

PHYSICAL GEOGRAPHY

GIS and Remote sensing

RESEARCH OF THE ANTHROPOGENIC
TRANSFORMATION OF THE NATURAL LANDSCAPES
OF THE GREATER CAUCASUS USING MATHEMATICAL
STATISTICAL METHODS (WITHIN AZERBAIJAN)

Afag Z. Hajiyeva[✉], Firuza M. Jafarova

Received on December 20, 2024

Presented by H. Najdenski, Member of BAS, on June 24, 2025

Abstract

By applying modern research methods, by applying the processing of satellite images and Remote Sensing materials, it is possible to conduct research of larger areas in a short time. For the first time, we applied this method to our research area. Our main goal is to determine the increasing anthropogenic impact at any moment and prepare its future forecast. In the article, using mathematical statistical methods and space images, on the basis of GIS technologies, the characteristics of changes in natural landscapes are studied. During the study, we divided the 1:280 000 scale map into 294 squares with sides of 2.5 cm. We calculated the number of types of contours (n) and species diversity (m), irregularity ($K = m/n$), asymmetry, and C_v -variation coefficient of each square. During the study, we used ArcGIS, Mapinfo, and Surfer 8 GIS software. As a result of study we determined that crop husbandry had developed in the areas where the inclination was low, and animal husbandry had developed in the areas where the inclination was high. This trend is expected to continue in the future.

Key words: Greater Caucasus, natural landscapes, anthropogenic transformation, digital methods, geoinformation systems, GIS technologies

Introduction. In modern times, it is possible to conduct multi-year observations in the shortest possible time [1]. It is important to use satellite images and Remote Sensing during this research. As a result of their processing in

<https://doi.org/10.7546/CRABS.2025.08.10>

Geographic Information Systems, it is possible to make multi-year comparisons and draw conclusions, which helps to diagnose future development [2]. In this regard, using Geographic Information Systems is an urgent requirement of the time. During our research, we analyzed the anthropogenic transformation of landscapes in the Greater Caucasus using Geographic Information Systems.

Geographic Information Systems are one of the most modern methods for monitoring and forecasting spatial data and its nature, vegetation, water basins, and environment [3]. At this time, our base data can be the results of field studies, or satellite and aerial data [4]. Our initial database can be in raster and vector formats, which also have their own characteristics [5]. For example, it is possible to explore larger areas with raster data [6]. With the help of this system, we can get data, and also process and store it [7].

It is clear from the research that geocomplexes are formed and develop as a system. The elements of this system are geographic components and their elements [8]. The sustainability of the landscape depends on these components being constantly stable and resistant to the environment within the geosystem. If one of the components that make up the geosystem does not participate in this system [9], then a weakening occurs within the system and its stability decreases [10]. If the connection between most of the components is weakened, then geosystems change from one form to another. For example: the semi-desert becomes a desert, the forest-steppe turns into a desert [11]. If the connections of the leading components of geosystems become too weak, then after a while the geosystem will lose its structure and another complex will be formed in its place [12]. For example: if a forest massif is completely destroyed, a steppe or forest-steppe is created in its place.

Material and methods. Data on both quantitative and qualitative characteristics of landscapes and its components are collected by mathematical statistical methods and analyzed based on special criteria. Through mathematical methods, a number of patterns of differentiation, structural-functional characteristics, quantitative and qualitative characteristics of landscapes are evaluated more accurately. The method of equal squares network was used in the implementation of this work. When creating digital mathematical cartographic map models of anthropogenically transformed landscapes of the Greater Caucasus region, the method of a grid of equal-area squares was first used. For this purpose, the scanned map is imported into any GIS software. In our example, the Map-Info GIS software was used. After that, the structure of the map model we have mentioned is arranged in the following sequence. The map previously included in the software is divided into squares of equal area. In our example, the map is divided into 294 squares with a side of 2.5 cm. Considering that the scale of the map is 1:280 000, the real size of each square is 49 km. Then, the number of types of contours (n) and the type diversity (m), irregularity ($K = m/n$), asymmetry, and coefficient of variation of C_v are found in each square.

We used Surfer 8 GIS software to create digital mathematical cartographic map models from the results we obtained. At this time, we record the conditional coordinates of each square in the program (X ; Y) and for each square, we calculate the number of species (n) and species diversity (m), irregularity ($K = m/n$), asymmetry, and coefficient of variation $C_v(Z)$. Then, using the interpolation method, we compile digital mathematical cartographic map models of the anthropogenically transformed landscapes of the Greater Caucasus region.

