December 2024

GEORGIAN GEOGRAPHICAL JOURNAL

Vol. 4 No. 2 (2024)

ISSN 2667-9701

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Published in Georgia

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Georgian Geographical Journal

4(2) • December 2024

3D Model of Morphostructure of the Crystalline Basement of the Georgian Caucasus

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Georgian Geographical Journal, 2024, 4(2) 4-13

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Basheleishvili, L.; Beridze, G.; Gogia, B. 3D Model of Morphostructure of the Crystalline Basement of the Georgian Caucasus.
Georgian Geographical Journal 2024, 4(2). 4-13
https://doi.org/10.52340/ggj.2024.04.02.01

Abstract

Thus, for the first time for Georgia and the region, a plasticine model of the morphotectonics of the crystalline basement was created on a horizontal scale of 1:500 000 m and a vertical scale of 1: 200 000, which contributed to a clear visualization of the morphostructure of one of the main structural-tectonic elements of the upper part of the Caucasus crust within Georgia. The technique for reproducing the plasticine model of the morphology of the relief of a crystalline basement consists in removing the mass of plasticine that corresponded to a thick sedimentary cover below the zero mark, and above this mark, on the contrary, in building up to the required height. As a result, the obtained model clearly shows the modern picture of the relief morphology of the crystalline basement, and its mosaic-block structure.

Keywords: Georgia, crystalline basement, structural geology, 3D model

Introduction

In the structure of the upper part of the Earth's crust of the Caucasus, one of the main structural and tectonic elements is its crystalline basement, which was formed by the processes of pre-Alpine tectono-magmatic cycles and in the modern structure represents a rigid basement for the thick, mainly Mesozoic-Cenozoic sedimentary, volcanogenic, and volcanogenic-sedimentary deposits.

Georgia is a part of the Caucasus, which represents a complicated polycyclic geological structure involving mountain fold systems of the Greater and Lesser Caucasus and adjacent foredeeps and intermountain troughs. Paleomagnetic and paleo kinematic, as well as traditional geological data (character of sedimentation and magmatism, geology and age of ophiolites, paleoclimatic and paleogeographic data), indicate that with a typical oceanic crust, which separates the Afro-Arabian and Eurasian continental plates, in the geological past relatively small continental or subcontinental plates (terranes) were situated, having diverse geodynamic nature and characterized by specific lithologic-stratigraphic section and magmatic, metamorphic, and structural features (Gamkrelidze, 1997). During the Late Precambrian, Paleozoic, and Early Mesozoic times, these terranes experienced horizontal displacement in different directions within the oceanic area of Proto-Paleo- and Mesotethys (Neotethys) and underwent mutual accretion and ultimately joined the Eurasian continent. In the Caucasian segment of the Mediterranean mobile belt, the Greater Caucasian, Black Sea-Central Transcaucasian, Baibut-Sevanian, and Iran-Afghanian terranes, which in geological past represented island arcs or microcontinents, are identified. In terms of modern basis, they represent accretionary terranes of the first order separated by trustworthy or supposed ophiolite sutures of different ages. Terranes of the first order, in their turn, consist of a great number of subterranes delimited as a rule by deep faults (Gamkrelidze, 1997).

The territory of Georgia covers the southern part of the Greater Caucasian terrane, the Black Sea-Central Transcaucasian terrane, and the northern part of the Baiburt-Sevanian terrane (Somkhito-Karabakh subterrane). Each of these units is characterized by distinctive rocks that were formed under different geodynamic conditions (Gamkrelidze & Shengelia, 2005).

Recently, using U-Pb LA-ICP-MS dating of zircons, the ages of their constituent metamorphites and granitoids have been established. In particular, within the exposed part of the Greater Caucasian terrane (in the Main Range zone of the Greater Caucasus) based on the study of the in situ zircons from metamorphozed and granitoid rocks the following figures were obtained: 1) 626±2 and 627±19 million years, which corresponds to the earliest – Cadomian (Late Precambrian) stage of regional metamorphism, 2) 461±5.3 million years and 457±12 million years, which corresponds to the Caledonian (late Early Paleozoic - early Late Paleozoic) stage of regional metamophism, 3) figures 454±9, 468±5 and 471.7±4.6 million years obtained for granitoid rocks corresponds to Caledonian tectogenesis, 4) figures: 312.5±4 and 317.0±8.3 million years correspond to regressive regional associated with Late Variscan (Late Paleozoic) tectogenesi,s and 5) figures: 309±8, 310.9, 325±4 Ma, 311±5.9 and 357±5.9 Ma, corresponding to the formation of synmetamorphic Late Variscan granitoids. These data are in good agreement with geological and petrological data for the Greater Caucasus (Gamkrelidze et al., 2020).

Within the exposed part of the Black Sea-Central Transcaucasian terrane – in the Dzirula crystalline massif, five genetic and age-types of zircons are distinguished: 1) detrital zircon >1200 Ma; 2) zircon formed presumably at the Grenville stage of regional metamorphism - 1000- 800 Ma; 3) zircon developed during the crystallization of quartz-diorite orthogneisses - 650-540 Ma (Baikalian stage); zircon 4) formed presumably during the crystallization of tonalite-granitic series - 530-500 Ma (Late Baikalian stage of regional metamorphism) and 5) zircon formed during the crystallization of Late Variscan granitoids and also under the impact of high-temperature fluids over pre-Late Variscan rocks – 330-310 Ma (Gamkrelidze et.al., 2011).

In the Khrami crystalline massif of the same terrane, the results of age determination of 26 zircon crystals from the Late Variscan potassic granitoids by U-Pb LA-ICP MS dating show the mean age 325.6±2.3 Ma covering the interval 319-332±6 Ma. Only in one case, in the crystal core, the hereditary age 931±6 Ma is determined, which presumably corresponds to the Grenville stage of regional metamorphism of the Neoproterozoic gneiss-migmatite complex (Tediashvili, 2013).

In the Loki crystalline massif of the Baiburt-Sevanian terrane (in the Somkhito-Karabakh subterrane), U-Pb zircon age of gneissose quartzdiorites is 370±59-35 Ma (Bartnitsky et al., 1992; Vashakidze, 1999; Vashakidze, 2000), but K-Ar age of granitoids is 327±6 Ma (Vashakidze, 2000; Dudauri et. al., 1999). These data confirm without a doubt that quartz diorites are pre-Late Variscan (Late Devonian) and granites are Late Variscan formations.

On the surface, rocks of the crystalline basement are exposed in the form of salients at different hypsometric levels (the central zone of uplift of the crystalline core of the Greater Caucasus 3500-5000 m (Fig. 2), Dzirula-1000 m, Loki, and Khrami 1200-1300 m massifs). In the rest of the territory, the crystalline basement is buried under thick Meso-Cenozoic sediments. According to the available literature data (Gudzhabidze & Gamkrelidze, 2009; Gamkrelidze et al., 2013), the crystalline basement is dissected by latitudinal, meridional, and diagonal faults, which create a picture of its mosaic-block structure. Its individual sections are located at different hypsometric levels, where the surface of the basement is located above sea level at a maximum altitude of 5000 m, and below this level it is maximum at a depth of 12000-14000 m (Fig. 3).

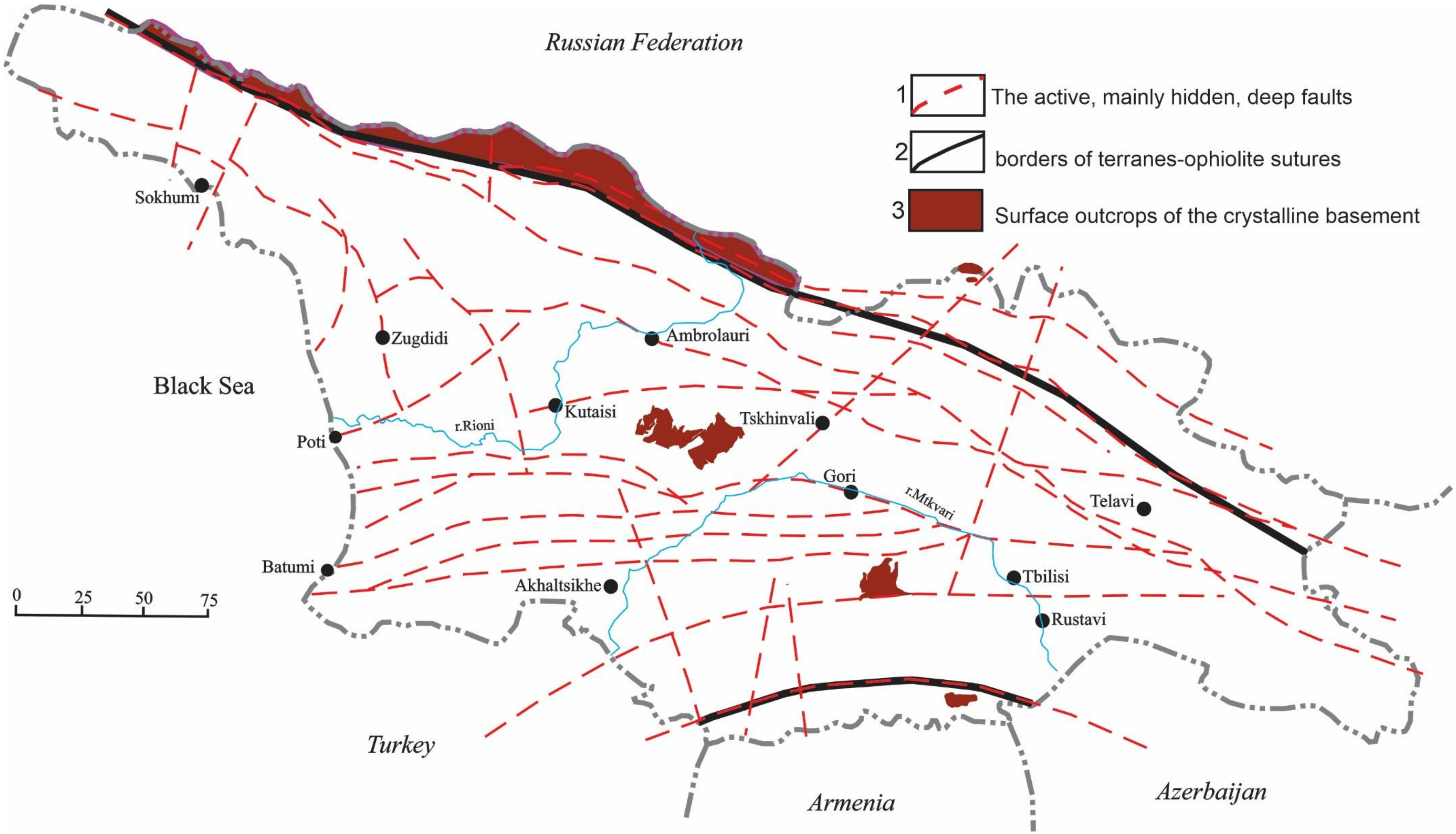

Figure.1. Active seismic faults of the territory of Georgia

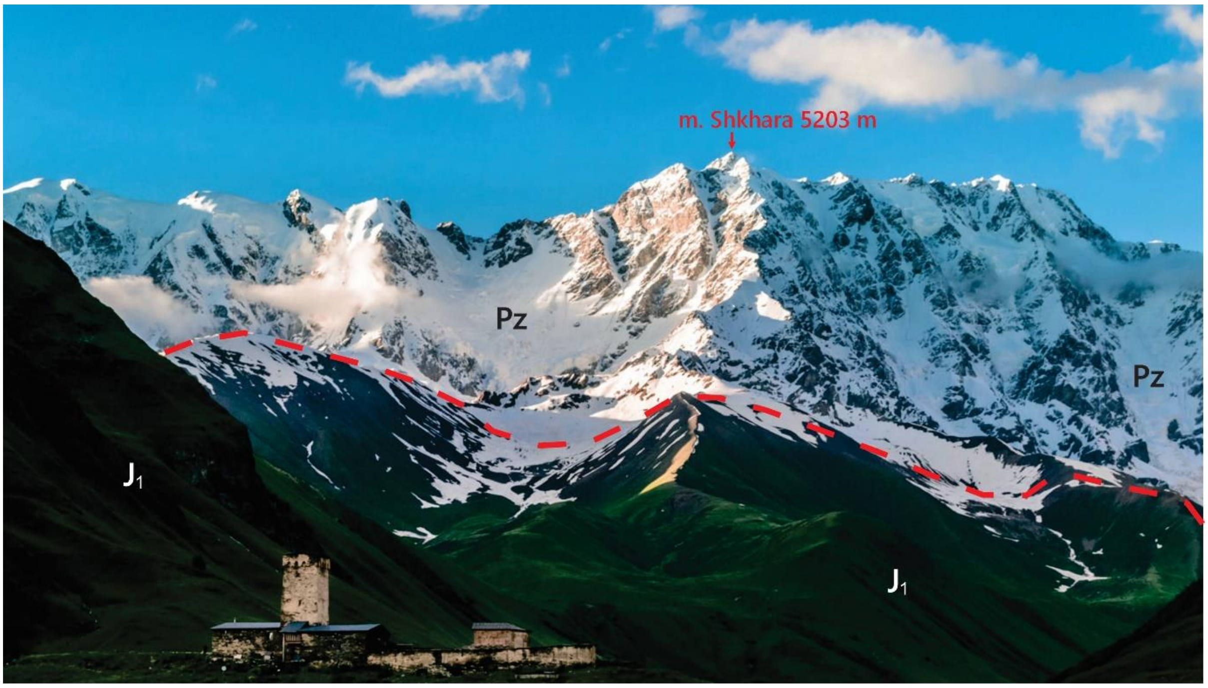

Figure.2. Pass subzone of the Greater Caucasus Main range zone - maximum uplift mark of crystalline substrate from the sea level. Dashed line indicates the Main Thrust zone.

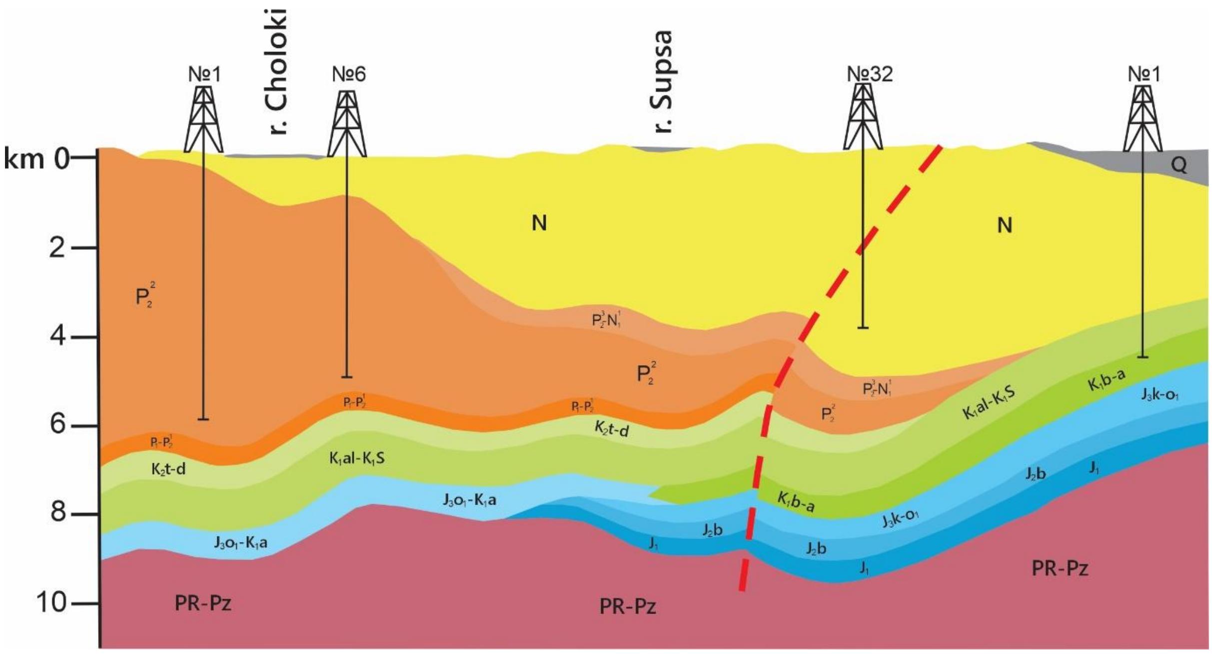

Figure. 3. Guria trough – one of the most subsided areas of the crystalline substrate – 9000 m [22]

Methodology for creating a model

To implement the 3D model, plasticine bars were taken as the main material, and after melting it into a pre-prepared container, a volumetric plasticine briquette with parameters 60 cm - 10 cm - 110 cm was obtained, where the upper horizontal surface corresponded to zero isohypsum, i.e., sea level. A tectonic map of Georgia was drawn on this surface at a scale of 1:500,000 (Gamkrelidze et al., 2013). Then, because of the analysis of numerous geological and geophysical profiles of the territory of Georgia, the modern morphology of the crystalline basement was reconstructed where below the zero isohypsum, part of the material that corresponded to the sedimentary cover was removed. Further, in some areas where the substrate rises above the zero isohypsum, it was necessary to complete the construction according to the existing geological and tectonic maps (Gudzhabidze & Gamkrelidze, 2009; Gamkrelidze et al., 2013) on which surface outcrops of crystalline rocks are recorded in the area of the Central uplift of the Main Range of the Greater Caucasus, Dzirula, Khrami, Loki, and Gveleti massifs. As a result, a picture of the modern morphology of the surface of the crystalline basement was obtained, the vertical scale of which corresponds to 1:200,000. Analyzing numerous literary data on geological and geophysical structure in the form of many profiles, unfortunately, we have to note significant discrepancies between some authors in the interpretation of data on the deep structure, which raises doubts about the choice of an optimally objective profile (Gamkrelidze et al., 2013a; Krasnopevtsova, 1966; Gamkrelidze, 1976; Terekhov, 1979; Basentsyan et al., 1981; Gamkrelidze, 1984; Yusupkhodzaev et al., 1986; Basheleishvili, 1987; Ioseliani et al., 1989; Philip et al., 1989; Banks et al., 1997; Nadareishvili, 2002; Pangani et al., 2003; Basheleishili & Kloshvili 2004; Kundadze et al., 2005; Gamkrelidze et al., 2013b, JMauvilly et al., 2016; Gusmeo et al., 2021; Mosar et. al., 2022; Gamkrelidze et. al., 2024; Cavazza, et al., 2024) We gave preference to those profiles that were compiled based on geological data. Lithological-sedimentary, stratigraphic, and thickness data

Morphostructure of the crystalline basement

The formation of the modern morphostructure of the crystalline basement within Georgia is largely determined by a fault network of latitudinal, meridional, and diagonal strike, covering different depths of the Earth's crust. Analysis of the lithofacies and thickness of the sedimentary cover developed within their boundaries indicates their autonomous and inversional nature of development. Subsequently, when constructing a model of the surface of the crystalline substrate, we removed the entire mass of the sedimentary cover (Fig. 4).

As is known, faults in the Earth's crust often change their character with depth and become gentler, representing thrusts and nappes. The model we constructed reflects the modern hypsometric position of the basement surface. The most elevated area is the area of the Main Range of the Greater Caucasus, from 2000 m to 5000 m. From the south, the marked structure is limited mainly by the Main Caucasian Thrust, the plane of which dips at an angle of 50-60. The total vertical amplitude of this thrust is more than 16 km and can be traced throughout the entire stretch. Only to the west of the city of Sokhumi does the amplitude decrease to 8-10 km. This thrust is the southern border of the Greater Caucasus terrane and the northern border of the Black Sea-Central Transcaucasian terrane. This kind of subsidence also appears further south, in the zone of the Gebi-Lagodekhi fault, where the depth of the basement subsidence is 10-12 km.

Within the Georgian block, the crystalline basement is also located at different hypsometric levels, but within its limits, meridional and submeridional faults predominate (Gudzhabidze & Gamkrelidze, 2009). Five blocks are distinguished in the western Colchis subsidence zone. Of these, the most submerged part (10-12 km) is in the Ochamchire-Kulevi block. In the eastern direction, the basement rises stepwise, and around the Dzirula salient, it reaches the surface at around +1000 m. Following to the east, within the Kura depression, the basement again sinks stepwise through listric faults (Basheleishvili 1993; Basheleishvili, 1999), and around the Middle Kura depression (in the Dedoplistskaro area) it plunges to a maximum depth of 12-14 km.

Within the Adjara-Trialeti zone, the basement is quite dissected. This is especially clearly expressed in the latitudinal structures, but at the same time, a meridional zonality emerges (Gamkrelidze, 1976). Its western and eastern parts are immersed at the lowest levels (12-14 km), and the central part rises to zero value, and above this area within the Adjara-Trialeti corresponds to the Transcaucasian transverse elevation of the northwestern strike. This refers to the Trialeti Cordillera or the Peli–Uriuli uplift.

The crystalline basement within the Javakheti highlands is located higher, where, in addition to the surface outcrops of the Loki and Khrami massifs, at an altitude of 1200-1300 m above sea level, a dive of up to 3000-4000 m is noted.

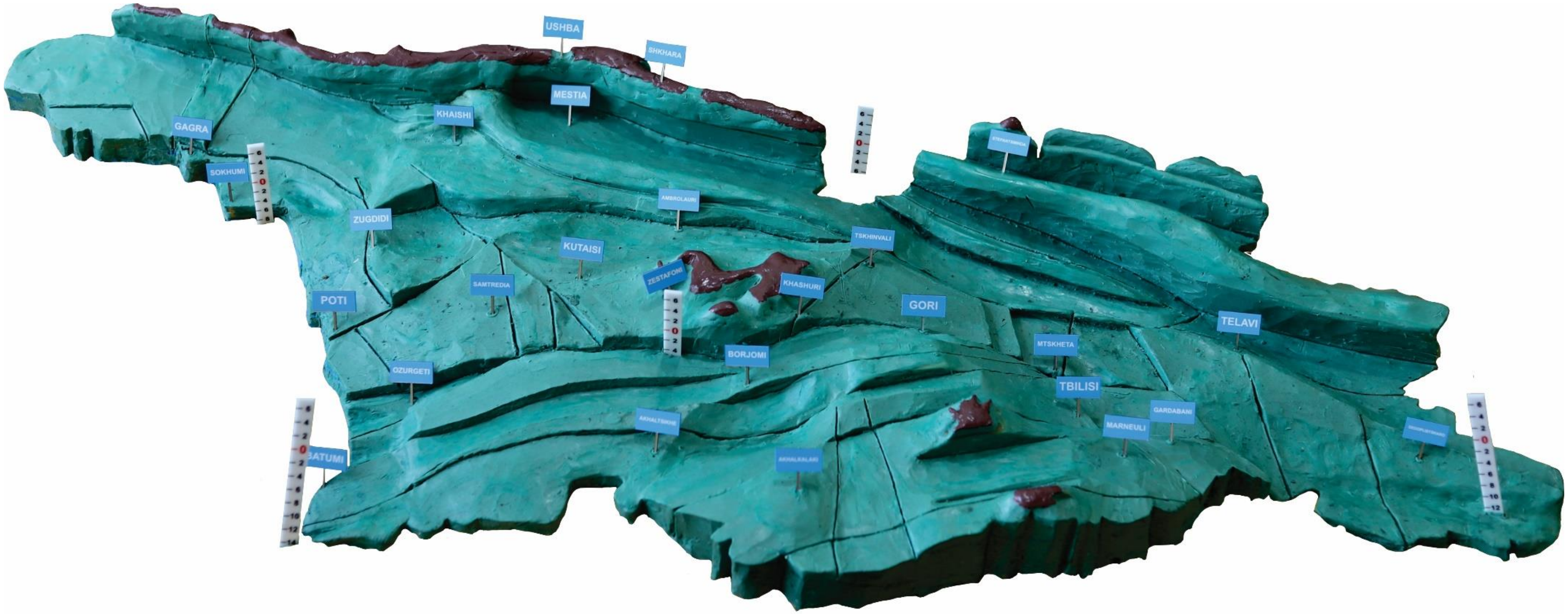

Figure. 4. 3D Model of Morphostructure of the Crystalline Basement within Georgia (plasticine); Scale: horizontal 1: 500000, vertical 1:200 000

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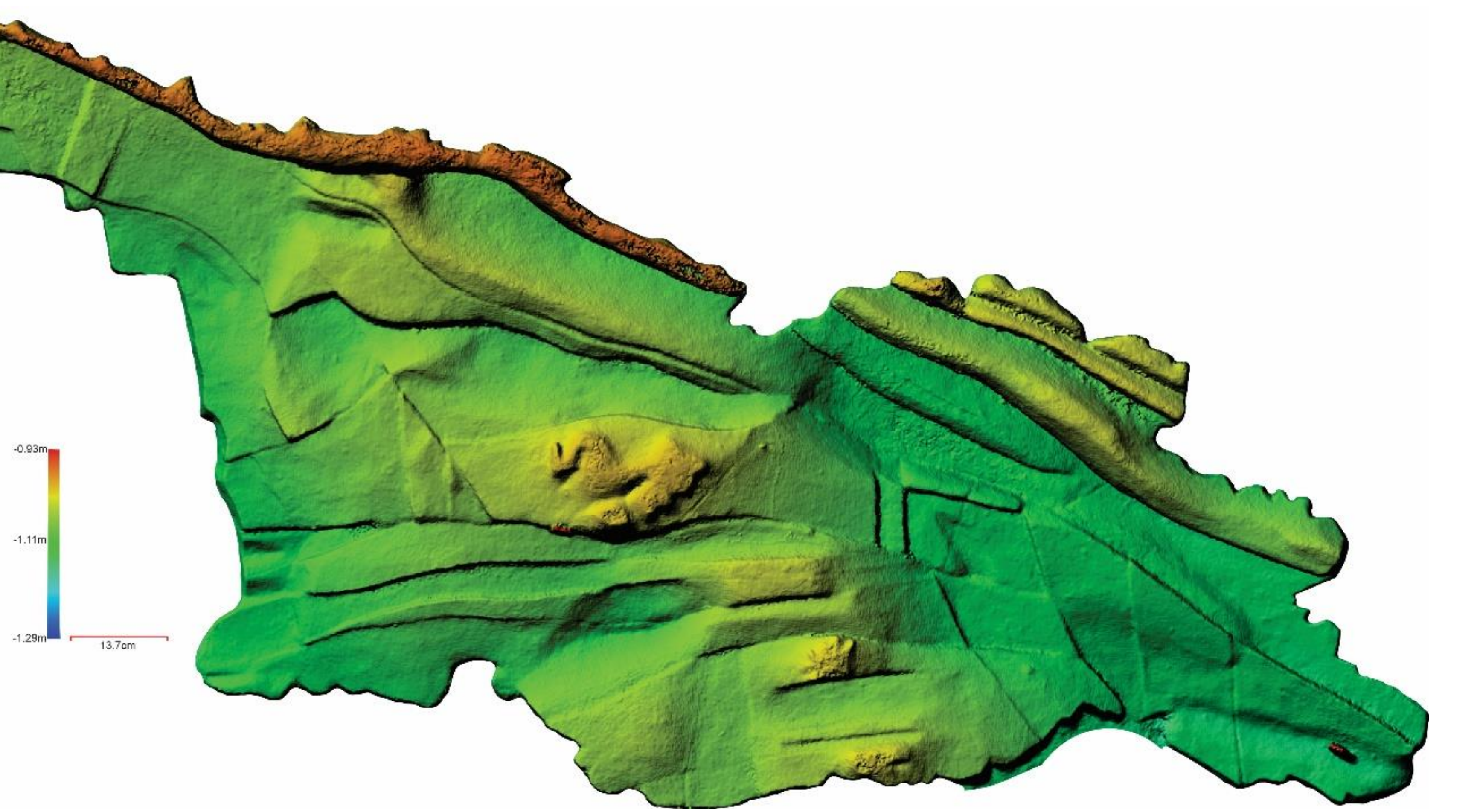

Figure. 5. 3D Model of Morphostructure of the Crystalline Basement within Georgia

Conclusion

Thus, for the first time for Georgia and the region, a plasticine model of the morphotectonics of the crystalline basement was created on a horizontal scale of 1:500,000 and a vertical scale of 1:200,000, which contributed to a clear visualization of the morphostructure of one of the main structural-tectonic elements of the upper part of the Caucasus crust within Georgia. The technique for reproducing the plasticine model of the morphology of the relief of a crystalline basement consists of removing the mass of plasticine that corresponded to a thick sedimentary cover below the zero mark and, above this mark, on the contrary, building up to the required height. As a result, the resulting model clearly shows the modern picture of the morphology of the relief of the crystalline basement and its mosaic-block structure.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

L.B., G. B., and B.G. contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

Acknowledgements

The authors would like to thank Mrs. Tamar Tsutsunava, director of the Alexandre Janelidze Institute of Geology, for the financial support of the work.

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Assessment of the stability of some landslide bodies in Georgia using a numerical-analytical approach

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Georgian Geographical Journal, 2024, 4(2) 14-21

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Japaridze, L.; Chikhradze, N.; Akhvlediani, T.; Gobedzhishvili, T. Assessment of the stability of some landslide bodies in Georgia using a numerical-analytical approach. *Georgian Geographical Journal* 2024, 4(2). 14-21 https://doi.org/10.52340/ggj.2024.04.02.02

Abstract

Numerical-analytical methods of stability of consequential, block-flexure and creep-plastic landslide-prone slopes are being developed at the G.Tsulukidze Mining Institute. These methods have been used: to determine the degree of stability of the landslide-prone blocks remaining after the 2015 landslides in Tskneti-Samadlo, to calculate the stability of the landslide bodies of M. Machavariani and Sheshelidze Streets in Tbilisi, and then - to develop their strengthening projects together with the specialists of the German-Bavarian Bureau of Engineering Geology and the construction company CRP.

