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F assessment of landuse/landcover (LULC) change of Tbilisi and surrounding area using remote sensing (RS) and GIS

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ABSTRACT

In this study, LULC changes are investigated by using Remote Sensing (RS) and Geographic Information Systems (GIS) in Tbilisi, capital of Georgia. A number of factors contribute to the changes in the LULC. Rapid urbanisation has led to dramatic changes in land use practice. The expansion of the population of Tbilisi peaked in the 1970s. This resulted in a high demand for living space and an active phase of urbanisation of the outskirts of Tbilisi begun, ending with the collapse of most social systems after the dissolution of the USSR in 1991. A new wave of urbanisation hit the city in the beginning of the 2000s. This process was accelerated by the incorporation of nearby recreational zones into the city's administrative area in 2007. In this study, digital image processing was used in the analysis and assessment of the land use changes since 1987 throughout 2016. After the classification of the Landsat 5 and Landsat 8 OLI it became apparent that there were 5 different classes of LULCs. The change in the size of the surface area of each class during the previous 29 years was also determined. Sharp rise in the built-up area was discovered after the change detection. Built-up area increased 13.9% in 2016 compare with 1987. Therefore, available data on LULC changes can provide critical input to decision-making of environmental management and planning the future.

Introduction

To understand recent changes in the Earth system, the scientific community needs quantitative, spatially-explicit data on how land cover has been changed by human use over the last 300 years and how it will be changed in the next 50–100 years [1]. These changes in terrestrial ecosystems are closely linked with the issue of the sustainability of socio-economic development since they affect essential parts of our natural capital such as climate, soils, vegetation, water resources and biodiversity [2,3]. Much study in recent years point out that, land cover is changing rapidly in many parts of the world, particularly in areas with high population density. Traditionally land use and land cover (LULC) is a core information layer for a variety of scientific activities and administrative tasks (e.g. hydrological modeling, climate models, land use planning). In the last two decades, land use land cover (LULC) change became an additional irreplaceable observation feature not only within Europe but on a global context [3]. As aforementioned the changes in LULC are especially visible in heavily built-up areas. Such areas are usually found in big cities and the suburbs surrounding them. It is widely recognized that, the LULC alterations are generally caused by mismanagement of agricultural, urban, range and forest lands which lead to severe environmental problems such as landslides, floods etc [4].

Over the past years the observation of global-scale land cover (LC) is of importance to international initiatives such as the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto protocol, governments, and scientific communities in their understanding and monitoring of the changes affecting the environment, and the coordination of actions to mitigate and adapt to global change [5]. It is well-known that urban populations are increasing worldwide. The percentage of people in Europe living in cities increased from 51% in 1950 to 70% in 2000 and is expected to reach 84% in 2050 [6]. The share of the world's population living in urban areas increased from just 3% in 1800 to 14% in 1900. By 1950, it had reached 30%. Today, this number stands at more than half. In the advanced countries, three-quarters of people live in urban areas [7]. Nevertheless, other factors attributing to Land Use Land Cover (LULC) change are directly or indirectly dependent on population growth [8].

Over the past ten years, remotely sensed data is used in most cases when studying the changes of LULC (including case studies concerning particular settlements). The advantages of remote sensing have been acknowledged by many stakeholders world-wide. High resolution

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satellite imagery or aerial orthophoto are the most useful tools to employ when studying the changes of LULC in large cities and their suburbs. However, such methods can be greatly limited due to the financial factor, as they are expensive to implement. In this respect we also have limited archive of historical imagery and have inconsistent temporal cover. On the other hand, Landsat imagery is practically free and the oldest records in the archive date back to the 1970s.