After that, mathematical-cartographic models of the anthropogenically transformed landscapes of the Greater Caucasus were created using the Surfer program, determining their areas. A 3D hypsometric model of the Greater Caucasus was developed using Geographic Information Systems (GIS). For this purpose, we used ArcGIS software. We used the Digital Elevation Model of the area. For this, SRTM was downloaded. The SRTM payload consisted of two radar antennas, one located in the shuttle's payload bay and the other installed at the end of a 200-foot mast that extended from the payload bay. Each SRTM radar assembly contained two types of antenna panels: C-band and X-band. C-band radar data were used to create near-global topographic maps of Earth called Digital Elevation Models (DEMs).

Data from the X-band radar were used to create slightly higher resolution DEMs but without the global coverage of the C-band radar. The two radar datasets were combined to create interferogramatic maps of scanned areas.

Results of the research. Each natural and anthropogenic landscape complex is formed as a result of long-term natural-historical processes. The anthropogenic factor plays a leading role in the replacement of forests, grasslands, steppes, forest-deserts, and others with artificial complexes. Therefore, modern natural and anthropogenic complexes cannot be separated from each other by sharp boundaries. Modern anthropogenic landscapes have a unique pattern of anthropogenicization of farmlands, garden plantations, agricultural complexes, and various infrastructures. The systematic study of these regularities has both practical and great scientific importance.

The modern landscape map of the Greater Caucasus, i.e., the map depicting the transformed territorial units of natural landscapes in a modern form, was compiled as a result of long-term research (2000–2013) and the analysis of both visual and satellite images. In the following years, the anthropogenization and transformation of natural landscapes were clarified with GIS technology and the obtained scientific results were systematized.

With the mathematical statistical method used in the research work, geoinformation is collected within each square (soil, vegetation, landscape, etc.) and then written in the centre of each square. At this time, geoinformation can be in the form of numbers and words. Numerical information represents the component characteristics within each square. For example: number of plant species, their average area, number of soil types and their mechanical and chemical character-

istics, diversity of geological structure and other indicators are written near the central point of the square. The geographic coordinates of each are determined, then the data is collected in a special table in the form of coordinates. After setting the table, isolinear two- and three-dimensional models of the distribution of the characteristics of natural objects in the area are made. The measurement and collection of spatial geoinformation in the specified sequence is currently performed through geoinformation systems. So, the measurement of information in these systems is automatically entered into the geoinformation systems on the computer. After examining the data, 2- and 3-dimensional models of objects in the studied area are drawn up. We have prepared 3D model (Fig. 1a) of the area based on Digital Elevation Model (DEM) of the area. For this purpose we used ArcGIS 10.8 software.

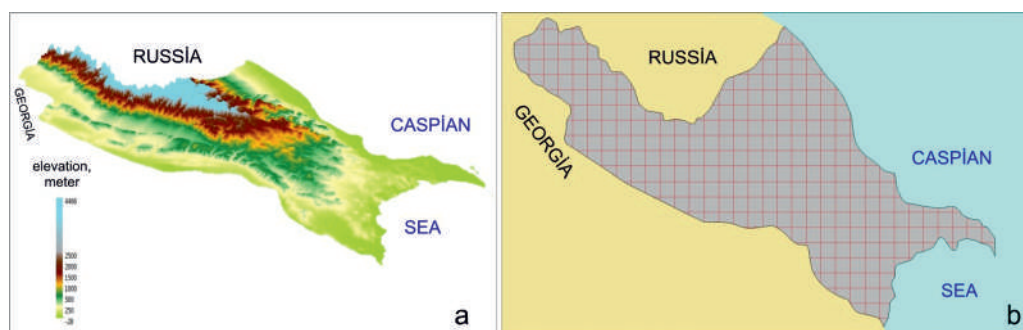


Fig. 1. a) 3D hypsometric model of the Greater Caucasus based on GIS (ArcGIS software);
b) Vector map model of anthropogenically transformed landscapes of the Greater Caucasus

Development of digital mathematical cartographic models of anthropogenic transformation of natural landscapes. For the creation of mathematical-cartographic models of the landscape, the research area was divided into 294 squares (Fig. 1b) on the map scheme, and after vectorizing the landscape types in them with the MAPINFO 11 program, their areas were determined and mathematical-cartographic models of the anthropogenically transformed landscapes of the Greater Caucasus were created with the Surfer program. We calculated the area of the contours within each square. However, since these studies are extensive, we have presented a certain part in the article (Table 1).

As we mentioned above, during the compilation of the digital mathematical cartographic map models of the anthropogenically transformed landscapes of the Greater Caucasus region, the grid method of equal area squares was first used (Fig. 2). For this purpose, the scanned map is entered into any GIS software. In our example, MapInfo GIS software was used.