Keywords: numerical-analytical method; stability of consequential block-flexure and creep-plastic slopes.

Introduction

The history of calculating the stability of landslide-prone slopes dates back 250 years. To date, more than 5000 articles or monographs have been published. Most of them are simplified methods for calculating the stability of landslide bodies of assequental and consequental (fig.1, a) type, i.e. without stratification and sliding on stratification planes. In their calculation schemes, the landslide body is divided into vertical blocks, the stability coefficients of the individual block and then of the entire landslide body are determined by solving systems of equations with many unknowns under simplified assumptions. The weaknesses of this type of methods were noted by the authors themselves (Janbu, Bishop and others). Their critical analysis is also given, for example, in (Stability Modelling with SLOPE/W 2012). These shortcomings remain in a number of recently created computer programs (for example, "Rocscience" Slide 2, Slide 3, Slide 6 and others), which are specially designed for landslides and do not consider the stress-deformed state analysis of the landslide body.

In contrast to asequential and consequental, the first papers on the stability of block-flexure (Fig.1, b) landslides have appeared in recent years, and the first steps are still being taken to develop their stability calculation methods.

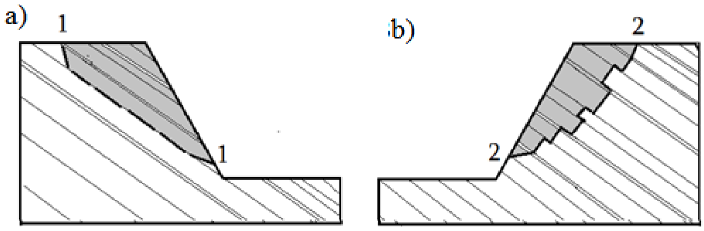

Figure 1. Schematic images of a) consequental and b) block-flexure landslides

Estimating the stability of block-flexure landslide bodies is much more difficult and calculation methods are less compared to consequential ones. As early as 1976, R. Goodman and J. Bray (Goodman & Bray1976) wrote that "our knowledge of this type of phenomena is still in its infancy". They compiled possible calculation schemes and identified the forms of collapse: flexural toppling, block toppling, block-flexural toppling (Goodman & Bray 1976), whose corresponding calculation methods are still in the study and development stage (Amini et. al., 2008).

In the vast majority of the methods developed for the study of landslide events, the stability of the slope is evaluated under the conditions of limit equilibrium, Coulomb-Moir and similar strength theories, and the influence of the time factor can only be reflected indirectly, according to the studies of recent years, through the limit values of the rock adhesion and the internal friction coefficient, i.e. the strength indicators, at the expense of degradation. This was called the "Shear Strength Reduction Factor" and its use in conjunction with the "Finite Element Technique method new era in the theory of landslide stability calculation (Rocscience, 2004).

Consideration of the "shear strength reduction factor" is very important when calculating the stability of block-type slide bodies that maintain a completely stable state for a long time and suddenly lose their stable equilibrium as a result of extreme meteorological challenge or other effects. Until then, long-term monitoring of such landslide-prone slopes may not show any significant rock movement.

In contrast, creep plastic deformation is more rheological in nature. Depending on the intensity of the active forces acting in a particular scheme and the mechanical parameters of the massif, creep deformation can occur very rapidly or very slowly, in periods ranging from a few hours to a hundred years. It is not only the strength (stress, angle of internal friction) but also the deformation characteristics (modulus of elasticity, creep parameters, etc.) of the rock that should be most characteristic. These can be determined by laboratory testing of samples of geological material and/or by processing images obtained from preliminary monitoring. "Natural analysis method (back analysis). The means for its full use will be created after the creation and improvement of the apparatus for the direct analysis of self-creeping plastic landslides. In all these directions, the development of methods for calculating the stability of landslide bodies and anchored constructions is a scientific and technical problem of international level.

Methods and Materials

The numerical-analytical version of the method for assessing and calculating the stability of landslide bodies, both unstratified and consequential, was developed at the G. Tsulukidze Mining Institute. This was done by combining a stress analysis apparatus and computer programs, in particular Phase2, developed by Rocscience not for landslide problems. Unlike existing methods, this version makes it possible to simulate design schemes of various forms of possible collapse of landslide bodies, based on an analysis of the stress-strain state of both an unstratified and a consequent structure; the necessary measures to ensure its stability under normal and extreme conditions under the influence of gravitational and seismic forces must be calculated.

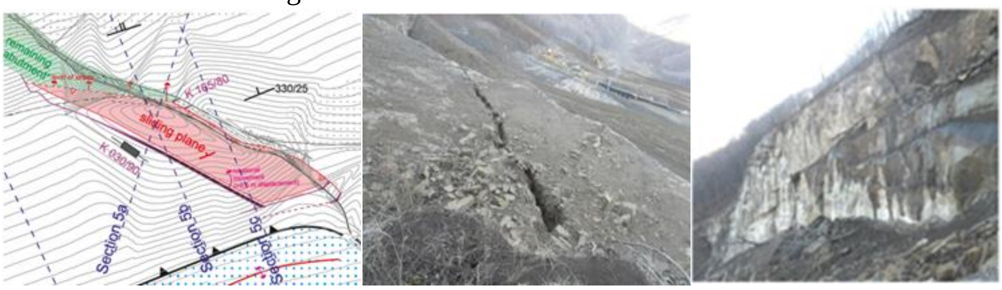

Figure 2. The topographic plan, top view and a section of remained rock block - "Southern Cliff".

The computerised numerical-analytical method for determining the stability of landslide-prone blocks was used to ensure the safety of the remaining blocks after the 2015 landslide events in Tskneti-Samadlo and is described in (Japaridze et. al. 2020). Situation images of one example of them are shown in Fig. 2. Using the calculation diagram and the Rocscience Phase2 computer program, horizontal (XX), vertical (YY) and shear (XY) stresses caused by gravitational and seismic forces were determined. The corresponding polychromes of vertical and shear stresses are shown in Fig. 3.

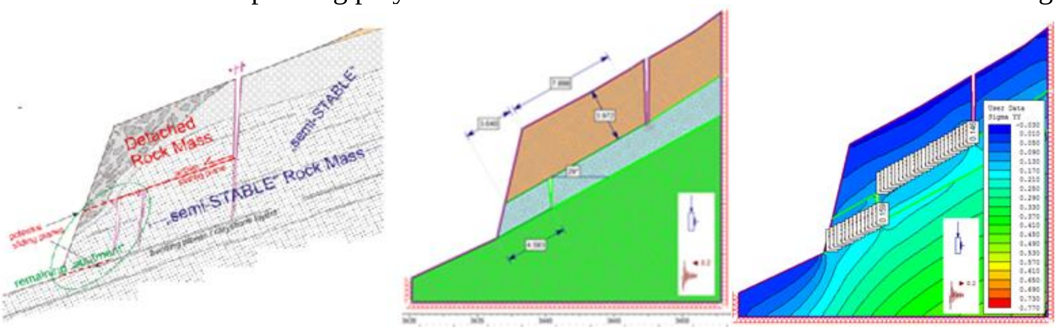

Figure 3. Finite element model of the "upper cliff" of the 2015 large landslide of Tskneti-Samadlo

The values of engineering geological elements, cohesion (c) and angle of internal friction (φ) for the sliding surfaces of the blocks were determined by preliminary exploration studies (Table 1).

Table 1. The values of engineering geological elements for the sliding surfaces

Type of discontinuity Sliding plane	Filling	Cohesion c' [MN/m^2]	Friction φ [o]
Slickenside (normal fault)	Locally fault gouge	0	15-20
Join (rough, medium transection)	Locally clay/silt	(0.005)	28
Bedding plane in claystone	-	0.05	22.5
Bedding plane in strongly weathered claystone/clay	-	0.01	20

Using Rocscience Phase2, the values of horizontal (XX), vertical (YY) and tangential (XY) stresses at 30 points of the potential slip planes were determined and entered into Excel Table 2. At the same points on the slip planes with an angle of θ, the normal N and shear T stresses are calculated according to the following relationships:

$$N = 0.5(XX + YY) + 0.5(XX - YY)cos2\theta + XYsin2\theta \qquad (1)$$

$$T = 0.5(YY - XX)\, sin2\theta + XY\, cos\, 2\theta \qquad (2)$$

where θ is the angle from the positive direction of the x axis to the plane on which the stresses (1), (2) are determined.

By inserting them and the rock cohesion C and the coefficient of internal friction φ on the sliding surface into the Coulomb-Maure limit equilibrium formula (3), stability is estimated at each (30) point and then over the entire area of the slope under normal and extreme conditions.

$$[T] = C + Ntg\varphi \geq T \qquad (3)$$

The values of the holding stresses [T] are entered into the Excel 2 table and the safety factors are calculated at the points of the potential slip surface (Fig. 3). For the given natural conditions C = 50 kPa, φ = 22.50, θ = 190, the total safety factor is SF = 6,07 and stability is maintained by a large margin.

Table 2. Excel table for determining safety factors at potential sliding surface points

№	XX kPa	YY kPa	XY kPa	N kPa	T kPa	[T] kPa	SF
1	1.3	95.4	12.1	19	4.9	15	2.97
2	0.9	92.5	10.8	17	5.0	15	2.90
3	0.6	86.9	9.3	15	4.9	14	2.93
4	1.0	76.9	9.6	15	4.0	14	3.56
5	5.8	66.9	20.7	25	0.6	15	23.93
-	-	-	-	-	-	-	-
26	1.3	95.4	12.1	19	4.9	15	2.97
27	0.9	92.5	10.8	17	5.0	15	2.90
28	0.6	86.9	9.3	15	4.9	14	2.93
29	1.0	76.9	9.6	15	4.0	14	3.56
30	5.8	66.9	20.7	25	0.6	15	23.93

Due to the possible reduction of the rock strength characteristics in extreme conditions, the results of the calculation for the reduced rock shear strength indicators obtained as a result of additional investigations by the specialists of the Bavarian State Office for Engineering Geology are given in Table 3, from which it can be seen that with zero cohesion (c=0) and the coefficient of internal friction φ=150. In this case, the safety factor is less than one (SF=0.88), i.e. the slope will not be stable. Appropriate geotechnical measures were therefore recommended.

Table 3. Safety factors due to a possible reduction in the strength characteristics of rocks

Cohesion C, kPa	Internal friction φ, (0)	Safety Factor SF

50	22.5	6.07
10	20	2.13
0	15	0.88

The proposed numerical-analytical approach for calculating the stability of a block-flexure landslide-prone slope, whose finite element model is shown in Fig. 4, reflects the block-flexural toppling mechanism much more accurately than the current kinematic schemes of Goodman and Bray (Goodman & Bray 1976). Analytical and numerical methods have been developed. It differs substantially from the special computer program "RocTopple 1.0" recently developed by the company "Rockscience", which literally repeats the idealised calculation scheme of Goodman and Bray with very important simplifications and assumptions about the stiffness of the blocks, the equal thickness of the layers and their stability shapes. As an example of non-sequential landslides, we considered the landslide-prone areas on the slopes of the orographically left bank of the Vere River on the Chabua Amirejibi road. The stability coefficient of one of the slopes against gravitational and seismic loads was determined (SF=16.5).

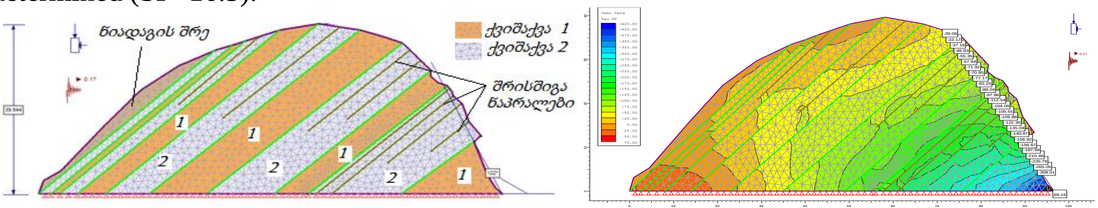

Figure 4. Finite element model of block-flexure slope on Chabua Amirejibi Street

In a large number of mechanical models describing landslide phenomena, rock masses are considered from the point of view of solid body mechanics. The stability of slopes is assessed under the conditions of limit equilibrium, the Coulomb-Moire theory and similar strength theories. Research in recent years has shown that the influence of the time factor can only be reflected indirectly in these methods by reducing the limit values for rock adhesion and the coefficient of internal friction, i.e. strength indicators. This has been termed the "shear strength reduction factor" and its use in combination with the finite element method has been described as "a new era in landslide stability analysis" (Stability Modelling with SLOPE/W, 2012).

Consideration of the 'sliding strength reduction factor' is very important when calculating the stability of block-type consequential and non-stratified landslide bodies, which maintain a stable state for a long time and then suddenly lose equilibrium as a result of extreme meteorological or other effects. Until then, long-term mini-tours of this type of landslide-prone slope may show no significant rock movement.

Creep-plastic deformations occur practically everywhere in rock massifs, and depending on the intensity of the active shear stresses acting in a particular scheme and the mechanical parameters of the massif, creep deformations can develop very rapidly or extremely slowly, in periods ranging from a few hours to hundreds of years. Active compressive stresses are mainly those caused by the gravitational forces acting in the rock mass. As far as the mechanical parameters of the massif are concerned, the most characteristic are not only the strength (density, angle of internal friction), but also the deformation characteristics of the rocks: modulus of elasticity, creep parameters. These can be determined by laboratory analysis of samples of geological material taken from the likely landslide-prone slope and/or by processing the image obtained by preliminary monitoring. using the "natural-analytical", i.e. reverse analysis (back analyse) method (Japaridze,1987). It should be noted that the means for the full use of the latter will be created in the wake of the creation and improvement of the direct analysis apparatus for creep-plastic landslides, which is still a current problem.

It is difficult to assess the stability of creep-plastic landslide bodies in terms of completeness, accuracy and practical possibility of taking into account the factors, and there are practically no calculation methods. Therefore, the modern stage of development of mining massif rheology can be considered only the beginning, when the primary stock of information, ideas, methods and results has been accumulated, but the main researches and practical application of their results are still ahead.

In this case, a study on the stability assessment of creep-plastic landslide slopes was considered in order to develop a calculation method which, unlike the method for calculating the stability of a block-type landslide body, should take into account the elastic-plastic and rheological deformations occurring continuously in the massif containing metamorphic clay rocks and the time factor. This problem is important and relevant both theoretically and practically in general, and also because there are geological formations in many places in Georgia where we have "creep-plastic" landslide-prone places. Local or large-scale landslides of this type are to be expected in areas with hilly terrain (Ministry of Environmental Protection and Agriculture of Georgia 2019) if, under the conditions of intensification of infrastructure construction, special attention is not paid to their prevention even at the early stage of design.

At present it is possible to determine the functions representing the displacement of the points of the array, to assess the stress-strain state of geotechnical objects taking into account creep, if the analytical solution of the task within the theory of elasticity is known. Such tasks include underground structures, namely tunnels, which can be mathematically modelled, for example, using the methods of complex potentials of N. Muskhelishvili. However, it is very difficult to do the same when assessing the stability of slopes prone to landslides.

The use of finite element methods in a limit equilibrium framework to analyse the stability of geotechnical structures is a significant step forward and has many advantages:

- It is no longer necessary to make assumptions about internal stresses (between prisms);
- The stability factor is determined after the stresses have been calculated, so there are no iterative convergence problems;
- The problem of mobility compatibility is solved;
- Calculated stresses are closer to reality;
- Stress concentrations are considered indirectly in the stability analysis;
- Dynamic stresses resulting from an earthquake can be considered directly under stability conditions.

Thus, the finite element approach overcomes many of the limitations inherent in limit equilibrium methods. The tools needed to perform stability analysis of geotechnical structures based on stresses calculated by the finite element method are available today, but they also have some weaknesses, and unforeseen problems may arise in the future. Such problems are currently the subject of research and will be solved over time as the method is increasingly used in geotechnical practice (Stability Modelling with SLOPE/W, 2012).

Due to the great practical importance of the task and the theoretical difficulties of a strict solution, the modelling of the creep-plastic landslide body can also be considered as a so-called "variable module" (Nicholson et. al. 1990; Technical Manual for Design and Construction of Road Tunnels, 2009)

The results of the research were used in the creep-plastic landslide reinforcement project of Tbilisi's Vashlijvari district, prepared by Caucasus Road Project LLC and the Bavarian Office of Engineering Geology, whose plan and section C-C as of the beginning of March 2021 is shown in Fig. 5.

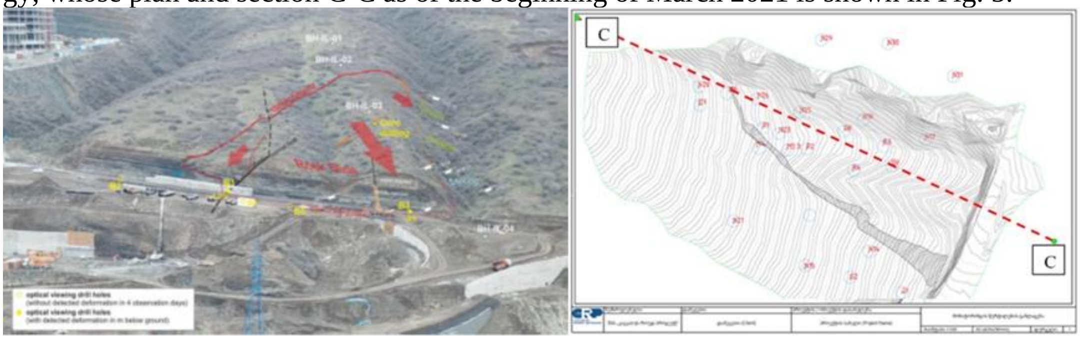

Figure 5. Top view and plan of "Vashlijvari Landslide" with observation points

To detect morphological changes in the landslide area, scientists from the University of Vienna carried out observations and satellite measurements using the Sentinel satellite's Interferometric Synthetic Aperture Radar (InSAR). Observation points were placed on the landslide body and beyond (Fig. 5). The displacements of the geodetic markers in the direction of the landslide were recorded for 100 days.

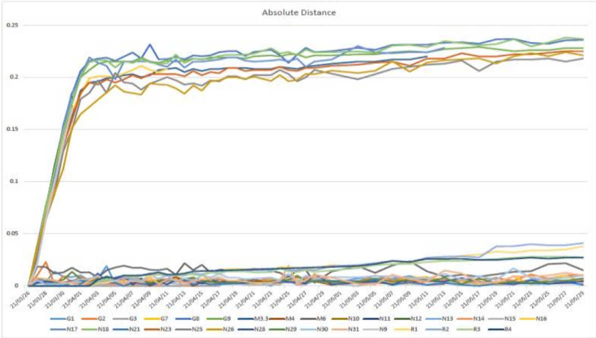

Figure 6. Movements of observational geodetic markers in the direction of the landslide

The displacements caused by the gravitational forces of the observational geodetic markers shown in Fig. 6 make it possible to determine the creep parameters of the entire landslide body massif using the proposed natural-analytical method, the so-called use of time-varying modules.

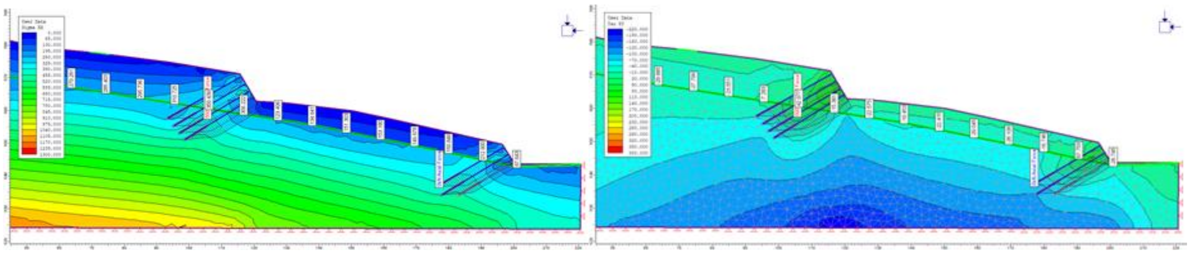

Figure 7. Polychromy of stresses XX and XY acting in the CC plane when anchors are placed at two levels

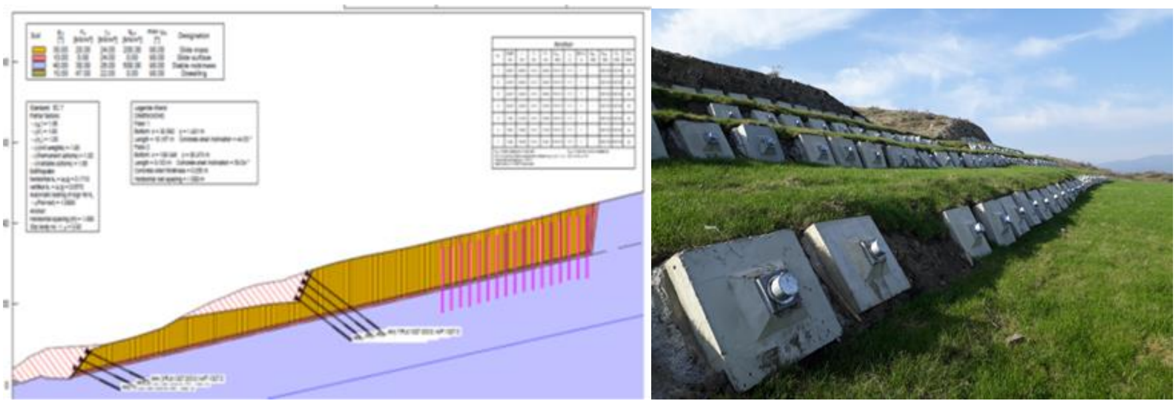

Figure 8. Project of anchor reinforcement of the Vashlijvari landslide slope and its fragment

These data, obtained by the natural analytical method carried out on the landslide body of M. Machavariani Street, were used for the calculation of the stability of the landslide body, for the preparation of the strengthening project (Fig. 7, Fig. 8) and its implementation.

Results

1. The original numerical-analytical version of the method for assessing and calculating the stability of landslide bodies, both unstratified and consequential, was developed. Unlike existing methods, this version makes it possible to simulate design schemes of various forms of possible collapse of landslide bodies, based on an analysis of the stress-strain state under the influence of gravitational and seismic forces;

2. Proposed numerical-analytical approach for calculating the stability of a block-flexure landslide-prone slope reflects the toppling mechanism much more accurately than the current kinematic schemes. As an example of non-sequential landslides, landslide-prone areas on the slopes of the orographically left bank of the Vere River were considered.

3. Morphological changes and displacements of geodetic marks in the direction of a creeping-plastic landslide body in the Vashlijvari region of Tbilisi were established together with scientists from the University of Vienna using the interferometric synthetic aperture radar (InSAR) of the Sentinel satellite. These data were used to calculate the stability of the landslide body using the natural-analytical method, to prepare a project for strengthening the slope and its implementation.

Conclusion

When checking the condition of stability of landslide-prone slopes and calculating their Safety Factor (SF), the rock mass should be characterised by its long-term shear strength and full deformation expected in all parts of the sliding plane. In cases where the laboratory study of the engineering-geological material of the object as a result of practically instantaneous tests gives indicators of the peak strength of the rocks, the stability condition cannot be lower than the ratio of the immediate and long-term strength;

It is well known that the rock mass passes through different stages of deformation before collapsing and undergoes significant plastic deformations, the magnitude of which depends on lithology, density, moisture, liquefaction during seismic impact and many other indicators. All the rocks that make up the stratified massif and that participate in the landslide event are characterised by different deformation properties. Therefore, even if they undergo almost the same deformation at each moment, the stresses acting on them are different. In the less plastic layer, the shear deformation stresses reach the limit, while in the more plastic layer they are still far from the limit. The magnitude of the resistance to slope displacement is not equal to the sum of the resistances of the individual layers at any stage of deformation;

The value of the creep-plastic landslide stability coefficient depends not only on the Coulomb-Mohr strength characteristics, but also on the deformation parameters of the rocks in general, including the creep characteristics;

The treatment of displacements caused by the gravitational forces of observational geodetic marks by the proposed "natural-analytical method" compared to the cylindrical dilatometric method indicated in the normative documents of the Eurocodes, provides a better opportunity to determine the equivalent creep parameters of the entire landslide body array.

Due to the great practical importance of the task and the theoretical difficulties of a strict solution, the possibility of modelling a creep-plastic landslide body should be studied by the so-called Using the idea of a "variable module". In this case, it is necessary to consider the proposal and development of the "Shear Modulus Reduction" factor similar to the already established "Shear Strength Reduction" factor;

The value of the creep-plastic landslide stability coefficient depends not only on the Coulomb-Mohr strength characteristics, but also on the deformation parameters of the rocks in general, including the creep characteristics;

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Due to the great practical importance of the task and the theoretical difficulties of a strict solution, the possibility of modelling a creep-plastic landslide body using the so-called "variable modulus" idea should be studied. In this case, it is necessary to consider the proposal and development of the "shear modulus reduction" factor, similar to the already established "shear strength reduction" factor; geological investigation of a specific landslide-prone site, together with other rock parameters, "natural-analytical" and/or laboratory methods should determine rock creep parameters, or in extreme cases - peak and residual deformation modulus. The quantities are as required, for example, in the "Material Properties" table of the Phase 2.7 program. It should also be noted that the magnitude of the "time-varying modulus" of deformation depends on the stress-strain state of a particular rock mass, i.e. on the overall calculation scheme of the geotechnical situation. Similarly, the creep characteristics will not be invariant to stress, since their curves reflect the evolution of both creep and creep-plastic deformation over time.

The proposed natural-analytical method has been used: to determine the degree of stability of the landslide-prone blocks remaining after the 2015 landslides in Tskneti-Samadlo; St. to calculate the stability of the landslide bodies of M. Machavariani and Sheshelidze Streets in Tbilisi, and then - to develop their strengthening projects together with the specialists of the German-Bavarian Bureau of Engineering Geology and the construction company CRP.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

L. J. conceived of the presented idea and performed the numerical-analytical calculations, N. C. conceived of the presented idea, T. A. provided critical analysis, T. G. provided critical analysis and performed the analytic calculations.

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Development History of the Migaria Massif Karst Terrain

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Georgian Geographical Journal, 2024, 4(2) 22-29

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Lezhava, Z.; Tsikarishvili, K.; Bolashvili, N.; Tolordava, T.; Avkopashvili, I.; Gaprindashvili, G.; Kumladze, R.; Nosenko, A.; Chikhradze, N.; Asanidze, L. Development History of the Migaria Massif Karst Terrain. *Georgian Geographical Journal* 2024, 4(2). 22-29
https://doi.org/10.52340/ggj.2024.04.02.03

Abstract

On the basis of many years of field, experimental and laboratory (dye tracing, laboratory study of bedrocks, data analysis of geological sections, etc.) studies and analysis of available literary sources, the history of karst terrain development was restored on the Migaria limestone massif. Based on the mentioned materials, it can be said that the karstification on the Migaria limestone massif took place throughout the Pliocene and partially in the Upper Miocene, and therefore, the beginning of the formation of the karst terrain can be considered the entire Pliocene and possibly the Upper Miocene as well. The Rhodanian orogeny phase (after the Middle Pliocene, during the Cuialnic era), which was continued into the Wallachian orophase, led to a new uplift of the Caucasus, followed by the activation of karst processes on the surface and underground. New orogenic movements of the Early Pleistocene enhanced the splitting of limestone suites and the activity of karst formation processes. The same period should be related to the formation of caves (Shurubumu, Koko, Khuru, etc.) developed in the gorges of the rivers of Khobistskali, Ochkhomuri and their tributaries, namely, the transition from the phreatic to the vadose period and their further development. Thus, it can be said that the formation of the karst cavities of the Migaria massif occurred mainly before the Pleistocene or in the Lower Pleistocene. In the post-glacial period, along with karst processes, rockfalls, landslides, and mudflows played an important role in the change of the terrain of the study area, as indicated by the displaced boulders of volcanic origin of the Bajocian age (tuff sandstone) distributed in the gorges of the Khobistskali River and its tributaries, as well as on the terrace steps and verified by our laboratory tests. The bedrocks are found in the upper reaches of the Khobistskali River and thay are brought as a result of powerful landslide-mudflow processes. In the last stage of the modern geomorphological cycle, surface and underground karst forms are actively modified by the flows of melted snow and rain water.

Keywords: Karst, Cave, Limestone massif, Georgia

Introduction

Georgia is a mountainous country located in the Caucasus region, between Russia, Turkey, Armenia, and Azerbaijan. As found in many countries in the world, Georgia is home to multiple, widespread karst massifs with well-developed karst areas and their associated landforms (Asanidze et al., 2017a; Asanidze et al., 2019; Lezhava et al., 2020; Lezhava et al., 2021). Different types of karst and pseudokarst features exist in abundance, due to the tectonic influences, nature of the bedrock, geologic structure, and hydrological complexity of the area (Tintilozov, 1976; Maruashvili, 1971).

