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# LAND-USE CHANGE RELATED TO TOPOGRAPHY AND SOCIETAL DRIVERS IN HIGH-MOUNTAINS – A CASE STUDY IN THE UPPER WATERSHED OF THE TERGI (KAZBEGI REGION), GREATER CAUCASUS

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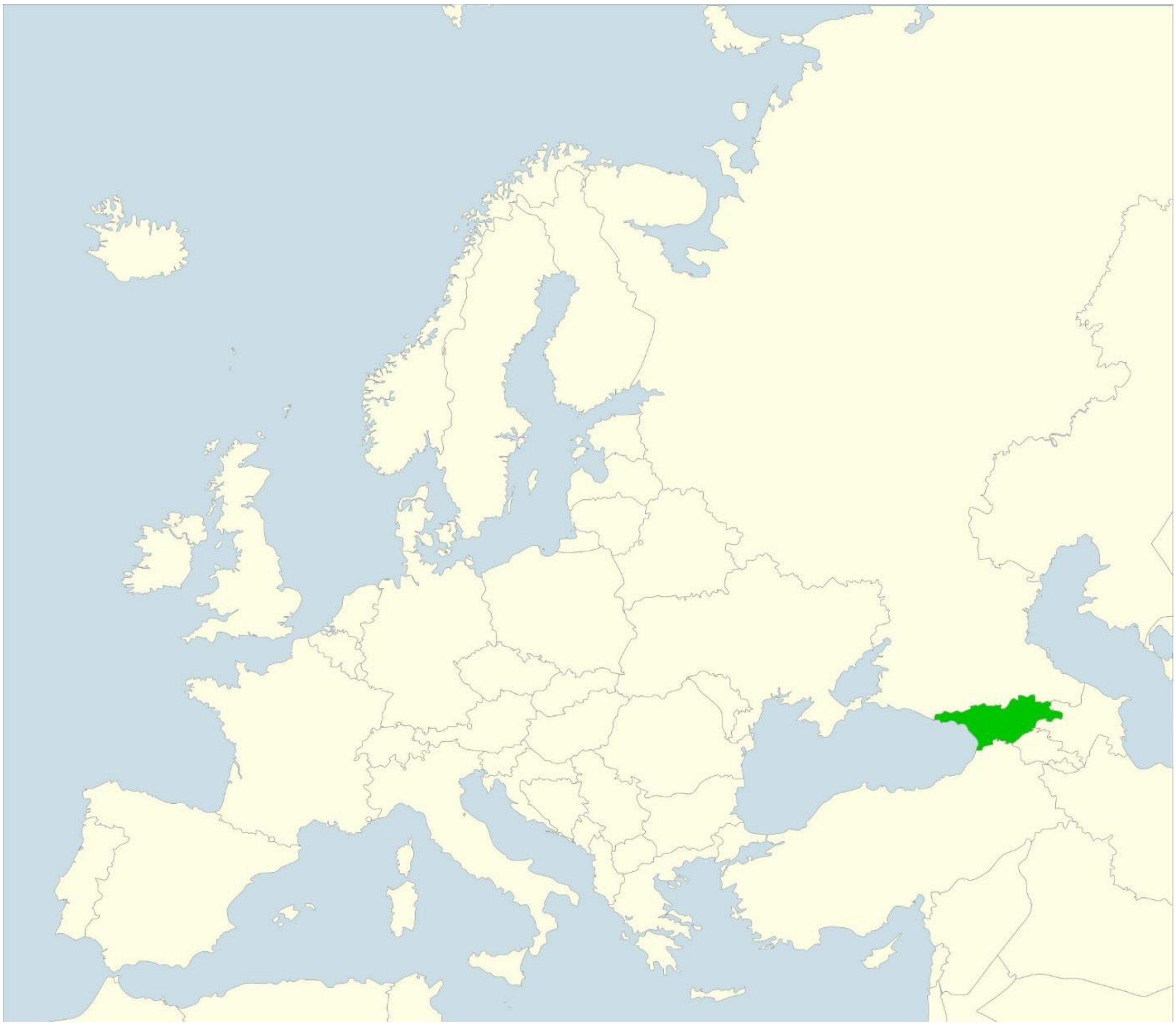

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**Abstract:** High mountain ecosystems, with strong topographic and climatic gradients, are fragile and particularly sensitive to changes in land use. The abandonment of historic cultural landscapes has often led to changes in the pattern of land cover and thus, to a shift in the functions of high mountain landscapes, like fresh water supply, productivity or erosion control. In order to understand the effects of land-use change on the land-cover pattern at the local and regional scale, we analyzed and classified the mountainous landscape structure in the Kazbegi region in Georgia, located in the Central Greater Caucasus. For 13 settlements, we determined the land cover as present in 1987 and 2015, and quantified the changes over time to detect land-cover development trends for each settlement. Using a cluster analysis, the study area was analyzed regarding to topography (altitude, aspect, slope) and distance to settlements at the regional scale to gain six groups with separating conditions. Furthermore, each settlement was classified according to topography and land-cover change to obtain site-specific, comparative development trends. Our results show that this Caucasian high-mountain landscape is characterized by open grassland (67%) used as pasture and hay meadow, and natural birch forests (7%) in patches in the upper half of the subalpine belt. Within the settlements but also in their surroundings, field vegetables are cultivated in home gardens (1%). Land-cover change during the observation period mainly affected the cultural grassland with hay meadow abandonment. Moreover, shrubbery and forest expanded considerably on abandoned pastures. We further detected a strong relationship to topography that considerably varied between settlements resulting in specific trends in land-use change. Hay-making and arable land cultivation are focused today on sun-exposed and gentle slopes near the settlements. Shrub encroachment and reforestations were localized on farther distances and mostly on north-exposed slopes. Besides providing basic information about the historic and current land-use and land-cover patterns, our results quantify the landscape change during almost 30 years. A spatio-temporal analysis revealed an understanding of how land-use decisions influence the landscape pattern. In the context of societal development, regional socio-economic processes, like shifts in the agricultural structure and population outmigration, seem to be societal drivers of changes. Our findings reveal linkages and interrelationships between natural, human-induced environmental and socio-economic processes within high-mountain socio-ecological systems. Moreover, we suggest that sustainable land-use strategies for spatial development on sub-regional level, especially in marginal high-mountain regions, should consider topography and its influence on land-use change.

**Key words:** Landscape structure; GIS; Land-use change; Remote sensing; Georgia; Caucasus

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**აბსტრაქტი: მიწათსარგებლობით გამოწვეული ცვლილებების კავშირი მაღალმთის ტოპოგრაფიასთან მდ.თერგის ზემო წელის წყალშემკრებ აუზში (ყაზბეგის რ-ნი) დიდი კავკასიონი.** მაღალმთის ეკოსისტემები მიწათსარგებლობის ცვლილებების მიმართ განსაკუთრებით მგრძნობიარე და მოწყვლადია. ისინი გამოირჩევიან რთული ტოპოგრაფიული და სპეციფიკური კლიმატური მახასიათებლებით. სასოფლო-სამეურნეო სავარგულების მიტოვება ხანგრძლივი პერიოდის განმავლობაში ხშირად იწვევს გარკვეულ ცვლილებებს „მიწის საფრის“ კონფიგურაციაში და, შესაბამისად, მაღალმთიანი ეკოსისტემების ფუნქციებშიც, როგორიცაა მაგ.: მტკნარი წყლით მომარაგება, პროდუქტიულობა და ეროზიის კონტროლი. ჩვენ გავაანალიზეთ ყაზბეგის რაიონის (საქართველო), რომელიც მდებარეობს მთავარი კავკასიონის ქედის ცენტრალურ ნაწილში, მაღალმთიანი ლანდშაფტების სტრუქტურა და მოვახდინეთ მათი კლასიფიცირება იმისათვის, რომ გასაგები გახდეს მიწათსარგებლობით გამოწვეული ცვლილების შესაძლო

