Detecting Land Use/Land Cover change using Landsat Imagery: Jumgal District, Kyrgyzstan

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Abstract

One of the important problems of Geographical Science in the XXI century is the study of quantitative and qualitative changes observed in the land use. In this study, we present two datasets of land use/cover in the Jumgal District derived from Landsat TM and OLI/TIRS images in 1996 and 2014. We used these data to investigate changes in land use/cover between 1996 and 2014. The satellite data has been geocoded to the Universal Transverse Mercator (UTM) coordinate system, Zone 43 North, World Geodetic System (WSG-84) coordinate datum. The information provided by satellites to quantify the various parameters of land use of the district has been evaluated by applying various image-processing techniques. The images were classified using Maximum Likelihood classification method and mapped using ArcGIS 10.1. From 1996 to 2014, the water body's area increased by 530 ha (98.1 %); agriculture area decreased by 9720 ha (14.4 %); mixed forest decreased by 7010 ha (33.3 %); wetland decreased by 1080 ha (9.5%); grassland increased by 540 ha (0.2 %); barren land increased by 18360 ha (14.3 %); and perennial snow/ice decreased by 1620 ha (16 %). The overall accuracies for 1996 and 2014 were respectively 97 % and 92 % with Kappa Statistics of 96 %, and 90 %. User and producers' accuracies of each information class ranged from 77 % to 100 % in most cases. From these findings, it is highly recommended that the local government initiate measures to protect the forest in Jumgal district whose continuous retreat would expose the land to erosion and other related environmental concerns.

1. Introduction

Studies have shown that there remain only a few landscapes on Earth that are still in their natural state. Due to anthropogenic activities, the earth surface is significantly altered in any way and the human presence on Earth and his use of land have had a profound impact on the natural environment in such a way that leads to observed patterns of land use/land cover over time. The Land Use and Land Cover Change (LUCC) project is an interdisciplinary combined central project of the International Geosphere–Biosphere Program (IGBP) and the International Human Dimensions Program on Global Environmental Change (IHDP) (Turner et al., 1993 and Turner et al., 1995).

The land cover is determined by the attributes of the earth surface captured in the distribution of vegetation, water, desert and ice and the immediate subsurface, including biota, soil, topography, surface and groundwater, and it also includes those structures created solely by human activities such as mine exposures (Lambin et al., 2003, Chrysoulakis et al., 2004 and Baulies and Szejwach, 1998). Land use is a more complex term.

Natural scientists define land use in terms of syndromes of human activities such as agriculture, forestry and building designs that change processes at the land surface, including biogeochemistry, hydrology and biodiversity (Ellis, 2013). According to Giri et al., (2013), human-induced land cover change is increasingly affecting the biophysics, biogeochemistry, and biogeography of the Earth's surface and the atmosphere. Because humans control land use and, mainly, land cover, individuals, businesses, nonprofit organizations, and governments can make land decisions to adapt and/or mitigate the effects of climate change (Brown et al., 2014).

Since the 1972 beginning of the Landsat program, satellite remote sensing has provided an opportunity for manipulation and analysis of satellite images at different scales by using computer-based image processing software. RS and GIS software such as ESRI (Environmental Systems Research Institute) ArcGIS software packages offer many tools that facilitate data processing, data analysis, and classification of earth surface features

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such as forest cover, soils and land use/cover for the compilation of thematic maps (Jensen, 2005 and Lillesand et al., 2008). Land-cover change monitoring requires high spatial and temporal resolution satellite data (30 m resolution Landsat has become the standard) (Lambin et al., 2005). The Landsat program has provided over 40 years of calibrated high spatial resolution data on the earth's surface to a broad and diverse user community, including agribusiness, global change researchers, academia, state and local governments, commercial users, national security agencies, international community, decision-makers, and the general public (Department of the Interior U.S. Geological Survey, 2015). The SRTM digital elevation data, produced by NASA originally, is a major breakthrough in digital mapping of the world and provides a major advance in the accessibility of high-quality elevation data for large portions of the tropics and other areas of the developing world (Jarvis et al., 2008).