The Migaria limestone massif is part of the medium and high mountain karst in western Georgia (Tintilozov, 1976; Lezhava et al., 2022). It is on the southern slope of the Samegrelo (Egrisi) range, between the Khobistskali and Tekhuri river gorges (Maruashvili, 1964; Gergedava, 1968; Gergedava, 1989; Tatashidze et al., 2009; Bolashvili et al., 2017; Asanidze et al., 2019; Lezhava et al., 2022).

Administratively, the massif is located within the limits of Chkhorotsku and Martvili municipalities (Fig. 1).

Figure 1. Location of the Migaria massif on the general map of Georgia

The massif is separated from other areas by deep gorges: in the north and west it is represented by the gorge of the Khobistskali River, and to the east by the gorge of the Tekhuri River; to the south it borders the wide depression of the Ochkhomuri River, the left tributary of the Khobisskali River. The maximum stretch of territory within the mentioned borders is 17 km from west to east, and it reaches 6-7 km from north to south. The massif covers a surface area of approximately 100 km^2, with karst phenomena developing on an area of about 62 km^2.

The crest of the massif reaches its maximum height in the east (2025 m. - Peak Migaria; 1980 m. - Peak Jvari) and gradually lowers to the west, in the direction of Otsindale village, up to 650 m. These peaks are separated by deep saddle-like recesses. The northern slope of the massif, which descends into the valleys of Khobistskali and its left tributary, is characterized by steep cliffs.

To the west of Peak Jvari, the massif's tectonic zone is made up of two anticlinal hills that are parallel to each other. These hills surround a system of unfilled hollows that have formed in a synclinal structure that is 8 km long and 3 km wide (Maruashvili, 1964).

As a result, a big part of the Migaria massif is made up of a synclinal structure. In the middle of this structure is a closed basin made mostly of Barremian rocks. Their lowest points are located at a height of 900-1000 m above sea level and are represented by sinkholes, ponors, and underground forms (mainly, wells and shafts). The hollow divides into several secondary hollows, each with its own karst genesis. Among them, the Tsipuria hollow is notable for its size (length 5.5-6 km, width 2.5 km) and it occupies the western part of the unified hollow. We refer to the system of single hollows mentioned above as the Tsipuria hollow. It is much smaller than the Tsipuria hollow and is located northwest of the Tsipuria basin. It is made up of Barremian (Urgonian facies) limestones and is closed off from the Tsipuria basin (Fig. 2).

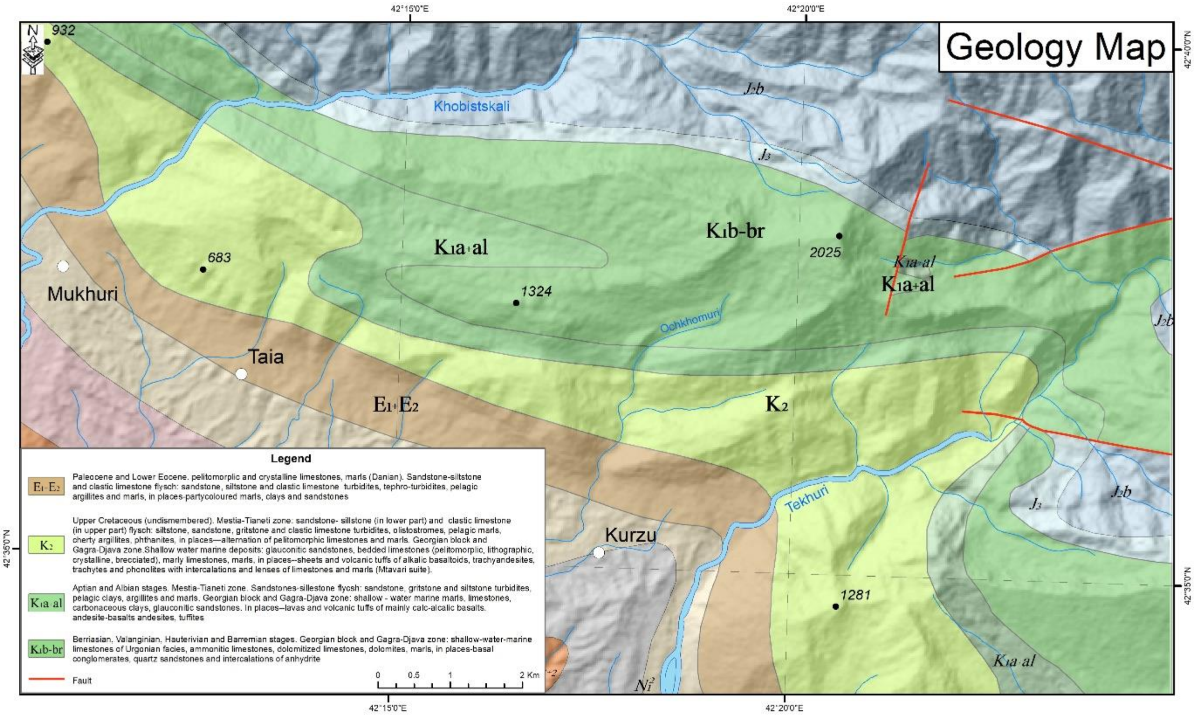

Figure 2. Geology of the Migaria limestone massif (Gudjabidze, 2003)

The hill of the monoclinic structure is on the southern slope of the Migaria massif. It is connected to and sticks to the Tsipuria synclinal core, which is made of Urgonian facies (Barremian) rocks from the Migaria massif (Maruashvili, 1963; Maruashvili, 1973; Gorzohon et al., 2004; Lezhava et al., 2015; Lezhava et al., 2022). It is built with Upper Cretaceous and Paleocene-Eocene limestones, and from west to east, its height increases from 1000 m to 1200-1300 m. The mentioned hill is separated from the high syncline massif by dry ravines and uvalas and is fragmented by the gorges of the Ochkhomuri River and its tributaries (Atamana, Vau, Khuru, etc.) (Fig. 3).

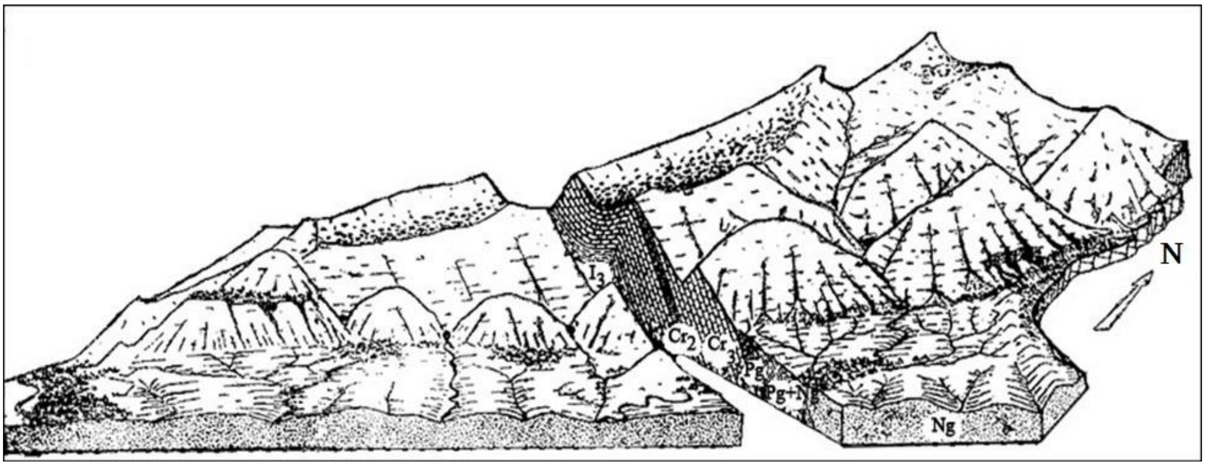

Figure 3. Block diagram of the Migaria limestone massif (Tabidze, 1966)

There are many karst sinkholes in the Tsipuria synclinal hollow, on the anticlinal hills that surround it, and on the tops of Migaria and Jvari peaks. There are also Corrie surfaces to be found. With its high energy level (2000 m) and other helpful factors, the terrain supports the active flow of karst processes. This creates caves, wells, shafts, and abysses underground in the core of the massif. The theoretical depth of massif karstification and penetration here is 1500-1600 m.

Methods and Materials

The work employs field, experimental, and laboratory research methods. In the research process, the study of existing cartographic and geological material was carried out as well as the field geomorphological and karst-speleological large-scale survey of the territory. In order to study the terrain and identify the karst features, an unmanned aerial vehicle (Phantom 4) was used. We identified the composition of the displaced boulder by laboratory examination of its fragment sample, which allowed us to identifie the place of the boulder's break off and, accordingly, the distance of its displacement. We identified the movement routes of underground karst waters and discharge areas using the dye tracing (indicator test) method. It was found that there is a shared karst-hydrological system called the Deidzakhi hydrogeological system and separate flows of fissure-karst water.

Results and discussions

It is difficult to argue about the formation of karst cavities in ancient times, especially when the region has been uplifted several thousand meters from its original location and has also been exposed to exodynamic agents for a long time. The development of the karst terrain took place against the background of the geological development of the study area and the formation of the terrain in general (Maruashvili, 1963; Tintilozov, 1976; Lezhava et al., 2019a). It can be said that on the Migaria limestone massif, as well as on the massifs of the karst sone of western Georgia (Lezhava et al., 2019b; Lezhava et al., 2019c; Asanidze et al., 2021), karst formation and the formation of karst terrain begin in the Upper Miocene-Lower Pliocene, when the Attic phase of the orogenesis caused a significant uplift of the study area and, accordingly, intensive washing of the surface (Edilashvili & Gudjabidze, 1954; Tsagareli & Astakhov, 1971).

This process was further influenced and activated in the Late Sarmatian period, in particular, in the Meotian and Pontic centuries, which is confirmed by the faunistically dated (Meotian-Pontic) Samegrelo (Odishi) foothill sediments washed off from the southern slope of the Caucasus, represented mainly by limestone conglomerates. In the Cimmerian (Middle Pliocene), as a result of the sea abrasive action on the southern slope of the Migaria massif (also the Gaucha massif), the Cimmerian Sea abrasion flatland is developed, known as the Tarzen-Otsindale flat surface (level) and currently presented at 700-750 m a.s.l. So, the Migaria massif went up 700 meters after the Cimmerian transgression. This means that by the end of the Tertiary period (Upper Sarmatian age), the massif was at least 1300 meters a.s.l. (Maruashvili, 1964). But if we take into account the denudation processes (Lezhava et al., 2019d; Lezhava et al., 2021), which followed the differentiated uplift and which should have caused its lowering, then it would be much higher. Therefore, it can be said that the uplift of the Migaria massif and the phase of continental development should have been started at a rather distant moment in the Tertiary period, and it is logical that already in the Upper Sarmatian age, when large-grained molasses (in particular, limestone conglomerates) began to accumulate in the Transcaucasian highlands, Migaria was hypsometrically on the border of hilly and medium-mountainous terrain (Maruashvili, 1964). Based on the above, karstification on the Migaria massif took place throughout the Pliocene and possibly in the upper Miocene as well, and therefore, the mentioned period can be considered as the beginning of the formation of the karst terrain.

The Rhodanian orophase (after the Middle Pliocene, during the Cuialnic era) caused a new uplift of the Caucasus (along with the Migaria massif), which was followed by the activation of karst processes both on the surface and in the underground (Tintilozov, 1976). It was during this phase that the modern structures of Georgia's folded mountain system were fully formed. This process continued during the Wallachian orophase, which happened at the start of the Quaternary period, between the Cuialnic and Chaudian eras (Tsagareli & Astakhov, 1971).

By our assumption, these phases should be connected with the formation of the Migaria deep fault, other fault dislocations, and block tectonics of the entire Migaria massif, as a result of which karstified rocks acquire collector properties. Among the disjunctive dislocations identified for today, the Migaria fault, which passes between the Jvari and Migaria mountains and extends from the northeast to the southwest, is noteworthy surface (Edilashvili & Gudjabidze, 1954). As a result of faulting, the Barremian, Aptian, and Albian-Cenomanian suites are shorn, and they reach the porphyritic suite. The mentioned fault should create a kind of barrier and make it difficult for the underground karst waters formed in the eastern half of the massif to move westward (representing the watershed of the Deidzakhi hydrogeological basin), which is also confirmed by the indicator tests we have conducted.

In the mentioned period, along with an important uplift of the study area, destructive processes were revived-weathering and denudation intensified, as well as deep erosion of rivers. As a result of the latter, the area was intensively fragmented. Karst processes have intensified. They formed both surface and underground karst features. Based on the mutual comparison of the levels developed in the Khuru and Ochkhomuri river gorges, L. Maruashvili (1964) indicates the 3-4 intermittent uplifts of the Migaria massif in the recent geological past (in the Middle and Upper Quaternary). The area's periodic upward movement also led to the formation of caves at various hypsometric levels.

It seems that the evolution of karst cavities, like other limestone massifs of Georgia (Asanidze et al., 2017b; Asanidze et al., 2017c; Asanidze et al., 2017d), was closely related to the action of pressurized waters in the early stage of their development. In the karst cavities of the Migaria massif, clear traces of the mechanical and chemical impact of these waters have been preserved so far (smoothed, levelled and perforated surfaces, ceiling corries, rounded arches, deaf pockets and niches). Even today, pressurized water plays an active role in the formation of karst cavities (Shurubumu, Ko, Khuru, and other caves) and their systems.

Early Pleistocene (Pasadena phase) new orogenic movements enhanced the fissuring of limestone suites and, therefore, the activity of karst formation processes. Further evolution of the river network and karst cavities along with it takes place. Before the Middle Pleistocene, L. Maruashvili (1964, 1971) indicated different directions of the rivers of the Migaria massif. In particular, the Ochkhomuri River joined the Tekhura River and the Skurcha River joined the Khobistskali River, and the Khobistskali River flowed through the bed of the current Shiksha River. In the middle Pleistocene (Old Euxine-Uzunlan-Karangat time) the uplift of the southern slope of the Caucasus continues, which naturally affected the activity of groundwater movement and the development of caves. Based on the correlation of the terrace levels, L. Maruashvili (1964) indicates the uplift at the height of 130-140 meters of the Migaria massif after the Riss era, which should be connected with the formation of the modern gorges of the Ochkhomuri, Skurcha, Tekhuri, and Khobistskali rivers. The formation of caves (Shurubumu, Koko, Khuru, etc.) developed in the gorges of the Khobisskali and Ochkhomuri rivers and their tributaries should be related to the same period; in particular, the transition from the phreatic to the vadose period and exposure to daylight. Thus, it can be said that the formation of the karst cavities of the Migaria massif occurred mainly before the Pleistocene or in the Lower Pleistocene.

On the southern monoclinal slope of the Migaria massif, the widespread depressions devoid of constant flow - "dead gorges" - seem to have been developed before the last uplift of the massif, which caused the lowering of the karst drainage level. After the deep shifting of the hydro-network, many caves remained completely without water, and in some areas, where there was a significant mass of water moving in depth along the crack, groundwater has produced caves at lower levels and in some cases reached the level of the main river. Based on the results of the indicator tests we did on the Migaria massif, we can say that the different conditions that led to the formation of caves in the study area showed that separate water streams were formed. In addition, in the modern stage, individual karst caves, shafts, wells and channels of vaucluse springs, formed in the early stages, were united into a single karst aquifer system of "Deidzakhi", which is still impenetrable to humans and within which the development of karst cavities is yet underway (Fig. 4).

Figure 4. Deidzakhi vaucluses. a) Deidzakhi karst streams during the flooding period. b) The junction of the Deidzakhi karst streams with the Khobistskali River (UAV-Phantom 4 images)

In the post-glacial period, rockslides, landslides, and mudflows played an important role in the change of the terrain of the study area, together with karst processes. This period (in the Upper Quarternary) should be related to a landslide of grandiose size (more than 1 km wide) that developed on the southern slope of the Migaria massif in the vicinity of the village of Doberazen. Individual areas of the mentioned landslide continue to periodically activate. In general, landslides, rock avalanches, and rockfalls are common events in other parts of the southern slope of the Migaria massif as well. Here, together with the landslide events in Tertiary clays and marls, the limestones are also destroyed and lead to the occurrence of rock avalanches and rockfalls. To the mentioned period should be related developed in the Khobistskali river gorge the landslides, rock avalanches and mudslides and huge displaced boulders brought by the latter to the gorges of the Khobistskali River and its tributaries. One of these displaced boulders (its mass reaches 150-160 tons) was observed by us on the first terrace level above the left floodplain of the Khobistrskali River, at a height of 2-3 m above the river level (298 m a.s.l.), in the distribution zone of the Lower Cretaceous carbonate rocks (limestones), (Fig. 5).

Figure 5. Deidzakhi displaced boulder in the Khobistskali river gorge

As a result of the laboratory examination of the sample fragment from the boulder, it was identified that it is a volcanic, fine-grained tuff sandstone of Bajocian age, the bedrocks of which are found in the upper reaches of the Khobistskali River, 4-5 km from the current location of the boulder (it extends for two tens of km in the upper reaches of the Khobistskali River). So, the Deidzakhi boulder was brought to the direction of the Khobistskali riverbed in the limestone distribution zone, at least from 4-5 km. Based on the mentioned fact, we can assume that in the upper reaches of the Khobistskali River, as a result of a landslide, rock avalanche, or their combination, caused by a strong earthquake, the river bed was completely blocked and a lake appeared; after the accumulation of water mass, its sudden breakthrough took place, and a strong stone-muddy mudflow caused the distribution of boulders and mudflow material on the bed and slopes of the Khobistskali River and its tributaries. In this regard, it is particularly noteworthy the lower part of the Gvalashara river gorge (the right tributary of the Khobistskali River, Lugela vicinities) flowing through the Middle Jurassic-Bajocian porphyritic rocks, where the mass of individual smoothed boulders scattered over the flattened right level of the gorge reaches several tens of tons. We observed boulders of similar size in the gorges of other tributaries of the upper stream of the Khobistskali River. In the same period, the lower level of the Shurubumu cave system should have been filled up with rock avalanches and mudflow materials. It seems that during the mentioned period, some of the karst cavities developed in the Migaria massif collapsed and were partially or completely filled with boulders and debris material, or were blocked as a result of the tectonic activity of the region. Based on the study of the karst cavities detected so far on the Migaria massif, it can be said that the conditions of their conception and evolution in relation to the peculiarities and the hydrological regime of the terrain considerably differ from the contemporary conditions. Namely, the evolution of cavities seems to have been more intense in the past, as indicated by the morphological-morphometric indicators of karst cavities, as well as corridors, halls, etc. Currently, surface and underground karst features are actively modeled by melting snow and rain water flows.

Conclusion

It is worth noting that according to the scientists (Edilashvili & Gudjabidze, 1954; Maruashvili, 1971; Tintilozov, 1976), the leveled surface (Tarzen-Otsindale step) with the height of 700-750 m a.s.l. belongs to the step formed as a result of the abrasive action of the Cimmerian Sea at the end of the Tertiary period. Therefore, it seems that after the Cimmerian transgression, the Migaria massif experienced an uplift of 700 meters. From this, we can conclude that at the end of the Tertiary period, the massif reached at least 1300 m a.s.l. Based on the above mentioned, the uplift of the Migaria massif and the phase of continental development should have started at a distant moment of the Tertiary period (Attic phase), and already in the Upper Sarmatian age, when large-grained molasses (in particular, limestone conglomerates in the mountainous area of Odishi) began to accumulate in the Transcaucasian intermountains, the hypsometric evolution of Migaria should have crossed the edge of the hilly and medium mountainous terrain. Thus, we can conclude that the erosion on the Migaria massif took place throughout the Pliocene and possibly in the Upper Miocene as well.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

L.Z. wrote the manuscript. T.K. B.N. T.T. A.I. G.G. K.R. N.A. A.L. helped to assist general review of the manuscript. C.N. did text and language editing. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

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Supervised Machine Learning in Drought Evaluation

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Georgian Geographical Journal, 2024, 4(2) 30-37

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Palavandishvili, A. Supervised Machine Learning in Drought Evaluation. *Georgian Geographical Journal* 2024, 4(2). 30-37
https://doi.org/10.52340/ggj.2024.04.02.04

Abstract

Among natural disasters, drought is one of the most common threats to many regions of the world and to Georgia as well. The monitoring and prediction methods of drought and precipitation distribution, the possibilities of their application in the reality of Georgia are considered in proposed work. Simulation methods such as Machine Learning (ML), namely Supervised Machine Learning (SML), optimal for similar complex tasks are presented as the alternative research methods. To conduct research, 1960-2022 period data were taken from database of National Environment Agency and the reanalysis data of the 1960-1990 Copernicus ERA5 rainfall, which were compared with the data of the stations on the territory of Georgia for the validation purpose. Standardized Precipitation Index (SPI) was selected as the research parameter. Using the prediction model and algorithm, drought-vulnerable areas in the Kakheti region were identified. As a result of comparison, lowest correlation rate was 0.309 at Shiraki, maximum was 0.657 at Omalo; minimum mean absolute error 1,662 at Udabno, the maximum 3,041 in Shilda. The smallest standard deviation 4,047 was fixes at Udabno, largest 7,624 at Lagodekhi. By analyzing stations data and satellite sources, it was determined that using the regression method of Machine Learning, it is sufficient to evaluate 1960-2000 period data for learning and 2001-2022 period data for training. The training time of Bagged Trees Optimized Algorithm was recorded as 326.21 sec, prediction speed ~ 7900obs/sec, RMSE - 0.5046, R2-0.64, MSE-0.25466, MAE-0.38065, training process minimum leaf size 19, and 40 iterations are assigned for optimization. CHIRPS satellite data were taken for next generation of the model. For prediction, it was necessary to calculate linear regression equation for each station. In the first case of forecast scenario, the amount of precipitation was determined from 0 cm to 10 cm. Gurjaani was highlighted, where forecast assumed SPI value from -0.008 to -0.901, and Kvareli- the SPI value from -0.002 to -0.138. The use of the presented ML model and algorithm for the analysis of precipitation distribution, drought monitoring and prediction is appropriate for Kakheti and other regions too in conditions of proper observation data base (60 years). It is recommended to use obtained results in early warning system for drought monitoring.

Keywords: Drought, Machine Learning, Big Data, early warning system.

Introduction

Big Data is a rapidly generated amount of information from a variety of sources and in a different format. Data analysis is the examination and transformation of raw data into interpretable information, while data science is a multidisciplinary field of various analyses, programming tools, and algorithms, forecasting analysis statistics, as well as machine learning that aim to recognize and extract patterns in raw data. The applicability of big data techniques is also significantly enhanced by the novel tools that support data collection and integration. The interoperability of the systems can be improved by data warehouses and the related ETL (extract, transform, and load) functionalities that can also be used to gather information from multiple models and data sources. Artificial intelligence (AI) and machine learning (ML) are also the key enabler technologies of big data analysis (Tatishvili et al., 2022a). Analysis of Big Data combines traditional methods of statistical analysis with computational approaches. The analysis of big data is a synthesis of quantitative and qualitative analyses. Climate computing combines multidisciplinary research regarding climatic, data, and system sciences to efficiently capture and analyse climate-related big data as well as to support socio-environmental efforts (Tatishvili et al., 2022). The significance of big data in climate-related studies is greatly recognized, and its techniques are widely used to observe and monitor changes on a global scale. It facilitates understanding and forecasting to support adaptive decision-making as well as optimize models and structures.

Drought is a climatic event that cannot be prevented, but interventions and preparedness to drought can help to: be better prepared to cope with drought; develop more resilient ecosystems; improve resilience to recover from drought; and mitigate the impacts of droughts.

Methods and Materials

Drought indices have been developed in large numbers and are widely used in drought evaluation, monitoring, and forecasting. Machine learning is a subset of artificial intelligence. Machine learning (ML) algorithms are a set of commands that allow systems to learn and improve from prior data without requiring complex programming. ML techniques have been used to implement prediction or forecasting of drought. These algorithms work by simulating a model from input datasets known as test sets and then using the model findings to forecast, predict, or make various types of judgments in various application domains. Various machine learning techniques are extensively used in the prediction of drought.

In order to conduct research, available data from the NEA database is used. Unfortunately, databases aren't perfect: data series aren't continuous and are less reliable, which is a big problem for index calculation and machine learning. Therefore, ERA5 reanalysis data were selected for historical data. Based on the comparison of satellite CHIPRS and IMERG information, it was determined that CHIRPS has a good correlation with the data of the stations in the territory of Georgia (Tatishvili et al., 2023). Those stations where 50% of the data were missing or did not correspond to reality were not subjected to analysis. Als, the satellite cannot perceive the mountainous region; the sea is not subject to observation because a filter (mask) has been applied, so in many cases it is impossible to obtain satellite data on the coastline; in this case, a nearby grid box of another grid must be selected.

Figure 1 shows a list of stations with insufficient data and whose data were not subjected to statistical analysis, and Figure 2 shows the results of the inventory of all (50) stations made using the program R-instat and covers the 2000-2020 period.

Figure 1 shows a list of stations with insufficient data and whose data were not subjected to statistical analysis

A comparison of CHIRPS and station data was made, for which the systematic error (BIAS) was calculated, which refers to the estimation of the difference between the monthly totals of precipitation measured from the satellite and the ground station.

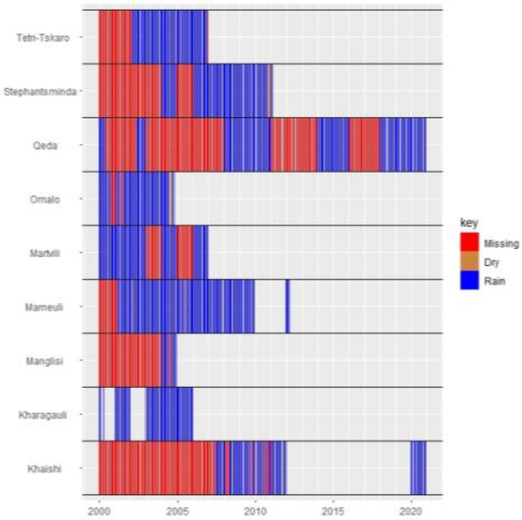

Figure 1. 2000 - 2020 list of stations that were not subjected to statistical analysis.

Results

Figure 2 shows the results of the inventory of all (50) stations made using the program R-instat and covers the period 2000-2020. The SPEI index was calculated for 1960 – 2022 period using the software package R—programming language Climpact2. Because data on daily precipitation and maximum and minimum temperature are needed to calculate this index, sufficient data for calculations were found for only 4 stations out of 17. As for the calculation of SPI, the total precipitation data of each month is required; the data of 10 stations that have at least 40 years of data series have been subjected to the analysis.

When calculating the three-month SPI, the index for the first January and February of the time series does not exist; to recover it, it is necessary to take the average of the month of January or February of each year of the entire series (Tatishvili et al., 2022b).

Correlation for the observations entire period, for all months and years, mean absolute errors and standard deviation were also calculated according to the same principle. The counting results are presented in Table 1.

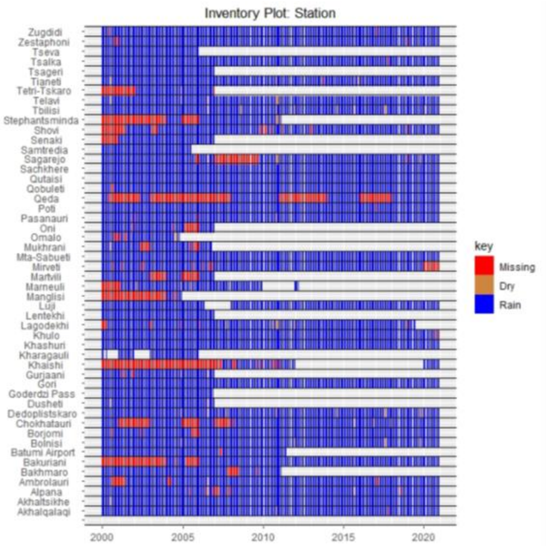

Figure 2. Inventory of 50 stations, the absence of data is marked in red, brown - dry period, blue - precipitation

Table 1. Calculated statistical parameters

Station	Correlation	Mean absolute error	Standard deviation	Correlation SPI3month_CHIRPS	Correlation IMERG SPI_3month	Correlation SPI3 month _CHIRPS check
Akhalqalaqi	0.66759	28.7	26.84318	0.416248	0.291970887	0.443102744
Akhaltsikhe	0.460294	38.1	33.55621	0.352573	0.484119499	0.352572913
Batumi Airport	0.58213	83.2	112.5929	0.448736	0.340454562	0.448736396
Borjomi	0.641079	24.1	25.26509	0.244318	0.310999227	0.244318316
Chokhatauri	0.578691	46.6	66.39357	-0.07615	0.165519382	-0.076151789
Gori	0.600696	18.8	23.40047	0.374053	0.424890006	0.374053213
Khashuri	0.602859	20.7	25.35372	0.384062	0.356057737	0.384061993
Manglisi	-	-	-	-		-
Mta-Sabueti	0.331451	41.3	51.98547	0.300716	0.31919611	0.300716118
Mukhrani	0.670568	22.5	24.8989	0.235464	-0.102300227	0.235464432
Pasanauri	0.633913	33.4	42.5678	0.290633	0.309023193	0.290632874
Poti	0.456032	72.8	111.9462	0.344086	0.375124979	0.344085861
Qeda	-	-	-	-		-
Qobuleti	0.623388	77.5	102.4052	0.286832	0.363684022	0.286831685
Qutaisi	0.66483	35.2	45.62226	0.483474	0.201479561	0.483474128
Sachkhere	0.592227	26.6	34.78904	0.27458	0.441969055	0.27458026
Sagarejo	0.619239	27.7	37.34099	0.076687	0.233896552	0.076687323
Senaki	0.647958	47.3	60.19786	0.747709	0.544157721	0.747709077
Shovi	0.717298	30.0	36.37001	0.440142	0.34740251	0.440141859
Stephantsminda	-	-	-	-		-
Tbilisi	0.678032	21.1	28.35372	0.208955	0.236983184	0.208954519
Telavi	0.693299	26.0	35.45118	0.271435	0.362963042	0.271434581
Tianeti	0.588555	22.0	31.88968	0.191648	0.321092386	0.191647776

Tsalka	0.504015	32.4	39.38712	0.285891	0.353743633	0.285890812
Zugdidi	0.603897	51.9	62.13524	0.477354	0.417972195	0.477354223

The calculations showed that in those stations where more than 50% of the data from the observation period are missing, for example, in Manglis, it is impossible to conduct a statistical analysis. A total of nine such stations were identified. From the analysis of the calculation of statistical characteristics, it is clear that the lowest correlation values are 0.33 at the Mta-Sabueti station and the maximum is 0.72 at the Shovi station; the minimum average absolute error is 18.8 at the Gori station and the maximum - 83.2 at the Batumi station; the smallest standard deviation is 23.4 at the Gori station; and the largest - 118.46 at Mirveti station, which is understandable considering the coastal and mountainous terrain. A high correlation coefficient better expresses the agreement between satellite and station data.