ზემოქმედება ლოკალურ და რეგიონულ დონეებზე. 1987–2015 წწ. შედგენილი რუკების საფუძველზე ყაზბეგის რაიონის 13 დასახლებული პუნქტისთვის განვსაზღვრეთ "მიწის საფრის" ტიპები, რათა დროსა და სივრცეში თითოეული დასახლებისთვის გამოვლენილიყო მისი განვითარების ტენდენციები. საკვლევი ტერიტორია შევისწავლეთ ტოპოგრაფიისა (სიმაღლე ზღვის დონიდან, ექსპოზიცია, ფერდობის დახრილობა) და დასახლებული პუნქტიდან მანძილის მიხედვით, რისთვისაც გამოვიყენეთ კლასტერული ანალიზის მეთოდი. შედეგად გამოიყო სხვადასხვა ეკოლოგიური მახასიათებლების ექვსი ჯგუფი. მეტიც, მოხდა თითოეული დასახლებული პუნქტის კლასიფიცირება ტოპოგრაფიისა და „მიწის საფრით“ გამოწვეული ცვლილების მიხედვით. ჩვენი შედეგები გვიჩვენებს, რომ საკვლევი ტერიტორიის ძირითად ლანდშაფტს ქმნის უმთავრესად სათიბ-საძოვრებად გამოყენებული მდელოები (67%) და ბუნებრივი არყნარის კორომები (7%). ეს უკანასკნელი გვხვდება სუბალპური სარტყელის ზედა ნაწილში. ბოსტნეული კულტურები, როგორც წესი, გაშენებულია დასახლებებსა და მათი შემოგარენის საბაღე ფართობებზე (1%). კვლევის პერიოდში ცვლილებები დაფიქსირდა ძირითადად კულტურულ ლანდშაფტებში, რაც გამოვლინდა სათიბების მიტოვებით. გარდა ამისა, ტყე და ბუჩქნარი უმეტესად ფართოვდებოდა მიტოვებული საძოვრების ხარჯზე. უფრო მეტიც, დადგინდა ძლიერი კავშირი ტოპოგრაფიასთან, რომელიც მნიშვნელოვნად იცვლებოდა დასახლებული პუნქტების მიხედვით და დაკავშირებული იყო მიწათსარგებლობის ტიპთან. დღესდღეობით, სახნავი და სათიბი სავარგულების ძირითადი ნაწილი კონცენტრირებულია მზიან, ნაკლებად დახრილ ფერდობებზე დასახლებების მახლობლად, მაშინ როდესაც ტყის და ბუჩქნარის აღდგენა ხდება დასახლებული პუნტებიდან შორს და ჩრდილოეთის ფერდობებზე. გარდა არსებული ძირითადი ინფორმაციისა ისტორიული და მიმდინარე მიწათსარგებლობის შესახებ, ჩვენმა შედეგებმა აჩვენა, რომ მცირე რეგიონის ფარგლებში მიწათსარგებლობით გამოწვეული ცვლილებები მჭიდრო კავშირშია ტოპოგრაფიასთან და ცვალებადია დასახლებების მიხედვით. სოციალური განვითარების კონტექსტში, რაოდენობრივი ცვლილებები გამოიხატება რეგიონული სოციალურ-ეკონომიკური პროცესებით, როგორიცაა სოფლის მეურნეობის სტრუქტურისა და მოსახლეობის საემიგრაციო ცვლილებები. ჩვენი შედეგები გვაძლევს შესაძლებლობას გამოვავლინოთ კავშირი და ურთიერთდამოკიდებულება ბუნებას, ადამიანის შექმნილ გარემოსა და სოციალურ-ეკონომიკურ პროცესებს შორის მაღალმთის სოციალურ-ეკოლოგიურ სისტემაში. ზემოთ მოყვანილ შედეგებზე დაყრდნობით შეგვიძლია დავასკვნათ, რომ რაიონულ დონეზე მდგრადი მიწათსარგებლობის სტრატეგიის სივრცითი დაგეგმარებისას, განსაკუთრებით კი მაღალმთიან რეგიონებში, გათვალისწინებული უნდა იყოს ტოპოგრაფია და მისი გავლენა მიწათსარგებლობით გამოწვეულ ცვლილებებზე.

**საკვანძო სიტყვები:** ლანდშაფტების სტრუქტურა, გეოინფორმაციული სისტემები, მიწათსარგებლობით გამოწვეული ცვლილება, დისტანციური ამოცნობა, საქართველო, კავკასია

## 1. Introduction

Mountainous regions provide important landscape functions for biomass productivity, regulation and cultural purposes. Heterogeneous mountain landscapes serve as a source for local food production and the supply with freshwater, even for lowlands far away. Forested mountains regulate the climate and water circles, and reduce the risk of gravitational natural hazards, like downslope mass movement (Grêt-Regamey et al., 2012). Today, they are also the main areas for tourism and recreation offering scenic beauty (Zoderer et al., 2016). Further, mountain landscapes often possess a high habitat and species richness within small territories (Becker et al., 2007; Nakhutsrishvili, 1999).

Mountains have been shaped by humans since ancient times. The impact of land use, i.e. mostly by livestock grazing, has led to the development of cultural landscapes with large, unfragmented habitats that are characterized by high biodiversity and an aesthetical appeal. As a result, they have a significant conservational and historical value (Körner et al., 2006). Human use of the landscape through agriculture and forestry caused the establishment of the typical landscape appearance visible today – a mosaic of open grassland and wooded areas along a diverse topography with a strong altitudinal gradient. The effects of long-lasting impacts of land use adapted to heterogenic site conditions have thus formed a specific diversity of land-cover types.

Land-use and land-cover changes, often induced by either political and/or climate changes, severely affect landscape functioning in high mountain landscapes, like for example, the productivity, the biodiversity or the landscape´s appearance with related habitat types (Hietel et al., 2004; Körner, 2000). At present, land-cover changes in cultural high-mountain landscapes can be observed from over- or under-utilization in contrast to prior use (Spehn et al., 2006). In European mountainous regions, the use of fertile agricultural land has been intensified whereas remote areas that are difficult to access and to manage have been abandoned (MacDonald et al., 2000; Niedrist et al., 2009; Török et al., 2016). Land-use change can lead to the loss of high mountain biodiversity, especially species richness, in addition to affected productivity and system integrity and, therefore, can affect the livelihood of the local population (Körner, 2004; Poschlod et al., 2005; Tasser and Tappeiner, 2002).

Georgia´s Greater Caucasus is facing severe changes in land use since the soviet time (1922–1991) until today (Wiesmair et al., 2016). Nevertheless, this mountain range with an east-west extension of 1,500 km (Walter, 1974) in the distant southeast of Europe is one of the global biodiversity hotspots, characterized by an exceptional species richness and outstanding number of endemics, especially in the subalpine belt (Myers et al., 2000; Nagy and Grabherr, 2009). The plant species diversity within the subalpine grassland is a result of the macro-relief (aspect), the micro-relief (convex and concave landforms) and the land-use intensity, such as the long-term and extensive grazing pressure (Lichtenegger et al., 2006; Pyšek and Šrůtek, 1989). The land-use intensity was driven by society changes: from the middle of the 20th century until 2014, there had been substantial transitions in population development and agriculture in the Kazbegi region (National Statistics Office of Georgia, 2014 and 2015). Former traditional alpine farming had been replaced by intensive livestock husbandry and afterwards, after the breakdown of the Soviet Union, by de-intensified agriculture. These transitions have been reflected in the land-cover structure of this agro-pastoral system. The upper watershed of the Tergi River with its tributaries in the Central Greater Caucasus is considered to be prone to current and future land-use change affecting the diversity, productivity and integrity of the grassland ecosystems (Magiera et al., 2013; Tephnadze et al., 2014). Consequently, concepts of sustainable, agricultural land use considering site-specific carrying capacity as well as profitability of land use are urgently needed to maintain the valuable cultural landscape and to strengthen the rural development of remote areas. Spatial-explicit land-cover and land-use maps in high resolution provide a sound base for the development of concepts for integrated and sustainable land-use. Based on landscape analysis findings, i.e. with the knowledge about the environmental conditions and the landscape´s multifunctionality, such concepts provide the opportunity to balance the three dimensions of sustainable development: the economic, social and environment, as stated in the Agenda 2030 (United Nations 2015).

Our study aims at the observation of the landscape structure for several settlements as illustrated in GIS-based land-use and land-cover maps. Further, and based on a two-date comparison, we identified spatio-temporal trends in land-use and land-cover patterns on landscape and regional scale. Changes in land cover often demonstrate a small-scale variability, depending on different physical site conditions, like topography and climate, and on socio-economic and structural conditions (Lueker-Jans et al., 2016). Accordingly, typifications of the patterns of change on a small-scale and precise landscape level are useful. Therefore, the objectives of our study are:

i) to analyze the landscape patterns in 2015 and in 1987 at high resolution, and to quantify the changes in land use and land cover during that period,

ii) to identify development trends in land-use changes on settlement level and along a classified study area.

Based on these objectives, the interrelations between topography, societal change, and land-use change in the high-mountain Kazbegi region are analyzed and discussed.

## 2. Study area

The study was carried out in the Kazbegi district of the Mtskheta-Mtianeti municipality, north of the Jvari cross pass, in the eastern part of the Central Greater Caucasus of Georgia, in the upper watershed of the Tergi and its tributary, the Snotskali (Fig. 1). The geomorphology of this region, embedded in the northern macroslope of the Greater Caucasus, is highly complex with high elevations and steep slopes (Nakhutsrishvili, 1999). The highest peak in the study region is the extinct volcano Mount Kazbek (5,047 m a. s. l.) (Ketskhoveli et al., 1975). The bedrocks of the study region consist of Jurassic sedimentary rocks. Besides volcanic rocks (andesite and dacite) with pyroclastic products, glacial and fluvial sediments from the quaternary period characterize the soil. On these materials Leptosols, Skeletic Regosols, Skeletic Cambisols and Umbrisols are prevailing soil types (Hanauer et al., 2017).

The climate of the study region belongs to the sub-continental climate and is moderately humid, with dry and cold winters and cool summers (Nakhutsrishvili, 1990; Togonidze and Akhalkatsi, 2015). Rain events occur mainly in the growing season, with only a mean annual precipitation of 806 mm (Lichtenegger et al., 2006). July is the warmest month (mean temperature 14.3 °C) and January the coldest (mean temperature -5.2 °C), whereas the mean annual temperature is 4.9 °C (Lichtenegger et al., 2006; Togonidze and Akhalkatsi, 2015). As located in the northern macroslope of the Greater Caucasus, the mean annual precipitation in the Tergi valley decreases from south to north: from 1,192 mm in the village Kobi, near the Jvari cross pass, to 806 mm in Stepantsminda, the main settlement in this region (Walter, 1974). Simultaneously, the mean annual temperature increases from 3.0 to 4.1 °C (by Hijmans et al., 2005 with a global dataset and extrapolated values).

