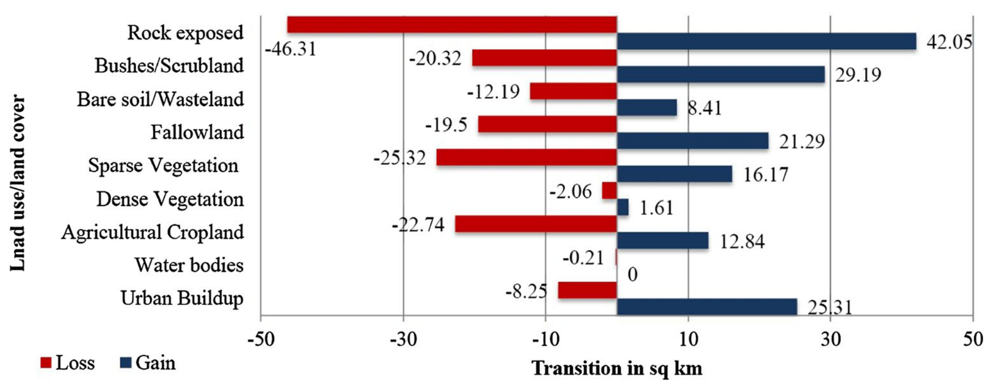
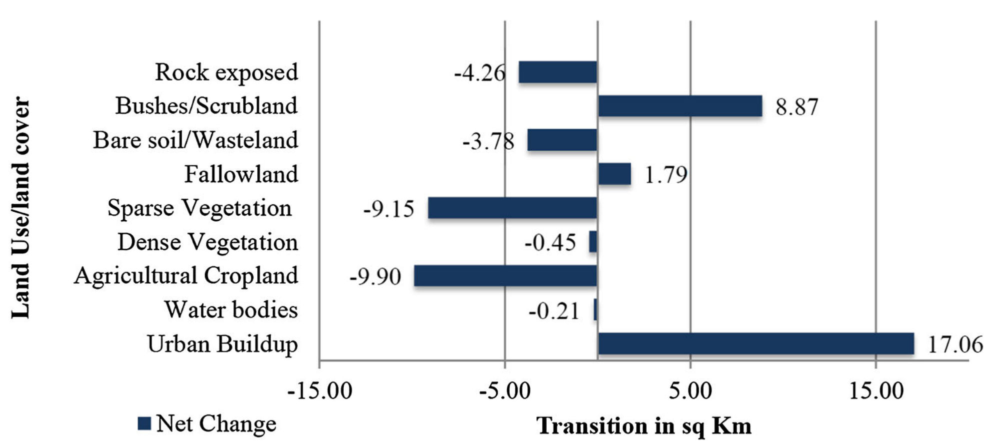