We chose this area to show whether there were changes over the last two decades in the intermountain Jumgal district of Kyrgyzstan. This study used Remote Sensing (RS) and Geographic Information Systems (GIS) technologies to detect, delineate and quantify the rate of land cover change that has occurred in Jumgal district for the 18-year period from 1996 to 2014. Specifically, the purpose of this paper was to investigate the changes in LULC over a period of 18 years in Jumgal District, Kyrgyzstan using RS and GIS techniques.

2. Data and Methods

2.1 Study Area

The study area of about 5398.5 km^2, is situated between Longitudes 72°20′ 17″- 74°22′57″ East and Latitudes 42°14′45″- 41°32′33″ North. Jumgal district is located in the northwestern part of the Naryn oblast (province), Kyrgyz Republic and is limited to the north Jumgal-Too, Sandyk from west Suusamyr-Too and Sary-Kamysh, in the south Kabak-Too and Song-Köl, and to the east Kyzart ranges. The district is bordered on the north by the lands and farms of Panfilov and Kochkor districts, in the west - with the lands of Panfilov district and Jalal-Abad province, in the south – Toguz-Toroo and Ak-Talaa districts in the east - to the lands of Kochkor and Ak-Talaa districts of Kyrgyz Republic (Barataliev, 2010). The mountain area is characterized by high fragmentation of the topography and the large gravitational energy slopes (Figure 1). The differential absolute marks of the bottom trough vary from 1500 to 2600 m and the mountainous zone ranging from 2600 m to 4185 m. However, about 11% of the territory belong to the valleys, and 89% are mountain structures, covered by permafrost at 5% of permafrost.