R - instat software was used to calculate Pearson's correlation and other statistical parameters. Stations that were omitted could not be analyzed.

Historical precipitation data from 1961–1991 were compared with ERA5 precipitation reanalysis data. 19 stations were selected for the Kakheti region. Of course, those points where there was insufficient data were not subjected to the analysis (Tatishvili et al., 2022c).

In the result of the data comparison, the lowest correlation index (0.309) was revealed at the Shiraki station, the maximum (0.657) at the Omalo station. The minimum average absolute error (1.662) was recorded at Udabno station, the maximum (3.041) at Shielda station. The smallest standard deviation (4.047) is at Udabno station, the largest (7.624) at Lagodekhi station. By comparing the historical and ERA5 reanalysis data of the station for 1961 – 1991 period, reanalysis data can be used as an alternative database for the model, both in Kakheti and in the entire territory of Georgia.

Table 2. Comparison of station and ERA5 reanalysis precipitation1961-1991 data

Stations	Standard deviation	Correlation	Mean abs. error
Akhmeta	5.76054943	0.5936142	2.22960019
Artana	6.81349292	0.58776933	2.34396992
Birkiani	7.62295759	0.63601722	2.50106601
Dedoplistskaro	5.177286	0.57295248	2.34935663
Gombori	5.48090201	0.57076494	2.1249113
Gurjaani	6.29609913	0.61040494	2.13628114
Kachreti	5.37111452	0.5144723	2.64170272
Khvareli	7.51038719	0.58870058	2.30064283
Lagodekhi	7.62411052	0.55838778	2.39522353
Lechuri	7.26083196	0.48469664	2.65489445
Omalo	5.06645709	0.65703807	2.28134972
Sabue	7.18089762	0.5644877	2.44340144
Sagarejo	6.09202268	0.60668778	2.295695
Shilda	6.35923532	0.48506866	3.04148853
Shiraki	5.45504798	0.30906783	2.58658036
Tsiauri	4.83284442	0.5361194	1.87135863
Telavi	6.16741437	0.61484533	2.13956842
Tsnori	5.19081531	0.62222577	1.96229826
Udabno	4.04739384	0.51336395	1.66217209

Discussions

At the initial stage of machine learning, the station coordinates, station name, year, month, monthly precipitation total, and 3-month precipitation index were included in the training (Mastering Machine Learning). A 30-year observation period was analysed at all. As a result of counting, we got a good result only for those stations that are located close to each other and the overfit for the stations located at a relatively long distance, e.g., Omalo, Akhmeta.

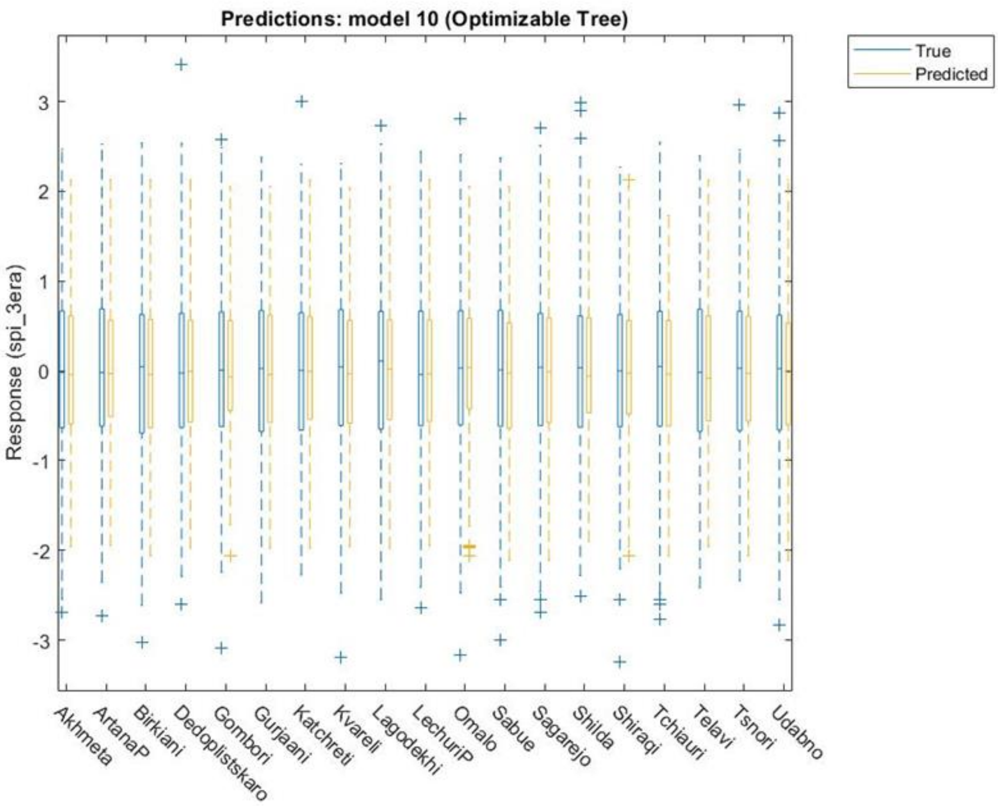

Figure 3. Comparison of the model created by the SVM optimized algorithm with the real data. True data values are marked in blue and values generated by the model in yellow

The parameters for estimating the model generated by the support vector machine (SVM) of the first model are: RMSE - 0.58848, R2 _0.64, MSE_0.34631, MAE_0.45479, prediction speed ~430000 obs/sec (observations per second), training time - 30,296 s, minimum leaf size - 45 (optimized parameter), hyperparametric search ranking: minimum leaf size_1-3420. All these parameters are needed to estimate the model. To avoid excessive adjustment, 30 additional stations in the Kartli region were added.

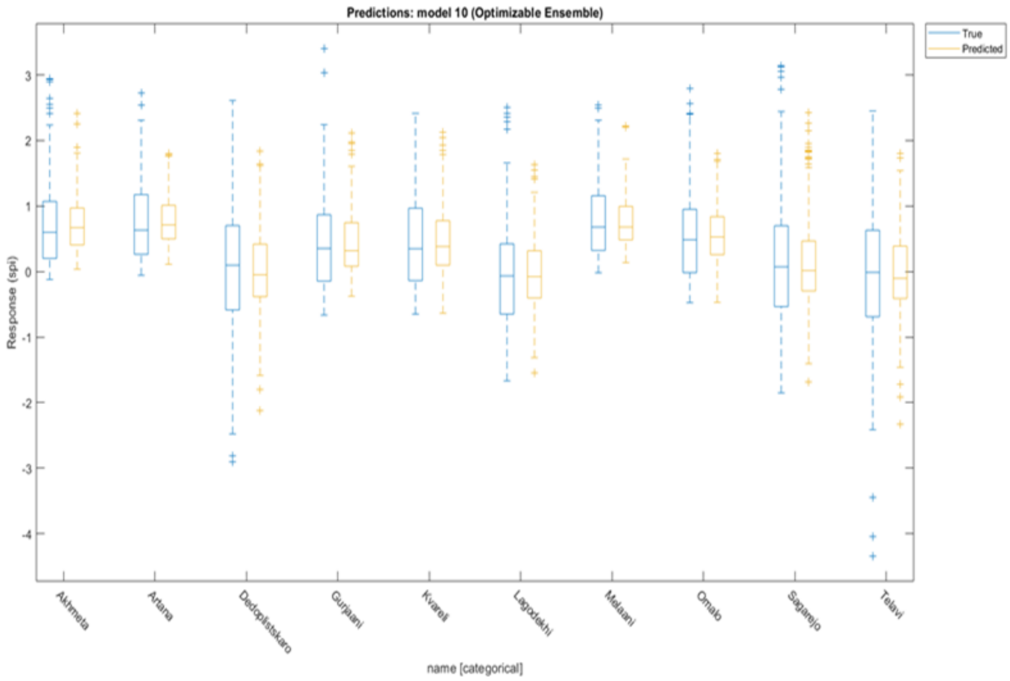

Figure 4. Comparison of the model generated by MatLab and the actual observation data

Figure 4 shows a visual comparison of the actual and predicted results generated by MatLab. Actual data value is marked in blue, predicted data value in yellow.

Bagged trees assembled by an optimized algorithm showed the best results in regression algorithm training. Learning time is 326.21 s, prediction speed - ~ 7900 observations/second, characteristic parameters: RMSE - 0.5046, R2 - 0.64, MSE - 0.25466, MAE - 0.38065.

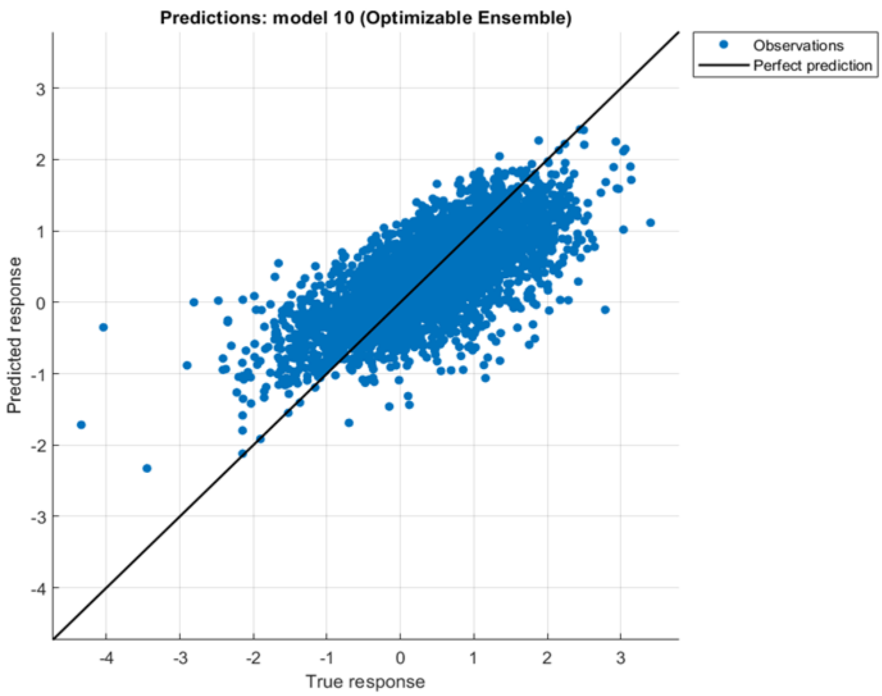

Figure 5. Prediction response generated by MatLab

Figure 5 shows the observation points and the best forecast. Based on the analysis of this drawing, we can judge what kind of model it is. If the data (points) are very scattered, this indicates underfitting, while points that are close to the prediction curve (line) indicate overfitting (McHanay, 2014). When many points are gathered in one area, it can be concluded that the model is a good fit, i.e., satisfactory.

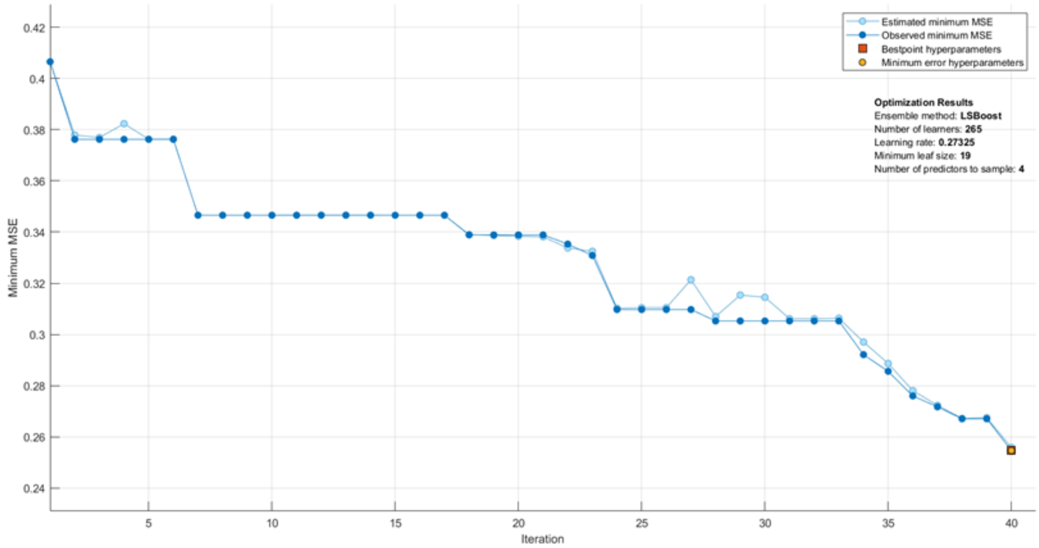

Figure 6. Learning process of optimized Bagged Trees generated by MatLab

Figure 6 depicts the optimized Bagged Trees learning process. The minimum leaf size is 19, with 40 iterations instead of 30 iterations assigned for optimization. Estimated minimum mean square deviation is marked in blue, observed minimum mean square deviation in blue. The learning rate is 0.27325.

After the training stage, the model was subjected to fitting to the data of 2001-2022 for further processing. It is also worth noting that for the adjustment and forecasting process, those stations that operated between 2001 and 2022, at least for several years, were selected. They were then filled with CHIRPS satellite data (Palavandishvili, 2021).

To perform the prediction, it was necessary to calculate a linear regression equation for each station using the polyfit function in MatLab space. After calculating the coefficients, polynomials were calculated in the MatLab space with the polyval function.

$$y=ax+b$$

From the parameters included in this equation, the following were selected: a - the standardized precipitation index calculated by the model, x - the value of the sum of the monthly precipitation for a specific scenario, b - the standardized value of the actual precipitation.

In the first case of the forecast scenario, the amount of precipitation was determined from 0 cm to 10 cm because we are interested in the process of drought development in the case of a small amount of precipitation.

Table 3. Standardized Precipitation Index (SPI), 0 cm to 10 cm inclusive precipitation forecast for some regions of Kakheti

Precipitation forecast (sm)	Dedoplistskaro	Sagarejo	Gurjaani	Khvareli	Lagodekhi	Omalo	Telai
0	-0.270	-0.336	-0.008	- 0.002	-0.524	0.270	-0.568
1	-0.021	-0.057	-0.097	-0.012	-0.269	0.429	-0.325
2	0.227	0.220	-0.186	-0.026	-0.014	0.587	-0.083
3	0.475	0.498	-0.275	-0.041	0.240	0.746	0.159
4	0.724	0.776	-0.365	-0.054	0.495	0.905	0.402
5	0.973	1.054	-0.454	-0.068	0.750	1.064	0.645
6	1.222	1.333	-0.543	-0.082	1.005	1.222	0.888

7	1.470	1.611	-0.633	-0.096	1.260	1.381	1.131
8	1.719	1.889	-0.722	-0.110	1.514	1.540	1.374
9	1.968	2.167	-0.811	-0.124	1.769	1.698	1.617
10	2.217	2.445	-0.901	-0.138	2.024	1.857	1.860

Conclusion

The analysis showed that Gurjaan and Kvareli are more vulnerable to a small amount of precipitation, and less vulnerable regions were also identified: Dedoplistskaro, Sagarejo, and Lagodekhi. When analyzing these results, station altitude and humidity should be considered, as well as the fact that in the case of Artana and Melaani stations some satellite data were not found; that's why the model could not cover the full Kakheti region.

To increase the accuracy of such research, it is necessary to determine additional parameters—temperature, humidity, soil moisture, and indices calculated from the satellite—their validation and adjustment for the machine learning algorithm. Also, the period of education and training should be determined separately; the appropriate method for forecasting will be selected, by means of which we will get the regression equation.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

A. Palavandishvili conceived of the presented idea, performed the analytic calculations, and took the lead in writing the manuscript.

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Hydrological Modeling in Studies of Mountain River Basins of Central Asia

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Georgian Geographical Journal, 2024, 4(2) 38-47

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Kalashnikova, O.; Niyazov, J.; Nurbatsina, A. Hydrological Modeling in Studies of Mountain River Basins of Central Asia. *Georgian Geographical Journal* 2024, 4(2). 38-47
https://doi.org/10.52340/ggj.2024.04.02.05

Abstract

Nowadays, hydrological modeling is widely used both in the scientific and practical studies of mountain river basins. The purpose of this study is to review the developed and adapted hydrological models in Central Asian countries. The models have different methodological approaches and peculiarities in data requirements, which the authors describe in more detail in the paper. Model calibration and testing results are given for mountain rivers located in Kyrgyzstan, Kazakhstan, and Tajikistan. For the high-mountain river basins with small river basin areas (in our study, the average catchment elevation is 2,652-4,170 m.a.s.l. and river basin area starts from 6.6 to 13.7 thousand km^2) and availability of the representative meteorological stations, the use of whole hydrological models such as HBV light and HBV-EHT show good quality (NSE=0.65-0.94, R=0.82-0.97) and practical applicability for rivers runoff estimation. However, such models have a loss of accuracy as they consider the basin a single unit. The Snowmelt Runoff Model (SRM) also performed well (R = 0.71), but requires additional input information on snow cover area from satellite images. The Soil and Water Integrated Model (SWIM), as a distributed type of model, uses a partitioning of the basin into hydrotopes, which complicates the calibration of the river basin model but allows a more accurate description of the processes in its basin (has good calibration quality for a river basin NSE = 0.88). The Water Evaluation and Planning system (WEAP) has a user-friendly interface and good calibration quality (NSE = 0.61, R = 0.88) for large river catchments (in our case 52.2 thousand km^2) and can be applied for water management purposes both at national and regional levels. The paper outlined the main conclusions on the application of these models for research purposes.

Keywords: hydrological modelling, Central Asia, mountain river, SRM, HBV, WEAP, SWIM

Introduction

Central Asia is particularly vulnerable to climate change, as this region is mainly irrigated agriculture, which depends on river runoff formed mainly by snowmelt and glacial waters.

Mathematical modeling in Central Asia has been developed since the 1970s at SANIGMI (Central Asian Scientific Research Hydrometeorological Institute) in Tashkent (Borovikova, 1972). Mathematical modeling made it possible to move from the use of indirect characteristics of runoff-forming factors used in physical-statistical methods to approximate calculations of these factors. Water reserves in snow cover, their distribution by height, and other factors influencing the formation of mountain river runoff began to be determined by mathematical expressions.

Studies have shown that in the Tien Shan, snow accounts for up to 70 % of the total precipitation and provides 60% of the total river runoff (Aizen, 1995). The use of remote sensing data, AVHRR satellite images (Baumgartner, 1988), and MODIS has provided information on snow reserves in inaccessible mountainous areas of Central Asia (Gafurov & Bárdossy, 2009). Over the following decades, hydrological models were developed by various scientific institutes and applied to the different Central Asian river basins. Research work has been carried out for the Syr Darya and Amu Darya river basins, ranging from small river basins such as the Ala-Archa (Hagg, 2006) to rivers with significant basin areas such as the Tarim (Duethmann, 2016) and Ak-Shyirak in the High Tien Shan

(Hagg, 2018). Modeling has been applied both to calculate intra- and inter-annual variability of the streamflow (Gafurov, 2017) and to calculate individual streamflow components, mainly glacial runoff (Hagg, 2007). In addition to research purposes, some hydrological models are used by state organizations (national hydrometeorological services) for practical purposes. For example, HBV light is actively used for river basins in Kazakhstan (Bolatova, 2018), and in the 2000s SRM for rivers in Uzbekistan (Baumgartner, 2000).

Several different types of hydrological models have been created so far. These models can predict changes in streamflow with varying levels of accuracy and consider both natural and human-caused changes in the environment.

This paper presents hydrological models implemented and tested in various organizations and institutions in Central Asia (national hydrometeorological services, research institutions, etc.). The authors evaluated the success of these hydrological models on the example of Central Asian River basins. The presented hydrological models were tested by the authors in previous studies and published in scientific journals and reports for the river basins of Kyrgyzstan (Kalashnikova, 2023), Kazakhstan (Nurbatsina, 2019) and Tajikistan (Niyazov, 2020). The publication presents the main methodological approaches, a brief characterization of hydrological models, and the main conclusions and recommendations obtained by the authors when using them.

Methods and Materials

River basins of Central Asia with basin area from 6,602 km^2 to 52,187 km^2 with an average catchment elevation of 240 - 4170 m.a.s.l. were selected as the main study sites. Most of the studied rivers (Naryn, Gunt, and Chatkal) have the snow-glacial type of feeding, with a glaciation area of 0.6 - 4.6 % of the basin area as estimated by Konovalov in 1985 (Konovalov, 1985) and Shabunin in 2018 (Shabunin, 2018), with flood peak in June. In addition, two river basins were selected, the headwaters of the Naryn River up to the Naryn and Kyzyl-Suu (western, headwaters of the Vakhsh River), with glacial-snow type of feeding, with a glaciation area of 7.7-11.9 % of the basin area (Konovalov, 1985) with flood peak in July-August, the Oba and Buktyrma rivers are belonging to the basin of the Ertis River (Irtysh). Basic information on the river basins is presented in Table 1.

Table 1. Basic information about the river basins under study.*

№	Name of the gauging station	Catchment area in km^2	Mean elevation in m.a.s.l.	Glacier area		Mean annual water discharge in m^3/s
				in km^2	percentage of the basin area	
1	Naryn river – tributary to the Toktogul reservoir.	52,187	2,851	1063*	2.0	404
2	Gunt river – Khorog town	13,700	4,170	634	4.6	104
3	Naryn river - Naryn town	10,500	3,570	511*	4.9	92.9
4	Oba – Shemonaiha village	8,550	1,228	-	-	173
5	Kyzyl-Suu river - Dombrachi	8,470	3,540	578*	6.8	76.2
6	Bukhtyrma – Lesnaya Pristan	10,700	-	-	-	218
7	Chatkal river – Khudoydodsay	6,602	2,652	42.3*	0.6	110

Note: *- glacier area according to Landsat images for 2013-2016 (Shabunin, 2018).

The most widely known hydrological model is HBV. *Hydrological model HBV light 2.0* were used for runoff model calibration for the upper Naryn (Naryn town) and Gunt river basins. Also were used *hydrological model HBV3-ETH9* for runoff model calibration for the Kyzyl-Suu and Chatkal river basins. The HBV model was developed in 1973 at the Swedish SMHI (Swedish Meteorological and Hydrological Institute) (Bergstörm, 1992), has been tested for regions of Switzerland (Braun, 1992), Alpine mountain basins (Hottelet, 1993) and further it was improved at the ETH Zurich. The model has been modified many times, and there are various versions in many countries. Currently, the model has a user-friendly interface that allows to visualize data and retrieve them both in graphical form and in the form of tables. The “runoff – precipitation” model HBV3-ETH9 we use to calculate runoff of high mountain rivers is an advanced model HBV, which allows us to calculate the daily runoff hydrograph based on meteorological and hydrological ground observation data. The HBV3-ETH9 model has a simple non-deterministic structure and does not require a large set of meteorological parameters. Another model that we use is HBV light 2.0 with semi-distributed parameters, which includes subroutines for meteorological interpolation, calculation of snow accumulation and snowmelt, total evaporation, soil moisture, and runoff generalization to calculate the transformation of water movement across rivers and lakes.

Data preparation, work with the model, and model optimization were carried out according to the HBV ligh 2.0t user manual (Seibert, 2005). The authors of the article used the allowable ranges of the model parameters given in the manual and the materials of previous studies for the mountain rivers of Kazakhstan (Bolatova, 2018). Data preparation, work with the model HBV3-ETH9, and model optimization were also carried out according to the HBV3-ETH9 user guide (Konz, 2003). Parameter ranges for model optimization were taken from previous studies prepared for the Enylchek of the Central Tian-Shan River (Mayr, 2014).

The Snowmelt Runoff Model (SRM) was developed by J. Martinec (1975) first for small European basins and is intended for modeling and predicting daily runoff in mountain basins where snowmelt is a major factor in the runoff. The SRM has been successfully tested at WMO for runoff modeling (WMO, 1986) and is partially used for simulated conditions of real-time runoff forecasts (WMO, 1992). The WinSRM provides the user with a complete modeling environment in which snowmelt is simulated for mountain basins where snowmelt provides a significant contribution to that runoff.

The SRM can be used for the following purposes:

1. Modeling of daily runoff in a snowmelt season, a year, or a series of years. Results can be compared with measured runoff to evaluate model performance and verify model parameter values. Modeling can also serve to evaluate runoff patterns in unmeasured basins and under hypothetical climate change.
2. The short-term and seasonal runoff forecast. The microcomputer program includes the formation of upgraded recession curves, which are the ratio of snow-covered areas and cumulative snowmelt depths when SRM is calculated.

These curves provide the ability to extrapolate snowpack area values manually by the user several days ahead from temperature forecasts so that this input of values is available for runoff forecasts. Modernized recession curves can also be used to estimate snow resources for seasonal runoff forecasts. Model performance may deteriorate if predicted air temperature and precipitation differ from actual values, but errors can be reduced by periodic upgrades.

The SRM calibration parameters include: runoff coefficient from snow, runoff coefficient from rainfall, degree-day factor (swarming factor), temperature gradient, critical temperature, rain coverage area, regression coefficient, and run-up time.

The SRM parameters are not calibrated or optimized with historical data. They can be obtained either by measurement or estimated by hydrologic judgment, considering basin characteristics, physical laws, and theoretical or regression relationships. Random successive fits should never exceed the range of hydrologically or physically acceptable estimates.

The German hydrological *model SWIM (Soil and Water Integrated Model)*, which was developed at the Potsdam Institute for Climate Impact Research (Germany) by Krysanova et al. in 1996, was tested in this study (Krysanova, 1996). The hydrological model SWIM performs calculations using the GRASS GIS software, which is freely available online (Geographic Resource Analysis Support System GRASS GIS, 2023). The user manual GRASS 4.1 was used for working with hydrological modeling (GRASS 4.1 Reference Manual, 1993). At the heart of the calculations is the division of the entire study basin into hydrotopes - areas with relatively homogeneous conditions and flow indicators, including unified characteristics of soils and land use.

In order to put the model into operational practice, it is necessary to thoroughly test it and verify the quality of the results. The following tasks were addressed during the testing: adaptation of the SWIM hydrological model to the conditions of the studied river; obtaining predictive meteorological information and processing data format in RStudio; conducting model calibration and verification; development of automatic procedures for making forecasts; evaluation of forecast quality.

The following meteorological parameters were used in SWIM for hydrological modeling: maximum, minimum, and average air temperature, precipitation amount, relative humidity, total solar radiation, and average wind speed.

The main methodological approach for modeling hydrology in *WEAP (Water Evaluation and Planning system)* is the soil moisture method. This method uses a one-dimensional equation that calculates the water balance for the surface soil profile (upper bucket, shallow soil zone) and the deep soil profile (lower bucket, deep soil zone) (User's Manual WEAP, Integrated water and energy modeling for the Syrdarya River basin).

The method considers the effect of soil water-holding capacity on runoff, evapotranspiration (ET), intermediate runoff, percolation (infiltration), and baseflow. Each watershed is delineated based on land use, soil types, and topography. Automatic watershed delineation separates catchments based on land use and elevation. Land use type and climatic parameters in the soil moisture method together determine how much water infiltrates into the ground, evaporates, or drains to the river. Meteorological parameters of the weather stations were used in WEAP for hydrological modeling: average air temperature, precipitation amount, relative humidity, and average wind speed.

The following optimization parameters were considered when evaluating the model calibration for the basin:

1. Pearson's correlation coefficient (R) is an index of the degree of linear relationship between observed and simulated data. It ranges from −1 to 1. If R = 0, no linear relationship exists. If R = 1 or −1, a perfect positive or negative linear relationship exists;
2. Pearson's coefficient of determination (R^2) also compares simulated and measured data; it describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, with higher values indicating less error variance; typically, values greater than 0.5 are considered acceptable.
3. The Nash-Sutcliffe Efficiency (NSE) coefficient is commonly used in hydrological modeling to evaluate how well modeled stream flow matches observed streamflow. The ideal value is 1, Values of 0.5 are acceptable; most modelers aim for values that are at or above 0.7.
4. The ratio of the root mean squared error to the standard deviation (RSR) is a measure of how much simulated flows deviate from observed hydrographs. An ideal value is zero, but values less than 0.7 are considered acceptable.
5. Percent bias (PBIAS) is a measure of the model's ability to match the total volume of flow. An ideal value is zero, but PBIAS of plus or minus 25% of the observed streamflow is considered acceptable.