The study of LULC change of Tbilisi has been the focus of interest of many researchers [9–11]. The aforementioned sphere of research remains important to this day as Tbilisi faces an serious challenge in terms of environmental degradation and housing problems. The development of a modern city does not only entail the study of the surface area already within the boundaries of the settlement, as such cities tend to grow into their surrounding territories and change their landscape. Therefore, as the city grows it becomes significant to rationally put in use the newly merged territories. Thus, Tbilisi and its surrounding areas must be understood as a single geographic entity, in order to develop a cohesive general plan for the future development of the city. Due to unrestricted and poorly structured constructions within the city, the greenery is in disrepair with buildings springing up in parks and recreational zones. It is often the case that the urban development of Tbilisi comes at the cost of devastating the green areas of the city, shrinking them considerably. In the general plan of the city of 2009 there is greenery of 5.6 m squared per capita in Tbilisi, which is a significantly lower number than in the previous decades or even in the 1980s and does not live up to the legal standards of the city. Forests provide numerous environmental benefits to urban/suburban settings, including reduction of urban heat island effects, enhanced water and air quality, regulation of storm water drainage and run-off and provision of wildlife habitat [12,13]. This is exactly why during the expansion of the boundaries of the city within the framework of the general plan for the city the improving the ecological situation must be under focus, further extending the green areas [10]. Increasing suburbanization is a direct threat to forests because it transforms forests and other land use/land covers to impervious surfaces (i.e. buildings, roads, parking lots), which can impact downstream biogeochemical and hydrological processes from water infiltration and increased storm water run-off. Based on the considerable environmental and societal benefits of forests and the rapid global population increases in both urban and suburban areas, it is vital to consistently map and monitor the spatial and temporal changes of urban/suburban forest cover [13,14].

Understanding the proportion of land use and its changes over time is essential for planning and development of control measures [15].

The objective of this research is to quantitatively assess the LULC processes in Tbilisi and its surrounding area within the set period from 1987 to 2016 using the Landsat satellite imagery and GIS technology.

Methods and materials

Capital city of Georgia-Tbilisi is an important political, economic and cultural center. Tbilisi has been mentioned as a city since 5th century [16]. The longitude of study area is 44° 47′ E and the latitude 41° 43′ N (Fig. 1). The river Mtkvari splits the city in two. The left bank of the city is larger than the right both in land area and population. The river spans from the part of Tbilisi called Avchala to the north all the way down to the river Lochini. In terms of landscape, the right bank of the city is situated on the Trialeti mountain range, which is known for its steep slopes delving right into the river. However, there is a number of densely populated areas on the right bank of the river, as it is still the most hospitable area for urbanisation topographically. The South-

Fig. 1. Study area.

eastern part of the city lies 350 m above the sea level. The aforementioned slopes of the right bank in the center of the city (Mtatsminda), on the other hand, are situated 700–1000 m above sea level. The Landscape of Tbilisi is rather complex. Such a diverse landscape is the result of its geomorphologic substance. The landscape has undergone serious changes due to the centuries of anthropogenic activity. The climate in Tbilisi and its surroundings is a transition from a moderate temperate climate of the steppe to a mild humid subtropical climate [17].

Tbilisi has a centuries-old history of urbanisation. Natural and historical circumstances lead to the city growing along the river Mtkvari, - a trend still visible after hundreds of years of development. The direction of this development becomes quite clear as the city continues to grow upstream, towards the North-western parts of Tbilisi. This is a traditional trend dating back to the middle ages [9]. The rapid urban development of Tbilisi began during the XIX century, with the second wave of speedy growth in the second part of the XX century. This period included the 1950-s through to the 1980-s, when a significant amount of sizable factories were constructed within the bounds of the city, increasing demand on the work-force, causing a higher rate of immigration. By the year of 1990 such inducstrial zones made up 17.4% of the

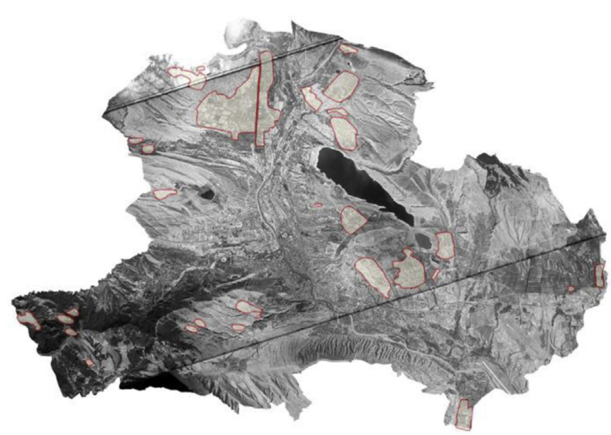

Fig. 2. Agriculture areas (red polygons) on the imagery by CORONA 1971, covered by built-up areas now.

