Land Cover Change in Bamyan, Afghanistan from 1990 to 2015
—Land Degradation and Lack of Land Management—

Abdul Aziz Mohibbi*, Hasi Bagan**, Motoko Inatomi*** and Tsuguki Kinoshita****
* The United Graduate School of Agriculture, Tokyo University of Agriculture and Technology,
** Institute of urban studies, Shanghai Normal University,
*** Department of Forest Soils, Forestry and Forest Products Research Institute,
**** College of Agriculture, Ibaraki University

Lack of management and years of conflict have resulted substantial stress over natural and semi-
natural ecosystem in Bamyan, Afghanistan. In this study, we evaluated the spatio-temporal changes in
land cover in Bamyan from 1990 to 2015 and lack of land management issues. To achieve the objective
a comprehensive field work survey was conducted with 97 local people and farmers with a framed
questionnaire. 88 local people and farmers stated that land cover has changed with 30 years. Both
respondent groups specified the reasons as population increase, overuse of resources, overgrazing,
shrub collection, drought and mismanagement. The result of interview with governmental organizations
and NGOs demonstrated, land degradation is acute problem due to vegetation cover removal,
overgrazing, dependency on natural resources, fodder collection and cultivations on steep slopes.
Moreover, we applied the Maximum Likelihood Classification method to produce land-cover maps
using Landsat images of 1990, 1999, 2008, and 2015. Defining grid cells with unique cell IDs allowed
us to quantify spatio-temporal changes in land-cover classes. Rangeland decreased from 60.2% to
37.9%, accompanied by rapid increases in bare soil and built-up classes. This suggests the extension of
anthropogenic influence into surrounding natural and semi-natural ecosystems. Statistical comparison of
the land-cover changes in 0.81 km$^2$ grid square cells showed that the decrease in rangeland was strongly
negatively correlated with that of bare soil. Furthermore, around Bamyan city, the expansion of built-
up areas was strongly positively correlated with that of plantation areas, and negatively correlated with
bare soil increases. This is due to the rapid socio-economic changes between 1999 and 2015. The result
indicates that years of conflict, absence of management, and socio-economic change caused land cover
change in Bamyan between 1990 and 2015.

**Key Words**: conflict, land degradation, land management, natural resource, semi-arid land
1. Introduction

Afghanistan has been front-page news over the last decade due to the ongoing conflict. Various factors, along with severe human damage from three decades of war and extensive corruption, have led to extensive environmental problems in Afghanistan.

Approximately 16% of Afghanistan’s land area is severely affected by anthropogenic activities, whereas the country’s vulnerability to desertification is one of the highest in the world. More than 80% of Afghanistan’s population depends directly on natural resources to meet their regular needs. The extensive environmental degradation produces a massive threat to livelihoods. The impact of more than three decades of battle, military actions, migration processes, breakdown of national, provincial and local government, lack of management and institutional capacity compounded by year of drought has strongly damaged Afghanistan’s natural resources (UNEP 2008). Therefore, Overgrazing, ‘de-shrubification’ (the uprooting of shrubby vegetation), soil erosion, soil salinization, water pollution, climate change, threats to biodiversity, and natural hazards are serious problems in Afghanistan (Shroder 2012).

Much of the land surface of Afghanistan is used as rangeland for grazing livestock, and soil erosion is also a serious problem due to the loss of protective vegetation cover (UNEP 2008, Norgrove et al. 2008; Mohibbi and Cochard 2014).

Satellite remote-sensing data collected over a span of years can be used to identify and characterize both natural and anthropogenic changes over large areas of land (Bagan et al. 2010, Arsanjani et al. 2013; Gómez et al. 2016). The United Nations Environment Programme (UNEP) used satellite images for land-use analyses in the northern province of Badghis and Takhar from 1977 and 2002 (UNEP 2003). Assessment of satellite imagery from UNEP has revealed that forest and woodland declined by more than 50% in Afghanistan between 1987 and 2002. After the invasion of Afghanistan by Russia in 1979 and following that civil war and conflict, a few studies analyzed land cover changes in Afghanistan (UNEP 2008). Pervez et al. (2014) utilized Normalized Difference Vegetative Index (NDVI) data from the Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite instrument and that shows that irrigated areas in Afghanistan increased from 2000 to 2013. Simms et al. (2014) used time-series MODIS NDVI data to estimate crop information across Afghanistan, focusing on the main opium-producing provinces in Afghanistan between 2005 and 2009. However, this study lacked detailed land and soil change information. There is still a lack of studies using high-spatial-resolution remote-sensing images to determine detailed land-cover changes in Bamyan, Afghanistan.

The objective of this study was to investigate the spatio-temporal changes in land cover due to human activities in Bamyan province from 1990 to 2015 and impact of absence of management policy by integrating remote sensing images and detailed field work. Environmental policies and laws are a recent development in Afghanistan with the first Environmental Law passed by the newly elected National Assembly in 2007. Since then other laws and strategies such as the Rangeland Law and Natural Resource Management Strategy are in the pipeline, but lack of technical capacity and financial mechanisms have been a challenge for implementation at the field level. To do this, we applied the Maximum Likelihood Classification (MLC) supervised classification method to accurately classify land cover from Landsat images recorded in 1990, 1999, 2008, and 2015. These land cover maps were then combined with 900 m × 900 m grid cells to analyze spatio-temporal land-cover changes and investigate their statistical properties. This allowed us to determine land-cover changes and consider the impacts of human activities and lack of management on the environment over a 25-year period.