In our study, first of all, the main two parameters were taken into account to evaluate the calibration results of all presented hydrological models for streamflow - Nash-Sutcliffe Efficiency (NSE) and Pearson's correlation coefficient (R). Additionally, two morindicators—therratioio of throotomeanasquaredeerroror to the standard deviation (RSR) anpercentnt bias (PBIAS) are considered. The ideal values and interpretation of these ten embedded statistics are summarized in Table 2.

Table 2. Optimize calibration based on visual and statistical assessment.

Statistical measure Ideal and acceptable values Interpretation	Statistical measure Ideal and acceptable values Interpretation	Statistical measure Ideal and acceptable values Interpretation
Pearson's correlation coefficient, R	If R = 1 a perfect positive linear relationship exists	describes the degree of collinearity between simulated and measured data
Pearson's coefficient of determination, R^2	The ideal value is 1, values of 0.5 to 1 are considered acceptable	is an index of the degree of linear relationship between observed and simulated data
Nash-Sutcliffe Efficiency (NSE)	The ideal value is 1; values > 0.5 = acceptable > 0.6 = desired > 0.7 = good > 0.8 = very good	how well modeled stream flow matches observed streamflow
Ratio of the Root Mean Squared Error to the standard deviation (RSR)	An ideal value is zero, but values less than 0.7 are considered good.	a measure of how much simulated flows deviate from observed hydrographs
Percent bias (PBIAS)	An ideal value is zero, but PBIAS of plus or minus 25% of is considered acceptable	tendency of consistent over or underestimation of flows / match of simulated to observed total volume

Result

The calibration of the HBV-light model. The authors have used data for the Naryn river (Naryn town) period2010-201919 and for the Gunt river (Khorog), 2012-2016*For thehe calibration of the HBV-EHmodell*, for the Chatkal and Kyzyl-Suu rivers we used data periods 2012-2016. The data from gauging stations Khudoydodsay for Chatkal river, Dombrachi for Kyzylsu river, Khorog for Gunt riv,er and Naryn town for Naryn river were used as input data. The weather stations Tien-Shan, Javshangoz, Chatkal and Sary-Tash, which were used focalibration, wereon mainly located in the upper reaches of the rivers. The gauging stations should be located at the exit from the mountain gorge, as well as located above the points of water intake for irrigation and communal services.

The data for the calculations were obtained from the historical data archive of the national hydrometeorological services under existing agreements with scientific institutes. Preparation of data in GIS required a digital elevation model with a spatial resolution of 30 meters (https://earthexplorer.usgs.gov) and shapefiles of modern glaciation, digitized for 2013-2016 using Landsat 8 images and Randolph Glacier Inventory 6.0 (2017) (Shabunin, 2018). There was a division into altitudinal zones for all watersheds above 200 meters. Model HBV3-ETH9 calculates in MATLAB and has the same set of input data as well as glacier mass balance data. We used input data on the simulated mass balance of the Abramov glacier for 2012-2016 (Barandun, 2018).

The HBV-light and HBV-EHT models were calibrated for the selected basins. The calibration showed the following results for river basins (Fig. 1): Naryn NSE = 0.84, R = 0.91 (R^2 = 0.83); Gunt NSE = 0.65, R = 0.82 (R^2 = 0.67); Chatkal NSE=0.94, R=0.97 (R^2 = 0.95); Kyzyl-Suu NSE = 0.74, R = 0.91 (R^2 = 0.82).

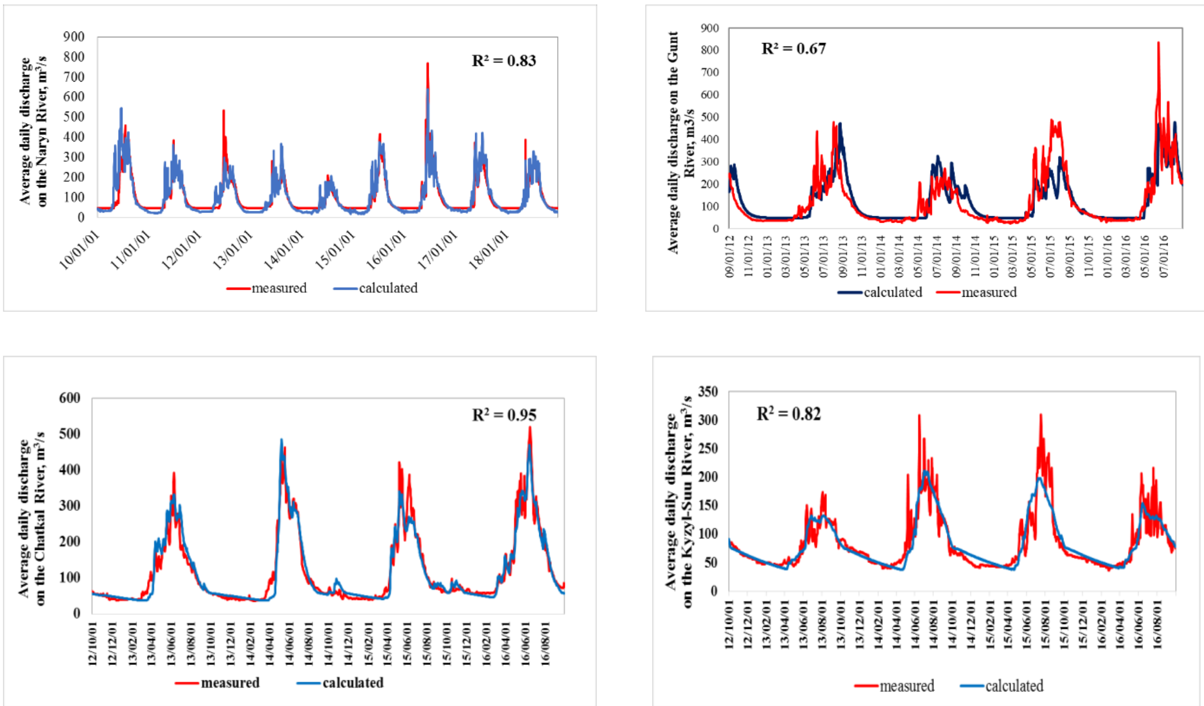
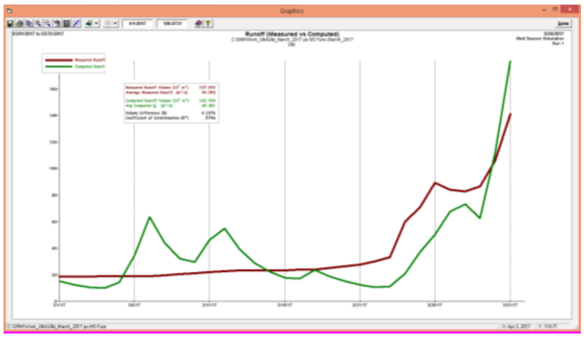


Figure 1. The HBV-light model calibration for the Naryn river (SG Naryn town) and for Gunt river (SG Khorog); the HBV-EHT model calibration for Chatkal river (SG Khudoydodsay) and Kyzyl-Suu River (SG Dombrachi).

To work with the Snowmelt Runoff Model (SRM) necessary to prepare the basin area and altitude zones, for this purpose the basin boundary is defined by the location of the stream gauge on the river and the watershed is identified from the topographic map. For meteorological parameters are needed the air temperature, precipitation and snow cover area data, and for hydrological parameters is needed a water discharge. For the SRM model calibrati,on we used hydrological data of the river Oba (SG Shemonaiha) and meteorological data (MSs Leninogorsk and Ust-Kamenogorsk) of the period 2014 - 2017. The result of calibration is R = 0.71 (fig. 2).

The comparison of March 2017 flood volumes using the annual analog method.



The comparison of March 2017 flood volumes by Fourier analysis

Figure 2. The calibration of the SRM model for the Oba river basin.

To prepare input information for Soil and Water Integrated Model *(SWIM)*, maps of elevation zones, soil types, land use, and vegetation were prepared. A digital elevation model SRTM with a spatial resolution of 30m was used to prepare the map of elevation zones. The soil types map was prepared based on data from the FAO Soils Portal (Food and Agriculture Organization of the United Nations, 2023). The land use/vegetation maps were based on data from the "Global Land 30" project for 2014, which used satellite images from the Landsat project with 30 m resolution for a multi-year series for the period 2009-2011. In digital format, as of the end of 2015 (www.globeland30.org) land use maps became fully available and contained more detailed division into classes (Globeland30. Publicly available global geoinformation product, 2023). To calibrate the model SWIM, we used hydrological data of the river Bukhtyrma (SG Lesnaya Pristan) and meteorological data (MSs Katon-Karagai, National Park Markakol, Ulken Naryn, Leninogorsk, Seleznevka) for the period 2001 - 2010. The calibration result is a NSE = 0.88 (fig. 3).

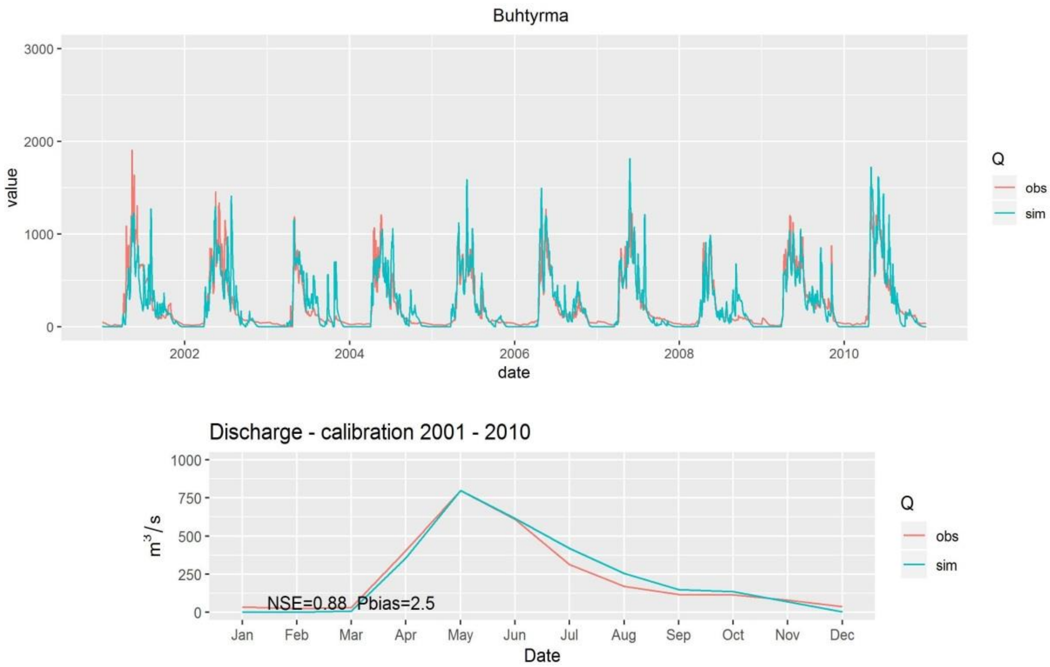


Figure 3. The SWIM model calibration for the Bukhtyrma river basin

To build the model for the Naryn River in the *WEAP software*, initial data from the Stockholm Environment Institute (SEI) from the water-energy model for the entire Syr Darya River basin and Kyrgyzhydromet data for the Naryn River basin were used. The basis for modeling was spatial data from the Stockholm Environment Institute (SEI) - the HydroSHEDS digital elevation model with a spatial resolution of 500 meters, glacier area from Randolph Glacier Inventory 6.0 (2017), glacier extent and land use data from the European Space Agency (ESA).

Climatic data for the Naryn River basin were interpolated using a temperature and precipitation gradient from weather stations located at the three altitude zones of Toktogul (at 983 m.a.s.l.), Naryn (2039 m.a.s.l.), and Tien Shan (3614 m.a.s.l.). Water inflow to the Toktogul reservoir, data on water discharge and volume were used according to the data of the site of JSC "Electric Power Plants". Calibration of the model was carried out in PEST tools.

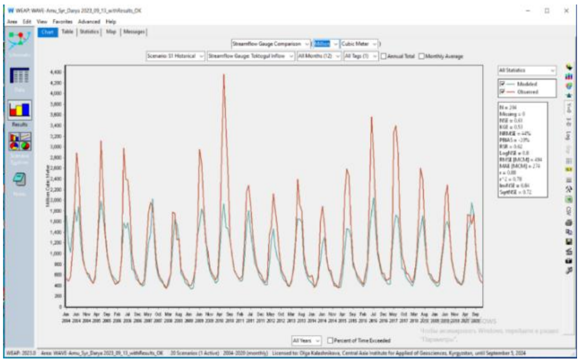
There are four charts we recommend considering in the process of calibration:

1) The monthly time series for observed and modeled streamflow. This chart allows us to observe how well the modeled flow matches base flows, wet weather flows, and seasonality for a range of dry and wet years.

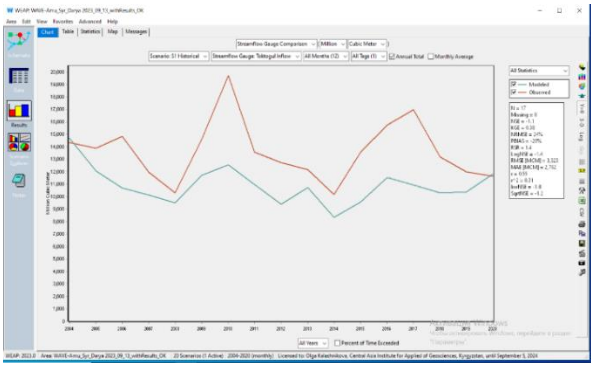
2) Annual total of observed and modeled streamflow. The annual total provides a good sense of the general fit of the model over time and of how well the modeled total annual volume of runoff matches observed values. 3) Monthly average of observed and modeled streamflow. The monthly average shows how the modeled flow values deviate from the historical record, on average, each annual cycle.

4) Exceedance Probability for observed and modeled streamflow. The exceedance probability chart ranks each flow measurement by value, the lowest on the right and the highest on the left, for both the modeled and observed streamflow. The values on the x-axis show the percentage of flows that exceed the values of flow. The modeled and observed streamflow should show a close match of exceedance percentages for the two flow records.

The monthly time series for observed and modeled streamflow were NSE=0.61 and R=0.88. Figure 4 shows the results of WEAP model calibration.



A



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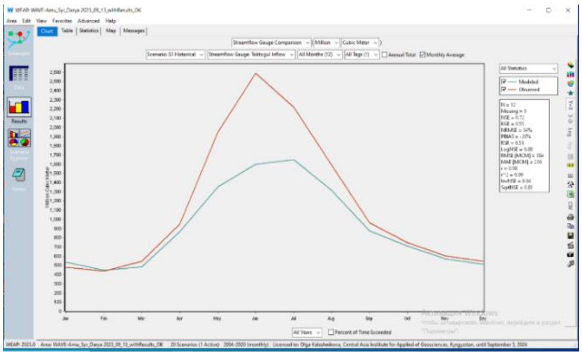
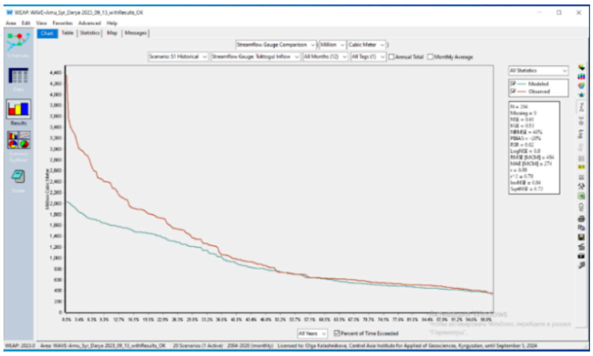


C



D

Figure 4. Calibration of the WEAP model for the Naryn river basin – inflow to Toktogul reservoir.
A: The monthly time series for observed and modeled streamflow, B: Annual Total of observed and modeled streamflow, C: Monthly average of observed and modeled streamflow; D: Exceedance probability for observed and modeled streamflow.
Blue color: modeled, red color: observed.

Thus, the study covered 5 main hydrological models (HBV light, HBV-EHT, SRM, SWIM and WEAP) with different methodological and model calibration approaches for the river basin.

Discussion

The choice of hydrological models HBV light 2.0 and HBV-EHT was due to the fact, that they are freely available and do not require a license. The model has a simple interface and a small set of input data: daily data on air temperature, precipitation and evaporation from a weather station representative of the watershed, and average daily water discharge from a gauging station with natural flow. To prepare the data in HBV-EHT, also are needed data on the mass balance of glaciers and the area of modern glaciation in the shape file. Calibration of models for small river basins (up to 13,000 km^2) with representative meteorological stations in Monte-Carlo and Gap-Optimization tools appears to be the simplest and can be successfully supplemented by manual calibration.

In contrast to HBV models, the SWIM hydrological model requires a large amount of incoming spatial data and complete calibration but is flexible in interpreting different situations introduced during scenario preparation. For example, changes in land cover, land use, etc. can be additionally considered.

The SRM hydrological model, like the HBV models, considers the river basin (as a whole), but requires input information on the spatial distribution of snow cover. The creation of the MODSNOW-Tool program (Gafurov, 2016) greatly simplifies the acquisition of this data for elevation zones of 200 meters or more. The SRM model has a simple interface and does not require a license.

The WEAP software has a user-friendly interface and models river runoff well for large river basins (in our case 52,000 km^2), which cannot be modeled in other simpler models, such as HBV, showing low statistical calibration performance. The WEAP software works in integration with QUAL2K, MODFLOW, MODPATH, PEST, Excel, and GAMS programs. It is currently actively integrating with LEAP, NEMO, MABIA, and MACRO programs. This integration allows for an integrated approach to the planning of water resources management activities, considering the full range of possibilities of their multipurpose use.

Conclusion

The main task of hydrological modeling is to obtain reliable hydrological forecasts of future water resource change. In the arid conditions of Central Asia, when irrigated agriculture requires significant water resources in the summer, advance forecasting is important for planning water allocation between upstream and downstream countries. An advance forecast of low water availability during the growing season, to carry out preventive measures for rational water use by water and energy companies, is the most important.

Assessment of hydrological models' efficiency, carried out by the authors based on long-term experience, allows using in practice the best models depending on the goals set by users (stakeholders).

Water availability forecasts based on the developed methods in the presented hydrological models and software, which have good quality and high efficiency, should be used in hydrometeorological services and water management.

Reliable and early forecasts will allow ministries and agencies to plan water use measures for the growing season, as well as to take timely preventive measures to avoid consequences of low water (water shortage, hydrological drought) and high water (mudflows/floods).

Authors' contribution

Kalashnikova O.Yu.: Conceptualization, methodology, formal analysis, writing original draft, visualization, writing, reviewing and editing, data collection, investigation. Niyazov J.B.: conceptualization, methodology, writing original draft, visualization, investigation, data processing. Nurbatsina A.A.: conceptualization, methodology, formal analysis, writing original draft, writing, reviewing and editing, data collection, investigation.

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Anthropogenic Transformation of Landscapes and Ecological Risk Factor Assessment

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Georgian Geographical Journal, 2024, 4(2) 48-53

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Seperteladze, Z.; Davitaia, E.; Aleksidze, T.; Rukhadze, N. Anthropogenic Transformation of Landscapes and Ecological Risk Factor Assessment. *Georgian Geographical Journal* 2024, 4(2). 48-53
https://doi.org/10.52340/ggj.2024.04.02.06

Abstract

All components of the landscape (especially living nature) are affected by anthropogenic effects, which disrupts the relationships established between them over a long geological time and ultimately leads to a change in the natural complex, which in most cases is of a negative nature and determines its degradation. Ecologically, anthropogenic transformation of wildlife is particularly harmful, which is carried out by taking advantage of the unreasonable, reckless nature of man, which is based on a purely consumerist spirit. When human society affects nature, a new variety of natural-territorial complexes is formed - anthropogenic complexes, which currently occupy a significant part of the terrestrial part of the entire earth. It originated with human society and will exist if there is mankind. Therefore, the essence of anthropogenic landscapes, its features, regularities and tendencies of development, productivity; Also, issues of sustainability, its potential opportunities and protection against external influences are one of the main tasks of geographical science.

Keywords: Geochemical association, anthropogenic landscapes, Anthropogenicity coefficient, Ecological problem, Total fouling rate

Introduction

At the modern stage of the interaction between nature and society, the interaction of society with nature has reached unprecedented levels, and its results have equalled the geological factor itself. There are almost no natural landscapes left in their original form due to direct or indirect human impact. The research of anthropogenic complexes, in particular the issues of their classification, mapping, and rational use of nature, is relevant.

By influencing the nature of human society, various genetic origin complexes—anthropogenic landscapes—are formed. We cannot but agree with the opinion that (Milkov, 1978) the role of anthropogenic landscapes in the structure of the Earth's landscape envelope is growing at such a pace that in this case the role of the anthropogenic factor in the differentiation of modern landscapes is one of the main problems of landscape science.

As for the research of anthropogenic landscapes of Georgia, even though the territory has been inhabited by human society since time immemorial and the anthropogenic impact on nature, in the conditions of the mountainous side, is increasingly growing and intense, its theoretical issues have not been fully studied and agreed upon. In this regard, D. is worthy of mention. Davit Ukleba monograph (Ukleba, 1983), where the theoretical, methodological, and constructional issues of the anthropogenic landscapes of the mountain and intermountain bar of Georgia are discussed for the first time. The close relationship between natural and anthropogenic factors is covered, and their connection with the main types of land use is shown. The author provides a scientific prediction of anthropogenic changes in landscapes, and measures are set for their more effective (optimal) use in the case of economic impacts. Refers to the same issue in the E. Davitaya, Z. Seferteladze textbook (Davitaia & Seperteladze, 2009) for students of higher education, which represents the first attempt at theoretical and practical research of modified landscapes in the native language.

Methods and Materials

Each type of land use leads to the formation of a special category of anthropogenic landscapes. In addition, landscapes formed by one type of use are noticeably different from landscapes formed by other types of impacts. The degree of transformation of anthropogenic landscapes also varies in a very wide range. On an infinitely large area, man has changed its structure through agricultural, forestry, and agricultural impacts, mining operations, hydropower facilities, expansion of industrial enterprises, road construction, and urbanization. It should be noted here that the role of the human factor in arid landscapes is relatively small; mountain tundra, polar and high mountain deserts, as well as some sections of equatorial forest and northern tundra are practically preserved naturally. However, there are also signs of human expansion: separate industrial hubs and transport routes, as well as the results of the Some researchers (Preobrazhensk & Haase, 2003) believe that the change of natural landscapes and, accordingly, the creation of anthropogenic landscapes occurs at the level of elementary landscape (facies) and microlandscape (Urocishche). There is also an opinion that the change of landscapes takes place at other levels of taxonomic units, and not only elementary and micro-landscapes are under anthropogenic influence but also higher-ranked taxonomic units—species (Ukleba, 1983; Davitaia & Kikvadze, 2009) and this is understandable since the landscape The character of one of the main taxonomic units-species and its physiological "face", in addition to zonal and azonal factors, is mainly determined by local physical-geographical conditions and processes, The latter is easily subject to artificial regulation, namely anthropogenic influence. For this reason, as rightly noted by A. Ryabchikov (1974), not infrequently, several anthropogenic landscapes of different genetic order are formed within the same natural landscape. As for the higher rank of the landscape—class-type-subtype—their change is hardly subject to the anthropogenic factor. We share this opinion; we point out that until the fundamental change of the geostructure of the territory and the radiation process-landscape-creating main factors by humans, the complexes of the above-mentioned rank will exist in a natural form. Here we note that in the rank of anthropogenic landscape, at the level of facies and urochishche, it is possible to consider (in mining-industrial regions and riverside) terrykons, earthworks, korghans, guthagrovi, etc.

When studying anthropogenic landscapes, as in the case of studying background (natural) landscapes, different methods are used, more often a complex of methods. Since anthropogenic complexes develop in the core of the natural landscape and represent one of the latter's genetic types, we used all the methods used in the study of natural landscapes in their study. In addition, since any kind of anthropogenic and natural complex is dynamic and constantly changing, a historical, retrospective method was used to study the issues of their dynamics, functioning, and further forecasting.

When analyzing the topical issues discussed in the article, along with all the above-mentioned methods, it becomes necessary to use such effective research methods of anthropogenic landscapes as landscape-ecological and landscape-geochemical. With the latter method according to the local (regional) features of the chemical "behavior" of the main topomorphic elements, we assessed the environmental situation of several objects in Georgia (Seperteladze, et al., 2007; Seperteladze, et al., 2010). planetary migration of man-made waste, etc.

Results

Anthropogenic landscapes are characterized by changes in the exchange and circulation of biophilic chemical elements, disruption of the heat balance, changes in the type and quantity of vegetation and animal world, changes in soil processes, etc. In addition, the transformation of anthropogenic landscapes occurs significantly faster than the self-development of natural (original) landscapes. This indicates, on the one hand, that we should be especially careful and attentive to unwanted changes, which can be catastrophic, and on the other hand, it allows us to regulate and transform them into highly productive cultural systems in a relatively short period of time (one generation of people).

Man's intervention in the natural environment first disturbed its chemical balance. In this case, both the removal of chemical elements from circulation and their technogenic migration into the natural environment are important. As mentioned above, because of human economic impact, a large number of chemical elements and their compounds reach the earth's surface, which, in case of volatility, move to a dispersed state and engage in intensive migration.

The nature of the reaction to the technogenic impact of natural systems depends, first, on the landscape-geochemical situation (state) itself and the geochemical activity of the impact, one of the indicators of which can be considered the Clarks of chemical elements (the higher the Clark, the more natural these elements are). ability to adapt to systems) and chemical forms of substance accumulation. Geochemically inert technogenic flows (Neef, 1974) adapt to practically any natural situation, are not characterized by sharp differences from natural geochemical parameters, and do not cause significant changes. On the contrary, when the technogenic impact is not in agreement with the local conditions, there is a deviation from the state of normal functioning of natural landscapes to the formation of a fundamentally new geochemical situation.

One of the main reasons for the breakdown of internal relations in natural-territorial complexes is the specific nature of human impact on nature. This impact (especially on the ecosystem) in a relatively short period of time is often so sudden, strong, and arrhythmic that the living organism cannot adapt to it. The second important problem is the disruption of biogeochemical cycles in anthropogenic landscapes and chemical balance in natural landscapes, which was formed during the long geological period of their development.

As a rule, because of human economic impact, there is a deterioration (simplification) of landscapes as a material system, as well as an increase in their productivity, which at the same time is accompanied by a decrease in the complexity and diversity of their structure, both qualitatively and quantitatively. A typical example of simplification of a material natural system is monoculture agricultural landscapes. Cultivation of a monoculture, the productivity of which man is interested, is accompanied by monotony of the landscape and deterioration of its balance (disruption). Thus, the high specialization of farming ultimately leads to the formation of monotonous, intensive, and cultural, but at the same time, unsustainable, landscapes. Therefore, one of the important problems is to develop a mechanism for regulating the productivity and sustainability of anthropogenic landscapes and overcoming the contradiction between human economic activity. In addition, it should be noted that the disturbed forest is poor in species composition; the quality of its wood has deteriorated. However, it should be noted here that it is more resistant to external anthropogenic influences; the species that create it are characterized by the ability to easily adapt to new conditions and a wide ecological spectrum. The growing trend of disturbed forest areas indicates that eventually, the natural forest gives way to secondary forests and forest scrubs.

Table 2. Total indicators of chemical pollution of ore waters of Chiatura manganese deposit

#	points	Chemical composition formula	concentration coefficient	Coefficient of total chemical fouling
1	Akhali darkveti	M M2,5 SO475HCO328 (Na +K)62Ca27	194,5	188,5
2	Akhali Itkhvisi	M Mo,85 SO457HCO341 Ca38Mg35(Na+K)26	197,85	190,85
3	Shukruti	M M1,45 SO481HCO317 Ca64Mg28	191,45	186,45
4	Mgvimevi	M M1,44 SO473HCO325 Ca51(Na+K)26Mg23	199,44	192,44
5	Koroxnali	M1,97 SO480HCO318 Ca60Mg18	187,97	172,97
6	Perevisa	M0,98 SO473HCO324 Ca63(Na+K)22	182,98	176,98

Based on the above, it can be noted that the complexes formed by the long-term effects of technogenesis are highly resistant, already adapted, and agreed with the environmental conditions. Because of this, the restoration of such soils and landscapes in general is difficult and often almost impossible.

One of the necessary characteristics for the landscape-ecological assessment of mining regions and their key areas is the indicator of an anomalous level of concentration of chemical elements. For this purpose, the value of the concentration coefficient (K) was determined—the sum of the indices of the elements included in the geochemical formula of the ore. The latter gives a certain idea about the qualitative and quantitative assessment of the geochemical association of the mining region. For the overall quantitative assessment of the level of abnormality, the total rate of pollution was determined for each object by the formula (Sorokina, 1983).

$$Zc = \sum_{i=1}^{n} Kc(i)\ (n - 1)$$

where n is the numerical value of the number of chemical elements included in the association, Kc(i)- is the concentration coefficient of chemical elements. According to the mentioned attitude, the total indicators of chemical pollution of ore waters of the Chiatura mining region (Table 1) are a clear confirmation of the rather severe and anomalous ecological level of the technogenic landscapes formed here of concentration.