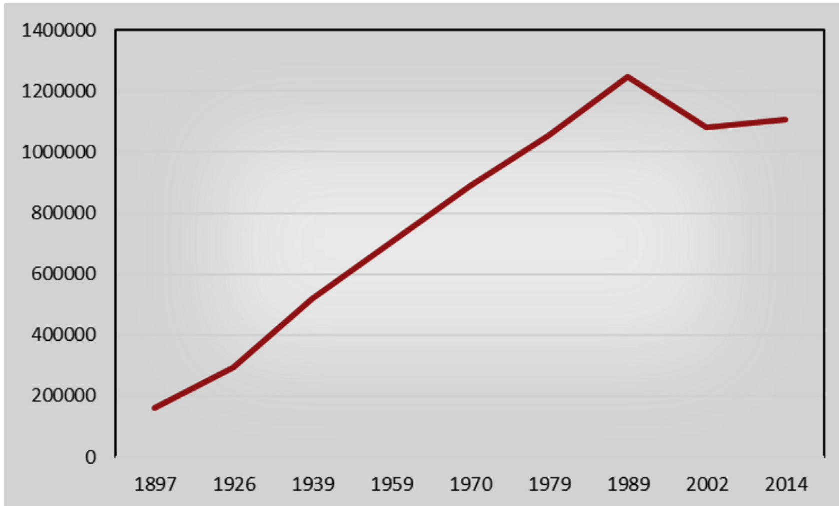

Fig. 3. Dynamic of Tbilisi population during 1897–2014 according to the National Census of Georgia.

Table 1
Characteristics of remotely sensed data.

Acquisition date	Satellite images	Resolution	Source
08–1989	Landsat 5	30 m	USGS
08–2016	Landsat 8	30 m	USGS

Table 2
Area transition for LULC classes between 1987 and 2016.

LULC type	1987		2016	
	Area (km^2)	% Area	Area (km^2)	% Area
Water Body	12.87	2.45	14.22	2.86
Other	183.46	36.54	162.98	32.88
Built up Area	118.54	23.63	190.97	37.53
Agriculture	41.51	8.26	16.67	3.29
Green Area	146.21	29.12	117.86	23.45

city's total surface area. The same period saw the sonstruction of large dwelling areas of the city including Gldani, Mukhiani, Vazisubani, Didi Dighomi, etc. (Fig. 2). Each of these borroughs were to hold up to and sometime even more than 100 000 people. The aforementioned areas used to be cultivated and the agricultural products were traditionally supplied to the city. This was topped off by the spike in internal migration, which was especially visible during the first half of the 1990s, when, in Georgian villages, we are really dealing even with a lack of human resources (especially in mountainous regions of Georgia) [18].

Today the administrative lands of Tbilisi encompass 503 sq. km., which is the result of the change of borders in 2007, (at the time Tbilisi only spanned 365 sq. m.) when the surrounding outskirts (Tskhneti, Kojori, Tabakhmela, Shindisi, Tsavkisi, Kiketi, Betania, Akhaldaba, etc.) of the city were incorporated into its administration. According to the National census conducted in 2014 the population of Tbilisi amounts to 1 108 717 people, which is 2.5% more than depicted in the previous census conducted in 2002 (Fig. 3). This tendency is mostly the result of these outskirts being transferred from the Mtskheta and Gardabani