2. Materials and Methods

1) Study Area

Bamyan province is located in the central highlands of Afghanistan (Fig. 1). The province is characterized by a dry, mountainous climate, with highly variable microclimates within the numerous
Mohibbi et al. Land Cover Change in Bamyan, land degradation and land management

steep valleys that make up the Baba and Hindu Kush mountain ranges. Much of Bamyan province is above 2000 m elevation with remarkable areas located above 4000 m. The highest location in the province is 5029 m.

The few records that are available from Bamyan province highlight three outstanding features of the annual climate. First, intense cold periods occur in winter when air temperatures commonly do not exceed \(-5^\circ C\) during the day, while minimum air

Fig. 1 Study area boundary. The grey area shows Bamyan province, and the blue area shows the study area in the central Bamyan district. The right-hand image shows the August 1999 Bamyan district Landsat TM image (RGB= bands 3, 4, 5). The red outline indicates the area around Bamyan city.
temperatures below –20°C are common. Second, large diurnal temperature variations are recorded in the summer months, when daily temperatures may exceed 20°C. Third, mean annual precipitation in Bamyan is less than 165 mm, with much of this falling as snow (Cook 2011).

According to Shroder (2014) land degradation in the headwaters of all main Afghan drainage basins is caused mainly by overgrazing, deforestation, and de-shrubification (in which shrubby plants were pulled up by the roots for fuel). Population increase was another cause of natural resource over-use in Afghanistan, especially in Bamyan. As specified by the Afghanistan Central Statistics Organization (2016). The population of Bamyan province nearly doubled from 1990 to 2015. As stated by Karim (2013) as the population growth rapidly, although the huge number of population needs food, water and habitats which bring unpredicted burden on natural resources and land. As theorized by Timah et al. (2007) population increase will direct the indigenes of an area to feed further away of sustainable limits, causing the extinction of fauna and flora before it potentially uses for the advantage of current and future generations.

2) Field work survey

Along with ground reference data collection, we conducted interviews with farmers, local councils, and governmental & non-governmental organizations to understand land degradation issues and causes. The interview questions were randomly completed with local people (the people whose jobs were not farming or indirectly involved in farming) and with famers (their occupation is farming). The questionnaires were completed from areas such as villages in upper part of the valleys, the villages in middle part of the valleys and villages in lower parts or flat area. Fifty-nine questionnaires were completed by local people with sex ratio of 49 males and 10 females with age composition between (20–29) 36 people, among (30–39) 9 people, between (40–49) 2 people, between (50–59) 8 people and between (60–70) 3 people of local people and 38 questionnaires by farmers which all of them were male with ages between (20–29) 9 people, between (30–39) 7 people, between (40–49) 5 people, between (50–59) 9 people, and between (60–70) 8 people. The questions were the same for both groups.

Q1. Have you been collecting bushes and shrubs from rangeland for your livelihood?

Q2. Do you think the land cover has changed over the last 30 years?

Q3. What is the reason for this land cover change?

3) Dataset

We acquired Landsat TM and Landsat 8 scenes (Level-1T, provided by USGS) from four different dates (1990, 1999, 2008, and 2015) to investigate land-use/land cover changes for the study area over a 25-year period in Table 1.

We select the years of 1990, 1999, 2008, and 2015 based on the following reasons: after the Russian invasion and the resistance against the communists starts to take out them from Bamyan. Therefore, conflict began in Bamyan city between 1979 and 1989 with the migration of people out of Bamyan province to other provinces or countries, and the migration process became stronger during the Taliban era until 1999, when the cultivated area decreased and provincial and local government broke down and mismanagement occurred (Wily 2004). In the post conflict period, migrants began returning home between approximately 2001 and 2008, and thus more land was used for raising livestock and cultivating crops, which caused a shortage of natural resources (Wily 2004; Winterbotham et al. 2011).

Landsat scenes provided by the USGS have already been corrected using ground control points and a digital elevation model. All Landsat images

| Year | Date       | Source         | resolution |
|------|------------|----------------|------------|
| 1990 | 1990/8/26  | Landsat-5 TM   | 30 m       |
| 1999 | 1999/8/19  | Landsat-5 TM   | 30 m       |
| 2008 | 2008/7/10  | Landsat-5 TM   | 30 m       |
| 2015 | 2015/7/14  | Landsat 8 OLI  | 30 m       |
were geometrically rectified to a common map reference system: Universal Transverse Mercator (UTM) projection, UTM Zone 42 North, WGS-84 geodetic datum. Only images from June to August, the green vegetation season, and those with low cloud cover were used to maximize the vegetation information content for each monitoring date. All analyses were based on the optical and thermal infrared bands of the Landsat data.

For the land use pattern are very small in populated area such as Bamyan city and it is very difficult to recognize by Landsat images, we used high resolution 39 images such as Worldview-2 and GeoEye-1 as reference data to assist with our field investigation in the determination of typical land-cover classes and in selecting ground reference sites for each Landsat recording date.