It is clear from the table that the high concentration of elements and the total rate of chemical contamination are observed directly in the ore mining area (with a radius of 100-200 m). The same regularity is observed in the river Kvirila and in the waters of the Rion, from the ore body to the mouth Kvirila and from the ore body to the confluence in the Rion waters (Table 2).

Table 2. Chemical pollution of Rion and Kvirila waters total figures

#	Sampling location	Chemical composition formula	concentration coefficient	Coefficient of total chemical fouling
1	KKvirila (Above Chiatura)	M M0,23 HCO378SO415 Ca65Na31	189,23	184,23
2	Kvirila (ander Chiatura)	M Mo,41 HCO373SO443 Ca76Mg76	268,41	263,41
3	Kvirila (v. Shoraphani)	M0,23 HCO372SO421 Ca66Na26	185,23	180,23
4	Kvirila (v. Simoneti)	M0,27 HCO355SO425 Ca65Na26	171,27	166,27
5	Rion (under Samtredia)	HCO364SO414 M0,17 Ca59Na30	167,17	162,17
6	Rion (above Poti)	M0,24 HCO375SO414 Ca63Mg19	171,24	166,24

It should be noted that we touched on only a few aspects of the geochemical functioning of the landscapes of mining objects (the geochemical functioning of the atmosphere, underground and surface waters and soils under the influence of technogenesis), and as a result of considering the problem with a complex approach that takes into account the human economic impact on the surrounding landscapes of mining regions, it is possible to study them in every way. Perfect forecasting of the further transformation and planning of the necessary measures that lead to maintaining the sustainability of the environment even in a highly critical ecological situation. In the process of interaction between man and nature, one of the interesting things is to consider the risk factor.

It is generally accepted that risk is an integral part of every living organism. Any unwanted human impact is always accompanied by risk. what is the solution? No impact on nature! This is impossible, therefore there is only one solution - the "risk" assessment of the possible impact, thereby achieving the minimization of the influence of the undesirable factor (Tsaava et al., 2007).

The concepts of danger and safety are also related to the concept of risk. Ecological danger is the possibility of unwanted processes and events in the environment that worsen the ecological condition of the environment. First, the safety of people and the natural environment is important for us. In its quantitative assessment, a "scale" is used, which is divided into risk units. According to the mentioned scale, G is the averaged unit of ecological safety, and the average life expectancy of a person is taken.

It should be noted that one of the main issues of anthropogenic landscape research and environmental monitoring is situational modeling. When modeling natural systems, first we should achieve sustainable development of natural processes. Here, it is interesting how we call development "sustainable". The same system can be sustainable according to one opinion (of the researcher) and unsustainable according to the other opinion. Sustainability is one of the fundamental concepts of BTK. When we talk about ecosystem sustainability, overtly or covertly, we mean the following: there is an ecosystem that experiences anthropogenic or natural impacts, because of which its components or parameters acquire a certain value (positive or negative). This means that when determining the quantitative characteristics of ecosystem sustainability, both the degree of impact and the critical values of ecosystem parameters or components should be determined According to Sumner (2008), an ecosystem's resilience to impacts is its ability to keep its internal structural connections and state or to change to a different type of stable state with different structural connections and state. This can happen when the system is put in a situation that could make it unsustainable. First, it is necessary to assess the amount of risk that brought the system to an unstable state in a certain period. This can happen with strong anthropogenic impacts or with small but frequent explosions. In this case, several scenarios will be played in the model (Fig. 1) and an approximate assessment of the transition of the system to an unstable state will be made. The numerical values of this assumption characterize the "risk" of an unstable system. The last stage of risk management is the correlation assessment of ecological damage and economic profit.

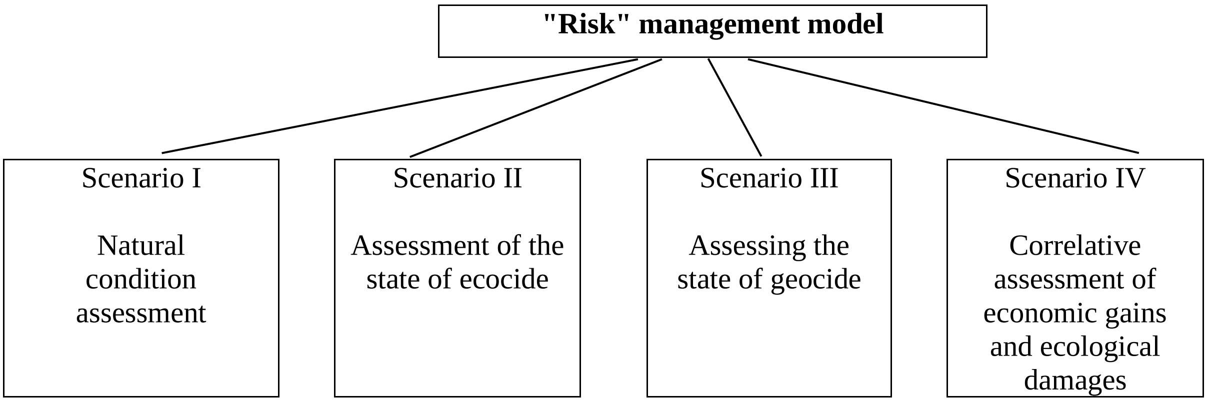

Figure 1. Risk Management Model

Conclusion

An in-depth study of how humans affect the environment and even create landscapes requires first classifying and mapping this system. This needs to be done based on several factors, such as looking at the system in different natural settings, types of farming, the amount of change in created landscapes, their growth, and natural landscapes and how they are connected to human-made changes and others.

Thus, because of the analysis of the geochemical features of underground and surface waters, soils, and atmospheric air of the landscapes surrounding the objects in an ecologically acute state, it can be concluded that in any region technogenic (mining, water, sedimentary, transport- communication, tourist-recreational, belligerent, etc.) as a result of the impact, there is a change in the appearance of both individual components and the entire complex and the deterioration of the landscape-ecological situation (condition). A high concentration of chemical elements is observed directly in the "epicenter" of impact (close to the ore body with a radius of 100-200 m), and in the following areal zones, the geochemical activity of elements is slowed down and depleted of ingredients (Davitaya, 1990).

Considering the above, we considered it possible to separate three main landscape-ecological zones on a separate technogenic region:

I. Ecologically dangerous zone—with significant pollution intensity and strongly expressed zonal-complex anomalies (area zones of the first order of migration of elements).

II. Ecologically less dangerous zone—with average pollution intensity and local-complex anomalies (areal zones of the second order of migration of elements - natural-technogenic and partially recultivated landscapes).

III. Potentially dangerous zone—with insignificant intensity of contamination and weak anomalies of small component composition (active quarries, bulk complexes and reconnaissance-research areas).

Competing interests

The authors declare that they have no competing interests.

Author Contribution Statements

ED and Z.S. developed the theory and performed the calculations. Z. S. and E. D. supervised the project and conclusions of this work. T. A. and N. R. worked out the technical details and performed the numerical calculations of the proposed experiment. All authors reviewed the results and contributed to the final manuscript.

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Differences in Socio-economic Transformations of Rural Communities in Russian Multi-ethnic Regions

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Georgian Geographical Journal, 2024, 4(2) 54-65

DOI: https://journals.4science.ge/index.php/GGJ

Citation: Imangulov L. Differences in Socio-economic Transformations of Rural Communities in Russian Multi-ethnic Regions. *Georgian Geographical Journal* 2024, 4(2). 54-65 https://doi.org/10.52340/ggj.2024.04.02.07

Abstract

The article analyzes the differences in the rural communities' transformation in some national republics of Russia. To verify the hypothesis put forward on the basis of a review of sources and field observations, demographic statistics, rural settlement and other indicators characterizing the rural population are analyzed. Among rural communities with different ethnic identities, there is a significant differentiation in the share of the rural population, birth rate and settlement structure. Differentiation is due to the different involvement of ethnic rural communities in urbanization processes and processes of social modernization. Analysis and classification of differences made it possible to identify options (inertial and modernization) and stages ("expansion", "from expansion to compression", "compression" and "disappearance in the previous format") of the post-Soviet rural communities transformation. Most of the Russian rural communities are undergoing active modernization. At the same time, in rural areas of Russia, there are still rural communities at the stage of "expansion" (largely Dagestani and Ingush rural communities). The discussion section presents a classification of ethnic rural communities in Russia according to their predominant variant and stage of transformation in the post-Soviet period. Based on the results of field studies, examples are given that confirm the presence of deviations from the predominant variant and stage of transformation of rural communities. For example, the leading factor in the differences in the variants and stages of socio-economic transformation of the surveyed Tatar and Chuvash rural communities of the Batyrevsky and Fyodorovsky districts is the development of the economic base of the region. Due to the more active Soviet industrialization of the economy of Bashkortostan, many communities in the Fyodorovsky district are at the stage of "compression" and "disappearance", while in the Batyrevsky district only in recent decades has the outflow of population to the cities accelerated. In addition, a comparative analysis of the rural settlement transformation of ethnic groups made it possible to confirm the universality of the stages of rural communities' transformation. In the Batyrevsky district this is expressed, for example, in the temporary lag of depopulation of Tatar and Chuvash rural communities.

Keywords: ethnic groups, migration, social modernization, local rural-urban systems, socio-economic transformation, rural areas

Introduction

In the post-Soviet period, rural areas of Russia have undergone large-scale transformations associated with the destruction of the collective-state farm system and large-scale depopulation of the rural population due to its migration outflow to the cities. Post-Soviet transformation processes in rural areas of Russian regions have different speeds and spatial coverage (Alekseev & Safronov, 2017; Nefedova, 2012b).

The socio-economic transformation of rural areas in the national republics of Russia has its own specifics (Nefedova, 2012ab). In 1992-2020, the share of the rural population living in the national republics of Russia increased by 4 percentage points or 0.8 million people, reaching 26% (9.6 million people), despite an overall decrease in the rural population in the country by 5% or 1.9 million people.

This illustrates the completely different functioning of rural areas in the national republics of Russia in comparison with the regions with predominantly Russian population shares. However, the dynamics of the demographic development of rural areas in the national republics is uneven: an increase in the rural population is recorded only in the republics of the North Caucasus and some national republics of Siberia.

The focus of research by Russian geographers has traditionally been on zonal features of rural settlement and zonal types of rural areas. Works describing the characteristics and problems of rural development in individual regions have become widespread. The rural areas of the Central Non-Black Earth Region with a historically high share of the Russian population have been studied most thoroughly (Averkieva, 2021). Particular attention is paid to its features of demographic and economic contraction, and then the revitalization of rural areas through the development of dacha recreation (Averkieva et al., 2021; Fomkina, 2017).

Ethnocultural differences in rural areas are most often considered as one of the factors of spatial differentiation of rural areas through the prism of demography, economics and lifestyle of the population (Nefedova, 2012b). There are also several works describing the ethnically expressed rural areas of Russian regions using the example of individual national republics: Buryatia - (Breslavsky, 2013), Tuva - (Gusakov, 2019) and Chuvashia - (Imangulov, 2021).

A comparative analysis of the results of post-Soviet regional studies of rural areas in Russia suggests the existence of prevailing variants of transformation of rural communities with different ethnic population structures. This hypothesis was also voiced by the leading researcher of rural Russia, T.G. Nefedova: *"…a comparison of modern rural communities of some non-Russian peoples on the territory of Russia with Russian demographically full-fledged communities of the beginning of the 20th century does not exclude the hypothesis of identical, but chronologically different phases of the life cycle of rural communities…"* (Nefedova, 2012b).

However, this scientific idea in Russian geographical science, despite the presence of studies in the field of ethnic differentiation of the rural population (for example, - (Alekseev&Imangulov, 2022; Imangulov, 2023; Cherkasov, 2018)), did not receive further development, which emphasizes the relevance of this study.

Abroad, there are often works describing ethnically expressed rural areas. However, it is extremely rare to find works directly linking the options and stages of development of rural communities and rural settlement. Among such works, one can highlight the study (Collins-Kreiner, 2013), in which the dynamics of the development of a network of villages in the central part of Israel is considered using the "Product Life Cycle" model.

In the actively industrializing and urbanizing PRC, the development of rural communities is considered in interaction with the external (mainly urban) environment, which can lead to the growth, decline, or even disappearance of rural communities (Yuheng et al., 2019; Hualou et al., 2021). For example, in the northern Chinese province of Shanxi, researchers identified 5 types of development of rural settlements and, accordingly, rural communities in the context of the active spread of urbanization processes: "growth", "maturity", "flourishing transformation", "stepwise regression" and "decline" (Yajing et al., 2022).

A review of Russian and foreign works did not find studies in which, when studying the development of rural communities, the ethnic structure of the population is considered in relation to the transformation of rural settlement of the population. Although the ethnic structure of the population based on the experience of studying local rural areas of Russia, is able to classify, for example, different trends in the population dynamics of villages (Imangulov et al., 2021) or the dynamics of agricultural production (Nefedova, 2012b; Fadeeva, 2015).

In this regard, the purpose of this study is to verify, based on open statistical data, the hypothesis about the existence of differences in the prevailing variants and stages of transformation of rural communities with different ethnic population structures. The result of this study should be a classification of ethnic rural communities in Russia in accordance with their prevailing variants and stages of transformation.

Methods and Materials

The titular population of the national republics has a number of aggregate differences from the Russian majority in the country. In Russia, this is due to the different involvement of ethnic groups in the socio-economic development trends that are common for the country and the world (Demographic, 2006; Zubarevich, 2003).

In this regard, the transformation of rural communities in national republics is determined not only by, for example, the universal processes of urbanization throughout the world but also by the economic, social, and cultural modernization of the non-Russian population, which either partially underwent modernization during the Soviet period or is just being drawn into it.

The object of this study is ethnic rural communities, by which the author means an ethnic community of people with a certain geographical localization (in a settlement/settlements) and the presence of close social ties between its members. The author in the study distinguishes between the concepts of ethnos and ethnic groups: rural communities of a region as a whole or an ethnos (for example, Russian rural communities of the Ivanovo region) and a specific rural community of a settlement (for example, the Russian rural community of the village of Vladimirovka in the Ivanovo region).

To verify the above hypothesis, the study first (1) analyzes the differentiation of rural communities of the titular peoples of the national republics according to their involvement (a) in urbanization processes and (b) in the processes of social (demographic) modernization of the population. For this purpose, the study uses the following basic indicators of the characteristics of the rural population, which serve as indicators of processes (Table 1).

Table 3: Indicators of options for transformation of rural communities and settlement communities

Characteristics rural communities	**Indicators**	**Data sources**
Demographics	Dynamics of rural population	Population censuses of the Russian Federation in 2002, 2010 and 2021
	Structure of rural settlement	
	Birth rate of rural population	BDPMO RF
Migration	Average size of rural household	BDPMO RF
	Rural population share	Population censuses of the Russian Federation in 2002, 2010 and 2021
Economic	Labor migration of rural population	Expert assessments
	Structure of employment of rural population	Expert assessments

Further (2) the post-Soviet transformation of rural settlement of the ethnic group in rural areas[1] is analyzed because changes in the distribution of the rural population across different classes of rural settlements by population may indicate trends in the compression, stabilization or expansion of the settlement of ethnic groups.

The study is based on two groups of materials. The first group includes open statistical data, in particular the All-Union and All-Russian population censuses of 1989, 2002, 2010 and 2020. The second group of materials is represented by the results of expeditions, in particular visual observations, and the results of expert and in-depth interviews with the rural population.

In the period from 2021-2024, within the framework of various projects, the author visited and surveyed 24 peripheral/semi-peripheral areas[2] with a predominantly rural population in 8 national republics of the Russian Federation. The surveyed republics: Bashkortostan, Buryatia, Dagestan, Ingushetia, Mordovia, North Ossetia-Alania, Tatarstan and Chuvashia. This sample of national

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1In the study, the rural settlement of an ethnic group in rural areas refers to the totality of rural settlements in which the share of the corresponding ethnic group in the ethnic structure of the population exceeds 60%.

2The choice of areas with peripheral and semi-peripheral locations for the survey is due to the fact that in areas with a suburban location, completely different socio-economic processes are recorded due to the agglomeration influence of cities.

republics almost completely covers the ethnocultural diversity of the main zone of settlement and economic development of Russia.

The verification of the research hypothesis is carried out on the example of rural communities of the titular ethnic groups of the visited and surveyed republics: Bashkir, Buryat, Dagestan (Avar, Dargin, Kumyk, Lak, Lezgin, Rutul and Tabasaran), Ingush, Mordvin, Ossetian, Tatar, and Chuvash rural communities.

Results

The spread of urbanization processes determines the transformation of rural communities of any ethnic identity in the post-Soviet space. With a systematic increase in the share of the urban population of an ethnic group, there is a "washing out of the population" from rural areas, which ultimately is reflected either in a decrease in the number of rural communities or their disappearance.

There is a certain differentiation of the analyzed ethnic groups of Russia according to the share of urban and rural population (Table 2). A high share of the rural population (above 50%) is found among the Dagestani peoples, except for the Laks and Lezgins, as well as the Buryats, Bashkirs, and Chuvashes (2020). Average and low values of the share of the rural population (less than 50%) are found among the Mordvins, Lezgins, Ossetians, Tatars, Laks, Russians and, Ukrainians.

The urbanization indicator of an ethnic group is primarily influenced by the time of the beginning of large-scale migrations of the rural population "village-city". Russians and Ukrainians initially have a richer experience of population mobility, especially in the pre-revolutionary period (resettlement to newly developed territories, seasonal migration of peasants to cities, etc.).

For other ethnic groups, the key barrier to migration from the village to the city was the lack of knowledge of the Russian language. For this reason, non-Russian ethnic groups began to migrate to the city with a certain time lag. In the 1980s, more than 50% of the Tatar, Ossetian, and Lak population already lived in urban areas. Later, in 1989, more than 50% of the Mordvins lived in cities, and in 2020, Lezgins. Other ethnic groups (Chuvash, Bashkirs, Buryats and other Dagestani peoples) never crossed the threshold of 50% of the urban population.

In 1989-2020 decrease in the rural population was recorded among Ukrainians, Mordvins, Chuvashes, Tatars, and Russians; stabilization—among the Buryats; growth—among the Bashkirs, Ossetians, Ingush, and Dagestani peoples (Table 1).

In addition to the scale of rural-urban migration, the dynamics of the rural population of ethnic groups is affected by the birth rate, which can, for example, in the Republic of Dagestan affect the growth of the rural population even in rural areas with migration-related population loss.

The maximum value of the total fertility rate of the rural population in 2019 (over 14 per mille) was among the Dagestani peoples, with the exception of the Lezgins and Nogais, as well as the Ossetians, Bashkirs, and Buryats, which indicates that the demographic transition of the rural population is not yet complete. The minimum value of the indicator (less than 10 per mille) is among Russians, Ukrainians, Mordvins, Chuvashes, and Tatars.

The average private rural household indicator gives an almost identical distribution of ethnic groups: the tradition of a large family has been noticeably preserved among the rural population of the peoples of Dagestan and Ossetia, while among Russians, Mordvins, Chuvashes, and even Tatars, the average size of a rural household is less than 3 people.

Table 2. Some indicators of transformation of rural communities with different ethnic population structures

Indicator	Rural population share, %	Dynamics of rural population, %	Total fertility rate, per mille*	Average household size, people*
Year / period	2020	1989-2020	2019	2010
Laks	28.5	27.0	14.9	3.8
Tatars	32.7	-18.5	9.8	2.9
Ossetians	37.5	34.1	15.7	3.7
Lezgins	44.8	52.1	11.6	4.2
Mordva	48.7	-54.0	6.5	2.8
Chuvash	51.0	-38.9	8.4	2.7
Bashkirs	51.4	18.4	14.9	3.2
Buryats	52.5	-0.2	15.4	No data
Kumyks	52.8	97.3	20.6	4.6
Tabasarans	52.9	31.8	16.0	4.4
Rutuls	57.4	43.0	16.0	4.4
Avars	62.0	70.4	18.7	3.7

Dargins	63.5	59.0	17.8	3.5
Nogais	66.3	19.6	11.8	4.5

**Note: the table presents average values of indicators for several peripheral mono-ethnic rural areas within the republics in which the ethnic group is the titular one*

In accordance with the characteristics of the rural population of different ethnic groups, the following groups of ethnic rural communities with similar indicator values are distinguished:

Group 1: Russian, Ukrainian, Tatar, Mordvin, Chuvash;

Rural communities of the first group as a whole have experienced or are still experiencing a significant migration outflow of part of the population to cities. Urbanization processes have undermined the demographic potential of most communities. Ethnic assimilation has an additional negative impact on the population dynamics of Mordvin and Chuvash rural communities.

Group 2: Bashkir, Buryat;

Rural communities of the second group have only in recent decades begun to experience a significant migration outflow of the population to cities. Rural communities have significant demographic potential for development, as a result of which either an increase in the rural population in the post-Soviet period (Bashkir) or its stabilization against the background of migration to cities (Buryat) is noted.

Group 3: Ossetian, Lezgin, Lak;

Rural communities of the third group as a whole experienced a migration outflow of part of the population back in the 20th century. This is illustrated by the indicator of the low share of the rural population of the corresponding ethnic groups in comparison with other ethnic groups of the North Caucasus. At the same time, Ossetian, Lezgin, and Lak rural communities demonstrate similar rates of natural growth as other Caucasian rural communities, which is reflected in the increase in their population in the post-Soviet period.

Group 4: Avar, Dargin, Nogai, Kumyk, Tabasaran and Rutul.

Rural communities of the fourth group in recent decades have generally demonstrated an explosive growth in population: from 20-30% to 100%. It is associated primarily with high birth rates, which are capable at this stage of compensating for the migration outflow of the rural population to the cities.

Differences in some indicators characterizing the demographic development of different ethnic rural communities are due to the different degree of involvement of ethnic groups in the processes of demographic modernization. Most ethnic rural communities are currently actively modernizing. At the same time, some rural communities are going through socio-cultural modernization of the Eastern type, expressed in the preservation of traditional elements (for example, rural communities of Dagestan, Ingush, etc.). Another part of rural communities is apparently going through modernization of the Western type, expressed in the active displacement of traditional elements by modern ones (for example, Bashkir, Buryat, Tatar, Chuvash and Mordvin communities).

At the same time, part of the ethnic rural communities, in connection with their more active social and, in particular, demographic modernization during the Soviet period,

At the same time, some ethnic rural communities, due to their more active social and in particular demographic modernization during the Soviet period (Demographic, 2006), are characterized by an inertial version of transformation, expressed, for example, in the preservation of established demographic trends in earlier periods (for example, Russian and Ukrainian rural communities).

Ethnic rural communities, in addition to differences in the variants of socio-economic transformation ("inertial - modernization"), differ in the prevailing stage of transformation of rural communities. This is most clearly confirmed by the structure of rural population settlement3 in terms of ethnic identity and its post-Soviet dynamics.

The distribution of the number of settlements by different population classes between ethnic communities confirms the thesis about the more vibrant ethnic rural communities of Dagestan from a demographic point of view (Table 3). The number of rural settlements with a population in the 501-1000 and 1001-2000 classes, on the contrary, is minimal in the ethnic rural communities of the Ural-Volga region.

3In this paper, the rural settlement of ethnic groups is understood as the entire set of rural settlements with a share of the corresponding ethnic group in their ethnic structure above 60%.

Table 3. Distribution of the total number of rural settlements of the corresponding ethnic group by population class, 2002, %

	Less than 50	51-200	201-500	501-1000	1001-2000	2001-5000	More than 5000
Settlement in dry steppe and semi-desert zones (500-1000 people)							
Nogais	2.8	16.7	19.4	25.0	25.0	5.6	5.6
Large dense settlement in the southern regions (1000-3000 people)							
Kumyks	0	6.8	6.8	8.5	23.7	35.6	18.6
Mountain focal settlement (200-500 people)							
Tabasarans	4.4	13.3	38.9	25.6	13.3	4.4	0,0
Lezgins	4.5	14.2	20.6	20.6	21.9	15.5	2.6
Rutuls	6.3	6.3	31.3	31.3	12.5	12.5	0,0
Dargins	7.2	25.3	26.3	18.1	13.4	7.2	2.5
Laks	9.6	35.6	35.6	9.6	6.8	2.7	0,0
Avars	10.9	27.4	22.8	15.5	13.6	7.5	2.4
Ossetians	33.7	14.0	10.5	8.1	16.3	9.3	8.1
Medium- and large-scale settlement in the central zone of Russia (200-500 people)							
Chuvash	9.9	44.5	30.3	11.8	2.6	0.8	0.1
Tatars	12.1	32.3	36.4	15.2	2.9	0.7	0.4
Bashkirs	15.2	34.1	34.2	13.8	2.0	0.3	0.4
Mordva	30.2	26.1	26.1	13.3	3.1	1.0	0.2
Medium-sized focal settlement (200-500 people)							
Buryats	8.7	24.3	29.6	22.8	12.6	1.5	0.5

The analysis of the transformation of rural settlement patterns of ethnic groups in 2002-2020 (Table 4) allows us to draw two important conclusions.

Table 4. Change in the number of rural settlements of the corresponding ethnic group by different population classes, 2002-2020, %

	Less than 50	51-200	201-500	501-1000	1001-2000	2001-5000	More than 5000
Settlement in dry steppe and semi-desert zones (500-1000 people)							
Nogais	3.9	-10.0	13.9	1.7	-5.0	-2.2	-2.2
Large dense settlement in the southern regions (1000-3000 people)							
Kumyks	1.5	-5.2	0.9	0.8	-0.7	-7.9	10.6
Mountain focal settlement (200-500 people)							
Tabasarans	1,1	4.2	-4.8	0.8	-1,2	0,0	0,0
Lezgins	1.3	3.3	-5.7	1.4	0.1	-0.5	0,0
Rutuls	16.0	-0.7	7.6	-14.6	-1.4	-6.9	0,0
Dargins	1,2	-2.7	-1.7	1.0	-0.2	1.6	0.7
Laks	1,1	-4.9	-0.9	3.7	-2.8	2.6	1.3
Avars	1.9	-5.1	0.4	2.0	-2.7	3.0	0.4
Ossetians	4.2	5.3	-5.5	-0.1	-0.8	-0.6	-2.5
Medium- and large-scale settlement in the central zone of Russia (200-500 people)							
Chuvash	7.7	5.7	-6.5	-5.7	-1,1	-0.1	0,0
Tatars	4.3	5.8	-5.1	-4.8	-0.2	0.1	-0.1
Bashkirs	6.1	3.7	-5.4	-5.0	0.3	0.1	0.2
Mordva	8.8	3.0	-2.8	-7.2	-1.6	0,0	-0.2
Medium-sized focal settlement (200-500 people)							
Buryats	5.3	3.7	-2.6	0.2	-9.1	1.0	1.5

Firstly, the simultaneous reduction in the number of medium-sized (201-1000 people) and increase in the number of small settlements (less than 50 people) among the peoples of the Ural-Volga region, some peoples of Dagestan (Rutuls, Lezgins and Tabasarans), Ossetians, and Buryats is the result of the processes of depopulation and compression of the corresponding rural communities.

Secondly, the simultaneous increase in the number of medium (201-1000 people) and very large settlements (more than 2000 people) against the background of a decrease in the number of large settlements (1001-2000 people) among the other peoples of Dagestan (Nogais, Kumyks, Avars, Laks) is the result of a gradual "erosion" of the middle link of rural settlements. It was observed among the peoples of the Ural-Volga region in earlier periods.

Discussions

Differentiation of the surveyed ethnic rural communities of Russia in accordance with demographic characteristics and features of rural settlement in dynamics confirms the put forward hypothesis, formulated on the basis of a bibliographic review of sources and visual observations.

The diversity of ethnic rural communities in the national republics of Russia in the post-Soviet period demonstrates different dynamics and directions of transformation.

Based on the transformation of the rural settlement of the population, it was found that the transformation of rural communities has a certain stage-by-stage nature, which can be reduced to the following stages observed in Russian regions: "Expansion", "From expansion to compression", "Compression", "Disappearance (community in the previous format)".

Taking into account the ethnic structure of the population, the rural areas of Russia can be described as a set of ethnic rural communities at different stages of transformation.

The "Expansion" stage, rarely encountered in Russian regions, is quite widespread among the rural communities of the North Caucasus. These rural communities are distinguished by a younger age structure of the population, high birth rates, and population growth. This is facilitated by the post-Soviet strengthening of the position of religion (Islam) among the population, the traditional structure of society, and conservatism. However, some of the North Caucasian rural communities do not belong to this stage (for example, Ossetian, Lezgin and Lak). In the case of the Lezgins, this is due to the historically higher spatial mobility of the population (rural Lezgins actively participated in labor migrations to oil fields in the 19th-20th centuries). Lak rural communities were significantly influenced by institutional conditions: the implementation of the program of "settling highlanders on the plain" and the resettlement of Laks to the lands of Chechens deported during the Soviet period.

The development of Ossetian rural communities is closely linked to the dynamics of the economic base of the Republic of North Ossetia-Alania. During the periods of Soviet industrialization, the urban population among Ossetians grew. As a result of the degradation of the economic base of the republic in the transition period (in the 1990s), on the contrary, there is an increase in the rural population (some temporary "rollback" to the past), which now, however, has begun to decrease again due to urbanization of a non-industrial nature.

