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Physical Geography

Satellite-Based Analysis of Landscapes Transformation in Tbilisi, Georgia

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In the modern world, landscapes are being actively transformed against the backdrop of intensified urbanization. Applications of remote sensing and GIS are excellent tools for the assessments of quantitative and qualitative landscape transformation. The aim of this research is to assess the degree of landscape transformation in Georgia's capital city of Tbilisi, over the past three decades. The analysis is based on satellite image classification (Landsat 5TM, Landsat 8 OLI, and Sentinel 2) in GEE. On the basis of the NDVI data calculated from the images of the selected study period, the ratio of green space at a particular time was determined. Using a linear regression of NDVI values, the decrease in the tendency of green spaces from 2013 to 2020 was determined. The obtained results indicate that in recent years, among Tbilisi landscapes being transformed over the centuries, landscape genera 18, 22, 25, and 51 have experienced a relatively high rate of transformation. © *2024 Bull. Georg. Natl. Acad. Sci.*

LULC, NDVI, RGS, landscape transformation

Urbanization is one of the main factors in the transformation of natural landscapes. The urban fabric absorbs different types of landscapes. Urbanization became particularly active at the beginning of the twentieth century [1]. According to the UN, 2007 was a milestone when the world's urban population exceeded the rural population [2]. In 2023, 56% of the world's population – 4.4 billion inhabitants – lived in cities [3]. Although 79.5% of the urbanization rate will be in developed countries and by 2021, 51.8% in developing countries the rate of Urbanization has increased in developing countries in the last 10 years, especially in Asia and Oceania [4]. Urbanization in developed and developing countries has different effects on the environment, urban planning, land use and land cover (LULC), landscape transformation, etc. The highest degree of landscape transformation is related to urban areas. It is important for researchers and decision makers to quantify this transformation. The development of remote sensing and geoinformation systems has allowed researchers to obtain detailed

data on the landscape's transformation in space and time [5]. Freely available satellite imagery analysis is actively used in the study of urban sprawl and LULC change. The access to multitemporal data and its analysis are getting easier with Google Earth Engine (GEE). The GEE is a cloud-based platform that makes it easy to access high-performance computing resources for processing extensive geospatial datasets, saving time and energy [6]. Thanks to similar applications and available data, the quantitative assessment of landscape transformation is already available for countries like Georgia, where there is a lack of appropriate data.

In Georgia, urbanization rate is 58%, according to 2018 data [7]. Rapid urban development in Tbilisi began in the 19th century and continues to this day with its modern patterns. At the beginning of the 19th century, 2% of the country's population lived in Tbilisi; in the 20th century, it was 10% [8]. In the same period, built-up areas expanded rapidly. According to data from January 2021, 32% of Georgia's population lives in Tbilisi [9]. This is quite a high indicator in relation to the area of Tbilisi and causes overcrowding. Tbilisi is an ancient city with a diverse landscape that includes eight genera (Fig. 1) [10].

The aim of the study is to evaluate the intensity of landscape transformation in Tbilisi via satellite-based analysis during 1987-2020 and to find out which of the landscapes has transformed the most, and in the mentioned 35-year period, in which period the intensity of landscape transformation observed is greater.

Study Area

Tbilisi, the capital of Georgia, with an area of 502 km^2 and an elevation of 380-1512 m a.s.l., is located in Eastern Georgia, on both banks of the Mtkvari River. The city has complex hydrogeology and topography [11]. At the same time, it is characterised by a diverse landscape; there are 2 classes, 4 types, 5 subtypes, and 8 genera (Fig. 1).