4) Ground reference data collection

For a full determination of the ground truth situation, we conducted field work across the study area from mid-July to Mid-August of 2015. Throughout the field survey, photos were taken for ground reference data with GPS facilities, and land cover types were recorded in the land-use/land-cover recording sheet. Fig. 2 shows some typical landscapes of the study area. In addition, farmers, local councils, and related governmental and non-governmental organizations were visited to validate present and past land-cover patterns and discuss the causes of land-cover changes. Using the field investigation results, land-use maps, visual interpretation of the remote sensing data, and with consideration of the Landsat scene acquisition dates, we designated eight land-cover classes Table 2. As Bamyan province is in semi-arid zone, there is no forested area. But in the area with water access along the stream and below irrigation canals are some species of trees such as poplars, willow, and orchard are planted.

Ground reference data sites were selected for each mapping class and for each Landsat recording date to accurately portray the spectral complexity and variability within each class. All initial digitized ground reference sites were compared with the corresponding Landsat imagery acquired in 1990, 1999, 2008, and 2015 to provide the correct interpretation for the time of the image date. In addition, as described above, other ancillary images were used to support image interpretation and to provide as much information as possible to help locate the ground reference sites.

A subset of the image-interpreted sites was also field visited and additional sites were collected
(except snow, shadow, and cloud). For example, in this study area, rangeland areas show large spectral variation because of the variety of the canopy. To determine the 5% and 50% thresholds of canopy cover for rangeland, 1m × 1m quadrat techniques were used, and the total plant canopy cover of the plot was estimated visually.

Then, based on the knowledge obtained by measurements in quadrats, different rangeland sample sites were selected, representing the spectral variation of rangeland.

The finally selected reference sites were recorded using Exelis Visual Information Solutions (Exelis VIS) ENVI 5.2, Esri ArcGIS 10.3 software package. The reference sites were then randomly divided into training and testing sets to ensure spatial disjointing and to reduce the potential for correlation between the training data and the test data (Table 3).

5) MLC Classification methods

The MLC supervised classification method, one of the most popular classification techniques in the remote sensing community, was applied to each of the four datasets (see Table 1) to produce land cover maps from the Landsat images. MLC is based on the assumption of a normal or near normal spectral

| Class               | Class description                                                                 |
|---------------------|-----------------------------------------------------------------------------------|
| Rangeland           | Vegetation with canopy coverage between 5% and 50%.                               |
| Water               | Lakes, reservoirs, and rivers.                                                    |
| Snow                | Permanent snow and glaciers                                                       |
| Plantations         | Cropland for cultivation; cropland that has water supply and irrigation facilities and planting crops; cropland planting and dense grass vegetables. Trees between fields and woody vegetation are also included in this class. |
| Built-up            | Buildings and other man-made structures.                                          |
| Shadow              | Mainly referring to the mountain shadow generated by relief and sunshine exposure as well as shadow. |
| Bare soil           | Areas of gravel and soil covered land that are exposed and with less than 5% vegetation cover during any time of the year. |
| Cloud               | Aerosol comprising a visible mass of liquid droplets or frozen crystals made of water or various chemicals. The droplets or particles are suspended in the atmosphere above the surface of a planetary body. |

Table 2 Description of land cover classification system

| Class | Training | Test |
|-------|----------|------|
| Rangeland | 9592 | 3383 |
| Water | 926 | 310 |
| Snow | 1389 | 436 |
| Plantations | 8909 | 1400 |
| Built-up | 13 | 9 |
| Shadow | 4994 | 1206 |
| Bare soil | 13709 | 4941 |
| Cloud | - | - |

Table 3 Number of training and test pixels for images acquired in 1990, 1999, 2008, and 2015

| Class | 1990 Training | 1990 Test | 1999 Training | 1999 Test | 2008 Training | 2008 Test | 2015 Training | 2015 Test |
|-------|---------------|-----------|---------------|-----------|---------------|-----------|---------------|-----------|
| Rangeland | 9592 | 3383 | 732 | 213 | 8794 | 3253 | 1830 | 1009 |
| Water | 926 | 310 | 128 | 55 | 176 | 83 | 955 | 317 |
| Snow | 1389 | 436 | 176 | 48 | 234 | 126 | 727 | 220 |
| Plantations | 8909 | 1400 | 247 | 76 | 882 | 300 | 3031 | 738 |
| Built-up | 13 | 9 | 32 | 12 | 65 | 27 | 70 | 28 |
| Shadow | 4994 | 1206 | 235 | 106 | 216 | 105 | 2429 | 1017 |
| Bare soil | 13709 | 4941 | 5502 | 1073 | 18841 | 7263 | 20856 | 7301 |
| Cloud | - | - | 419 | 167 | - | - | - | - |
| Total | 39532 | 11685 | 7471 | 1750 | 29208 | 11157 | 29898 | 10630 |
distribution for each class of interest. An equal prior probability among the classes is also assumed. This classifier is based on the probability that a pixel belongs to a particular class. MLC requires representative training samples for each class to accurately estimate the mean vector and covariance matrix required by the classification algorithm (Lillesand et al. 2008).

6) Post-classification change analysis
To detect and quantify the changes in land cover patterns from 1990 to 2015, we followed a post-classification change analysis approach, producing a matrix where different combinations of change are identified. In addition, this allowed us to quantify the changes by knowing how much of a given land-cover type had changed into other classes, and to identify trends in land-cover change that had taken place in the study area between 1990 and 2015.