In the Caucasus, sheep and goat grazing is a long-standing tradition and has been the predominant pasturage activity for centuries (Heiselmayer and Zazanashvili, 2004). In Georgia, a centralized agricultural program replaced traditional agricultural management practices during the Soviet period (Körner, 1980; Nakhutsrishvili et al., 2009). Up to Georgia´s independence (1991), the grassland was intensively used by a transhumance sheep grazing system with flocks originating from the bordering countries of Azerbaijan and Dagestan (Didebulidze and Plachter, 2002; Nakhutsrishvili et al., 2009). Along the military road – a North to South traverse through the mountain chain – intensive grazing by large herds of sheep caused pasture degradation, slope erosion and the reduction of subalpine forest vegetation (Cernusca and Nakhutsrishvili, 1981). However, the alpine belt was less grazed. Mass-wasting events seriously threatened the local settlements (Körner, 1980). Following Georgia´s independence and several internal political conflicts, subsistence agriculture has become predominant in rural areas of the country (Didebulidze and Urushadze, 2009). This self-sufficient agriculture is now characterized by less sheep grazing but increasing cattle husbandry (Haerdle and Bontjer, 2010). Both, cattle (up to 2,300 m a.s.l.) and sheep grazing (up to 3,000 m a.s.l.) are concentrated in high altitude. Today, the dominant land-use form in the Kazbegi region is still high-mountain grassland management as pasture and meadow, serving mainly the local demands (Haerdle and Bontjer, 2010; Lichtenegger et al., 2006).

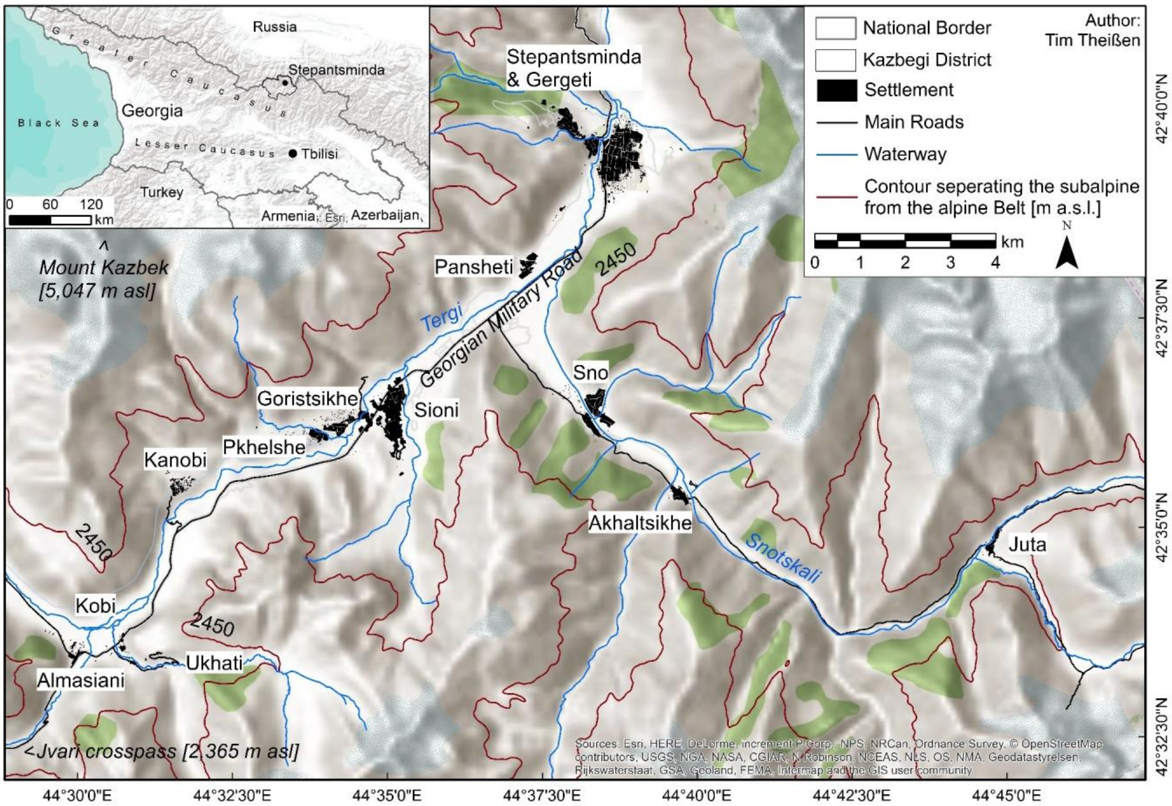


*Fig 1. Location of the study area within the Kazbegi district embedded in the eastern part of the Central Greater Caucasus, in Georgia. The 13 study settlements are settled along the rivers Tergi and Snotskali, in the subalpine altitudinal belt.*

Due to Georgia´s political and economic transformation, the population of the Mtskheta-Mtianeti municipality was declining enormously since the country´s independence (Didebulidze and Plachter, 2002) (Tab. 1), resulting in a decrease of approx. 18% from 1989 to 2002 in the Kazbegi district. In the period from 2002 to 2014, the population of the district decreased by approx. 28%, with the settlements of Kobi and Ukhati being completely abandoned. However, in larger settlements (Stepantsminda and Gergeti, Sno and Sioni) the relative decline was smaller.

For our study, we chose 13 out of 25 populated settlements in the Tergi and Snotskali valleys (Tab. 1 and Fig. 1), based on available data for both years, 1987 and 2015.

As situated along the Tergi and Snotskali valley, settlements are located along varying aspects and altitudes. The borders of the altitudinal belts run different in northern and southern slopes. According to climatic differences, on southern slopes, the belts ascends negligibly higher than on northern slopes (Otte et al., 2011). Therefore, besides altitude, the slope exposition determines the allocation of the settlements to the altitudinal belts, as it is the case for the settlement Goristsikhe (Tab.1).

According to the location, many settlements, and the most populated ones in particular, like Goristsikhe, Sioni and Stepantsminda, got direct contact to the region´s main road, the former military road. This road is the main transportation corridor in the region connecting the highland with the lowland, for example Tbilisi beyond the Jvari cross pass, and along with several connecting-nodes to tributary valleys. In contrast, other settlements are peripheral located, i.e. with limited connectivity to the market, characterized by long distance to the main road, unpaved and unsecured roads or bridges, like the disadvantaged settlements of Ukhati, Juta, Kanobi, Pkhelshe and Akhaltsikhe. The more isolated a settlement is, the more limited is the supply with goods and services.

*Tab 1. Altitude and population development of the study settlements and the Kazbegi district.*

The border between the lower-subalpine and the middle-subalpine belts varies on northern and southern slopes; brackets show the altitudinal borders at the southern slopes. Population data are composed from *National Statistics Office of Georgia* (2002, 2014). Data for the year 1989 were only available on district level. '-' indicates 'no data available'.

| **Settlement, district** | **Altitude** | **Altitudinal belt** | **Population** | | |
|---|---|---|---|---|---|
| | [m a.s.l.] | [m a.s.l.] | 1989 | 2002 | 2014 |
| **Stepantsminda & Gergeti** | 1,765 | Lower-subalpine belt | | 1.783 | 1.326 |
| **Pansheti** | 1,770 | | | - | 54 |
| **Sno** | 1,770 | 1,700 – 1,850 (1,930) | | 418 | 263 |
| **Akhaltsikhe** | 1,780 | | | 129 | 35 |
| **Goristsikhe** | 1,870 | | | 283 | 187 |
| **Sioni** | 1,875 | Middle-subalpine belt | | 384 | 324 |
| **Pkhelshe** | 1,930 | | | - | 167 |
| **Almasiani** | 1,950 | | | 13 | 22 |
| **Kanobi** | 1,985 | 1,850 (1,930) – 2,200 (2,300) | | 182 | 86 |
| **Kobi** | 2,010 | | | 25 | 0 |
| **Juta** | 2,160 | | | 62 | 26 |
| **Ukhati** | 2,190 | | | 9 | 0 |
| **Kazbegi district** | 1,230 – 5,047 | Montane - nival belt | **6.377** | **5.261** | **3.795** |

## 3. Materials and methods

### 3.1 Data and data processing

In order to map the current and historic land cover of the Kazbegi region, we used satellite images and black and white aerial-photographs from 1987. And we used five-band (blue, green, red, red edge and near infrared), high-resolution (5 m x 5 m), orthorectified (radiometric, sensor and geometrically corrected) RapidEye sensor images from 2014. Six tiles covering approximately 3,750 km² were recorded for June, July and August. We produced a false color composite that increased the distinction between land-cover types (Shalaby and Tateishi, 2007).

The aerial photographs were recorded (on photographic paper) by the Soviet Union military on September 4, 1987, and were provided by the institute of Geography at Ivane Javakishvili, Tbilisi State University (TSU) Georgia. The aerial photographs with a resolution of approximately 0.8 x 0.8 m were scanned, georeferenced and orthorectified using Erdas Imaging 8.5 (Leica Geosystems, Atlanta, Georgia, USA). We derived the topographic variables altitude, eastness, northness, inclination and distance to settlements from a digital elevation model (DEM, 20 m x 20 m) using the Spatial Analyst Toolbox in ArcGIS 10.2 (ESRI, Redlands, CA, USA). We used distance to town center as our fifth variable. According to the von Thünen theory, distance to town center is important for management/land-use decisions and therefore land-cover distribution – since the pattern of land use is strongly dependent on settlement-distance, considering accessibility and transportation costs (von Thünen, 1850).