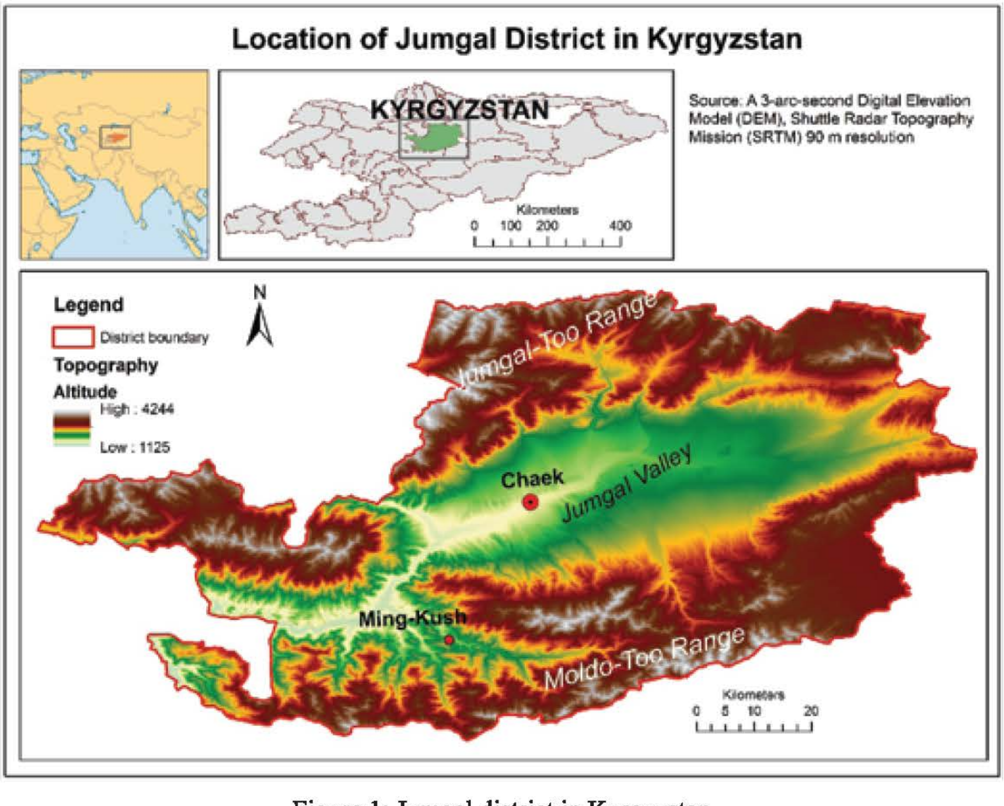

Figure 1: Jumgal district in Kyrgyzstan

The minimum air temperature can reach -25° C in the valley zone and -35° C in the mountain zone whereas the maximum air temperature can go as high as 34° C in the valley area and up to 20°C in the mountainous area of the district (Suranova, 2015). The population, according to the National Statistical Committee of the Kyrgyz Republic (2015) as of January 1, 2014, amounts to 42.2 thousand people. The average population density is 8.8 people per one km^2. The district has 28 villages belonging to 13 rural communities (aiyl ökmöts). Each rural community includes one or several villages. The administrative economic center of the region is Chaek village, located within 340 km from the capital of the Kyrgyz Republic – Bishkek and the regional center – Naryn city at 240 km (State Language Centre and Encyclopedia, 2004). Jumgal district is very promising in terms of animal husbandry and agricultural development.

2.2 Dataset

A 3-arc-second Digital Elevation Model (DEM) of a 90-meter resolution was used in this study to distinguish mountains from valley areas. This DEM is a product of the Shuttle Radar Topography Mission (SRTM), a joint project overseen by NASA and the National Geospatial-Intelligence Agency (NGA), which has provided topographic data for 80 % of the Earth's land surface. Landsat-5 TM (Thematic Mapper) images of 1996 and Landsat-8 OLI/TIRS (Operational Land Imager/Thermal Infrared Sensor) of 2014 from U.S. Geological Survey (USGS) (Table 1) with a spatial resolution of 30 m were used for land cover change analysis.

2.3 Pre-Processing

The satellite data (Landsat TM and OLI/TIRS) have been geometrically corrected and geocoded to the Universal Transverse Mercator (UTM) coordinate system, Zone 43 North, World Geodetic System (WSG-84) coordinate datum using the nearest neighbor interpolation algorithm (Jensen, 2005). The administrative district boundary map was also brought to UTM project in Zone 43 N and later the satellite imageries were clipped with the administrative boundary of Jumgal district. The information provided by the satellites to quantify the various parameters of land use of the district has been evaluated by applying various image-processing steps with ArcGIS 10.1 software.

2.4 Image Classification

The study depended on the use of computer-assisted interpretation of Landsat imageries. Once the training sites were determined, Maximum Likelihood classification was utilized. The Maximum Likelihood classifier is considered to give very accurate results (Mengistu and Salami, 2007, Reis, 2008 and Diallo et al., 2009). The classification scheme utilized seven land use/land cover classes representing water body, agriculture, mixed forest, wetland, grassland, barren land and perennial snow/ice. Separability analyses were done on the signatures files using ArcGIS 10.1 to select the best statistical training signatures to use for the MLC classification (Table 2).

Table 1: Data description

Satellite	Sensor	Path/Row	Date	Resolution (m)	Source
Landsat 8	OLI/TIRS	151/31	07-08-2014	30	glovis.usgs.gov
Landsat 5	TM	151/31	06-09-1996	30	glovis.usgs.gov

Table 2: Land use/land cover classification Scheme.

LULC	Description
Water body	Areas covered with water such as lakes and rivers
Agriculture	Crop production and grazing
Wetland	Wet meadows or perched bogs in high mountain valleys and seasonally wet basins
Mixed forest	Trees, shrubs and other plants that grow close to each other
Grassland	Naturally occurring grasses and forbs
Barren land	Areas of bare soil and exposed rocks
Perennial snow/ice	Snow, firn (coarse, compacted granular snow) and glaciers

2.5 Accuracy Assessment

Error matrices were generated to evaluate each land use/cover class accuracies. Accuracy assessment was measured through the matrix using user classification and reference image User and Producer's accuracy was measured using Equation 1 and 2 (Tilahun and Teferie, 2015).