7) Grid cell process
We developed a Landsat pixel-derived grid cell approach, with which we can facilitate a link between changes of land cover classes. Our approach directly uses the 2008 Landsat TM5 image to create the grid cells. The advantage of grid square cells is that it can avoid the potential problem of changing administrative unit boundaries during the time interval of interest, and it enables us to aggregate the categories for each map and to perform quantitative analysis (Bagan et al. 2014; Qian et al. 2014). The main steps of the proposed approach are as follows.

First, we converted the $30 \times 30$ Landsat pixels to create an empty grid square cell (polygon), and assigned a unique ID to each grid cell. Thus, the spatial resolution of grid square cells is $900 \text{ m} \times 900 \text{ m}$.

Second, we overlaid the land cover classification maps ($30 \text{ m spatial resolution}$) on the $900 \text{ m} \times 900 \text{ m}$ grid cells to compute the percentage of each land-cover type within each cell, and stored the results in a new attribute table. When calculating the percentage of a land-cover type within a cell, we divided the sum of the land-cover-type area by the area of the cell.

This approach computed the percentage of land-cover classes within each grid cell, allowing for spatially explicit evaluations of the relationships between changes in land-cover types.

3. Results and Discussions
1) Result of field work Survey
Forty-three responses from local people confirmed that they had been collecting shrubs from rangeland for cooking and heating, while 16 people answered that they had not. Fifty local people stated that land cover had changed over the last 30 years, while nine people said it had not. Reasons given for land cover changes were: population increase and overuse of natural resources (24), drought (13), weather changes (8), lack of land management (8), overgrazing (5), and war (1).

Conversely, all 38 farmers answered that they used bushes from rangeland for cooking and heating and that land cover had changed within the last 30 years. The reasons farmers gave for land-cover change were: population increase and overuse of natural resources (19), drought (8), overgrazing (7), war (2), weather changes (1), and lack of land management (1).

Semi-structured Interview with key informants including Department of Agriculture, Irrigation and Livestock (DAIL), National Environmental Protection Agency (NEPA) and the United Nation Environment Program (UNEP) were conducted to understand land management challenges. The DAIL explained that land degradation is a serious problem for Bamyan due to overuse of natural resources, removal of vegetation cover for heating and cooking, and overgrazing, and that the knowledge base of farmers and local communities’ hampers recognition of the damages and economics costs. The NEPA agreed that land degradation is a serious problem due to overuse and dependence on scarce natural resources, especially for cooking and heating.

In addition, the UNEP stated that people in Bamyan rely heavily on their natural resources and land for their livelihoods. This includes grazing livestock and collecting shrubs and native plants.
for fuel, fodder, and other household purposes, which contributes to land degradation. Climate change, drought, land use, population growth, and land characteristics each have an immediate and significant potential to lead to overall land degradation. Additional indirect factors include poverty, population growth, returning refugees, and inefficient fuel wood for heating and cooking. Furthermore, the Afghanistan Agricultural Support Programme mentioned that land in Bamyan is heavily degraded. The rain-fed agriculture used within Bamyan’s steep terrain is not an appropriate system for Afghanistan’s dry climate. Bamyan residents do not have access to alternative energy sources, so the cutting of bushes for heating and cooking leads to land degradation.

2) Spatio-temporal changes of land-cover classes

Fig. 3 shows the classification results for the study area. We applied the MLC with a none probability threshold, and thus, all pixels were classified. To assess the quality of image classification, confusion matrices (Congalton et al. 2009), comparing test pixels Table 4 to the classification results were created, and overall accuracy, producer and user accuracies, and kappa statistics of agreement were generated. The overall accuracy for the land-cover maps ranged from 84.76% to 92.79% and Kappa coefficient ranged from 0.7329 to 0.8823.

The built-up class was the most difficult of all categories to classify and was often confused with the bare soil class because buildings in Bamyan are mostly made of mud, so the rooftops reflect light in the same way as bare soil. Thus, built-up areas were the most challenging to classify; this explains the lower producer accuracy (11.11% in 1990 and 44.44% in 2008) of the built-up class.

Relatively low producer accuracies for the plantation class in 1999 (66.67%) reflect the difficulty of distinguishing plantation pixels from rangeland pixels four years of drought from 1998 to 2002, water tables dropped considerably such that orchards and most of agricultural land could not be irrigated (Faver 2004). Shroder (2012) also specified that droughts, floods, and rising temperatures represented the highest hazard to ecosystems and livelihoods in Afghanistan. As shown in Fig. 3, bare soil and built-up areas increased over 25 years with a rapid increase from 1999 to 2015, along with a decrease in rangeland. To detect these changes more accurately, we removed the shadow and snow classes from the four images, making them statistically comparable.

Fig. 4a shows the grid-cell-based spatial change of rangeland from 1990 to 2015 in Bamyan province. The value of each grid square cell was calculated by subtracting the rangeland area of 1990 from that of 2015 in each grid cell and then dividing the changed area by the cell area. Fig. 4(b-d) shows the grid-cell-based spatial change of built-up, plantation, and bare soil classes from 1990 to 2015, respectively, which were calculated in the same way as for Fig. 4a. Typically, rangeland area rapidly decreased around the populated central Bamyan area while the built-up area increased, as did plantation and bare soil. The bare soil increase in the area seems to be the result of over-use of natural resources such as over-grazing, cutting bushes for fuel, and lack of management in the area. The field work survey analysis showed that majority of people use bushes and shrubs for cooking and heating. From all surveyed local people 43 people and all 38 farmers are collecting bushes and shrubs from rangeland areas. They declared that, de-shrubification, lack of management and overgrazing are another source of rangeland lose and bare soil expansion.