Additionally, we included two topographic (1: 25,000 and 1: 50,000) and one historic land-use map (1:25,000) to improve the digitization. The topographic maps originated from the Department of the Army of the Soviet Union in 1958 and the land-use map, dated from 1963, was produced by the Land Use Project Institute of Georgian Soviet Republic.

### 3.2 Land-cover mapping and joining of spatial information

The 13 study settlements were visually interpreted and digitized along with their surrounding agricultural land for 1987 and 2015. The study area boundaries were set by altitude (3,000 m a.s.l.). During the digitization, polygons were generated at the scale of 1: 5,000. The land-cover and land-use classes of the applied classification key (Fig. 2) were developed in advance and proved in the field.

Overall, 26 maps were digitized. The size of the maps varies from 6.4 km² (Pansheti) to 22.5 km² (Stepantsminda plus Gergeti), the total digitized area amounts to 90 km². In-situ validation was required to correct possible misclassification due to the coarser 5 x 5 m resolution and shadowing during the visual interpretation and classification of the 2014 satellite images. In July and August 2014 and 2015, the digitized land-cover maps from 2014 were updated and validated in the field. Special attention was paid to the small-scale arable fields in home gardens and allotments, which were spatially explicitly mapped during the aerial image interpretation and in the GPS supported field validation. The digitized land-use maps of Stepantsminda and Gergeti are moreover based on a prior digitalization of a Quickbird image (Digital Globe©, with a resolution of 2x2 m) in 2011 (Waldhardt et al., 2011, based on Theissen 2011). This digitization was compared to the Rapid Eye imagery and consequently updated to the state of 2014/15 and validated during fieldwork. The river course and water level, especially in the Stepantsminda floodplain, is rather unstable during and within years. It was thus decided after visual comparison with the Rapid Eye imagery and field validation to keep the shape of the river course from 2011 (see Fig. 3 and appendix, map A.1.). The river courses in all other maps were defined by an average water level based on field validations in 2014 and 2015 (see appendix, map A.2. – A.8.). Further, we defined scree slopes, steep stony areas and gorges as sparsely or non-vegetated areas.

The vector-based land-cover maps of 1987 and 2015 were transformed into grid-based point-layer data sets at the same resolution and spatial extent as the altitude, eastness, northness, inclination and distance to settlements topographic raster data. The land-cover information of both years and the topographic variables were combined to a single point-layer in GIS. Finally, for each point (221,683 points in total) the land-cover change was determined by describing the transition of land cover from 1987 to 2015 (e.g. from pasture land cover in 1987 to shrub land cover in 2015).

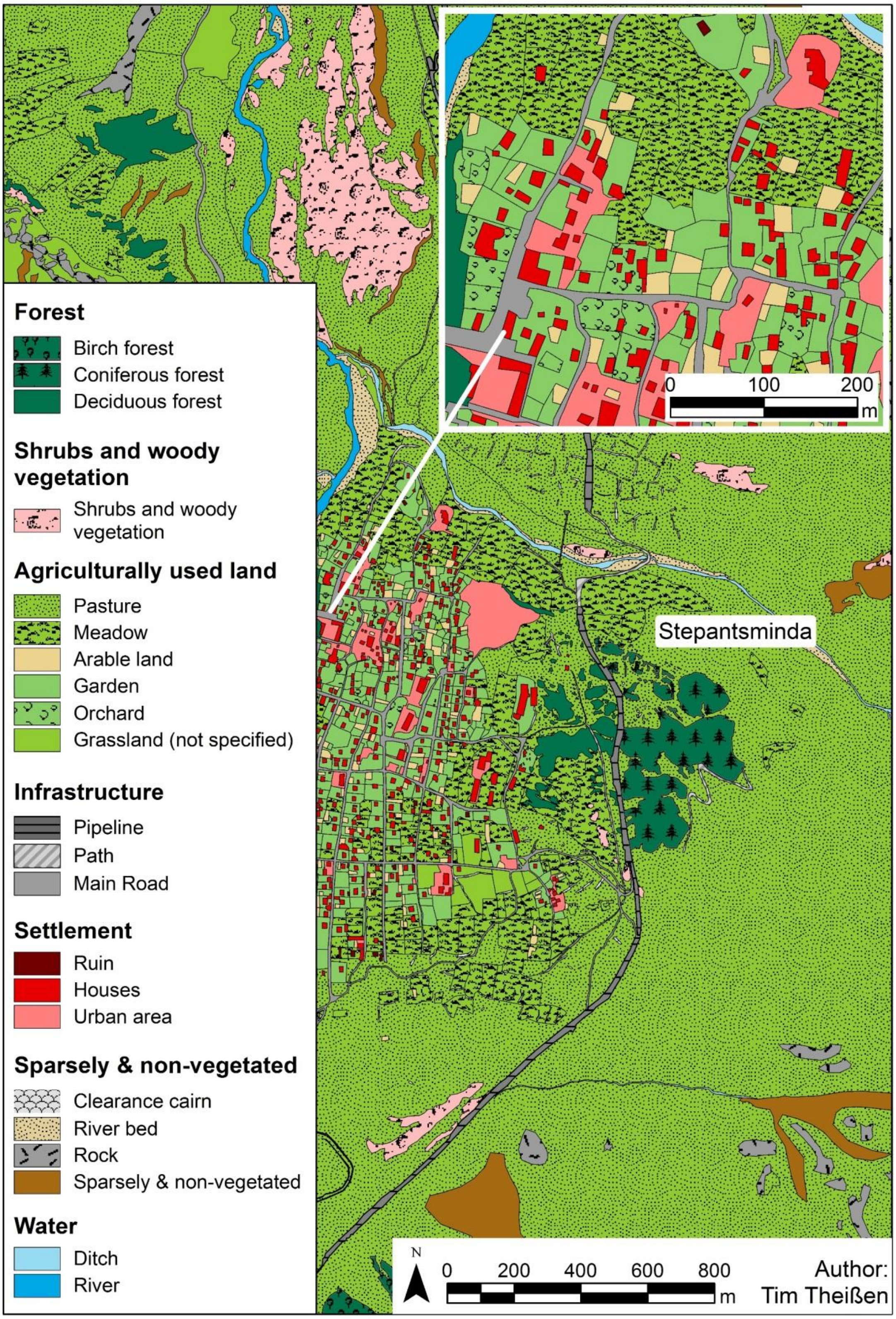


*Fig 2. Land-cover and land-use pattern of the eastern part of Stepantsminda as well as the surrounding area (1987), in a zoomed-in, detail view. The legend is hierarchically structured with seven land-cover and land-use categories and 26 classes, used for all study settlements and both dates (not visible here are the classes Road, Bridge, Lake, and Erosion). On the inset map (upper right corner), the settled area is mapped in detail, highlighting the distribution of arable land.*

### 3.3 Data analysis

#### 3.3.1 Spatial structuring of the study region using cluster analysis

A k-Means clustering (Hartigan and Wong, 1979; MacQueen, 1967) combined with a previous v-fold cross validation was applied (Lueker-Jans et al., 2016) to classify the study region according to topography and distance to settlements into classes with approximately equal conditions along the variables using STATISTICA 12 (StatSoft Inc., 1984–2014, Tulsa, OK, USA). The included variables were standardized and tested by Pearson´s coefficient of correlation for spatial autocorrelation prior to the analysis (Leyer and Wesche, 2008). Euclidean distance was chosen as a distance measure. The v-fold cross validation is a calculation to find a suitable number of clusters in a given data set. During the classification, the similarity within each cluster is maximized and minimized between the clusters. Cases are repeatedly changed between the clusters in order to receive the most significant differences between the clusters. This corresponds to an 'ANOVA in reverse' (StatSoft, 2013). In our study, the analysis resulted in clusters (sub-areas of the study region) with almost equal topographic conditions within the cluster.

#### 3.3.2 Spatial structure and land-cover change in the region

In order to show similarities and differences among the settlements based on land-cover change and topography, we used NMDS (non-metric multidimensional scaling)-ordination. The NMDS is an ordination technique to graphically display the similarity of data. Therefore, a distance measure is calculated which is placed stepwise into a multidimensional space to keep the original distance. The quality of ordination is indicated by the level of stress (Shepard, 1962). In our study, the NMDS was calculated with the percentages of each k-means cluster per settlement from the prior k-Means cluster analysis and the percentages of the respective land-cover changes. We used the metaMDS function of the 'Vegan' package for 'R 3.1.2 (Oksanen, 2013; R Core Team, 2016) to calculate a three-dimensional NMDS. After 20 tries, two convergent solutions with minimum stress were found in the iterative analysis. For assigning the new axis one to the direction of the largest variance, principal component (PC-) rotation was applied (Clarke, 1993).