$$User's\ accuracy = \frac{Reference\ value}{Row\ total} \times 100$$

Equation 1

$$User's\ accuracy = \frac{Reference\ value}{Column\ total} \times 100$$

Equation 2

Overall accuracy was measured using equation 3 (Tilahun and Teferie, 2015)

$$\text{Overall accuracy} = \frac{\text{Number of correct plots (Value)}}{\text{Total number of plots (Value)}} \times 100$$

Equation 3

The Kappa statistic was derived to include measures of class accuracy within an overall measurement accuracy of the classifier (Congalton, 1991). This provides a more accurate measure of the accuracy of a classifier than the overall accuracy since it considers the inter-class agreement. Kappa analysis yields a K_{hat} statistics that is a measure of agreement or accuracy. The K_{hat} statistic is computed equation 4

$$K_{hat} = \frac{N \sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})}$$

Equation 4

Where, r is the number of rows in the matrix, X_{ii} is the number of observation in row i and column i, and x_{i+} and x_{+i} are the marginal totals for row i and column i, respectively, and N is the total number of observations.

3. Results and Discussion

Figure 2 shows the LULC maps of the study area for 1996 and 2014. Tabulations and area calculations provide a comprehensive data set in terms of the overall landscape, the types and extent of changes, which have occurred. In the periods considered, grassland constituted the most extensive type of LULC in the study area. Accordingly, it accounted for about 301240 hectares (ha), contributing 55.8 % of the total area in 1996, followed by barren land and agriculture, occupying 127940 ha (23.7 %) and 67480 ha (12.5 %) of the total area respectively. LULC units under mixed forest, wetland, perennial snow/ice and water body covered 21050 ha (3.9 %), 11340 ha (2.1 %), 10260 ha (1.9 %) and 540 ha (0.1 %) of the area respectively.

In 2014, the land under grassland about 301780 ha (55.9 %) of the total area. Barren land and agriculture occupied 146300 ha (27.1 %) and 57760 ha (10.7 %), respectively. The remaining area is occupied by mixed forest, wetland, perennial snow/ice and water body, which accounted for about 14040 ha (2.6 %), 10260 ha (1.9 %), 8640 ha (1.6 %) and 1070 ha (0.2 %) respectively (Table 3) (Figure 3).

From 1996 to 2014, the water body's area increased by 530 ha (98.1 %, almost doubled); agriculture area decreased by 9720 ha (14.4 %); mixed forest decreased by 7010 ha (33.3 %); wetland decreased by 1080 ha (9.5 %); grassland increased by 540 ha (0.2 %); barren land increased by 18360 ha (14.3 %); and perennial snow/ice decreased by 1620 ha (16 %) (Figure 4).

Table 3: Comparison of areas (ha) based on the seven cover types between 1996 and 2014

Land use/ cover classes	1996		2014	
	Area (ha)	**%**	**Area (ha)**	**%**
Water body	540	0.1	1070	0.2
Agriculture	67480	12.5	57760	10.7
Wetland	11340	2.1	10260	1.9
Mixed forest	21050	3.9	14040	2.6
Grassland	301240	55.8	301780	55.9
Barren land	127940	23.7	146300	27.1
Snow/ice	10260	1.9	8640	1.6
Total	**539850**	**100**	**539850**	**100**