The stage "From expansion to compression" is characteristic of the Bashkir, Buryat, Ossetian, Chuvash and Lezgin rural communities. These ethnic rural communities only began to be actively involved in urbanization processes at the end of the 20th - beginning of the 21st centuries, which, for example, in Buryatia led to the rapid growth of the suburbs of Ulan-Ude, and in Bashkiria to the "indigenization" of the ethnic structure of the population of the regional capital - Ufa.

At the same time, the demographic potential of most of these ethnic rural communities has already been somewhat undermined, which is expressed in a fairly high share of the urban population (from 40 to 60%). The high migration outflow of the rural population is supported by a decrease in the birth rate and the destruction of traditional ways of life of communities.

The "Compression" stage is typical for Tatar and Lak rural communities. It is these rural communities, with the exception of the Russian and Ukrainian population, that have suffered the most from the urbanization processes. A high proportion of the elderly population and low birth rates generally characterize Tatar rural communities.

Lak rural communities look slightly better against the background of Tatar rural communities, but the demographic potential undermined during the Soviet period significantly limits their development. In mountainous rural areas with a Lak majority (Lak and Kulinsky districts), abandoned settlements can very often be found. Inhabited settlements are characterized by extremely small size, significant seasonal differences in population dynamics, and high values of the share of empty housing stock.

The "Disappearance" stage of rural communities is less common in the national republics. Most often, these are Russian and Ukrainian rural communities, represented by small settlements with a predominantly elderly population or medium-sized settlements with a minimum share of families with children under 18. It is noteworthy that the abandonment of some settlements is opposed by new city dwellers—former rural residents—who, in the status of recreationists, complement the rural community. However, this still leads to the disappearance of former rural communities with a traditional way of life.

This is facilitated by the demographic transition that Russians and Ukrainians have gone through and the total outflow of population to cities.

Mordvin rural communities complement the list of these two ethnic groups, despite the fact that in the structure of the Mordvins the proportion of the urban population is significantly lower (51.3%). This is due to the extremely active spread of ethnic assimilation. It, coupled with the low birth rate, leads to a significant reduction in the rural population (-54% in 1989-2020) and the depopulation of rural settlements. Often in the intercensal periods, one can observe how Mordvin villages simply disappear on the map, turning into Russian ones.

It should be said that behind such a rapid transformation of ethnic identity, even among rural Mordvins, there is, for example, the actual disappearance of traditional economic structures and practices (abandonment of traditional gardening for Mordvin peasants), transformation of the way of life (disappearance of pagan elements), etc.

The above stages of transformation illustrate well how much rural communities are alive at the present time. From the text above, it is clear that in addition to general characteristics (demography, settlement, etc.), a special role is played by whether ethnic rural communities have undergone demographic modernization. This is important since it determines their preservation until the appearance of external actors of influence.

Accordingly, the transformation of ethnic rural communities in the post-Soviet period can be "inertial" or "modernization".

The first case is typical for Russian, Ukrainian, and Mordvin rural communities, the Soviet and post-Soviet development trends of which are identical (the main trend is depopulation and polarization of rural settlement). The second case is typical for other ethnic rural communities, which are not homogeneous within themselves due to different rates of demographic modernization, which gives rise to many variations in the development of rural areas with different ethnic population structures. Thus, by correlating the options and stages of transformation of different ethnic rural communities, we can obtain their following distribution (Table 5).

Table 5. Prevailing variants and stages of post-Soviet transformation of ethnic rural communities

		Options for post-Soviet transformation of rural communities	
		"Inertial"	"Modernization"
Stages of transformation of rural communities	"Expansion"	-	Avar, Dargin, Ingush, Kumyk, Nogai, Tabasaran, Rutul
	"From expansion to compression"	-	Bashkir, Buryat, Ossetian, Chuvash, Lezgin
	"Compression"	-	Tatar, Lak
	"Disappearance (of the community in the previous format)»	Russian, Ukrainian	Mordvins

In one way or another, based on data from other ethnic groups in Russia, a researcher or reader can supplement this distribution or test the methodology for their own research purposes using another region or country with a different ethnic population structure as an example.

Above, we discussed the prevailing variants and stages of transformation of ethnically different rural communities. However, when turning to local areas, one can even find in places a complete discrepancy between the variants and stages of transformation of rural communities with the same ethnic identity due to the local context. Let us briefly examine the variants and stages of transformation of rural communities that deviate from the general population.

To do this, let us compare two pairs of rural districts in the Volga region and the North Caucasus with a similar ethnic set of rural communities and the same characteristics of the territories.

1. Fyodorovsky District of the Republic of Bashkortostan—Batryrevsky District of Chuvashia.

Both the Tatar and Chuvash populations live compactly in rural districts (Table 6).

Table 6. Some socio-economic characteristics of the surveyed areas of Bashkiria and Chuvashia

Characteristics	Year	Republic of Bashkortostan	Chuvashia Republic
		Fyodorovsky district	Batyrevsky district
Distance to the regional center, km		214	132
Rural population density, people/km2	2020	9,6 (For reference: in the region as a whole - 10,6)	34 (For reference: in the region as a whole – 23,9)
Zonal features of rural settlement		Continuous development, medium and large population	Continuous development, small-medium populated

Characteristics	Year	Republic of Bashkortostan	Chuvashia Republic
Population, thousand people	2020	16,2	32
Dynamics of rural population, %	1989-2020	-17,6	-28,1
Time of emergence of a stable rural settlement network		1850 - 1890	XVI-XVII centuries
Ethnic structure of the population, %	2020	Tatars – 31,8 Russians – 24,5 Bashkirs – 21,8 Chuvash – 10,9 Mordvins – 9,5	Chuvashes – 67 Tatars – 30,9 Russians – 1,3 Mordvins - less than 1
Average population of rural settlements in the district by ethnic group, people	2020	Bashkirs - 302 Tatars - 301 Chuvash - 156 Mordovians - 147 Russians - 48 In the district as a whole - 237	Chuvashes - 487 Tatars - 1016 In the district as a whole - 572

Tatar rural communities of Fyodorovsky District are at the stage of active "compression", while Tatar communities of Batyrevsky District are mostly at the stage of "expansion", or "from expansion to compression". Such a situation is largely due to the different time of involvement of the rural population in "village-city" migration.

Tatar communities in Fyodorovsky District are distinguished by an elderly age structure of the population: in some villages, young families with children are practically absent or are present in limited numbers (up to 5-10 families). For example, in the villages of Akbulatovo and Izhbulyak, out of 100-200 permanent residents, more than 50% are people over 50 years old. It is noteworthy that despite the demographic crisis of these rural communities, the traditional economic structure is preserved thanks to representatives of older generations (an indicator of social modernization of the eastern type).

Tatar communities in Batyrevsky District, on the contrary, have a comparatively young population structure: in the villages there are many young families with an average number of children of two or more people. The Tatar villages of Chuvashia are extremely populous (the average size of a settlement in 2020 was 1,016 people, compared to 301 people in the Fyodorovsky District[4]) and extremely religious. The communities are quite closed, traditional and conservative.

The same situation is observed in relation to the Chuvash rural communities of the surveyed districts. In the Batyrevsky district, they are mainly at the stage of "from expansion to compression". In the Fyodorovsky district, there are Chuvash rural communities of two stages - both "from expansion to compression" and "compression". It is noteworthy that the dynamics of the average size of Chuvash settlements in the two districts revealed that the Chuvash communities of the Batyrevsky district are also beginning to depopulate in the post-Soviet period, repeating the dynamics of the Chuvashes of the Fyodorovsky district with a time lag of 30-50 years.

It is interesting that the transformation of Chuvash rural communities of the same stage "from expansion to compression" in two remote districts proceeds differently. For example, in the Fyodorovsky district, the male population began to participate on a large scale in labor migration to the mining regions of Siberia to replace Soviet employment in collective and state farms. In the Batyrevsky district in the post-Soviet period, relatively large personal subsidiary farms of the population became a solid basis for family budgets of the rural population. The cases considered emphasize the importance of considering the dynamics of the economic base of the region in which communities live at the stage of active urbanization: in Bashkortostan, rural communities underwent active transformation back in the Soviet period, while in Chuvashia it is only observed, but already in different conditions.

2. Levashinsky-Botlikhsky districts of the Republic of Dagestan.

Levashinsky and Botlikhsky districts are in the inner mountain part of the Republic of Dagestan. Dargins and Avars inhabit the first district, the second only by Avars (Table 7). In these mountainous

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4In the Fyodorovsky district, the maximum average population of Tatar settlements of 916 people was recorded by the population census in 1926, after which there was a consistent decrease.

districts, the Soviet state program for resettling the mountain population to the plain was not implemented, because of which the districts have an extremely high population and population growth in the post-Soviet period.

For the Avar communities of the Botlikh district, the predominant stage of transformation of rural communities is "expansion" (corresponds to the stage of transformation of the Avar rural communities of Dagestan as a whole). This is due to both a high birth rate and minimal migration of the population (the local population works in private subsidiary farms and participates with families in labor migrations outside the republic).

At the same time, in some Avar rural communities of the Levashinsky district (for example, in the village of Kutisha), on the contrary, there is a large-scale migration of young people in the direction of "village-city". One of the main reasons is the different degree of competitiveness of the population in the urban labor markets due to differences in the education of the population.

A similar situation is observed between the Dargin rural communities of the Levashinsky district. In some Dargin rural communities, due to the extremely high religiosity of the population, it is not customary to send children to school at all or to send them until the 9th grade. Parents justify this by the low practical significance of education in the conditions of the availability of more profitable employment opportunities in rural settlements (growing white cabbage and vegetables, transportation, trade, etc.). As a result, some Dargin rural communities are distinguished by simply "explosive growth" in population, which outpaces the overall regional growth rates of the rural population.

Table 7. Some socio-economic characteristics of the surveyed areas of Dagestan

Characteristics	Year	Republic of Dagestan	
		Levashinsky district	Botlikhsky district
Distance to the regional center, km		94	145
Geomorphological region (altitude zone)		Intramountain region of mountainous Dagestan	
Rural population density, people/km2	2020	98,9	87,2
Zonal features of rural settlement		Mountain focal livestock and agricultural settlement	
Population, thousand people	2020	80,4	59,9
Dynamics of rural population, %	1989-2020	Has grown 2 times	Increased by 2,2 times
Time of emergence of a stable rural settlement network		Approximately one chronological period (more than 300 years)	
Ethnic structure of the population, %	2020	Dargins – 77,2 Avars – 21,2 Others – 1,6	Avars – 96,3 Others – 3,7
Average population of rural settlements in the district by ethnic group, people	2020	Dargins – 1128 Avars – 1918	Avars – 1619

Deviations in the stages and variants of transformation of ethnic rural communities of Dagestan are associated, among other things, with the level of education of the rural population, which somewhere has a positive effect on the stability of rural settlement. This is because the higher the level of education of representatives of rural communities, the more options they must choose from and, as a rule, the higher their migration mobility, which is reflected in the depopulation of, for example, the same Avar village of Kutisha.

Conclusion

Based on the analysis of the values of demographic indicators and the settlement structure of the rural population of different ethnic groups, it was possible to identify differences in the prevailing variants of the transformation of rural communities with different ethnic structures of the population.

In many ways, the recorded post-Soviet differences are determined by the involvement of Russian ethnic rural communities simultaneously in the processes of urbanization and, above all, demographic modernization. The entire diversity of rural community's transformations can be described through universal variants of the rural community's transformation ("inertial" and "modernization"), reflecting the nature of changes in rural communities, and stages ("expansion", "from expansion to compression", "compression" and "disappearance in the previous format"), reflecting their scale of change.

The transformation of the majority of the surveyed ethnic rural communities has a modernization character (communities of the North Caucasus, the Volga region and Siberia), only a small number have an inertial character (for example, Russians and Ukrainians). More significant is the differentiation of ethnic rural communities in Russia, according to the current stage of transformation of rural settlements (otherwise rural communities, since the population of each individual settlement is a separate local community). Ingush and many Dagestani communities are at the stage of "expansion", Bashkir, Buryat, Chuvash, Ossetian and Lezgin communities are at the stage of "from expansion to compression", Tatar and Lak communities are at the stage of "compression", and Russian, Ukrainian and Mordvin communities are at the stage of "disappearance in the previous format".

The concept of cycles is not applicable to the analysis of the ethnic rural communities' transformation, since we are talking about a fundamental change in the composition of communities as a result of their modernization. The revival/revitalization of settlements by new city dwellers—recreationists—does not contribute to the restoration of traditional elements and connections.

Field surveys of rural communities and data on the average size of a rural settlement have shown that there are certain deviations from the prevailing variant and stage of transformation among rural communities of one ethnic identity. They are usually associated with the action of local factors in the development of rural settlements (for example, the development of the economic base, the historical experience of local population mobility, the factor of human personality, etc.).

Examples of the transformation of Tatar and Chuvash, Avar, and Dargin rural communities located within territories with similar zonal characteristics and development conditions confirmed that these rural communities went through the same set of stages of rural community transformation with a certain time lag.

Competing interests

The authors declare that they have no competing interests.

Funding

The Russian Science Foundation Grant No. 24-17-00107 has provided financial support for this research.

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Mapping of Zoonotic Diseases in South Caucasus

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Georgian Geographical Journal, 2024, 4(2) 66-74

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Chichinadze, T.; Gulashvili, Z.; Suknidze, N.; Bolashvili, N. Mapping of Zoonotic Diseases in South Caucasus. Georgian Geographical Journal 2024, 4(2). 66-74
https://doi.org/10.52340/ggj.2024.04.02.08

Abstract

The presented article relates to geographical studies of the distribution of seven rare animal infections in the South Caucasus, digital mapping and geographic and cartographic analysis. The study focuses on mapping infections that are transmitted from animal to animal, from animal to human, and rarely from human to human. All diseases have a cause of spread (bacteria, insects, ticks, fleas) or transmission (mammals, rodents). Sometimes the provoking factor of disease and infection is a geographical variable favorable for bacteria (high temperature, humidity, flood, wind, runoff), favorable for bacteria (soil type, acidity or chemical composition of the soil, orography, perspective, landscape), etc. This article focuses on the process and methodology of digital mapping as digital mapping establishes the relationship between geographic variables and the spread of infections. Digital maps are also the main means of conducting dynamic research, analysis and further forecasting.

Keywords: Mapping, Geodata, Infection, Cartography, GIS Analysis

Introduction

The study area is the South Caucasus, located between the Black and Caspian Seas. The South Caucasus is bordered by the Russian Federation to the north, the Caspian Sea to the east, Iran and Turkey to the south, and the Black Sea to the west. Politically, it includes three independent states - Armenia, Azerbaijan and Georgia (Maruashvili, 1978).

There is a lot of different nature in the South Caucasus because of its location: it covers 190,000 km², its hypsometric height (the absolute height of the surface ranges from -28 m above the Caspian Sea to 5,208 m in Shkhara, Georgia) and its position on the border between temperate and subtropical climate zones (because it is mostly mountainous, it is also known as altitudinal climate zonality).

High mountains and plateaus occupy more than half of the South Caucasus' territory. The main orographic units are the Caucasus, the Transcaucasian Plain, the Lesser Caucasus, the Talysh Mountains, and the volcanic mountains of the South Caucasus. This geographical feature of the region shapes the natural diversity of the South Caucasus, which encompasses almost all natural landscape types. These are: desert landscapes; semi-desert landscapes; dry steppes; moderately dry steppes; wet steppes; humid subtropics; subtropical forest landscapes; mountain forest landscapes; mountain-steppe landscapes; and glacial-nival landscapes (Ukleba et al., 1970).

Due to the diversity of nature, the region often encounters various infectious and pathological diseases. Each geographical variable has a great influence on the activation of various infections (climate types) and their spread (runoffs, insects, ticks, rodents, and ungulates). The habitat of the bacteria causing the infection can be a specific type of soil, etc.

Methods and Materials

We created about fifty thematic maps to determine the relationship between infection and geographic variables.

First, data from seven zoonotic diseases was processed in Excel: infection in animals, infection in humans, ticks, and disease outbreak files, followed by a link to them in the ArcGIS program. Files of fleas, rodents, and ungulates, which contribute to the transmission and spread of diseases, were also processed (Malania, et al., 2014; Kracalik, et al., 2013). In the article, we will talk about only a few variables.

We created digital maps, conducted analysis in ArcGIS and ArcGIS Pro, and processed the atlas design in Adobe Illustrator.

Results

During the research process, it is important to prepare a general geographical basis for the study area. The general geographical basis of the South Caucasus was prepared in the ArcGIS at a scale of 1:100.000, however, since the publication of an atlas is planned, a cartographic generalization was made for A3 format. An important stage was the establishment of standards for general elements of the map, hydrographic network, and sorting of roads; The density of settlements was determined according to population census data and others (using digital maps). For maps prepared for publication, the width of lines, size of signs, colour, and others were determined for the above objects in accordance with the scale (Fig. 1, 2).

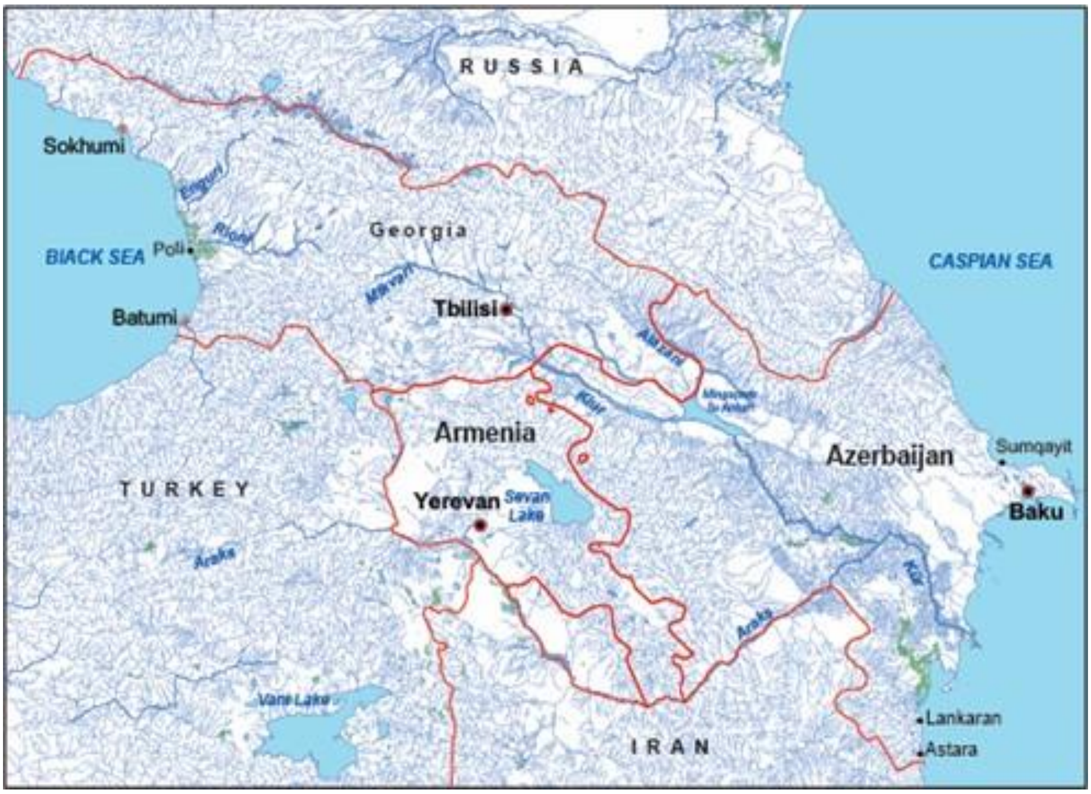

Figure 2. General hydrographic? basis of the South Caucasus

It is known that soil is a reservoir for a variety of microorganisms—including bacteria, fungi, protozoa, and viruses—that can be pathogenic to humans and animals. Human and animal pathogens in soil can be categorized into four broad groups that reflect their degree of residency in soil: permanent, periodic, transient, and incidental (Bultman & Fisher, 2013). Permanent pathogens are soil inhabitants that spend their entire life cycle in soil and sometimes become infectious for humans and animals. Examples include organisms such as Clostridium botulinum or Clostridium tetani, which produce neurotoxins when ingested in contaminated food or through contaminated wounds, respectively. Many zoonotic pathogens also either live in soil or their vectors live or spend part of their life cycle in soil (Stefan et al., 2020). Periodic pathogens are soil organisms that require the soil environment to complete part of their life cycle. For example, Bacillus anthracis, the causative agent for anthrax in humans or livestock, is often found in soils and can survive for long periods as endospores (Dragon & Rennie, 1995).

Figure 2. The general geographic basis of the South Caucasus

It is known that in order to analyze the spread of anthrax, it is important to study soil types (Fig. 3) and soil-forming rocks. To do this, we used a soil map of Georgia at a scale of 1:500,000 and determined the following parameters in the databases: soil pH, soil chemical elements, moisture index, etc. (Agrokavkaz, 2024; Matchavariani, 2012). We placed anthrax outbreaks on a digital soil pH map and calculated the frequency (Fig. 4).

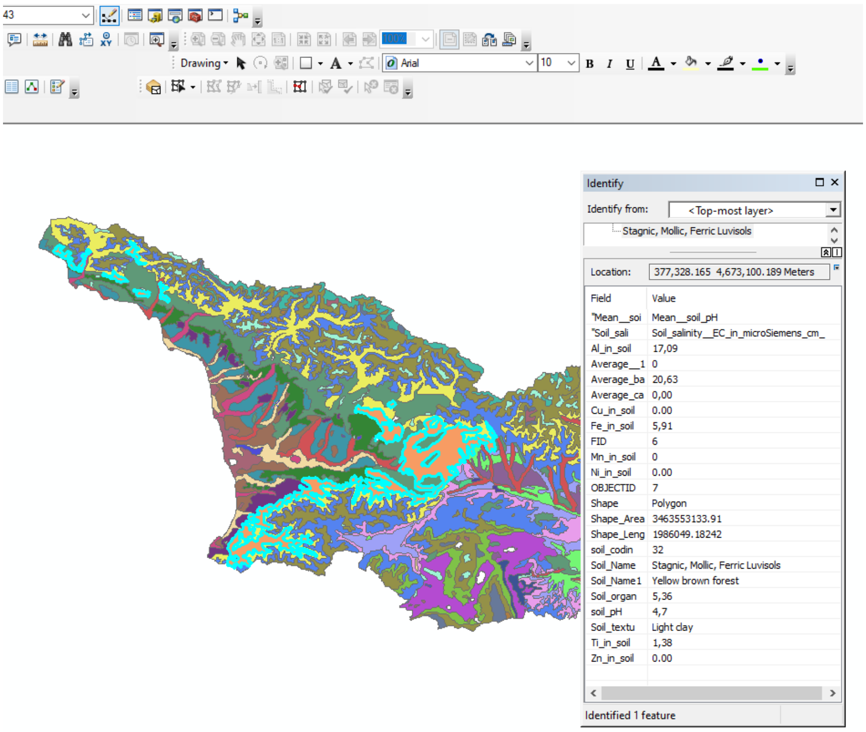

Figure 3. Soil type, important soil parameter, ArcGIS

Research has shown that the main foci of anthrax and high levels of intensity were observed mainly where the following type of soil with its own characteristics was observed: 1) *Alluvial calcareous*: Soil texture - Heavy loam, soil organic matter content 3,18 %, soil pH - 6,2, average base saturation 20,89mg, average calcium carbonate concentration 2,9%, "soil salinity (EC in microelements/cm)" 115,4, Fe in soil - 7,66%, not found here - Cu, Mn, Zn, Ni, as for Al in the soil is 15,81%, Ti – 0.55. Anthrax 155 foci have been identified in the distribution area of this type of soil; 2) *Cinnamonic*: 60 centres of anthrax have been identified in the distribution area of this type of soil. Soil characteristics are Soil texture - light loam, soil organic matter of the content of 4,9%, soil pH - 7,4, average base saturation 23,07 mg, average calcium carbonate of concentration 7,5%, "soil salinity (EC in microelements/cm)" 87,0, Fe in soil - 7,99%, not found here - Cu, Mn, Zn, Ni; in this type of soil, Al makes up 17.07% of the total, and Ti makes up 0.57; 3) Rendzic leptosols: 51 anthrax centers have been found in the area where this type of soil is found. Soil characteristics are Soil texture - light loam, soil organic matter content 4,95%, soil pH - 7,8, average base saturation 28,1 mg, average calcium carbonate concentration 20,13%, "soil salinity (EC in microelements/cm)" 68,8, Fe in the soil makes up 12.72% of it; Cu, Mn, Zn, and Ni are not found here. Al makes up 12.75% of it, and Ti makes up 0.68. There are the same number of foci in yellow soils and alluvial acid soils, and then they are spread out in this order: eutric cambisols, chernozems, yellow podzolic gley soils, andosols. Red soils, dystric cambisols, mountain forest meadows, and cleysols exhibit the lowest abundance of anthrax. Eutric cambisols and mountains have not recorded anthrax (Chichinadze et al., 2023).

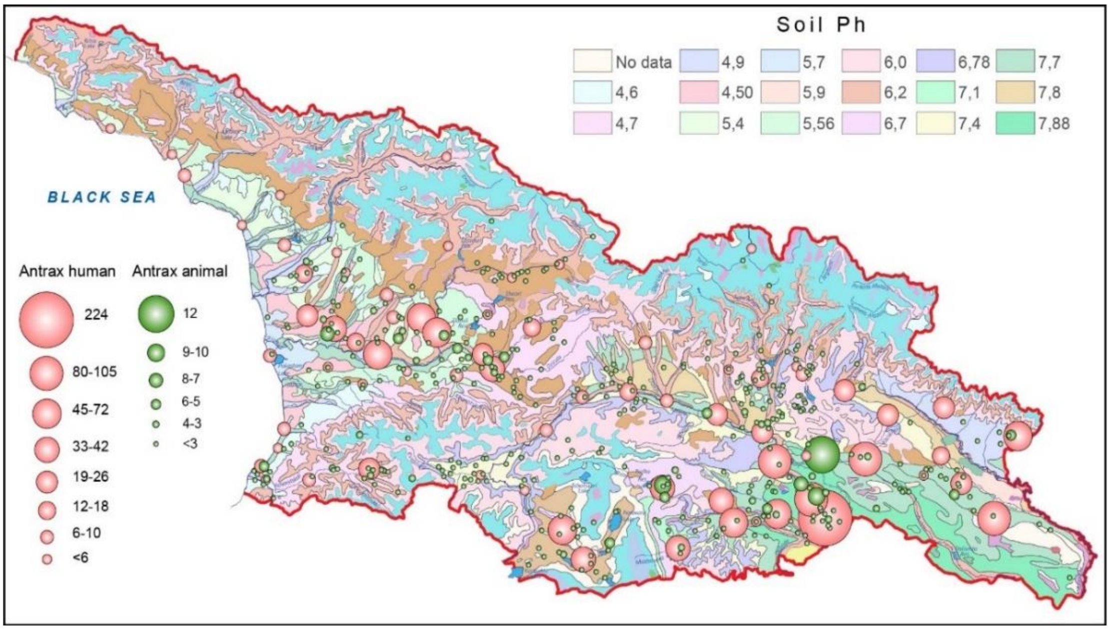

Figure 4. Anthrax density frequency

When studying zoonotic infections, we defined land use at a scale of 1:500.000. Overall, global research has shown that the prevalence and incidence of zoonotic diseases are increasing. This increase can be partly explained by changes in land use, including deforestation, urbanization and construction. Because after habitat destruction, animal carriers of infections move to different places (Bjornstad, 2021).

Our land use map databases include urban or developed land, agricultural land, grassland, forest, water, wetland, and barren land. We linked a map of land use to a map of anthrax outbreaks, distribution, and frequency. Based on the study, anthrax foci in humans are found in cities, foci in animals are found in agriculture, on pastures, farms, and in forests, and foci in soil are found in both urban and rural areas, as well as in forests (Fig. 5, 6, 7, 8).