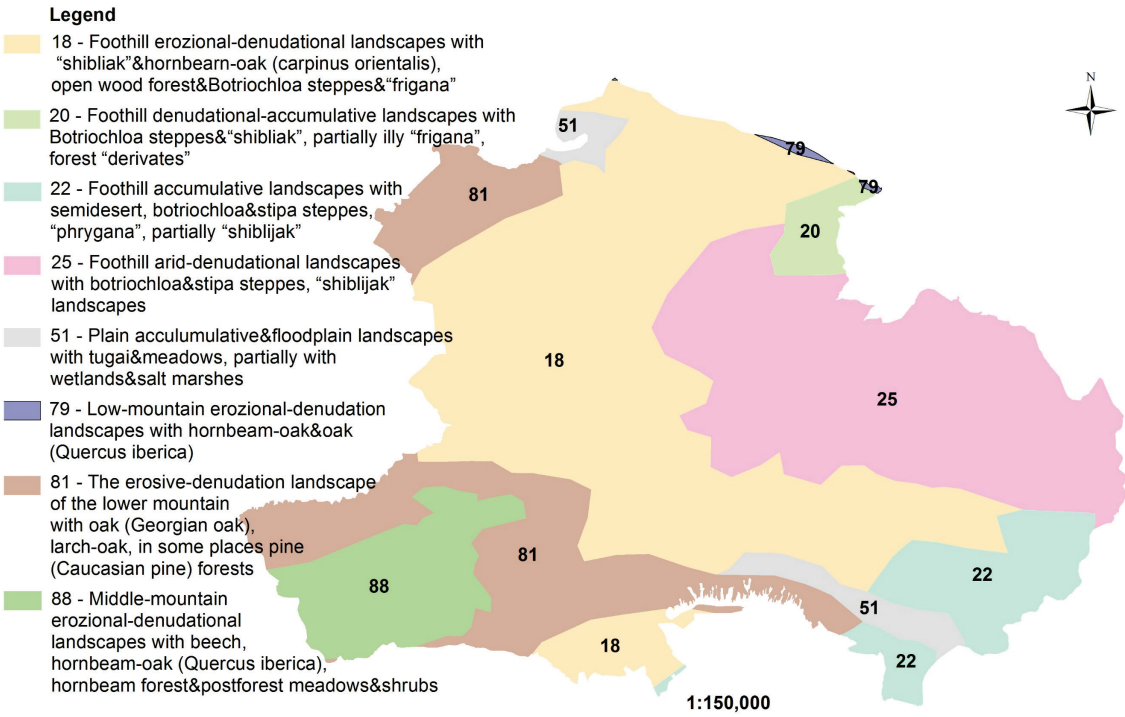

Fig. 1. Main landscapes of Tbilisi.

Methods

We used Landsat TM, Landsat 8 OLI, and Sentinel 2 imagery for analysis. Table 1 shows the dates and basic characteristics of the imagery used in the study. For comparison, we used Landsat 1987, 1997, 2005, 2015, and 2020 images. The spatial resolution of 30 m. The Sentinel 2 images used in the study are from 2013 and 2020, and their spatial resolution is 10 m. We selected the visible spectrum and near-infrared bands for the images of both satellites.

The majority of the calculations were implemented in GEE. Arc map 10.8 was used for data integration and visualization. For LULC classification we used the Random Forest algorithm. To select reference points, we used relatively high-resolution aerial images (captured in 2005, 2014 and 2020 with spatial resolution 15 cm, 6 cm and 5 cm), largescale topographic maps and Google Earth images. For our research we identified 7 LULC classes (water, trees, shrubs, grass, bare soil, crops and built up). For each class, we selected 20 reference points and divided them randomly. 70% of them participated in the classification process, and 30% in the accuracy assessment. At the same time, for each year, the annual mean values of the Normalized Difference Vegetation Index (NDVI) were determined (actually, we only took pictures from April to October, so that the winter period did not affect the NDVI values). As it is known, NDVI is an excellent indicator for monitoring the vegetation cover. NDVI values range from -1 (water, ice) to 1 (abundant healthy vegetation).

$$NDVI=(NIR-R)/(NIR+R), \quad (1)$$

where NIR is Near-infrared band and R is red band. Based on past studies [12], we have assumed NDVI values of 0.19 to 1 as green cover in the city. Based on this data, the Ratio Green Space (RGS) was defined.

$$RGS=S_{green\ area}/S_{land\ area}, \quad (2)$$

where S green area is the area covered with vegetation, and S land area is a total land area. We also determined the linear regression of NDVI values within Tbilisi landscapes in 2013-2020. According to the above-mentioned data, the degree of transformation of landscapes was evaluated.

Results and Discussion

Comparing the spatial distribution of landscapes and LULC classes, it was found that landscape genus 18 is the most transformed. At the same time in Tbilisi, it occupies more total area than other landscapes. Today, almost 42% of landscape genus 18 (originally covered by open forest and shrubs) is transformed as a built-up area. Within it, grass prevails from the green cover, while trees occupy only 18% of landscape genus 18, and shrubs occupy 3%. The reason for this circumstance is that from the 18th century to the 1990s, the development of the city took place only within the boundaries of this landscape genera [13]. Most of the high block of flats in the city are located here. 70% of the enterprises in Tbilisi, all of Tbilisi Metro stations and the main line of the old railway are gathered here.

The territory of Tbilisi has been expanding since the second half of the 1990s. In 1995, the part of landscape genera 22, 25 and 51 were officially included in the territory of Tbilisi. Against the background of the difficult social, economic and political situation in the country, the migration to the capital city increased, which led to the expansion of the area of Tbilisi [13]. In the above-mentioned landscapes, the built-up area prevails in landscape genus 22. Despite its small area, 38% of this landscape genera is built-up area, trees occupy only 10%. Genus 51 has the largest share of forest cover by reason of less anthropogenic impact (Table 1).

Table 1. LULC classes distribution according to landscape genera

Genera	Barren (%)	Built-up (%)	Crop (%)	Grass (%)	Shrubs (%)	Trees (%)	Water (%)	Wetland (%)
18	4.78	42.13	1.36	29.36	2.49	18.30	1.49	0.10
20	4.91	7.29	0.04	78.16	3.98	5.58	0.00	0.03
22	12.82	37.62	3.21	31.01	5.42	9.78	0.02	0.11
25	3.90	11.59	2.59	56.48	5.88	11.30	8.25	0.02
51	7.60	32.90	2.87	18.97	4.22	25.52	7.90	0.03
79	0.00	0.00	0.00	13.78	13.63	72.51	0.00	0.00
81	1.30	4.16	0.63	46.53	3.19	44.14	0.05	0.00
88	1.35	4.98	0.00	39.56	4.18	49.63	0.00	0.00

Landscape genera 88 and 81 underwent also relatively less transformation. In these landscapes, half of the area is occupied by forest and post-forest meadows. Built-up area here is only up to 5%. These landscapes are the greenest within Tbilisi. These territories joined Tbilisi in 2007. Historically, loose rural settlements existed in the territory of the mentioned landscapes. It is the rural settlements and complex topography that explain the low degree of transformation.