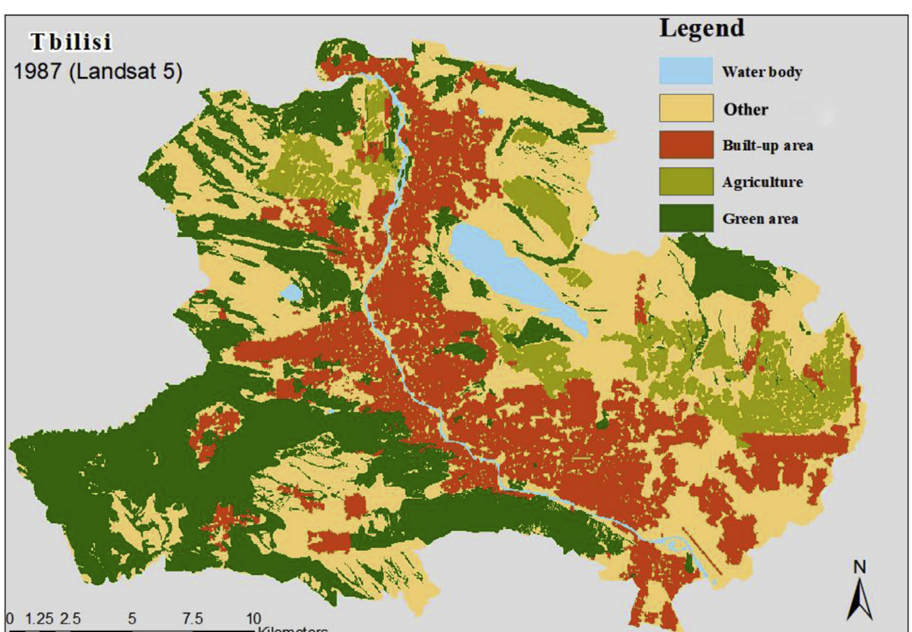

Fig. 4. LCLU classification map of the study area for the year 1987.

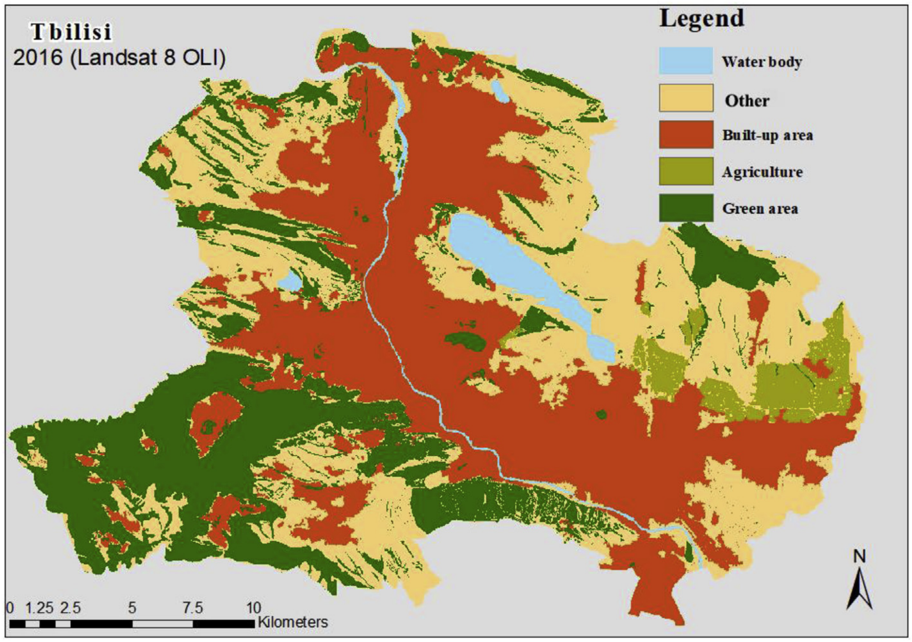

Fig. 5. LCLU classification map of the study area for the year 2016.