3) Land-cover change detection and analysis

To detect and quantify the changes in land cover patterns from 1990 to 2015, we followed a post-classification change-analysis approach using the land cover maps, producing a matrix where different combinations of change from 2008 to 2015 are identified Table 5 as an example. The classified images were also compared pixel by pixel to accurately understand the changes in each map. Table 6 show the land cover change trends of rangeland, bare soil, built-up, and plantation classes. Based on field result, 50 local people out of 59 local people and all 38 farmers in the survey argued that
land cover has been changed with 30 years, due to population increase, overuse of natural resources, drought, lack of land management, overgrazing and conflict.

Our results are consistent with historical narratives in this region. Afghanistan’s recent history demonstrates the importance of war and civil conflicts as drivers of land-cover and land-
Table 4  Confusion matrices of obtained land-cover maps.

|       | 1990 Rangeland | Water | Snow | Plantations | Built-up | Shadow | Bare soil | Total | UA (%) |
|-------|----------------|-------|------|-------------|----------|--------|-----------|-------|--------|
| Rangeland | 3135          | 2     | 2    | 134         | 0        | 0      | 385       | 3658  | 85.7   |
| Water   | 0              | 304   | 0    | 0           | 0        | 6      | 0         | 310   | 98.06  |
| Snow    | 0              | 0     | 427  | 0           | 0        | 0      | 0         | 427   | 100    |
| Plantations | 5         | 4     | 0    | 1210        | 0        | 0      | 1         | 1220  | 99.18  |
| Built-up | 1              | 0     | 41   | 1           | 0        | 49     | 0         | 92    | 1.09   |
| Shadow  | 72             | 0     | 12   | 0           | 1184     | 65     | 0         | 1333  | 88.82  |
| Bare soil | 170           | 7     | 3    | 8           | 16       | 4441   | 0         | 4645  | 95.61  |
| Total   | 3383           | 310   | 436  | 1400        | 9        | 1206   | 4941      | 11685 |        |
| PA (%)  | 92.67          | 98.06 | 97.94 | 86.43       | 11.11    | 98.18  | 89.88     |       |        |
| OA (%)  | 91.58          |       |      |             |          |        |           |       |        |
| Kappa   | 0.8823         |       |      |             |          |        |           |       |        |

|       | 1999 Rangeland | Water | Snow | Plantations | Built-up | Shadow | Bare soil | Cloud | Total | UA (%) |
|-------|----------------|-------|------|-------------|----------|--------|-----------|-------|-------|--------|
| Rangeland | 175            | 1     | 23   | 1           | 9        | 100    | 1         | 310   | 56.45 |
| Water   | 0              | 49    | 0    | 0           | 0        | 0      | 0         | 49    | 100   |
| Snow    | 0              | 0     | 47   | 0           | 0        | 0      | 0         | 47    | 100   |
| Plantations | 3         | 0     | 53   | 0           | 0        | 0      | 0         | 56    | 94.64 |
| Built-up | 1              | 0     | 0    | 8           | 0        | 57     | 0         | 66    | 12.12 |
| Shadow  | 0              | 0     | 0    | 0           | 97       | 0      | 0         | 97    | 100   |
| Bare soil | 34             | 5     | 1    | 0           | 3        | 916    | 12        | 971   | 94.34 |
| Cloud   | 0              | 0     | 0    | 0           | 0        | 0      | 0         | 154   | 100   |
| Total   | 213            | 55    | 48   | 76          | 12       | 106    | 1073      | 167   | 1750  |
| PA (%)  | 82.16          | 89.09 | 97.92 | 69.74       | 66.67    | 91.22  | 85.37     | 92.22 |       |
| OA (%)  | 85.66          |       |      |             |          |        |           |       |        |
| Kappa   | 0.7699         |       |      |             |          |        |           |       |        |

|       | 2008 Rangeland | Water | Snow | Plantations | Built-up | Shadow | Bare soil | Total | UA (%) |
|-------|----------------|-------|------|-------------|----------|--------|-----------|-------|--------|
| Rangeland | 2814          | 0     | 0    | 53          | 0        | 5      | 224       | 3096  | 90.89 |
| Water   | 0              | 82    | 0    | 0           | 0        | 0      | 0         | 82    | 100   |
| Snow    | 0              | 0     | 125  | 0           | 0        | 0      | 0         | 125   | 100   |
| Plantations | 0         | 0     | 245  | 0           | 3        | 0      | 248       | 98.79 |       |
| Built-up | 2              | 0     | 0    | 2           | 12       | 0      | 58        | 74    | 16.22 |
| Shadow  | 0              | 0     | 0    | 0           | 94       | 0      | 94        | 100   |       |
| Bare soil | 437           | 1     | 1    | 0           | 15       | 3      | 6981      | 7438  | 93.86 |
| Total   | 3253           | 83    | 126  | 300         | 27       | 105    | 7263      | 11157 |       |
| PA (%)  | 86.5           | 98.8  | 99.21 | 81.67       | 44.44    | 89.52  | 96.12     |       |       |
| OA (%)  | 92.7938        |       |      |             |          |        |           |       |       |
| Kappa   | 0.8512         |       |      |             |          |        |           |       |       |