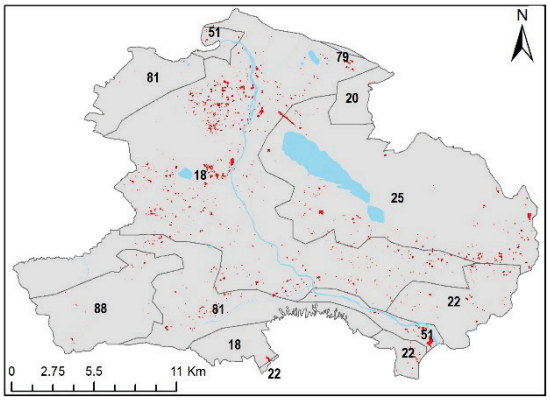

Fig. 2. NDVI linear regression (reduction of hot-spots).

The comparison of RGS by decade demonstrated that the proportion of green space increased significantly in the 1990s. This is due to the fact that, after the fall of the Soviet Union, the agrarian and industrial complex came to a complete halt as a result of the previously described difficult circumstances. Former agricultural regions are now engulfed in vegetation. Since the beginning of the 2000s, this trend is particularly related to urban sprawl and the transformation of verdant spaces into built-up areas. In 2016, a significant decline was observed, coinciding with a rise in demand for residential and commercial space in the city. We used NDVI linear regression to better comprehend the transformation according to landscape categories in light of the recent sharp decline in RGS.

The regression of NDVI according to individual landscapes (Table 2) looks as follows: In the period 2013-2020, the strongest regression of NDVI is recorded within the framework of landscape genera 22. It should be noted that within this landscape, no particular intensity of built-up area growth is recorded, therefore it cannot be named as the main cause of the reduction of green cover. According to some authors, the cause of this fact is the withering of conifers related to climate change and parasites.

Table 1. NDVI linear regression during 2013-2020

Landscape genera	Ratio of NDVI values decrease (%)
18	32
20	12
22	71
25	48
51	20
79	34
81	20
88	21
	Sum in Tbilisi 36

It makes sense that NDVI regression remains constant even within the genus 18. Eventually, this landscape experienced the most transformation within Tbilisi. A high rate of the NDVI regression

is also fixed within the genus 25. The cause for this is the increased demand for land parcels near the Tbilisi Sea, which has led to the urbanization of vast areas. Within the genera 81 and 88, the NDVI values decrease less drastically (Fig.2). The reasons include the terrain's complexity and the regulations imposed to preserve the landscapes.

Conclusion

The aim of this study was to determine the degree of landscape transformation over the last thirty years through the analysis of satellite images. Among the eight landscape genera on the territory of Tbilisi, genera 18, 22, 25, and 51 experienced the most transformation. The fact that they are all lowlands and foothills make them suitable for urbanization. Landscape genera 88 and 81 witnessed the least transformation. Complex topography, historical rural settlements that have been transformed into spots for recreation, and the presence of protected forest zones where a number of regulations apply are the reasons for this. Due to these factors, transformation of the landscape is not straightforward.

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თანამედროვე მსოფლიოში, გაძლიერებული ურბანიზაციის ფონზე, აქტიურად მიმდინარეობს ლანდშაფტების ტრანსფორმაცია. დისტანციური ზონდირებისა და გისის აპლიკაციები შესანიშნავი ხელსაწყოებია ლანდშაფტების ტრანსფორმაციის რაოდენობრივი და ხარისხობრივი შეფასებისთვის. კვლევის მიზანია, საქართველოს დედაქალაქ თბილისში, შევაფასოთ

ლანდშაფტების ტრანსფორმაციის ხარისხი ბოლო 30 წლის განმავლობაში. კვლევა ეფუძნება თანამგზავრული სურათების (Landsat 5TM, Landsat 8 OLI და Sentinel 2) კლასიფიკაციას GEE-ში. შერჩეული საკვლევი პერიოდის სურათებიდან გამოთვლილი NDVI-ის მონაცემებზე დაყრდნობით, განისაზღვრა მწვანე სივრცის ხვედრითი წილი. NDVI-ის მნიშვნელობების წრფივი რეგრესიით კი შეფასდა მწვანე სივრცეების დეგრადაციის ტენდენცია 2013-2020 წლებში. მიღებულმა შედეგებმა გვაჩვენა, რომ თბილისის ფარგლებში, ლანდშაფტების ტრანსფორმაციის მაღალი მაჩვენებელი განსაკუთრებით ბოლო პერიოდში ფიქსირდება 18, 22, 25 და 51 ლანდშაფტების გვარებში.

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