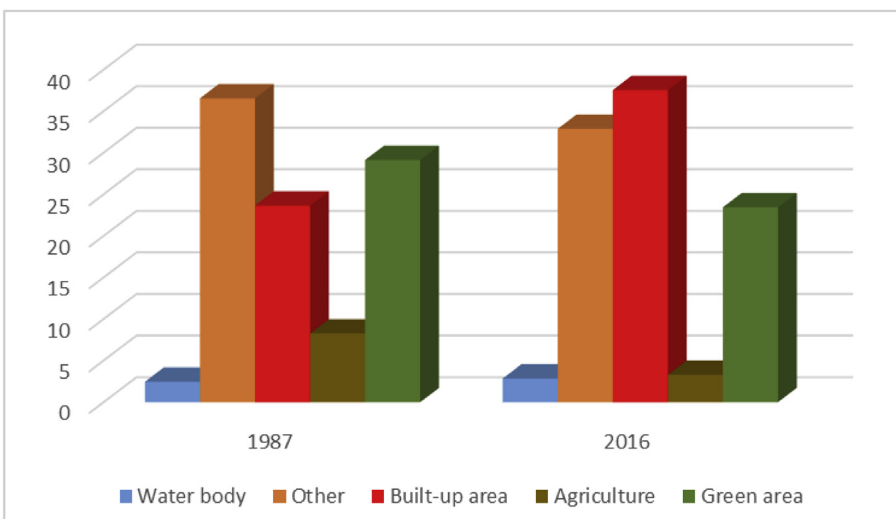

Fig. 6. Total area (in percent) covered by each LULC classes.

municipalities to the administration of Tbilisi.[1] The city has also significantly grown in the direction of the South-east, South-west, and North-West. These newly acquired lands consist mostly of agricultural, wooded, recreational and some dwelling areas. The incorporation of these new territories were mostly conducted under the pretexts that they needed to be developed. In 2009 the city hall published a new general plan of development for the city – The prospective development of Tbilisi. The new plan allowed for construction in all the newly incorporated areas of agricultural and wooded character. Therefore, it becomes clear that the construction of housing projects and their respective infrastructure will further deteriorate the environmental situation in said areas. In the Soviet period Tbilisi was the 15th among the capitals of the 15 Soviet republics with 12 m^2 of city green spaces per citizen. From that period the city population nearly doubled, but the green spaces remained at the same level. The European standard of green space per citizen is 25 m^2 [11].

Therefore, the main objective of the present research was to utilize GIS and Remote Sensing applications to utilize remotely sensed data and GIS tool to analyze the LULC of Tbilisi and surrounding area for the purpose of assess change in the area by comparing between two dates images.

Methods of LULC characterization using medium spatial resolution data (15–30 m) are well established and near operational [19,20].

Our aim was to produce a thematic LULC map of the study area using of various comprehensive geospatial data sets were used. The data used in this research were divided into satellite data and ancillary data. Ancillary data included ground truth data for the LULC classes and topographic maps. Topographic maps with scale 1:10 000 and 1:25 000 and Landsat 5 and Landsat 8 OLI (path 170 and row 31) with 30 m spatial resolution were used in this study. The Landsat imagery was

[1] http://geostat.ge/cms/site_images/_files/georgian/population/Census%20Release_GEO_2016.pdf.