As we mentioned in the Material and methods section, for each square we calculate the number of species (n) and species diversity (m), irregularity ($K = m/n$), asymmetry, and coefficient of variation (Z) (Table 2).

T a b l e 1

Areas of contours of anthropogenically transformed landscapes
located within square plots

1: Square No. and Contour No.

2: Area of contours (m^2)

1	2	1	2	1	2	1	2
sq1		sq3		sq6		sq8	
23	501.7	120	309.4	14	185	23	230.3
72	146.7	119	1983	14	325.8	14	90.84
114	446.7	118	18.71	70	36.8	26	239.4
26	22.75	131	765.5	13	494.5	72	1257
73	209.6	135	931.9	12	54.34	72	165.5
118	64.21	sq4		105	225.1	72	83.83
sq2		119	1289	sq7		72	15.52
73	88.07	131	59.65	12	98.54	23	417.6
26	237	131	235	14	23.2	23	7.016
69	100.7	120	396.6	13	14.39	21	644.8
118	979.8	135	1320	105	1069	sq294	
119	1515	sq5		11	239.6	36	546.09
120	43.05	120	450.6	11	17.42	a36	52.92
134	171.6	131	754.6	71	309.5	93	393.54
131	324.3	135	1624	108	400	54	301.2

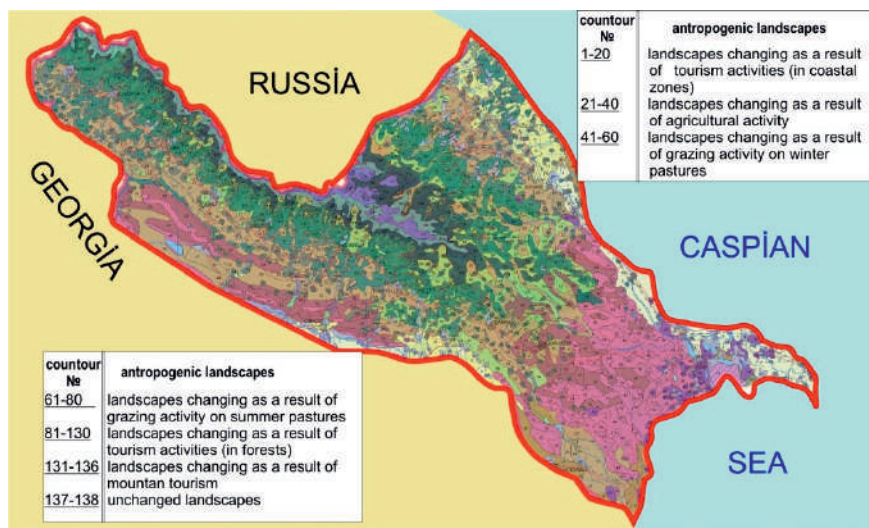


Fig. 2. Map of anthropogenic transformation of natural landscapes
of the Great Caucasus and surrounding plains

Then, using the interpolation method, we compile digital mathematical cartographic map models of the anthropogenically transformed landscapes of the Greater Caucasus region (Fig. 2).

T a b l e 2

Calculated mathematical statistical indicators of anthropogenically transformed landscapes of the Greater Caucasus

- 1:** Total area (m^2) (T) **2:** Number of species (n)
3: Average size of the contour areas (m^2) (T/n)
4: Area of the contour with the minimum area (m^2)
5: Area of the contour with the maximum area (m^2)
6: Asymmetry **7:** Coefficient of variation (Z) **8:** Species diversity (m)

No.	1	2	3	4	5	6	7	8
sq1	1391.66	6	231.94	22.75	501.70	0.57	0.86	6
sq2	3459.52	8	432.44	43.05	1515.00	1.62	1.23	8
sq3	4008.51	5	801.70	18.71	1983.00	1.03	0.94	5
sq4	3300.25	5	660.05	59.65	1320.00	0.43	0.91	4
sq5	2829.20	3	943.07	450.60	1624.00	1.26	0.65	3
sq6	1321.54	6	220.26	36.80	494.50	0.64	0.78	5
sq7	2171.65	8	271.46	14.39	1069.00	1.96	1.30	7
sq8	3151.81	10	315.18	7.02	1257.00	1.93	1.22	5
sq9	3056.88	10	305.69	39.06	678.60	0.55	0.85	8
sq10	3269.13	6	544.86	28.99	1469.00	0.95	1.25	6
sq294	1293.75	4	323.44	52.92	546.09	-0.64	0.64	3

Conclusion. Areas with weak differentiation correspond to the high mountain zone of the Greater Caucasus Mountains, the Ajinohur lowland, the Gobustan lowland, and the coastal zone in the form of a strip. The reason for this is that there are few agricultural areas in these regions, or only one or a few types of anthropogenic landscapes predominate. For example, the dominance of only pasture-meadow complexes in the high mountains is an example of this. On the contrary, we observe high differentiation in the Ganikh-Ayrichay valley, in the mountainous Shirvan, in the Samur-Devachi plain, etc. areas, where various sectors of agriculture have developed. The areas with a medium degree of differentiation account for more than 40% of the research area.