## 4. Results

### 4.1 The landscape pattern in 2015

In 2015, the landscape in the upper watershed of the Tergi River was dominated by subalpine to alpine open grassland (Fig. 3 with Stepantsminda and Gergeti; see Appendix for all maps). The region was either managed as pasture (59% of the study area) or as meadow (8%). Meadows were located in close vicinity to the settlements and were often fenced off from free-ranging cattle. Sparsely or non-vegetated areas, e.g., gorges and scree slopes, typical in high-mountain regions, were quite frequent (14%). Only a comparatively small area was covered by forest (7%). At high altitudes on steep north-facing slopes, the natural forest is dominated by *Betula litwinowii* and to a lesser extent by *Salix caprea* and *Sorbus caucasigena*. Coniferous (*Pinus sylvestris*) and deciduous forests (*Populus tremula*), planted as reforestation for firewood, occur at lower altitudes in near vicinity to the settlements. Beside the forests, different types of shrub vegetation (5%) were found in the study region. Shrub vegetation mainly comprises three species: *Elaeagnus rhamnoides,* which frequently occurs on Regosols of the floodplains and steep rocky slopes mixed with *Berberis vulgaris*, and *Rhododendron caucasicum* in the transition zone between the upper subalpine to the alpine belt, indicating the upper border of the tree-line ecotone. Small-cultivated arable land (1%) with an average field size of 290 m² was located in home gardens and orchards or even allotments outside but not far away from the settlements, often within fenced meadows. These family allotments were mainly used for subsistence potato and field vegetable cultivation. Settlements defined as 'urban area' covered 0.66 km², i.e., 1% of the study region. Along a gas-pipeline through the valleys and within the studied settlements of Stepantsminda, Gergeti, Pansheti, Sioni, Sno, Akhaltsikhe, Pkhelshe and Goristsikhe, greenhouses were built during the Soviet period. Their functioning depended on Russian gas, which was discontinued in the early twenty-first century.

We found 96 greenhouses of which 60 have been damaged but are partly still in use for cultivation. In 64 greenhouses, cultivation of mainly potatoes, cucumbers, tomatoes and lettuce is practiced.

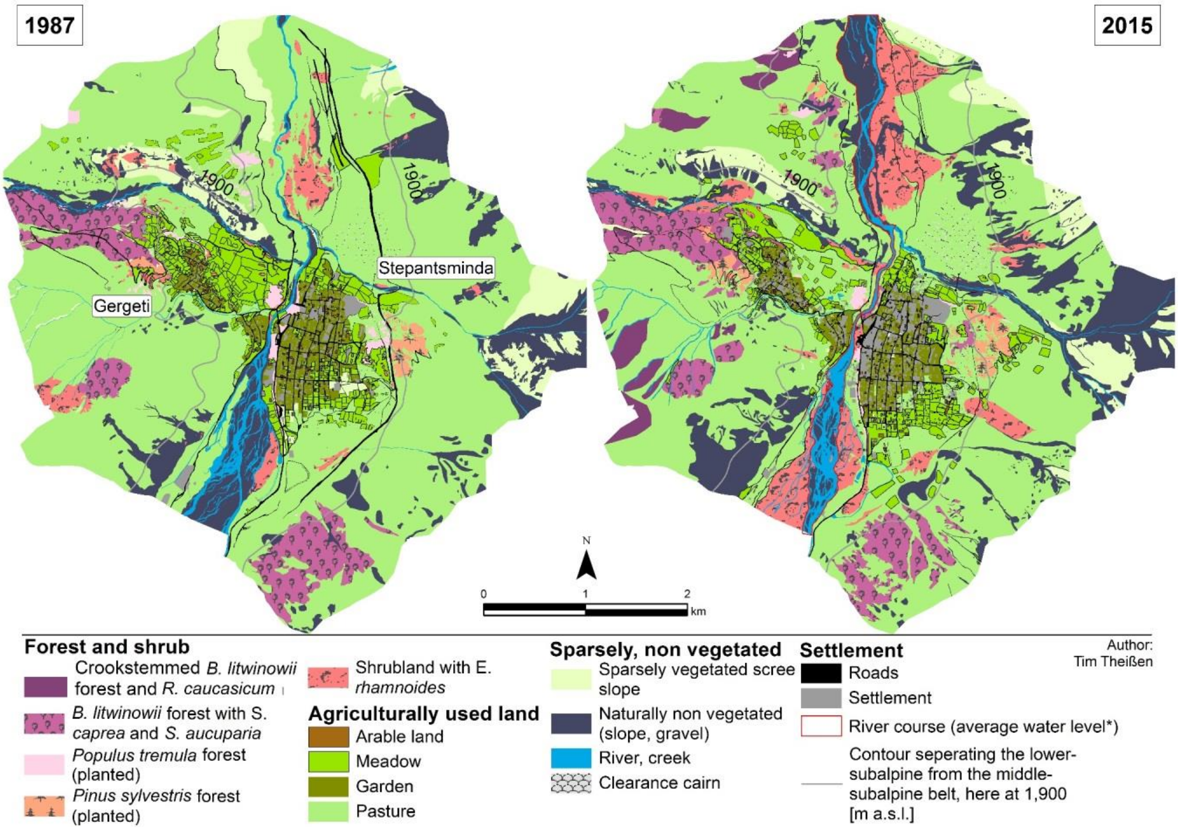


*Fig 3. Land-cover and land-use pattern of Stepantsminda and Gergeti in the years 1987 and 2015 (land-cover classes partly grouped). The 2015 map is from Theissen et al. (2019). *The water level of the Tergi River was validated in the field in 2011, 2014, and 2015.*

## 4.2 The landscape pattern in 1987 and land-cover change between 1987 and 2015

In 1987, the landscape pattern was characterized by less forest- and shrub cover, and by a lesser extent of urban area. Settlements (comprising the land-cover classes urban area, houses, ruins, garden, orchard and arable land) covered around 2 km², in total, in 1987. In 2015, the study settlements cover 2.4 km², with 0.7 km² accounting for the main settlement Stepantsminda. During the study period, the settlements have developed differently with small villages spatially decreasing and larger ones expanding.

The expansion of settlement area mostly took place on former (1987) garden land and meadows. However, Juta, a small and remote village with a size of 0.1 km² showed a different development: its settlement area nearly doubled from 1987 to 2015. The population decreased in all settlements except Almasiani, and to an even greater extent in remote villages (Tab. 1). Ukhati, for example, located offside the military road and hidden in the mountains, was completely abandoned. Nevertheless, in 2015, its former arable land was re-cultivated with potatoes and managed by farmers from Stepantsminda, because the soil properties are convenient for cultivation (in particular physical structures like deep soils with fine and loamy material, in plateau location). Arable fields expanded in most of the settlements, either from pasture or from garden land in 1987. In Almasiani, the largest area of potatoes was cultivated in 2015 (0.2 km²), but in the closed-by settlement Kobi arable land in home gardens almost vanished. The land-cover type characterized by the greatest changes was grassland. 6% (around 5.3 km²) changed from pasture in 1987 to sparsely and non-vegetated area in 2015 and 3% from pasture to meadow (around 2.5 km²). However, the grassland changes performed differently among the settlements. Sno and Juta showed the highest proportion and the highest increase of meadows (> 1 km²). Especially, the remote Juta had the strongest meadow increase (0.4 km² in 1987 to 1 km² in 2015). The settlements Sioni, Stepantsminda, Gergeti and Juta as well experienced a decrease in pasture combined with an increase in woody vegetation (shrubs, forests), especially in Gergeti, where shrubs increased strongly, from 0.2 km² up to 0.9 km². In contrast, pasture area increased in Almasiani, Goristsikhe, Sno and Pansheti, whereas meadow area decreased, together a decline of approximately 0.6 km² (Tab. 2).

*Tab 2. Land-cover sizes (ha) of the 13 study settlements from 1987 and 2015 and land-cover change in percent within this period. 'Trend indicates a constant, an increase or a decrease in land-cover sizes in each settlement.'*