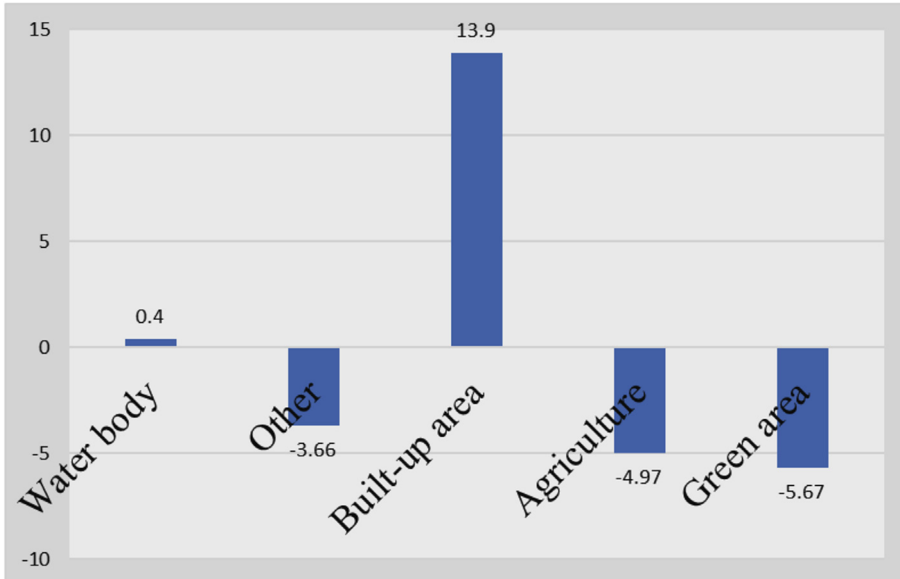

Fig. 7. Percentage change in LCLU categories in 1987–2016.

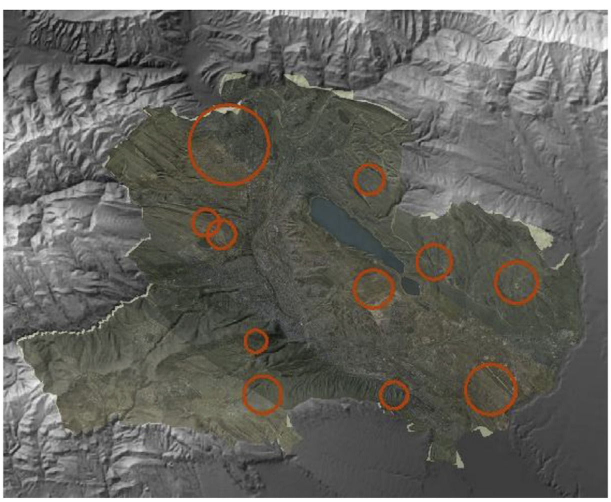

Fig. 8. Areas of main changes.

downloaded from USGS Earthexplorer (Table 1). The dates of both images were chosen to be as closely as possible in the same vegetation season. All visible and infrared bands (except the thermal infrared) were included in the analysis.

Topographic maps were used for preparation of base map and to validate the results. The methodology followed was on-screen digitization. Images with high quality were given priority during the selection. The images covering the study area were in UTM Zone 38N, WGS 84 Datum. These coordinate systems were maintained throughout the project.

Remote sensing image processing was performed using ArcGIS 10.3.1. for georeferencing, mosaicking and sub-setting of the image on the basis of Area of Interest (AOI). Image classification was done in order to assign different spectral signatures from the Landsat datasets to different LULC. This was done on the basis of reflectance characteristics of the different LULC types.

In order to get the comprehensive output the different LULC classes of the study area were grouped into five for easy analysis and assessment of change detection. The LULC classification includes Built up area, Water bodies, Agriculture land, Green areas and other (bare soil, grassland and etc.).

The water bodies include both natural and man-made water features such as ponds, lakes, tanks and reservoirs flowing as streams, rivers, and canals etc. This category comprises areas with surface water, either impounded in the form of ponds, lakes and reservoirs or flowing as streams, rivers, and canals etc.

Bare soil is described as the rock exposures of varying lithology often barren and devoid of soil cover with limited capacity to support life and having less than 5% vegetative cover.

The built-up land is described as an area of human habitation developed by virtue of non-agricultural use. It consists of buildings, transport, and communication [21]. In our study the built up area category includes high, medium and low densities; disperse settlements, and all other man-made structures such as schools, hospitals, industries, bridges and roads.

Agricultural land is described as the land primarily used for farming and for the production of food, fiber, and other commercial and horticultural crops. It includes land under crops (irrigated and unirrigated, fallow, plantations etc).

Green areas are the areas bearing an association predominantly of trees and other vegetation types (within the notified forest boundary).