Fig. 5 Net change in LULC during 2000–2010



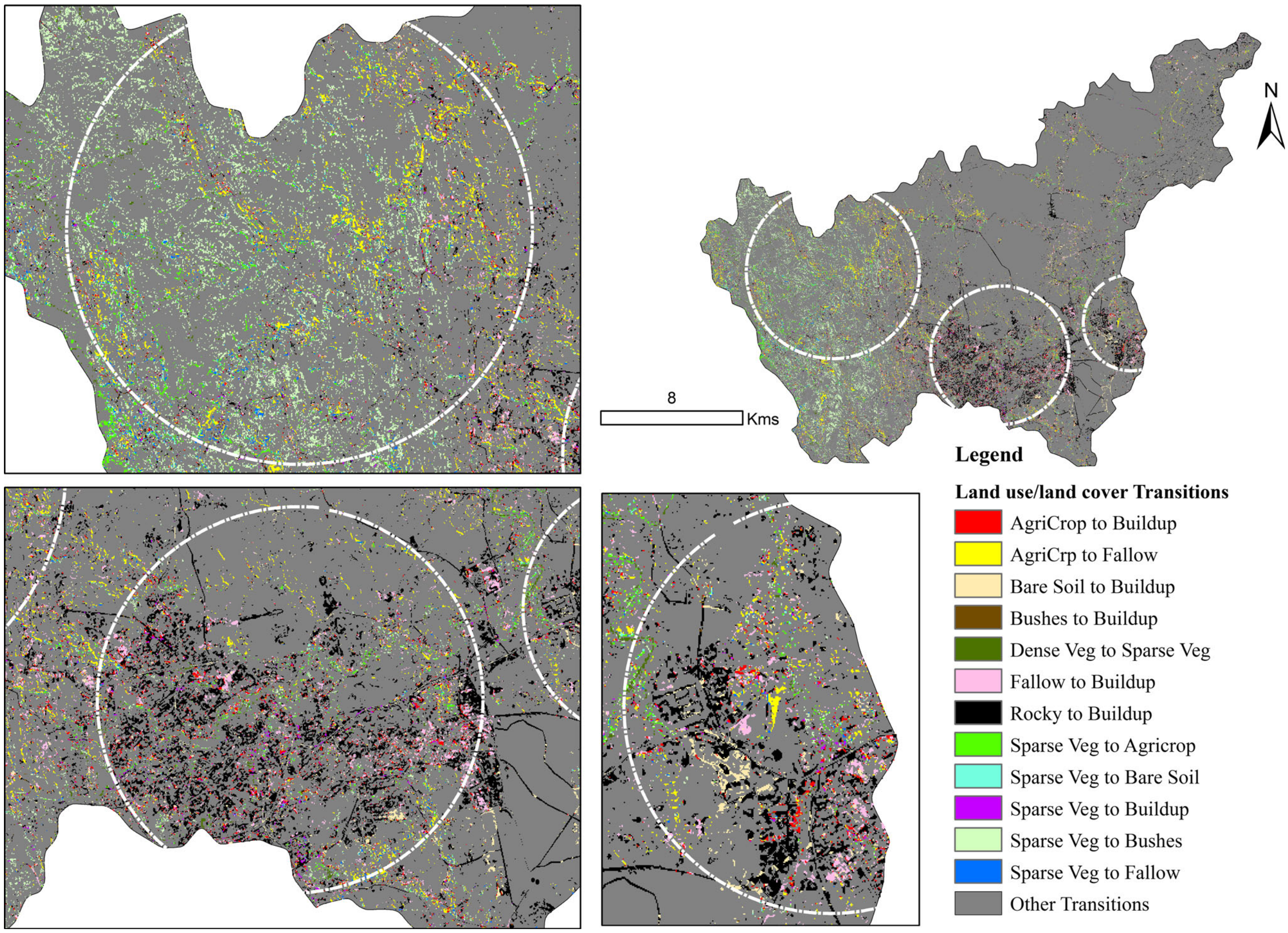


Fig. 6 Land use/land cover change Map 2000–2010

relatively insignificant change is noticed. The large-scale migration of people to these areas and physical expansion of the urban land lead to increase in built-up area. Table 6 shows which land use is converted to which class, and it can be seen that the 15.19 km^2 area of exposed rock has been converted to the urban build-up (Table 7). Since the study area is primarily dominated by agricultural land, urban built-up land growth through 'edge expansion and development' is happening mostly at the expense of such cultivable lands. Rural settlements located amidst predominately agricultural areas are urbanized when major roads pass through them and the urban development along these routes intensifies to engulf them. Figure 6 shows the major change from rock exposed to urban built-up area, which is shown in red color mainly located in central south of the study area. All other areas where insignificant changes have taken place are shown in black color.

Analyzing LULC changes according to topography and slope

The relationship between LULC and topography, during 2000-2010, was analyzed by using DEM. Figure 7 shows the results of analysis of LULC in 2000 according to elevation (altitude). According to Fig. 8, urban build-up areas are mostly located in regions with 1,950–2,350 m of altitudes. This is due the fact that the watershed is quite rugged. As a result of this rough structure, only small flat areas, located in this sections and valley channels (wadies), may be used as build-up land.

In 2010, Fig. 8 shows that agricultural cropland area decreases with increasing altitude. Economic and social living conditions are harder in small residential areas located in regions with high altitude. The agricultural activities are also very limited at high altitude. Consequently, the population of rural areas located in regions with high altitude is very low. Along with the commercial and educational opportunities, starting from 2,000 s, an important migration took place from rural areas to the urban areas and has not ended yet. However, some areas, used for agricultural activities in patches in 2,000, turned into fallow land when it came to the year of 2010. Likewise, sparse vegetation areas, mostly located in the regions with 2,551–2,982 m of altitude, have been decline in 2010, which transformed into bushes/scrublands (Table 8). This