| Settlement | | | Akhaltsikhe | Almasiani | Gergeti | Goristsikhe | Juta | Kanobi | Kobi | Pansheti | Pkhelshe | Sioni | Sno | Stepantsm | Ukhati |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total** | | [ha] | **779** | **566** | **995** | **407** | **1032** | **503** | **859** | **516** | **229** | **454** | **1021** | **1267** | **206** |
| **Settlement area** | 1987 | [ha] | 7 | 9 | 18 | 9 | 3 | 5 | 5 | 9 | 7 | 49 | 19 | 64 | 2 |
| | 2014 | [ha] | 8 | 6 | 26 | 13 | 5 | 5 | 3 | 11 | 7 | 54 | 26 | 70 | 1 |
| | Change | % | 25 | -33 | 47 | 45 | 92 | -10 | -36 | 19 | 5 | 9 | 41 | 11 | -26 |
| | Trend | | ↗ | ↘ | ↗ | ↗ | ↗ | ↘ | ↘ | ↗ | ↗ | ↗ | ↗ | ↗ | ↘ |
| **Arable fields** | 1987 | [ha] | 1 | 6 | 2 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 3 | 5 | 2 |
| | 2014 | [ha] | 1 | 16 | 4 | 2 | 1 | 4 | <0.5 | 1 | 3 | 4 | 3 | 5 | 1 |
| | Change | % | - | 165 | 58 | 84 | - | 73 | -81 | - | 55 | 206 | 21 | 11 | - |
| | Trend | | → | ↗ | ↗ | ↗ | → | ↗ | ↘ | → | ↗ | ↗ | ↗ | ↗ | → |
| **Meadow** | 1987 | [ha] | 34 | 58 | 83 | 54 | 42 | 101 | 16 | 23 | 64 | 76 | 123 | 64 | 15 |
| | 2014 | [ha] | 27 | 29 | 53 | 41 | 103 | 92 | 16 | 20 | 71 | 91 | 111 | 61 | 24 |
| | Change | % | -22 | -50 | -36 | -24 | 144 | -9 | 4 | -11 | 11 | 19 | -9 | -5 | 59 |
| | Trend | | ↘ | ↘ | ↘ | ↘ | ↗ | ↘ | ↗ | ↘ | ↗ | ↗ | ↘ | ↘ | ↗ |
| **Pasture** | 1987 | [ha] | 487 | 261 | 674 | 292 | 841 | 312 | 366 | 325 | 85 | 222 | 413 | 779 | 158 |
| | 2014 | [ha] | 480 | 337 | 574 | 339 | 718 | 302 | 565 | 348 | 75 | 188 | 475 | 642 | 162 |
| | Change | % | -1 | 29 | -15 | 16 | -15 | -3 | 54 | 7 | -12 | -15 | 15 | -18 | 3 |
| | Trend | | ↘ | ↗ | ↘ | ↗ | ↘ | ↘ | ↗ | ↗ | ↘ | ↘ | ↗ | ↘ | ↗ |
| **Shrub** | 1987 | [ha] | 5 | 37 | 21 | - | 38 | 1 | 126 | - | 2 | - | 38 | 39 | - |
| | 2014 | [ha] | 1 | 40 | 92 | - | 64 | - | 79 | 2 | 4 | 14 | 17 | 100 | 4 |
| | Change | % | -80 | 7 | 347 | - | 70 | -100 | -37 | 100 | 100 | 100 | -55 | 155 | 100 |
| | Trend | | ↘ | ↗ | ↗ | → | ↗ | ↘ | ↘ | ↗ | ↗ | ↗ | ↘ | ↗ | ↗ |
| **Forest** | 1987 | [ha] | 41 | 30 | 81 | - | 61 | - | 99 | - | - | 21 | 207 | 80 | 10 |
| | 2014 | [ha] | 41 | 26 | 99 | 1 | 64 | 7 | 105 | - | 10 | 29 | 179 | 75 | 9 |
| | Change | % | - | -10 | 21 | 100 | 5 | 100 | 6 | - | 100 | 37 | -14 | -6 | -7 |
| | Trend | | → | ↘ | ↗ | ↗ | ↗ | ↗ | ↗ | → | ↗ | ↗ | ↘ | ↘ | ↘ |
| **Sparsely, non-vegetated** | 1987 | [ha] | 185 | 132 | 82 | 46 | 29 | 62 | 188 | 124 | 52 | 52 | 183 | 172 | 15 |
| | 2014 | [ha] | 202 | 89 | 106 | 10 | 62 | 74 | 77 | 120 | 41 | 53 | 167 | 230 | 3 |
| | Change | % | 9 | -33 | 29 | -78 | 113 | 19 | -59 | -3 | -21 | 2 | -9 | 34 | -80 |
| | Trend | | ↗ | ↘ | ↗ | ↘ | ↗ | ↗ | ↘ | ↘ | ↘ | ↗ | ↘ | ↗ | ↘ |

Sparsely or non-vegetated localities covered large areas, although the patterns varied considerably between the settlements, where these sites occur either on steep, mostly high-elevated or unaccessible locations and on flat river bed terrain which is varying in extent due to seasonal flooding. In Akhaltsikhe and Stepantsminda approximately 2 km² were sparsely or non-vegetated in 1987, and this area increased in both localities from 1987 to 2015, in contrast to Ukhati where the area decreased.

### 4.3 Land-cover change trends along environmental conditions

Based on all compiled land-cover and land-use maps of the 13 studied settlements, the cluster analysis divided the whole study area into sub-areas with similar spatial structure regarding topography and distance to settlements. The k-means cluster algorithm revealed the six clusters with characteristic properties (see Fig. 4 and Tab. 3):

- North-west exposed slopes of the upper-subalpine belt,
- East exposed slopes of the upper-subalpine belt,
- South-west exposed slopes of the upper-subalpine belt,
- South-east exposed slopes of the middle-subalpine belt,
- North-east exposed slopes of the lower-subalpine belt,
- West exposed slopes of the upper-montane belt.

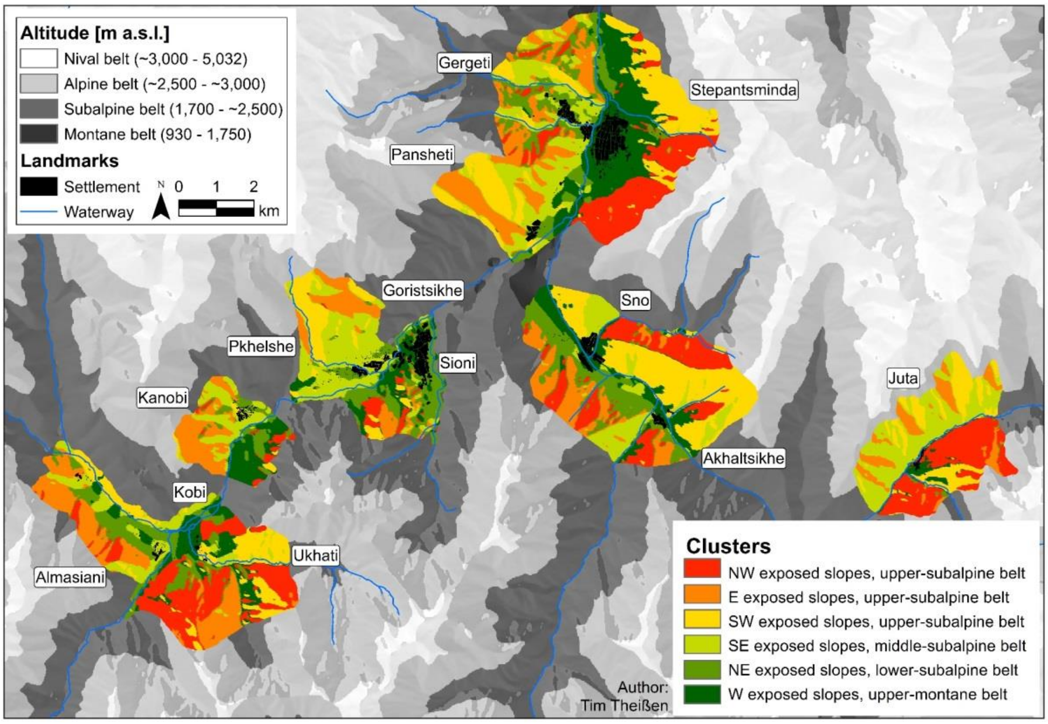


*Fig 4. Spatial pattern of the k-means cluster analysis based on topography and distance to settlements (calculated for the 13 study settlements).*

*Tab 3. Properties of the clusters, with the centroids (means) of the variables included in the k-means cluster analysis; Northness indicates slope position between north (value =1) and south direction (value = -1), and Eastness between east direction (value 1) and west direction (value -1).*

| | North-west exposed slopes of the upper-subalpine belt | East exposed slopes of the upper-subalpine belt | South-west exposed slopes of the upper-subalpine belt | South-east exposed slopes of the middle-subalpine belt | North-east exposed slopes of the lower-subalpine belt | West exposed slopes of the upper-montane belt |
|---|---|---|---|---|---|---|
| Altitude [m a.s.l.] | 2,276 | 2,242 | 2,278 | 2,117 | 1,920 | 1,878 |
| Slope [degree] | 32 | 32 | 32 | 24 | 14 | 12 |
| Eastness [1 to -1] | -0.4 | 0.9 | -0.6 | 0.6 | 0.4 | -0.9 |
| Northness [1 to -1] | 0.8 | 0.3 | -0.7 | -0.7 | 0.8 | 0.2 |
| Distance to settlements [km] | 1.6 | 1.8 | 1.8 | 1.3 | 1.1 | 1.1 |
| Area [km²] | 15.5 | 14.4 | 15.5 | 17.3 | 12.5 | 13.5 |
| Percentage | 17% | 16% | 17% | 20% | 14% | 15% |

The area sizes of the clusters (Tab. 3) were relatively balanced. Northness and Eastness, i.e., the aspect, showed the strongest variable differentiation. The area of the cluster ‘NW exposed slopes of the upper-subalpine belt’ is characterized by upper slope positions with steep slopes of 32° average inclination. In contrast, 'NE exposed slopes of the lower-subalpine belt' were less steep and closer to settlements. South facing slopes can be differentiated by altitude and the east-west axis as well: the clusters 'SW exposed slopes of the upper-subalpine belt' and 'SE exposed slopes of the middle-subalpine belt'. The upper south-west facing slopes are characterized by high altitudes, steepness and greater distances to settlements. South-east facing slopes include favorable sun-exposed areas, which are less steep and closer to settlements. Two further clusters ('E exposed slopes of the upper-subalpine belt' and 'W exposed slopes of the upper-montane belt`) can be distinguished by clear east-west separation. High altitudes, steep inclination and large distances to settlements characterize these east facing slopes. In contrast, the west-exposed low slopes represent the lowest and flattest terrain of the whole study region (around 1,880 m a.s.l., with an averaged inclination of 12°, Tab. 3). Stepantsminda – the largest settlement in the study region – is located on these gentle slopes.

The settlements were grouped by their topographic and land-cover change similarity in an NMDS ordination (Fig. 5). Land-cover changes and k-means cluster affiliation were fitted as vectors against NMDS ordination and the most significant ones ($p \leq 0.1$) are shown in the ordination graph, whereas non-significant vectors are left out. The graph shows the settlements with more similar properties closer to each other, like Stepantsminda and Akhaltsikhe, and the lesser similar ones in a greater distance to each other, like Pkhelshe and Ukhati.