Unsupervised classification was carried out using the six bands of the multi date images in order to classify the image into clusters and to identify the different change classes by using both IsoData and K – Mean. This classification did not produce the needed result because some classes were merged and misclassified.

On the other hand, the supervised classification was carried out using the Maximum Likelihood to select Region of Interest (ROI) for features like water body. The spectral signature of each class was obtained from the images using ENVI 5.0.

However, classification is challenging because of the high within-class overall brightness variation due to variability in impervious surface composition arising from aging, degradation and the use of different paints as well as illumination-viewing effects [22]. Accuracy assessment was critical for a map generated from any remote sensing data. Error matrix is in the most common way to present the accuracy of the classification results [4,23].

Results and analysis

As outlined in the introduction, for the better comprehensive development and management of the Tbilisi and its surrounding areas, it is needed to have proper information on LULC and the driving forces that affect the urban ecosystem.

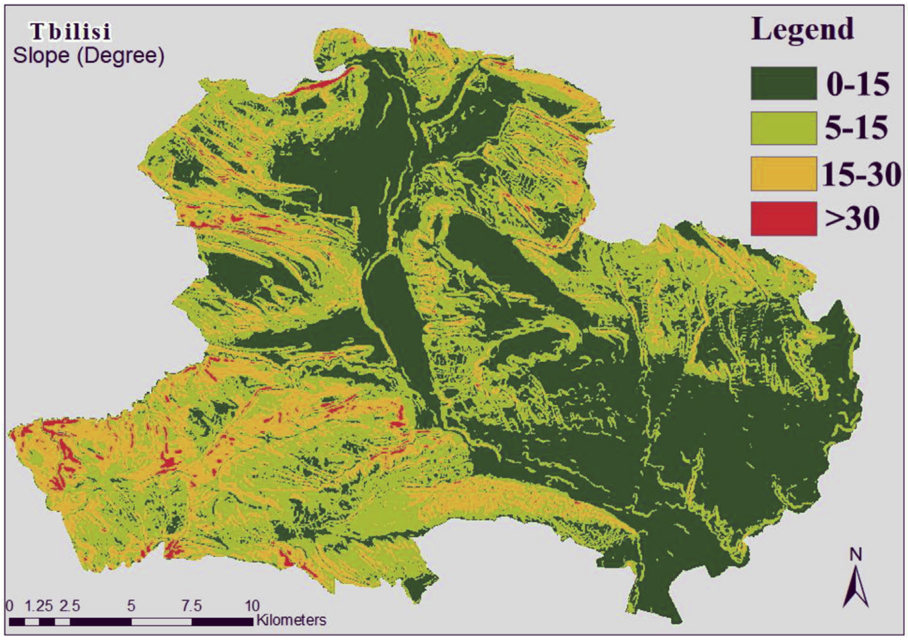

Fig. 9. Slope steepness.

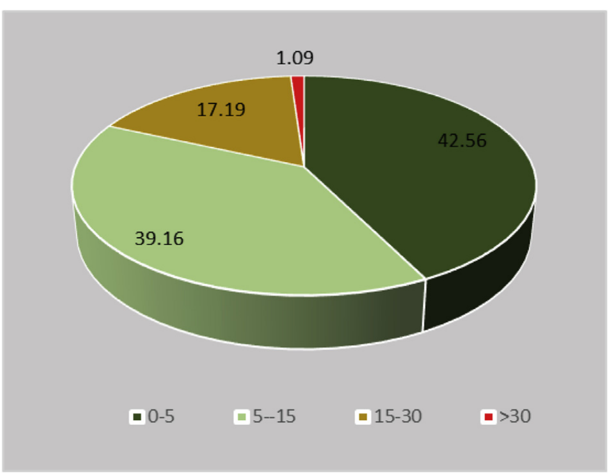

Fig. 10. Total area (in percent) covered by different slopes.

As mentioned earlier, our intention was to assess LULC changes in Tbilisi using the methods described above.

Firstly, the raster image of LULC classes was obtained by the Landsat 5 image classification. Afterwards the same procedure was implemented in case of Landsat 8 OLI. A quantitative analysis of the five categorized LULC of 1987 and 2016 can be seen in Table 2.