|       | 2015 Rangeland | Water | Snow | Plantations | Built-up | Shadow | Bare soil | Total | UA (%) |
|-------|----------------|-------|------|-------------|----------|--------|-----------|-------|--------|
| Rangeland | 834            | 0     | 0    | 111         | 0        | 0      | 368       | 1313  | 63.52 |
| Water   | 0              | 307   | 0    | 3           | 0        | 1      | 0         | 311   | 98.71 |
| Snow    | 0              | 1     | 206  | 0           | 0        | 0      | 0         | 207   | 99.52 |
| Plantations | 0         | 0     | 601  | 0           | 0        | 2      | 603       | 99.67 |       |
| Built-up | 35             | 1     | 0    | 16          | 18       | 0      | 564       | 634   | 2.84  |
| Shadow  | 13             | 1     | 0    | 1           | 0        | 1016   | 339       | 1370  | 74.16 |
| Bare soil | 127           | 7     | 14   | 6           | 10       | 0      | 6028      | 6192  | 97.35 |
| Total   | 1009           | 317   | 220  | 738         | 28       | 1017   | 7301      | 10630 |       |
| PA (%)  | 82.66          | 98.85 | 93.64 | 81.44       | 64.29    | 99.9   | 82.56     |       |       |
| OA (%)  | 84.7601        |       |      |             |          |        |           |       |       |
| Kappa   | 0.7329         |       |      |             |          |        |           |       |       |

UA = user accuracy; PA = producer accuracy; OA = overall accuracy; Kappa = kappa coefficient
use change (Berus and Henebry 2008). War and hostility in Bamyan broke down management and infrastructure, while a large mass of people left the area and migrated to other cities or out of the country. Thousands of households left Bamyan province during 1979 and 1989, relocating to

Fig. 4 Special temporal analysis from 1990-2015: (a) rangeland, (b) built-up, (c) plantation and (d) bare soil classes.
Pakistan and Iran or to another city in Afghanistan. This migration became even stronger during the Taliban era in 1999, in which 17% of houses were destroyed; nearly 90% of the population escaped and agricultural production dropped (Wily 2004). Qureshi (2002) indicated that war was the main reason for migration of farmers to other countries, and agriculture consequently plummeted. Subsequently, from 1999 to 2015, the bare soil, built-up, and plantation classes all increased, while rangeland decreased.

The socio-economic unrest that has affected Afghanistan over the last 20 years has been more than adequate to significantly affect the land surface. Wily (2004) explained that, as people returned to the area after Taliban withdrawal, starting in December 2001, the population of central Bamyan increased because the majority moved to Bamyan city. As stated by the Afghanistan Central Statistics Organization (2016) the population of Bamyan city nearly doubled over 25 years. In addition, rural communities in Afghanistan collect and store significant amounts of bushes and fuel wood to provide for their winter energy needs, creating an important impact on the structure and composition of rangeland vegetation and exposing land and soil to wind and water erosion (Norgrove et al. 2008).

4) Correlation among the land cover changes

To explore the relationships between land cover changes, we calculated the correlation coefficients ($r$) of the land-cover classes (rangeland, water, snow, plantations, built-up, and bare soil) based on 900 m × 900 m grid square cells. To evaluate the spatio-temporal changes of land-cover categories and compare them, the classified images were intersected with empty 900 m × 900 m grid square cells and the percentages of the six land-cover types within each cell were computed. Thus, the grid cells enable us to aggregate the categories for each map and to calculate their proportions. Furthermore, they enable us to evaluate the spatio-temporal changes in land-cover categories to allow a much easier statistical comparison of the land-cover changes. We calculated the correlation coefficients ($r$) of the land-cover classes (rangeland, water, snow, plantations, built-up, and bare soil) based on 900 m × 900 m grid square cells. Table 7 shows a summary of the linear correlation coefficient matrix between the changes in land cover groups from 1990 to 2015 based on

| Class        | 1990  | 1999  | 2008  | 2015  |
|--------------|-------|-------|-------|-------|
| Rangeland    | 60.21%| 53.06%| 51.24%| 37.90%|
| Water        | 0.13% | 0.01% | 0.01% | 0.05% |
| Plantations  | 7.80% | 6.35% | 6.74% | 8.15% |
| Built-up     | 0.88% | 0.55% | 0.96% | 1.47% |
| Bare soil    | 30.99%| 40.02%| 41.05%| 52.43%|

Table 6 Land cover class proportions (%) for the land cover maps

| Class Total 2015 | 2008 |
|------------------|------|
| 2008             | 2015 |
| Row Total        | 583853 | 583853 |
| Class Total      | 583853 | 583853 |
| Rangeland        | 502448 | 39  | 79434 | 583853 |
| Water            | 295    | 1  | 316   | 823 |
| Plantations      | 23932  | 100390 | 230  | 928  | 125480 | 125480 |
| Built-up         | 6181   | 4  | 2734  | 12619 | 22575 | 22575 |
| Bare soil        | 256477 | 47 | 11787 | 538973 | 807667 | 807667 |
| Class total      | 789333 | 177 | 103827 | 14791  | 632270 | 0  | 0  |
| Class changes    | 286885 | 51 | 3437  | 12057  | 93297 | 0  | 0  |
| Class Total 2015 | -205480 | 646 | 21653 | 7784  | 175397 | 0  | 0  |
Land cover changes in and around Bamyan City

Urban areas are growing rapidly worldwide due to population growth, rural-to-urban migration, and wealth increases in many parts of the world (Vliet et al. 2017). To investigate the impact of human activities on land cover change, we focused on Bamyan city (red outlined area in the right of Fig. 1), in which population is increasing rapidly due to the return of migrants and overall urban expansion.