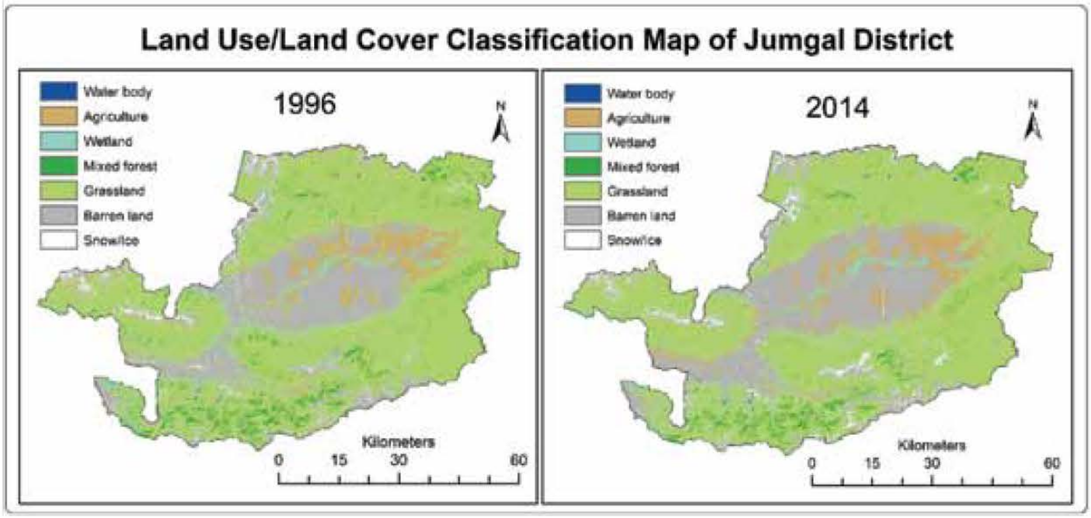

Figure 2: Land use/land cover map of the Jumgal district from 1996 to 2014

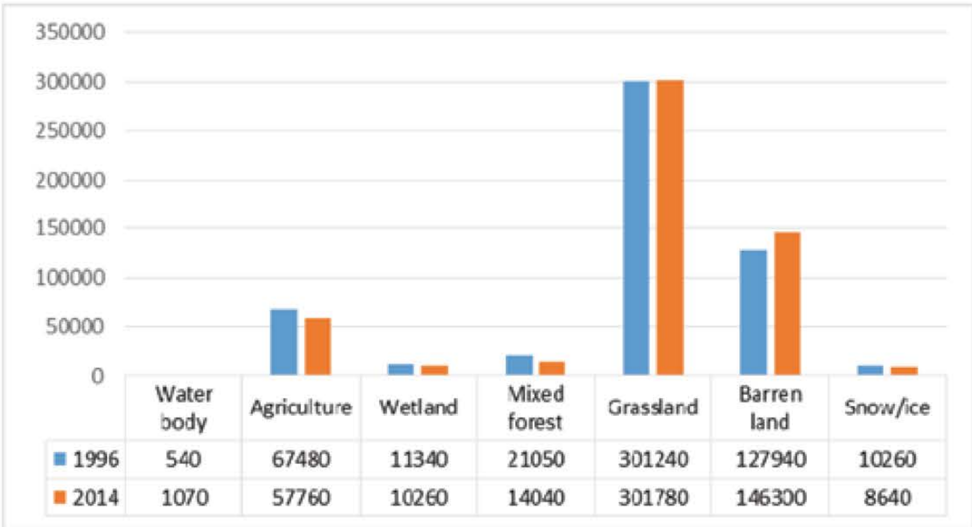

Figure 3: Land Use/Cover types (ha) for 1996 and 2014 by total area (5398.5 km^2)

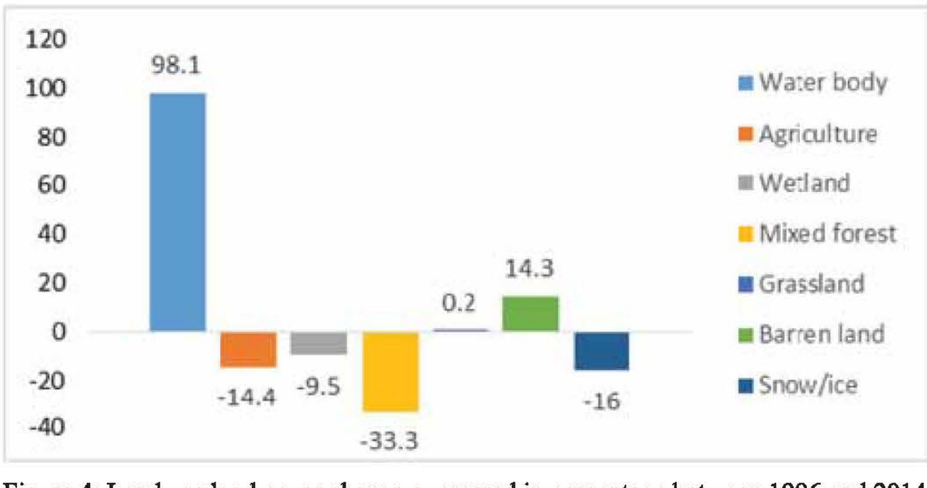

Figure 4: Land use land cover change expressed in percentage between 1996 and 2014