As detailed in Table 2, the list has been broken down into five groups each of which contains different LULC types. As illustrated by Fig. 4, in 1987 study area was mostly covered by bare soil and other (36.54%), followed by the green area (29.12%), and built-up area (23.63%), agricultural area spanned only a fraction of the overall surface (8.26%) and was mainly concentrated on the outskirts of the city. The urbanisation of these surrounding areas had already began at that point.

As can be seen, 29 years later in 2016 we see a clear change in the picture, comparing Figs. 4 and 5 shows that there is a sharp rise in the built-up area (37.53%) and as evident from Fig. 6 this was done at the cost of losing bare soil and green area. It may be reasonable to suppose that the changes we have received are not considerably high, but as mentioned before, natural and manmade landscapes are very sensitive to any kind of changes (see Fig. 7).

It is well known that the main reason for this is the expansion of the population which, in turn, is the result of internal migratory processes. This entails both the migration from villages to the city and the accumulation of refugees from the conflict zones. Another reason is the rise in demand on goods and the general increase in the standard of living of the population in the city, which, in turn, results in the construction boom evident today. On the whole, the results were predictable and make sense, as construction works has become the fastest growing sector in the economy of the city in the latter couple of decades. Nevertheless, this is unfortunate, as the ultimate result is the devastation of the environment.

Modelled raster image of 1987 was compared with topographic maps of the same period. To validate the classification results of Landsat 8 OLI we used SENTINEL images with higher resolution and the ground truth data. Since the main changes in LULC occurred on the agriculture and green areas, we investigated the areas with high rate of changes (Fig. 8). The development of the city in the direction of Northwest (Didi Dighomi territory) can be observed in Fig. 8. As mentioned before, the agricultural areas present there (see Fig. 2) are being quickly built-up starting back in the latter half of the 1980s.

It appears that terrain plays the key role in the urban expansion in case of Tbilisi and surrounding area. To investigate the relationship between city's terrain and LULC changes, firstly, we need to see the morphometry of study area (Fig. 9). As we can see in Fig. 10, most of the territory (42.56%) is occupied by 0-5° slopes while the less (1.09%) more than 30° slopes.

Lastly, it was interesting to determine how the abovementioned changes would be expressed on terrain and the results have been received. Table 3 reports that main part of the changes (7.88%) was

Table 3
Total area of (in percent) LULC change according to the slope steepness.

Slope (degree)	LULC Change percent
0–5	7.88
5–15	4.71
15–30	0.76
> 30	0.01

conducted on 0-5° slopes and it would seem that these changes are connected to the built-up area itself. On the whole, it makes sense because people always choose the convenient terrain for their settlement.

Conclusion

Hence, proper information on LULC is necessary for implementing various developments, planning, and land use schemes to meet up the increasing demands of basic human needs. The utilization of Remote Sensing and GIS tools were helpful in detecting the LULC change that has taken place in Tbilisi and surrounding area over the past 29 years. For these purposes the 1987 and 2016 Landsat imagery was analysed in this study. As a result of digital analysis 5 different categories of Tbilisi's surface area were classified: Built up area, Water bodies, Agricultural land, Green areas and Bare soil and other. The results show that during the past 29 years Tbilisi and its surrounding areas were heavily built-up (+13.9%) at the cost of losing bare soil and the green areas, respectively (−4.97%) and (−5.67%). The outskirts of the city are polyfunctional, urban development zones. However, in the case of Tbilisi the urbanisation and general growth does not only take place in the outskirts. It is usually the central areas that are subjected to the vertical development at the cost of the environment. Assessment of LULC changes in Tbilisi during 1987–2016 revealed that the speed of expansion was in fact worrying. In addition, analysis of the changes in the land use is of the most importance not only for quantitative evaluation of the changes already implemented, but for future modeling and prognosis of urban development. Raster data containing the classes of land use is an integral part of the city's prognostic models.

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