Fig. 6 shows detailed land-cover maps for the area around Bamyan city, and Fig. 7 shows the grid-cell-based percentage change of land cover classes from 1990 to 2015 around Bamyan city. The population of Bamyan city increasing rapidly, the built-up area increased due to gradual construction. Our field survey analysis explains that rapid growing population impact surrounding area and cause bare soil enlargement and decrease of rangeland areas. As 24 persons from local people and 19 farmers argued that population increase and overuses of natural resources are also roots of land cover changes in Bamyan. To investigate the relationship between the land-cover changes caused by human activities, we calculated the correlation coefficients (r) between the changes in land-cover categories based on the 900 m × 900 m grid square cells in Bamyan city from 1999 to 2015, Table 8. As Table 8 shows, there is a strong negative linear relationship between the bare soil and rangeland categories (r = –0.89), a moderate negative correlation between bare soil and plantation classes (r = –0.32), and a positive correlation between built-up and plantation classes (r = 0.51). Therefore, population increases and other human activities have had a direct impact on land-cover change. The result of field survey supports the increase of plantation area specifically by respondents from villages that are near to center of city, they stated that the rangeland has been changed to agricultural land, Table 9 as an example. Also, to
imply bare soil and built-up expansion majority of respondents from local people and farmers from the village near to the center explained that population has increased, consequently natural resource overused and alter the rangeland to bare soil as well as built-up increased. These findings concur with the findings of recent studies. Wily (2004) reported that, after Taliban withdrawal, the population of
central Bamyan increased because the majority of the returned population moved to Bamyan city.

6) Conclusions

This study detected and quantified trends in land-cover change as well as the land degradation...
induced by human activities and nonexistence of land management policy through classifying satellite imagery and detailed field work survey from the central Bamyan province, Afghanistan, which has suffered three decades of war, breakdown of traditional systems and socio-economic changes. This is the first study attempting to evaluate and understand land-cover changes in the area over time. 30 m spatial resolution land-cover maps were produced with an overall accuracy between 84.76% and 92.79%, satisfactory for all classes except built-up areas.

We employed grid cells with unique cell IDs to detect correlations between land-cover classes. There was a strong negative correlation between the bare soil and rangeland classes throughout the study area. Around Bamyan city, there was a strong negative linear relationship between bare soil and rangeland, and between bare soil and plantation classes. This implies that population increases, lack of management policy and human activities have a direct impact on land degradation. Due to population increase, human activities, and conflict, the land cover has changed, leading to an increase in bare soil and a decrease in grazing land and other vegetated areas, reflecting an overall reduction in natural resources over the 25 years between 1990 and 2015. From these results, the policy makers know that land degradation become serious, but they don’t know the seriousness by numerical number. One of the important results of this study is to let policy makers know the seriousness by numerical number. Secondly, potentialize, simulation of land policy effect by ecosystem model, because the simulation model needs past land cover change data.

Acknowledgement

This research was supported by the Environment Research and Technology Development Fund (S-10) of the Ministry of the Environment, Japan. Hasi Bagan was also supported by National Natural Science Foundation of China (Grant No. 41771372).

References

Afghanistan Central Statistics Organization (2016): Estimated Settled Population by Civil Division, Urban, Rural and Sex-2015-16, http://cso.gov.af/en/page/1500/4722/2014-2015. (accessed at 20 May 2016).

Arsanjani JJ, Helbich M, Kainz W and Boloorani AD (2013): Integration of logistic regression, Markov chain and cellular automata models to simulate urban expansion. International Journal of Applied Earth Observation and Geoinformation. 21; 265-275.

Bagan H, Takeuchi W, Kinoshita T, Bao Y and
Yamagata Y (2010): Land cover classification and change analysis in the Horqin sandy land from 1975 to 2007. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 3;168-177.

Bagan H and Yamagata Y (2014): Land-cover change analysis in 50 global cities by using a combination of Landsat data and analysis of grid cells. Environment Research Letters. 9.

Beurs D K M and Henebry G M (2008): War, drought, and phenology: Changes in the land surface phenology of Afghanistan since 1982. Journal of Land Use Science. 3; 95-111.

Congalton R G and Green K (2009): Assessing the Accuracy of Remotely Sensed Data: Principles and Practices, 2nd edition. Taylor & Francis, New York, pp 70-86.

Cook D E, (2011): Bamiyan Province Climatology and Temperature Extremes in Afghanistan, http://www.dta.mil.nz/wp-content/uploads/Bamiyan-province-climatology-and-temperature-extremes-in-Afg1.pdf , (accessed 30 May 2016).