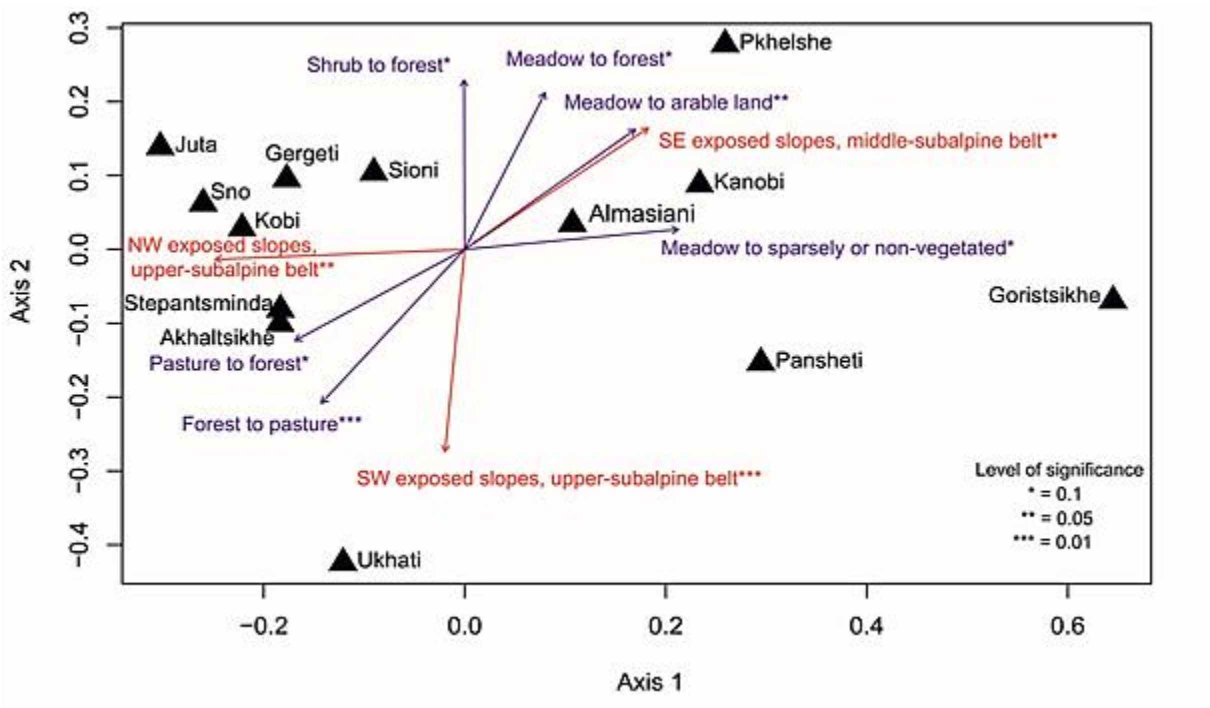


*Fig 5. NMDS-Ordination of the study settlements (n = 13).*

The settlements were sorted by their k-means cluster affiliation and land-cover change. Arrows indicate significant linear correlations for clusters (red) as well as for the land-cover change classes (blue), with $p \leq 0.1$ (*), $p \leq 0.05$ (**) or $p \leq 0.01$ (***).

The first NMDS axis displays a strong gradient of north-west facing areas, whereas the second axis represents a strong gradient of south-west facing areas. The NMDS ordination shows that Juta, Sno, Kobi, Gergeti and Sioni as well as Stepantsminda and Akhaltsikhe are characterized by a high number of steep northern slopes, up to high altitudes ('NW exposed slopes of the upper-subalpine belt'). In this cluster, grassland reduction and forest expansion is prevailing: grass- and scrubland of 1987 has changed to forest in 2015. Ukhati, as described above, is correlated to southwest expositions. The distinct ordination position of Ukhati suggests an increased amount of pasture and a decreased amount of forest (with a highly significant land-cover change class 'Forest to pasture'), which can be confirmed by the land-cover map of

Ukhati (see appendix). Ukhati and its surrounding (2.200–2.500 m a.s.l.) is located near the climatic limit for cultivation (short growing season, frequent late frosts), i.e., rather adverse conditions for cultivation, but provided with deep, fertile soils and favorable topography. Almasiani, Kanobi and Pkhelshe can be described by favorable climatic conditions on sun-exposed area, marked by 'SE exposed slopes of the middle-subalpine belt' and therefore by increasing arable fields, which are indicated by a land-cover change from meadow to arable land. This cluster combines locations at lower altitudes and close to settlements. However, in the middle-subalpine belt, sparsely or non-vegetated sites, i.e., agriculture-unfavorable locations, increased from 1987 to 2015, and, this is remarkable, meadow sites decreased. Pansheti and Goristsikhe are, therefore, located between the clusters 'SE exposed slopes of the middle-subalpine belt' and 'SW exposed slopes of the upper-subalpine belt', which explains their correlation to southern expositions as well. These settlements show the lowest proportion of forest and shrub (see Tab. 2).

## 5. Discussion

### 5.1 Landscape pattern in 2015

In Georgia, 43% of the total population lives in rural and mainly mountainous areas (National Statistics Office of Georgia, 2015). Usual and appropriate for mountainous regions, its population and most of the human activity is focused on flat valley locations, as it is the case in the upper watershed of the Tergi River and its tributaries, in the Central Greater Caucasus. A specific character of this Caucasian high-mountain landscape, in comparison to other European mountainous regions, is the relatively small amount of forest along the valley slopes, i.e. the high proportion of open grassland. Thus, below the timberline, in the upper montane and subalpine belts, most of the slopes in the region are unforested and used as cultural grassland, as either pasture or meadow. On the contrary, in Europe´s Mountains overall, forest covers 41% of the total massif´s area and is the main land-cover type (European Environment Agency, 2010). As described above, forest vegetation was strongly reduced throughout former mountain grazing (Cernusca and Nakhutsrishvili, 1981; Körner, 1980; Lichtenegger et al., 2006), which established extensive subalpine grasslands, with a mixture of forest and alpine species (Grossheim, 1936). Still today, agriculture is a major source of income and employment in Georgia´s rural areas (Ministry of Agriculture, 2016), and is mostly practiced as low-input, subsistence or semi-subsistence farming (EU-FAO, 2013; Oedl-Wieser et al., 2017). In the study region, livestock farming with cattle is practiced in family structures with 2–3 cows per family to produce milk, yoghurt and cheese (Haerdle and Bontjer, 2010; Heiny et al., 2017). Nearly every household is cultivating a home garden to produce field vegetables, mostly for their own consumption, and is mowing grassland-parcels once a year – manually, without machinery – in peripheral location to the settlements, to harvest winter fodder for the cattle. This agricultural land-use system is true for all 13 study settlements, but with varying extent dependent on population density. This system harbors a high biodiversity on the landscape level (a diverse pattern of ecosystems in the region) and the local level (species richness in pastures, meadows and arable fields) (Plachter and Hampicke, 2010). This cultural landscape reflects traditional, sustainable land use with a high biotic richness that strongly contributes to the status of the Caucasus as one of the species-richest ecoregion globally and because of its endemism, a biodiversity hotspot (Millennium Ecosystem Assessment, 2005; Mittermaier et al., 1999; Myers et al., 2000). Besides ecological effects, and considering the critical income situation in rural areas, this land-use system is functioning as an important safety net for the rural population (EU-FAO, 2013; Kötschau et al., 2009). However, the land-use situation today is basically a consequence of the nationwide land privatization process, beginning in 1992, high costs of agricultural inputs, a lack of machinery and a lack of access to markets that leads to a low level of production efficiency (Didebulidze and Plachter, 2002). Additionally, a Russian trade embargo negatively influence the Georgian agricultural production and its development (EU-FAO, 2013), and furthermore leads to a one way direction for the Kazbegi region with regard to access to sales markets, transportation, and trade out of the region. Accordingly, farmers in Kazbegi are relatively isolated and act independently in a high degree whereas most of them, as mentioned above, for self-supply. It can be assumed that subsistence farming in the region will remain as long as these above-described factors are stable. However, Shavgulidze et al. (2017) determined that labor input, commercialization of agricultural activities, and proper management practices are significant factors of the local production efficiency. Thus, applicable enhancements in the agricultural production can be seen as local measures to possibly overcome subsistence farming. Moreover, based on the natural productivity of the local extensive grassland, there is potential to optimize and increase the region´s livestock production even with the consideration of measures to protect soil fertility and biodiversity (Theissen et al., 2019) In contrast, increased livestock production means changes in the regional landscape pattern, as more area is needed for the agricultural production. Nevertheless, managed appropriately, a higher agricultural impact can lead to a more diverse landscape (Theissen et al., 2019).