The indicators of irregularity (m/n) do not correspond to differentiation as weak (0.3–0.6), medium (0.6–0.8) and high (0.8–1) m -diversity. On the contrary, it is weak in areas where differentiation is high, and high in areas where it is weak. This is because in a unit area (in our example, within one square) when the difference is small, the number of contours and the number of differences are the same, or there is a small difference, and their ratio is equal to unity or very close to unity. Note that the irregularity is maximum equal to 1.

We have clearly determined the relationship between asymmetry and the coefficient of variation, as well as the relationship between asymmetry and irregularity, from the calculated statistical indicators of anthropogenic landscapes spread across the study area, in the form of a graphical dependence and by superimposing map-schemes and intersecting contours.

REFERENCES

- [1] EHLERS M. (2008) Geoinformatics and digital earth initiatives: A German perspective, *Int. J. Digital Earth*, **1**(1), 17–30.
- [2] HAJIYEVA G. N., A. Z. HAJIYEVA, KH. D. DADASHOVA (2022) Impact of urban landscape pollution on human health, *News Nat. Acad. Sci. Rep. Kazakhstan*, **1**(451), 39–45.
- [3] KHAN F., T. RAO, H. BHAVE (2018) To classify the landuse/landcover of Nagpur City: using geoinformatics, *Int. J. Glob. Technol. Initiatives*, **6**(1), 71–80.
- [4] MHASKE S. Y., D. CHOUDHURY (2011) GIS-GPS based map of soil index properties for Mumbai. In: *Advances in Geotechnical Engineering*, 2366–2375.
- [5] AL-ANI H., E. OH, G. CHAI, B. N. AL-UZAIY (2014) GIS-interpolated geotechnical zonation maps in Surfers Paradise, Australia. In: *Proc. 6th Int. Conf. on Advanced Geographic Information Systems, Applications, and Services*, 178–185.
- [6] DONNELLY L. J. (2013) Use of geology in forensic science: search to locate burials. In: *Encyclopaedia of Quaternary Science* (ed. S. A. Elias), **4**, 521–534.
- [7] DONNELLY L. J., M. HARRISON (2013) Geomorphological and geoforensic interpretation of maps, aerial imagery, conditions of diggability and the colour-coded RAG prioritisation system in searches for criminal burials, *Environmental and Criminal Geoforensics: Geological Society of London, Special Publications*, **384**(1), 173–194.
- [8] WIMBERLY M. C., J. L. OHMANN (2004) A multi-scale assessment of human and environmental constraints of forest land cover change on the Oregon (USA) coast range, *Landscape Ecology*, **19**(6), 631–646.
- [9] AMANOVA S. S., G. N. HAJIYEVA, J. S. NAJAFOV et al. (2024) Investigation of urban biodiversity and factors influencing it based on modern technologies, *Geodesy and Cartography*, **50**(3), 141–149, <https://doi.org/10.3846/gac.2024.19626>.
- [10] WOLTER P. T., C. A. JOHNSTON, G. J. NIEMI (2006) Land use land cover change in the U.S. Great lakes basin 1992 to 2001, *J. Great Lakes Res.*, **32**(3), 607–628.
- [11] AMANOVA S. S., A. Z. HAJIYEVA, F. M. JAFAROVA (2024) Preparation of future development scenarios of urban landscapes in accordance with natural and socio-economic conditions (on the example of the cities of the Kura-Araz lowland), *Visnyk of V. N. Karazin Kharkiv National University, Series “Geology, Geography, Ecology”*, **60**, 305–322, <https://doi.org/10.26565/2410-7360-2024-60-22>.
- [12] HAJIYEVA A. Z., F. M. JAFAROVA (2024) Analysis of the regularity of distribution of natural landscapes in the Greater Caucasus depending on physical-Geographical characteristics using GIS technology, *C. R. Acad. Bulg. Sci.*, **77**(2), 221–229.

*Azerbaijan State University of Economics (UNEC),
6 Istigaliyyat St, AZ1001, Baku, Azerbaijan
e-mails: afaq.adiu@mail.ru, jafarova_firuz@mail.ru*