Table 7 Major land transformation between 2000 and 2010 LULC images

Sl. no.	Category-wise changes	Changes/transitions in Km^2
1	Rock exposed to urban build-up	15.19
2	Sparse vegetation to bushes/scrubland	11.67
3	Agricultural cropland to fallow land	6.63
4	Fallow land to urban build-up	3.95
5	Sparse vegetation to agricultural cropland	2.92
6	Agricultural cropland to urban build-up	2.61
7	Bare soil/wasteland to urban build-up	2.11
8	Sparse vegetation to fallow land	2.02
9	Dense vegetation to sparse vegetation	0.80
10	Sparse vegetation to urban build-up	0.78
11	Sparse vegetation to bare soil/wasteland	0.75
12	Bushes/scrubland to urban build-up	0.57

is due to denuded high slope, week geology, high soil erosion, and insufficient conservation practices. Rock exposed class is decrease with increasing altitude.

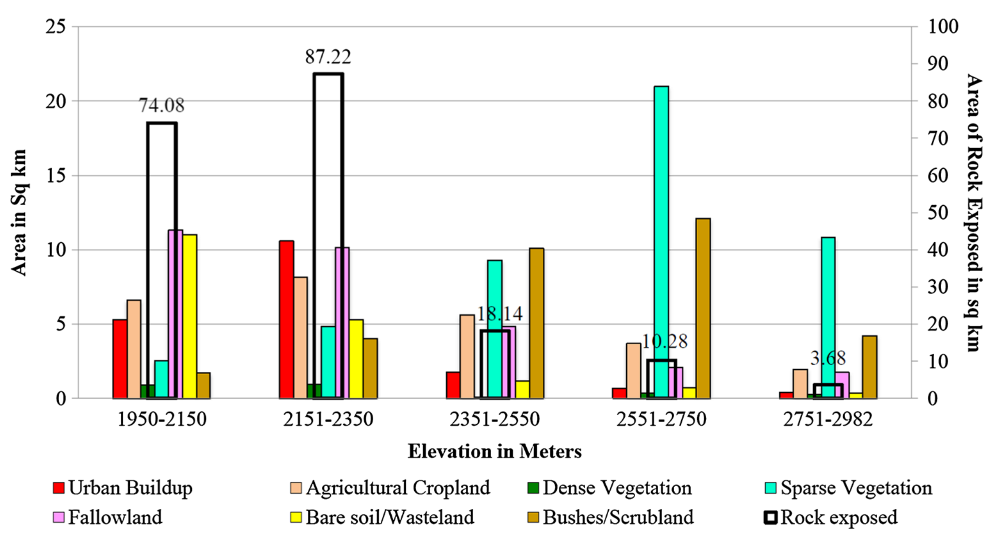
Slope gradient had an influence on people choices for land use. For example, cropland and orchards on terraces or slopes, which needed more human management, were generally distributed in areas with gentle slopes gradient where access was easier and comfortable. Contrarily, dense vegetation and sparse vegetation that required little management were found mostly on the steeper slopes gradient (Table 8). Table 8 shows that the agricultural lands were mostly distributed at lower slope (<2.6°), and its transformation to other land uses was higher at the lower slope gradient. Transformation of agricultural land to unutilized land (fallow land and bare soil) at the higher slope gradient (>6°) is considerably high. Consequently, it aggravates the soil quality and the soil erosion. The government policy makers should consider slope aspects into their land planning process and conversion of the unutilized land (at the higher slope) to forestland. Hence, it is important to understand the relationships between slope gradient and land use type and its sprawling, especially the distribution of agricultural land by slope category.

Conclusions

This study investigates the landscape dynamic characteristics of LULC variation of Abha watershed using RS data and GIS technology. The LULC transformations were also analyzed according to elevation and slope. During 2000 to 2010, the major change observed in build-up area was increased approximately 17 km^2, and sparse vegetation area was decreased approximately 9 km^2. The watershed regions having high altitudes were exposed to totally reverse change. In the regions having altitude lower (1,950–2,350), contrary to decrease in agricultural areas, build-up area was increased. This is due the fact that the watershed is quite rugged. As a result of rough structure, only small flat areas, located in this sections and valley channels (wadies), may be used as build-up land. Slope gradient had an influence on human choices of land use. The assessment of land use and land cover type distribution by slope category provided the baseline for the implementation of the nationwide land conservation policy of conversion of agricultural land to forestland in order to control high soil erosion risk.