### 5.2 Historic landscape pattern and change from 1987 to 2015

Before today´s stationary cattle husbandry, the grassland of the Kazbegi region was used as mountainous summer pastures for large flocks of sheep in a local-driven and transhumance system, based on a traditional Caucasian pasturage system (Didebulidze and Plachter, 2002; Onipchenko, 2004). The two-year comparison shows a greater area in both, pasture and meadow, as well as a smaller area in shrub and forestland cover in the 1987 landscape pattern. Agriculture was more intensively practiced in 1987 then it was in 2015, with strong landscape structure-forming effects, like extensive cultural grassland and reduced woody vegetation. Since the breakdown of the Soviet Union, the de-intensification of land use became evident and, in turn, the change affected the actual landscape pattern, characterized by abandoned cultural grassland, re-forestation and shrub-encroachment (Hansen et al., 2018). Changes in high-mountain land use can have major effects on land cover and are often driven by agricultural suitability (UNEP (United Nations Environment Program), 2002) – like intensification and abandonment affected the landscapes of Europe´s mountain regions (Drexler et al., 2016). In the Alps, fertile valley floors and slope terraces experienced agricultural intensification over the last 200 years, whereas marginal locations often got abandonment (Egarter Vigl et al., 2017). A worsening of socio-economic conditions in high-mountain agriculture (Tasser et al., 2007) had aggravated this land-use abandonment in the alps. Cultivating sloping areas is time-consuming with heavy workloads and thus means higher production costs (Zimmermann et al., 2010). In post-soviet, high-mountain countries, the situation is quite similar, with land-use intensification and abandonment being dependent of geophysical factors as well, like slope steepness and fertility (Alix-Garcia et al., 2012; Lieskovský et al., 2015). However, in post-socialist countries, land-use change was additionally affected by land reforms and market-price liberalizations after the breakdown of the USSR (Gunya, 2017; Kuemmerle et al., 2008). In southern and eastern mountains of Europe, agriculture is still particularly important but with land-use abandonment in areas far away from settlements and intensification nearby (European Environment Agency, 2010). This is especially true for the Kazbegi region, where grazing by cattle became more concentrated near settlements in the lower and middle-subalpine belt, whereas grazing by sheep at higher altitudes strongly decreased. With the independence, the agricultural management shifted, since the supply of the Georgian population with basic foods became the main priority (Haerdle and Bontjer, 2010). Similar effects, with a shift from transhumance to stationary grazing systems, were observed in many other former Soviet Union states and Asian countries (Food and Agriculture Organization of the United Nations, 2003). Besides livestock grazing, private farming on small-scale household plots played an important role in Georgia with the highest share of production during the Soviet period, compared to other Union states, and with increased importance after the Union´s disintegration and subsequent reformations (Kegel, 2003). This high affinity for self-supply production is still the situation in 2015 and clearly visible in the region. In 1987, nearly all settlements show a smaller area than in 2015, although the population mainly decreased from 1989 to 2014 (see Tab. 1). There might be two reasons to explain these opposing trends. First, settlements in favorable position, i.e., located in the flat valley and close to the main road, can benefit from further sources of income, like tourism. For instance, the involvement of the local population in tourism or the development of tourism infrastructure, like new constructed guesthouses and service offering, are higher in Stepantsminda than in remote located settlements, like Kanobi and Juta (Heiny et al., 2017;

Hüller et al., 2017). Second, remote settlements, like Pkhelshe with limited accessibility, focuses on agriculture because there are less further sources of income. Consequently, agricultural used area close-by, like meadows, arable land as well as garden and orchard, increased there. Nevertheless, the population decrease is more obvious in the remote settlements than in those close to the main road, as it is the case in other Greater Caucasus regions of Georgia (Kohler et al., 2017). The impacts just described are indicating an increasing importance of tourism for most of the region´s population.

### 5.3 Landscape change trends along environmental conditions

Spatial classification based on topographical variables is highly applicable (Hoechstetter et al., 2008) especially in mountain landscapes (Maurer et al., 2006; Sebastiá, 2004; Zimmermann et al., 2010). In our study, different development trends of the settlements have been spatially characterized and compared. Categorizing the whole study area into six clusters along environmental conditions revealed that the trends followed a clear pattern. The urban area of the settlements is mostly located within the clusters 'north-east exposed slopes of the lower-subalpine belt', 'south-east exposed slopes of the middle-subalpine belt' and 'west exposed slopes of the upper-montane belt', i.e., at lower altitudes and on relatively flat terrain. Accordingly, and besides the urban area, these clusters are characterized by a high amount of arable land, greenhouses and meadows, and although below the timberline, less of forest. In particular, these above-mentioned lower slopes with east exposition showed a high dynamic in grassland management. We found old hay meadows that were used in 1987 but fallow land in 2015. Simultaneously, on eastern slopes at a different location, hay meadows had been established in 2015. Furthermore, the increased area of arable fields in 2015 supports the fact that subsistence agriculture is still dominant in remote areas in Georgia after the independence (Didebulidze and Urushadze, 2009). The surrounding land of the settlements Pkhelshe, Sioni and Juta are representatives for settlements situated on lower eastern slopes, with favorable conditions for agriculture. On the contrary, 'west exposed slopes of the upper-montane belt' can be described by decreasing pasture area combined with shrub-encroachment and increasing sparsely or non-vegetated area. Reduced grazing in the valley bottom and in settlement-near locations results in the succession of woody vegetation as well and leads to a loss of montane grassland habitats (Barcella et al., 2016). In favorable locations for agricultural use, shrub (*Elaeagnus rhamnoides*) is expanding and will further expand when pastures stay abandoned (Magiera et al., 2016; Waldhardt et al., 2011). North of Stepantsminda, in the floodplain of the Tergi River, a huge area of fallow land was totally covered by shrub in 2015 (see Fig. 3). Natural birch forests mostly grow on steep 'north-west exposed slopes of the upper-subalpine belt' and to a minor extent on 'north-east exposed slopes of the lower-subalpine belt' at lower altitudes closer to settlements. Nakhutsrishvili (1999) explained the exclusive distribution of birch forests on northern exposures with favorable moist conditions protected by a longer snow cover during the winter – avoiding forest desiccation. The land-cover change from grassland into scrubland and forest mainly occurred on the northern slopes. The clusters 'east exposed slopes of the upper-subalpine belt' and 'south-west exposed slopes of the upper-subalpine belt' showed a high proportion of sparsely or non-vegetated area. Slope movements occur quite frequently on steep mountain flanks consisting of loose glacial sediments (Lichtenegger et al., 2006). In accordance with Kreeb and Nakhutsrishvili (1990), rocky outcrops and scree slopes scattered with tragacanth vegetation can be found mostly on southern slopes.

### 5.4 High mountain systems – evaluation and development

High mountain regions are large, coherent natural environments with a high level of diversity among natural and semi-natural habitats, and they provide several valuable ecosystem services, like agricultural products, water yield, slope stability or recreational value (Körner, 2000). Historical practices in agriculture and forestry often associated with heavy workloads, formed region-characteristic high-mountain cultural landscapes (Maurer et al., 2006; Plachter and Hampicke, 2010). Moreover, several landscape functions are closely related to land use and the evolved cultural landscape structure (Farina, 2000; Fleskens et al., 2009; Varotto and Lodatti, 2014). In Georgia´s Greater Caucasus, land-use abandonment and, thus, land-cover change are caused by complex interactions of socio-economic processes such as rural impoverishment and migration with changes in agricultural practices and natural processes. Changes in land use due to political, economic and societal transformation processes are evident, as described above, for marginal regions of post-soviet countries in Eastern Europe (Didebulidze and Urushadze, 2009; Fischer and Gelb, 1991; Tölgyesi et al., 2015) and especially in rural mountainous regions (Pedashenko et al., 2015). In our study region, in particular, the small and remote settlements experienced changes in land use (see Tab. 2) and depopulation, even total abandonment (see Tab. 1). Population out-migration, in this context, also signify the loss of local knowledge with concern to agroecosystems and various habitats, their characteristics, and the presence and usage of certain plants (Vogl and Vogl-Lukasser, 2015). However, to maintain cultural landscapes and to protect related habitat types with unique species, national and supranational subsidies are offered to increase profitability of low-intensive land utilization in the mountainous countryside in Central and Western Europe (Fleskens et al., 2009; Pôças et al., 2011). Sustainable management preserves the rural and cultural uniqueness and the diversity in habitat types and species. In that respect, the development of land-use strategies is important (Török et al., 2016). Concepts of land use include agricultural potential considerations and reflect the regional economy (Norton, 2016). Furthermore, they can assess the multifunctionality of the landscape in order to establish sustainable usage forms. Those integrated land-use concepts provide possibilities to support a sustainable spatial development in marginal mountainous regions and, at the same time, conserve the mountain ecosystems, as stated in the United Nations´ 2030 Agenda. However, our results suggest that there is an urgent need to locally adapt those concepts – since even within the study region land-use change affected the landscape in different ways.

## 6. Conclusion

This study is based on empirical landscape ecological research in a Caucasian high-mountain cultural landscape. Within an observation period from 1987 to 2015, land-use change in the grassland-dominated landscape is closely related to topography and thus shows different trends on settlement development. These trends are additionally affected by socio-economic processes during that period, as changes in population and the regional agrarian structure indicate. In order to show linkages between the spatial structure of a high-mountain landscape and changes in land use, the combination of geophysical factors with socio-economic parameters seems reasonable. This study quantitatively defines changes in land cover and puts this in relation to location-based factors and societal development. Thus, this approach can help to highlight interrelationships in socio-ecological systems in high-mountain regions. Moreover, it demonstrated how socio-economic transformations affect land-use decisions and the pattern of a cultural landscape. Maps of historical and current land-cover pattern and consequently the knowledge of the genesis and development of the local landscape structure offers an important orientation for future sustainable land use. In this context, the typification and topographic differentiation of landscape areas can be an appropriate tool to enhance the localization of site-adapted land use, especially in high-mountain regions with high environmental variability. The methodological approach of a spatio-temporal comparison combined with a GIS-based landscape analysis revealed an understanding of how land-use decisions influence the landscape pattern. Building on this approach, predictions can be made upon agricultural productivity, landscape diversity and services. This approach is transferable to other marginal or high-mountain regions, whereas the study outcomes can be compared or can serve as a sound base for landscape planning, aiming to ensure good agricultural and environmental conditions of mountain land use. The understanding of case specific land-cover development trends can further be helpful to indicate future changes as well as regional development strategies.

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