Favre R and Kamal G M (2004) Watershed atlas of Afghanistan. FAO, Kabul, Afghanistan, pp.174-175.

Gómez C, White J C and Welder M A (2016): Optical remotely sensed time series data for land cover classification: a review. ISPRS Journal of Photogrammetry and Remote Sensing. 116; 55-72.

Karim Z A H M (2013): Impact of a Growing Population in Agricultural Resource Management: Exploring the Global Situation with a Micro-Level Example. Asian Social Science. 9; No. 15

Lillesand TM, Kiefer RW and Chipman J W (2008): Remote Sensing and Image Interpretation. sixth edition, John Wiley & Sons, Hoboken, NJ, USA, pp. 562-565.

Mohibbi A A and Cochard R (2014): Residents’ resource uses and nature conservation in Band-e Amir National park, Afghanistan. Environmental Development. 11; 141-161.

Norgrove L, Bowling B, Modaqiq W, Haidari G H, Salari SS, Ali R, Manan A R and Sarwari G D (2008): Desertification, Rangeland, and Water Resources Working Group. http://postconflict.unep.ch/publications/afg_soef%20issues%2020Afghanistan.pdf, (accessed 31 May 2017).

Pervez M S, Budde M and Rowland J (2014): Mapping irrigated areas in Afghanistan over the past decade using MODIS NDVI. Remote Sensing of Environment.149 ; 155-165.

Qian T, Bagan H, Kinoshita T and Yamagata Y (2014): Spatial-temporal analyses of surface coal mining dominated land degradation in Holingol, Inner Mongolia. IEEE Journal of Selected Topic in Applied Earth Observation and Remotes Sensing. 7; 1675-1687.

Qureshi A S (2002): Water Resources Management in Afghanistan: The Issues and Options, https://cropwatch.unl.edu/documents/Water%20Resource%20Issues%20In%20Afghanistan.pdf, (accessed at 4 September 2016).

Shroder J F (2012): Afghanistan: rich resource base and existing environmental despoliation. Environ Earth Sci. 67; 1971-1986.

Shroder J F (2014): Natural Resources in Afghanistan: Geographic and Geologic Perspectives on Centuries of Conflict, Elsevier, San Diego, pp 458-467.

Simms D M, Waite T W, Taylor J C and Juniper G R (2014): The Application of Time-Series MODIS NDVI Profiles for the Acquisition of Crop Information across Afghanistan. International Journal of Remote Sensing. 35; 6234-6254.

Timah E A, Ajaga N, Tita D F, Ntonga L M and Bongsyisi B I (2007): Demographic pressure and natural resources conservation. Ecological Economics. 64; 475-483.

UNEP (2008): Afghanistan’s Environment, http://postconflict.unep.ch/publications/afg_soe_E.pdf, (accessed at 14 Jun 2016).

UNEP (2003): Afghanistan: Post-Conflict Environmental Assessment, http://postconflict.unep.ch/publications/afghanistanpcajanuary2003.pdf, (accessed at 1 July 2016).

van Vliet J, Eitelberg D A and Verburg P H (2017): A global analysis of land take in cropland areas...
和生产，以及从城市化所引起的生产位移。

Global Environmental Change. 43; 107-115.

Wily L A (2004): Land Relations in Bamyan Province: Finding from a 15 Village Case Study. Afghanistan Research and Evaluation Unit, http://www.neisci.edu/afghanistan/pdf_data/areu-afg-29feb.pdf, (accessed 31 May 2016).

Winterbotham E Rahimi F (2011): Legacies of conflict: Healing complexes and Moving Forwards in Bamyan Province. Afghanistan Research and Evaluation Unit, https://areu.org.af/wp-content/uploads/2016/02/1125E-Legacies-of-Conflict-Bamiyan-CS-2011.pdf, (accessed at 26 December 2016).

要旨

地管理の不足と紛争は、アフガニスタンのバーミヤンの生態系に大きなストレスを与えた。本研究では、1990 年から 2015 年までのバーミヤンの土地被覆の時間的変化と土地管理の問題を評価した。そのために、97 人の住民を対象にアンケート調査を実施した。住民へのアンケートの結果、88 人が土地被覆が 30 年で変わったと述べた。回答者らは、人口増加、資源の過度使用、過放牧、薪炭材収穫、干ばつおよび管理の理由を指摘した。政府組織や NGO とのインタビューの結果、植生の覆土の除去、過放牧、自然資源への依存、飼料収集、急な斜面での栽培が原因で、土地の劣化が発生しているとの結果を得た。また、1990 年から 2015 年のランドサット画像を用いて土地被覆マップを作成した。放牧地は裸地と居住地の急速な増加に伴って 60.2%から 37.9%に減少した。このことは、人为的な影響が周囲の生態系に影響を与えたことを示唆している。0.81 km²のグリッドにおける土地被覆変化の統計的比較では、放牧地の減少と裸地のそれと強く負の相関があることを示した。また、バーミヤン市周辺では、居住地の拡大は農耕地の拡大と強く正の相関がある一方、裸地の増加とは負の相関が見られた。これらにより、長期の紛争、土地管理の不足、および社会経済的変化が土地被覆に影響を与えたことを示した。

キーワード

自然資源、土壌劣化、土地管理、半乾燥地、紛争