The area under water bodies has also declined during 2000–2010. This is due to construction activities, disturbance in drainage network, and sedimentation in the watershed area. In the watershed region, the people were

Fig. 7 Land use/land cover 2000 according to elevation



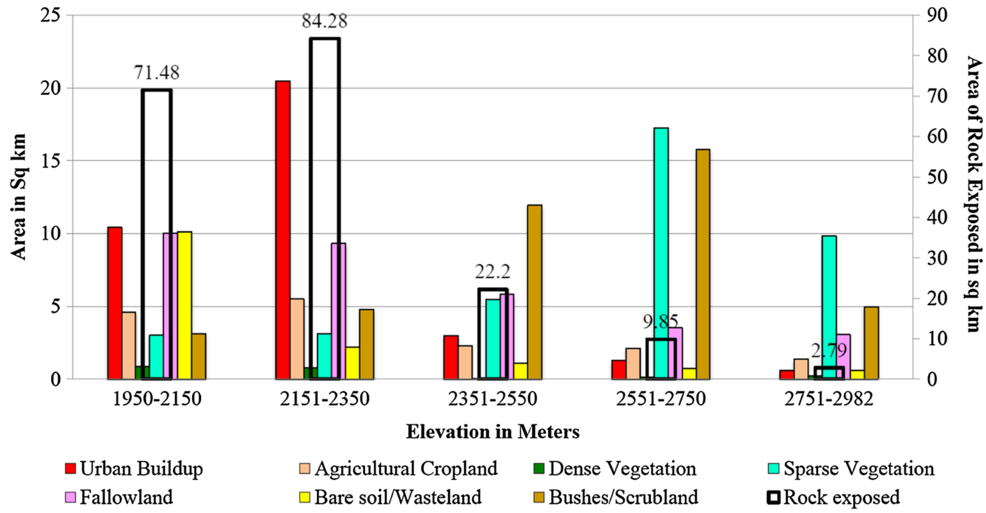


Fig. 8 Land use/land cover 2010 according to elevation

Table 8 Statistics of LULC changes according to topography

Year	Class I			Class II			Class III			Class IV			Class V		
	Height 1,950–2,150 m		Slope in degree	Height 2,151–2,350 m		Slope in degree	Height 2,351–2,550 m		Slope in degree	Height 2,551–2,750 m		Slope in degree	Height 2,751–2,982 m		Slope in degree
	2000	2010		2000	2010		2000	2010		2000	2010		2000	2010	
BT	5.3	10.43	1.38	10.58	20.48	2.49	1.79	2.99	6.72	0.68	1.26	5.8	0.41	0.61	6.61
AGC	6.62	4.62	1.16	8.17	5.51	2.62	5.63	2.32	6.03	3.69	2.13	7.04	1.97	1.36	8.17
DV	0.88	0.88	0.71	0.93	0.76	1.92	0.09	0.04	5.69	0.37	0.13	10.71	0.26	0.23	11.66
SV	2.53	3.01	1.06	4.83	3.14	2.55	9.3	5.47	7.98	20.97	17.25	9.96	10.84	9.82	10.32
FWL	11.31	10.03	1.27	10.34	9.32	3.11	4.83	5.83	6.38	2.09	3.52	7.09	1.75	3.06	5.67
BSW	11.32	10.13	1.68	5.32	2.2	3.26	1.19	1.12	6.14	0.74	0.73	6.61	0.37	0.58	6.28
BS	1.7	3.13	1.25	4.03	4.79	3.11	10.09	11.94	7.74	12.1	15.77	8.64	4.24	4.97	8.64
RCK	76.15	71.48	1.62	89.22	84.28	4.06	19.14	22.2	8.39	10.28	9.85	7.45	3.68	2.79	7.49
Total	113.44	113.7	–	131.22	130.48	–	51.06	51.91	–	50.92	50.64	–	23.52	23.42	–

migrated from rural areas to urban area. Since there were very limited and uneconomic agricultural areas, rural areas located in regions with higher altitude were converted to fallow land and bare soil/wasteland. The Abha mountainous watershed has witnessed faster decrease in land cover between 2000 and 2010. This is significantly changed in watershed, in particular; the build-up land has increased many folds. It seems that the watershed of Abha is confronted by the challenges of various environmental issues, such as soil erosion, urbanization, changes in water resources in terms of both quantity and quality, and environmental changes. The present study finding of application of satellite-based analysis is quite helpful in quantifying past and present LULC so that appropriate planning could be made for the better future development of the Abha.

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