Table 5: Results of the accuracy assessment of the 1996 and 2014 Land use/cover classification map produced from the Landsat TM and Landsat OLI/TIRS data expressed as percentages

Reference data (1996)									
	WB	**A**	**W**	**MF**	**G**	**BL**	**S/I**	**RT**	**UA**
WB	**30**	0	0	0	0	0	0	30	100%
A	0	**26**	0	0	1	0	0	27	96%
W	0	4	**30**	0	0	0	0	34	88%
MF	0	0	0	**29**	0	0	0	29	100%
G	0	0	0	0	**29**	2	0	31	94%
BL	0	0	0	0	0	**28**	0	28	100%
S/I	0	0	0	0	0	0	**29**	29	100%
CT	30	30	30	29	30	30	29	**208**	
PA	100%	87%	100%	100%	97%	93%	100%		
Overall Classification Accuracy: 97%					**Overall Kappa Statistic: 96%**				
Reference data (2014)									
	WB	**A**	**W**	**MF**	**G**	**BL**	**S/I**	**RT**	**UA**
WB	**28**	0	0	0	0	0	0	28	100%
A	0	**23**	0	0	0	0	0	23	100%
W	0	7	**30**	0	0	0	0	37	81%
MF	0	0	0	**27**	1	0	0	28	96%
G	0	0	0	3	**29**	0	0	32	91%
BL	0	0	0	0	0	**26**	0	26	100%
S/I	2	0	0	0	0	4	**30**	36	83%
CT	30	30	30	30	30	30	30	**210**	
PA	93%	77%	100%	90%	97%	87%	100%		
Overall Classification Accuracy: 92%					**Overall Kappa Statistic: 90%**				

For 1996 image, a total of 208 pixels were selected and evaluated for accuracy and 201 were correctly classified, which resulted in an overall accuracy of 97 % and a kappa statistic of 96 %. In terms of producer's accuracy, all classes were over 95 % correct with the exception of agriculture and barren land, which were 87 % and 93 % respectively (Table 4). For 2014 image, 210 pixels were selected and evaluated accuracy and 193 were correctly classified, the overall accuracy is 92 % and the Kappa statistic 90 %. In terms of producer's accuracy, all classes were over 90% with the exception of agriculture and barren land, which were 77 % and 87 % respectively (Table 5).

4. Conclusions

In this study, the main attention has been paid to the land use and land cover change in the Jumgal district, to study land use changes that have occurred in the area from 1996 to 2014, using Remote Sensing technology. The objectives were to demonstrate the usefulness of using satellite digital image processing coupled with GIS technology to map land use/cover and detect changes in land use/cover. The potential of using multi-sensor remotely sensed data, particularly, Landsat-5 TM, and Landsat-8 OLI/TIRS was evaluated. A Maximum Likelihood Classification approach was used to classify the image given that this approach takes advantages of supervised classification to improve the accuracy of the derived maps.

The study has shown that: From 1996 to 2014, the water body's area increased by 530 ha (98.1 %, almost doubled); agriculture area decreased by 9720 ha (14.4 %); mixed forest decreased by 7010 ha (33.3 %); wetland decreased by 1080 ha (9.5%); grassland increased by 540 ha (0.2 %); barren land increased by 18360 ha (14.3 %); and perennial snow/ice decreased by 1620 ha (16 %). This research has highlighted the obvious changes in Land use/ Land cover change in Jumgal district. The retreating of perennial snow and ice, well as decreasing forests' size, deserve management attention. We believe this study is a significant contribution towards improving the management of the environment in the context of sustainability. Finally, future studies are paramount to better understand the driving forces behind the observed changes in this area.

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