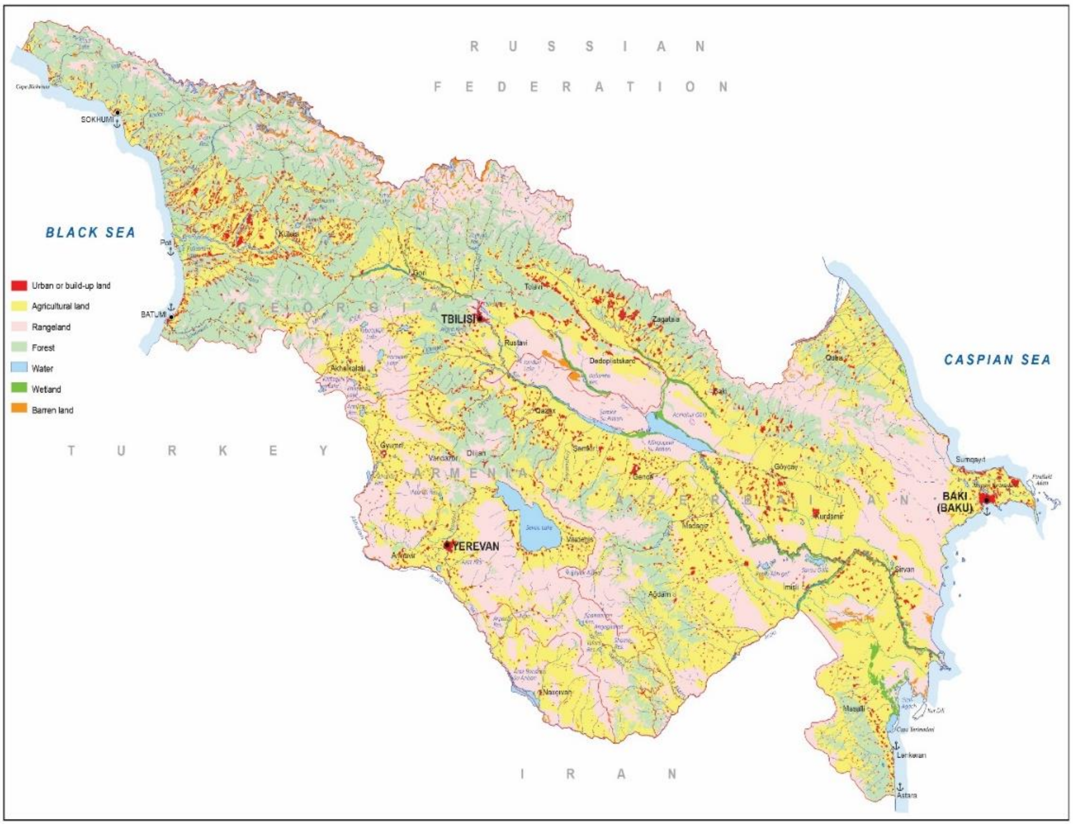

Figure 5. Land use

Figure 6. Incidence and frequency of anthrax in humans and land use

Figure 7. Incidence and frequency of anthrax in animals and land use

Figure 8. Incidence and frequency of anthrax in soil and land use

In addition to geographic variables, the movement of livestock on roads also contributes to the spread of the disease. For example, we compiled a map of cargo transportation routes and placed anthrax foci in the soil on it. These seasonal routes operate from July to October. A lot of people and places nearby are at risk of getting the disease right now because infected animals leave behind anthrax bacilli in their urine, feces, blood, and other bodily fluids (Fig. 9, 10).

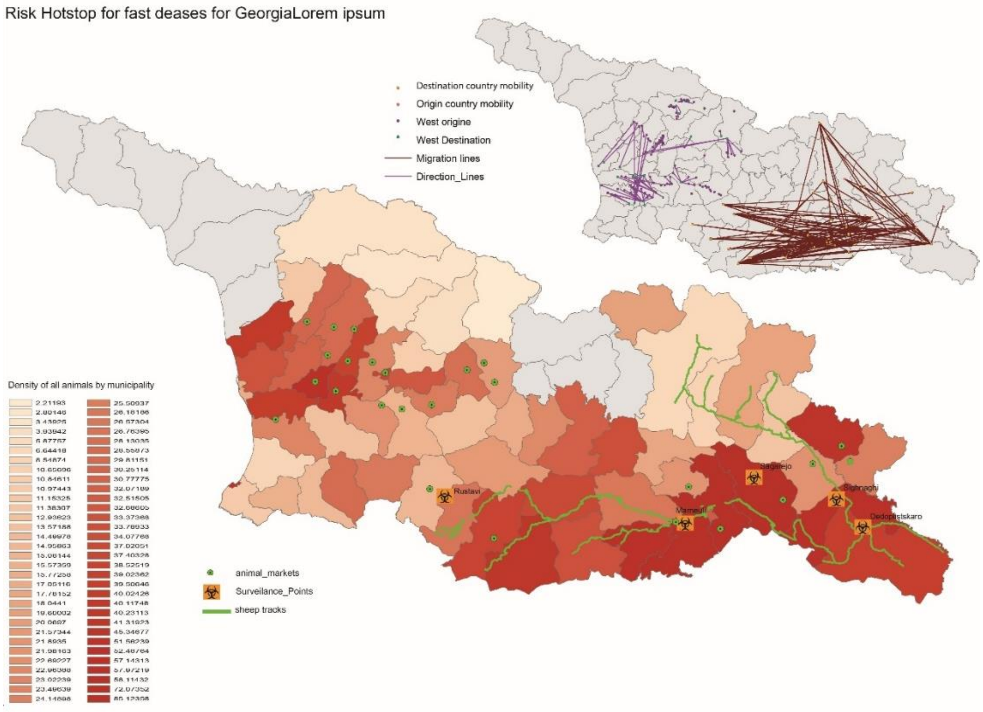

Figure 9. Livestock transport routes, density of domestic animals by municipality

Scavenger insects that feed on the carcasses of diseased animals can also act as mechanical vectors, causing and spreading the disease. Anthrax bacillus makes dormant (non-vegetative) spores when it is exposed to free oxygen. These spores are resistant to environmental conditions and stay infectious and viable in soil, animal fur, water, and plants for decades. (Chichinadze et al., 2023).

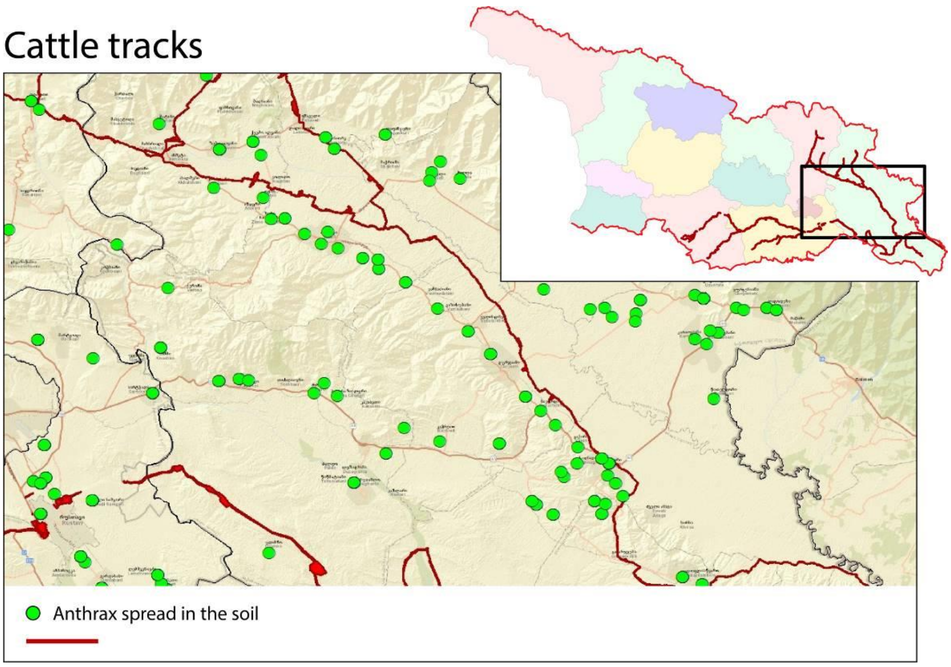

Figure 10. Cattle tracks, Small fragment, Kakheti region

One of the main factors in the spread of infections is the geographical component – climate. In this regard, climate maps of the Caucasus were compiled: elements of the average daily temperature TG, daily minimum temperature TN, daily maximum temperature TX, and the sum of daily precipitation RR. Where the database is available on a regular grid of 0.1 and 0.25 degrees, we took long-term daily data (1965-2010) and calculated the long-term average to create the map. Since the data on this site can only be viewed below 45 degrees east latitude, we have supplemented the climate maps with data from local weather stations. There was a data grid made from the Kriging method's average temperature, absolute maximum, average annual temperature (calculated from daily maximums), average annual temperature (calculated from daily minimums), and precipitation (multi-year average calculated daily amounts) (Fig. 11) **(**Chichinadze et al., 2023**).**

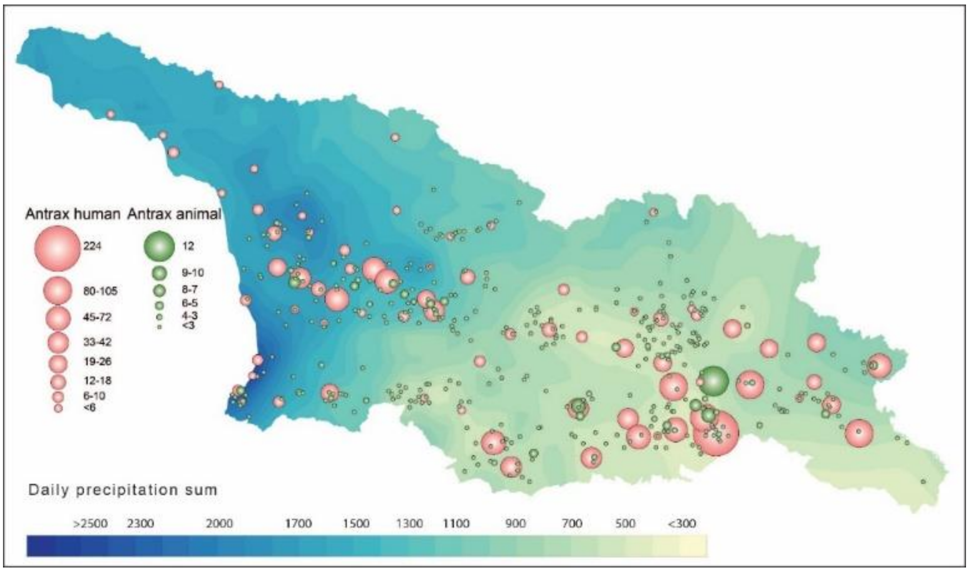

Figure 11. Intensity of Anthrax disease. Daily precipitation sum

Conclusion

When drawing up maps is it important:

The process involves determining the boundaries of the study area.

The task involves creating a large-scale map that outlines the general geographical basis of the study area for detailed analysis.

For cartographic generalization, classifying elements of a general geographic map is important.

The system should identify the specific thematic map required for a given disease and subsequently present the variables in the databases associated with that thematic map.

Two things are needed to easily find the link between a thematic map and a certain disease: correlation for a digital map and display of the case for a printed map.

It is necessary to update information since all data is constantly processed.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

T.C. and Z.G. conceived of the presented idea. N.S. performed the analytical calculations. N.B. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

Acknowledgements

The authors thank Lile Malania from the National Center for Disease Control for their exceptional support in supplying the data.

Funding

This research has been supported by Defence Threat Reduction Agency (USA), grant #HDTRA11910044 "Preparation of the Atlas of Zoonotic Infections in South Caucasus"

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Geographical Area of Meskheti According to the Ottoman Records of the XVI-XIX Centuries

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Georgian Geographical Journal, 2024, 4(2) 75-83

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Nikolaishvili, D.; Sartania, D.; Meskhishvili, N.; Arsenashvili, A. Geographical area of Meskheti according to the Ottoman records of the XVI-XIX centuries. *Georgian Geographical Journal* 2024, 4(2). 75-83
https://doi.org/10.52340/ggj.2024.04.02.09

Abstract

A certain part of the territory of Georgia was described in the Ottoman Defters of the Middle Ages. This is quite a large territory, which includes not only modern, but also historical Georgia. The aim of the research is the geo-informational cartography of the Georgian cultural heritage according to the Ottoman Defters of the XVI-XIX centuries and showing the geographical area that was described in these recors. From this point of view, 9 defters were processed and analyzed. As research has shown, these defters include the territories of Georgia that the Ottomans: 1) only conquered and tributed; 2) it was conquered and could not be fully preserved and today it is in modern Georgia and 3) it was conquered and it is still within the borders of Turkey. Some parts of the depicted areas in the defters covering each other's. Their detection is important for studying the dynamics of social-economical, traditional natural management, onomastic and a number of other issues. However, the territorial overlaps are not so large. For example, the defters of 1574 and 1595, both of which describe the province of Gurjistan, coincide only in a small fragment. The 1574 defter of big Artaan liva territorially coincides with the 1595 big Artaan and Fanak liva.

Keywords: Ottoman records, historical Georgia, Meskheti, Gurjistani

Introduction

Ottoman defters of the Middle Ages (XVI-XIX centuries) contain valuable information not only about the social-economic situation of the Ottomans but also about the countries conquered by them. In these defters, a certain part of the territory of Georgia is described, which is quite a large area. Within Meskheti, it includes not only the territories of modern (Samtskhe, Javakheti, Adjara), but also the territories of historical Georgia (Artan, Erusheti, Klarjeti, Kola, Tao, Shavsheti), the basins of the upper Mtkvari and the middle Chorokhi rivers and their tributaries.

According to the defters, a certain part of the works was dedicated to the research of the territories conquered by the Ottomans (Jikia, 1958; Nikolaishvili et al., 2021; Shashikadze, 2006; Shengelia, 1960; Svanidze, 1984), However, this issue has not yet been fully studied and analyzed. The issue of the territorial coverage of political/administrative units of different ranks depicted in the defters is particularly unclear. The low level of study of the mentioned issue is due not only to the fact that only a small part of these documents has been translated into Georgian today but also to the fact that these documents have not been studied in various aspects, even from a geographical point of view. With a few exceptions (Aslanikashvili, 1953; NikolaiShvili et al., 2021), nor were they fully mapped cartographically. Due to these reasons, the geographical area of the political/administrative units depicted in the books and the tendency of their transformation over time are unknown. And if this area is determined, it will give us the opportunity to:

- To avoid the mistake of considering different administrative units, which have the same name in different periods of time, as the same territory. An example of this is the province of Gurjistan, which in the records of 1574 and 1595, with some exceptions, includes a different territory.
- To carry out a social-economic analysis of different administrative units, on the one hand, by comparing the conquered territories and, on the other hand, the unconquered Georgian parts,

in order to make possible a retrospective analysis of the unified situation of the settlement of the Georgian nation.

- To determine the dynamic change of the Georgian substrate through the study of traditional natural management, toponymical, anthroponymical and a number of other issues, i.e. the process of transition to the "Ottoman rule" or, on the contrary, the process of preserving the Georgian substrate.

Therefore, it is very important to determine the territorial coverage of the political/administrative units recorded in the Ottoman records. The present work deals with this problematic issue.

The aim of the research is to determine the geographical area described by the Georgian translations of the Ottoman records of the 16th and 19th centuries.

Methods and Materials

The main research method is retrospective cartography and comparative geographical analysis by using GIS technologies. Accordingly, the data in the databases were identified, systematized, and classified, and a GIS database was created. Identification of objects was carried out on the basis of mutual agreement with other sources, for which comparative, semantic, retrospective cartography, and other methods of research were used. A field-expeditional research was also conducted within the borders of modern Georgia (Adjara, Samtskhe-Javakheti) and the Republic of Turkey (Artvini and Artaan provinces). The field research was mainly based on surveys and questionnaires of the local population.

Obviously, field research could not be carried out completely on the entire studying area because it required a lot of time and money. Therefore, the field work was carried out on such a scale that a modern picture of the facts recorded in the old defters could be presented in general terms. The fact that a significant part of the data is kept in archival funds of other countries (Russia, Turkey, Romania, Bulgaria and others) with limited access, so this fact also created some difficulty.

The object of our research was 9 Ottoman defters:

1. Grand and Short Defters of Ajara Liva of 1566-1574.
2. The Grand Defter of Gurjistan Vilayet of 1574.
3. The Grand Defter of Gurjistan Vilayet of 1595.
4. The Grand Defter of Artanudji of 1595.
5. Jaba Defter of Childir Vilayet of 1694-1732.
6. Grand Defter of Tbilisi Vilayet of 1728.
7. Defter of Shavsheti of 1835-1836.
8. Defter of Machakheli (Crdili Vilayet) of 1836.
9. Defter of Satleli Liva (Crdili Vilayet) of 1836.

In the Ottoman defters are recorded just conquered territories by the Ottomans, because conquered territories were described in order to impose taxes on them. Naturally, this conquest did not happen all at once. The Ottomans had separated Georgia from some side or part of it, and then Georgia had taken some of them back. During the years, these territories were lost again with new invasions. Due to the frequent change of the political owner, it is impossible to restore an exact sequence picture. Because Defters depicted exact moments, it became possible to present a general picture for certain periods of time.

As the analysis and comparison of historiographic works and Ottoman defters had shown, according to the Ottoman power, the territory of Georgia can be divided into three parts, namely, the territories that the Ottomans: 1) marched and conquered (but did not manage to completely conque)r. Their political subjugation lasted for a certain period. Such is the wester,e largest part of Georgia); 2) They were conquered for a certain period of time, but they could not keep i,t and today it is within the borders of modern Georgia. Such is Eastern Georgi,a and 3) conquered and incorporated these territories (such is the largest part of southwestern Georgia in the basin of the Mtkvari and Chorokhi rivers).

The Ottoman influence was less on the territories that were directly separated from Georgia, which was not conquered by the Ottomans. This mainly concerns the northern part of Samtskhe-Saatabago (Samtskhe, the northern part of Javakheti, Adjara, Shavsheti, Klarjeti), which is within the borders of modern Georgia. As for the rest of Samtskhe-Saatabago, located further south (Kola, Artaan, Erusheti, Artanuji, etc.), the Ottoman influence was much more here (Nikolaishvili et. al., 2021).

Our research includes the territory of Meskheti, incorporated by the Ottomans. Part of this territory is located in modern Georgia, and another part is in Turkey.

From the historiography, it is known that within Meskheti were located: Artaani, Erusheti, Klarjeti, Oltisi, Samtskhe, Speri, Tao, Potskhovi, Shavsheti, Javakheti, and others. But there are also parts whose territorial affiliation is debatable and needs some clarification, for example, Borjomi Valley, Kaikuli, and Chaneti.

Ivane Javakhishvili wrote that Georgia consisted of several "countries", whose names and borders had been changed over time, which was the result of political-national growth, but still there were permanent, native borders of each country. We investigate only those borders and territory that are included in the "permanent" borders of Meskheti. According to the latest studies, the "permanent" borders of Meskheti include: Soeri (upper river of Chorokhi), Tao (middle river of Chorokhi with right and left tributaries: Parkhalistskali, Tortomi, Oltis), Klarjet-Shavsheti and Adjara (lower river of Chorokhi), Kola, Artaani, Erusheti, Javakheti (incl. Ninotsminda, Akhalkalaki, Aspindze municipalities), Samtskhe and Potskhovi valleys (incl. Akhaltsikhe and Adigeni municipalities), Tori (Borjomi municipality) and others. (Abashidze et al., 2014).

According to the Ottoman defters of 1728, Tori, so Borjomi valley, is in Gori Liva, although it, together with Shida Kartli, did not experience the same long-term influence of Ottoman rule as Samtskhe and other parts of Georgia conquered by the Ottomans. But it is also known that the border of South Georgia started from Tashiskar and extended to the south. It is the same with the modern administrative division. Therefore, it was included in our research.

Chaneti, also known as Lazeti, was a bordering region of Meskheti. Politically, in a certain period, he was included in its area. Lazeti became one of the first incorporated parts of Georgia by the Ottomans. Moreover, if we trust Vakhushti Bagrationi, Meskheti extended to the borders of Chaneti (Vakhushti Bagrationi, 1941). We find a similar opinion in many scientific works. Therefore, it could not be included in our research.

Adjara was also a part of Meskheti, but Batumi and Kobuleti sides were not included in it. Today, Kobuleti is a part of the Autonomous Republic of Adjara, although in the Middle Ages this area was part of the Guria, which was captured by the Ottomans. The population was converted to Islam and seperated from Guria.

Kayikuli is mentioned in historical sources as Abotsi. It is reported in the defters of 1728. Due to the change of the political situation, it sometimes belonged to Kartli and sometimes to Meskheti. Ivane Javakhishvili had mentioned that Kaikuli was in Meskheti, but he also noticed that it was in the south of Javakheti. There was a community located between Meskheti and Kvemo Kartli, and sometimes it belonged to Meskheti, but often, in particular, in the XVII-XVIII centuries, it was within the borders of Kvemo Kartli. (Javakhishvili, 1998). However, there are different opinions; in particular, V. Nozadze marked that Kaikuli was in Meskheti (Nozadze, 1989). As for Pavle Ingorokva, when he discusses the issue of the territorial dispute between Georgia and Armenia, he says that Abotsi (the same as Kaikuli) belongs to Georgia and adds that Abotsi is geographically located between the districts of Meskheti and Bambak [Ingoroqva, manuscript].

Here, we should emphasize one important physical-geographic circumstance (Nikolaishvili et al., 2021). Historically, it is known that Javakheti and Kvemo Kartli are bordered by an important orographic barrier—the Javakheti ridge. Today, the northern part of the Javakheti ridge, which is located in Georgia, is a main orographic border. Therefore, due to orographic conditions, Abotsi belongs more to Kvemo Kartli than to Javakheti.

Based on the above, the geographical area of our research is limited to the historical territory of Meskheti, or the "natural border", which was spread from Tashiskar to Karnukalaki, but did not include Kaikul (Abots), Chanet (Lazet), nor Batumi and Kobuleti.

Results

According to the "defters of the Province of Gurjistan" of 1574 and 1595, the province of Gurjistan included the basins of the upper Mtkvari and the middle of the Chorokhi rivers. In particular, the right side of Chorokhi with tributaries (Oltissistskal, Banisstskal, Bardusstskal, Sevriststskal, Torthomistskal, Artanujitsskal). The upper part of Mtkvari was surrounded by the vilayet on both sides. According to the "defters of the Province of Gurjistan" in 1574, the province of Gurjistan was divided into 4 parts: Artanuji, Great Artaan, Tortomi and Oltis. A total of 19 Nahie were united in the vilayet. According to the 1595 "defters of the Province of Gurjistan", there are 9 livas and 41 Nahie named in the province, although S. Jikhia also writes that Oltis Liwa is a later inscription (The Grand Defter of Gurjistan Vilayet of 1595, 1941), i.e. It does not belong to the 1595 register.

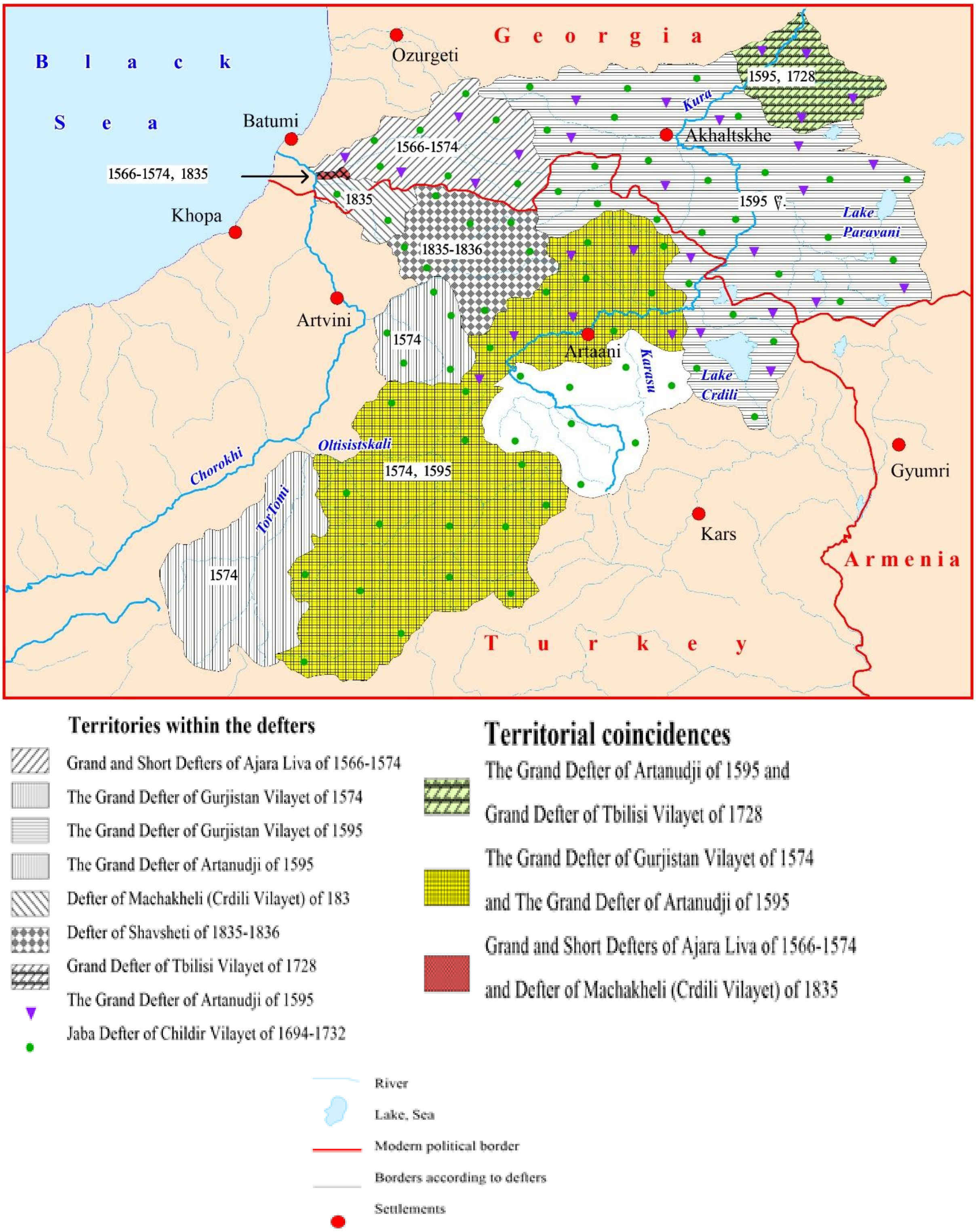

Figure 4. Geographical area of Meskheti according to Ottoman defters (XVI-XIX centuries)

Table 4. Administrative arrangement of provinces of Georgia According to the records of 1574 and 1595

Livas	Nahiye
Big Artaani *	Mzvare *
	Mishe *
	Chrdili *
	Kiamkhisi *
	Fanaki *
	Panaskerti *
Tortomi	Tortomi
	Kudrusuri
	Pertegreki
Oltisi	Anzavi
	Bardisi
	Gobi
	Marsasori
	Mzvari
	Chrdili
Artanudji	Artanudji
	Ishkhani
	Taoskari
	Khacheni

livas	Nahiye
Big Artaani *	Mzvare *
	Tkiani *
	Chrdili *
Fanak *	Kiamkhisi *
	Fanak *
	Panaskerti *
Akhalkalaki	Akshehiri
	Tmogvi
	Nialisyure
Akhaltsikhe	Aspindza
	Atskuri
	Mzvare
	Okroscikhe
	Otskhi
	Ude
	Kvabliani
	Chrdili
	Djadjaraki
Petre	Petre
	Kashveti
Potskhovi	Mzvare
	Chrdili
Chrdili	Mgeltsikhe
	Kanarbeli
	Djanbazi
Khertvisi	Buzmareti
	Forest Djavakheti
	Khertvisi

Matches are marked with an asterisk (*)

The mutual comparison of administrative units showed us that the province of Gurjistan, according to the 1574 and 1595 records, did not have the same territorial coverage, and only on a small fragment they coincided territorially (pic. 1): Didi Artaani Liva of the 1574 record (districts: Mzvare, Mishe, Sheti, Kiamkhisi, Fanaki, Fanaskert) territorially coincides with the 1595 Livas of Didi Artaan (Nahiyes: Mzvare, Tgiani, Shiti) and Fanak (Nahiyes: Kiamkhisi, Fanak, Fanaskerti) (Table 1). This means that in the 20-year period, there was more division of administrative units—didi artan liwa was divided into Didi artaan and fanak livas—but there was no more division of lower-ranking administrative units—nahiyes. The total area of this contiguous territory was 3353 square meters. It's not a big area. If we compare modern Georgia, it is slightly larger than the municipality of Mestia.

As for the "Short (Ijmal) Defter of Childir Vilayet" (XVI century) and "Jaba Defter", the available information about the administrative arrangement of the Vilayet is very scarce. The reason for this is that it is compiled based on a big database and contains brief information. It should be determined for which large books they are compiled. According to the current sources, it is impossible to give an exact answer to this question. Moreover, there are later inscriptions in defter, which the Georgian translators date from 1590 to 1622 ("Ijm. David.", p. 5). We can only make assumptions, namely, the Ottoman notebooks of the same period are connected to each other, and the data entered in the short notebooks should not belong to one notebook. Obviously, it is difficult to generalize this to all Ottoman books, although it is confirmed by the books we have. What gives us the opportunity to say that? First of all, the "Short (Ijmal) Defter of Chrdili Province" and "Short Defter" include villages from 1595 and the extensive Defter of Livy of Zemo Adjara (Tab. 2).

Table 2. Compliance of some villages according to different defters

Short list of Childir Vilayet		1595 Great defters of the Province of Gurjistan		Wide defters of Zemo Adjara	
Villages	Sum of taxes	Villages	Sum of taxes	Villages	Sum of taxes

Zarzma	11 600	Sersem(?)	11 600		
Tsaghveri	15 200	Tsaghveri	15 200		
Samda Sakhuri	13 000	Samzisokhevi	13 000		
Handakiri/Hakidi	30 000	?	30 000		
Ghordjomi	29 999			Ghordjomi	2999 *
Dabagha akhra	15 000			Big Adjara	15 000
Doskho	15 002			Potskho	15 002
Alme	29 999			Alme	2 999 *

* – probably, we have to deal with incorrect data collection

"Jaba defter of the chrdili Province" 1694-1732. It is a different type of document from the large (extensive) and short records, which records the changes in the lands (Khasi, Ziameti, Timari) granted by the Sultan. All material is arranged by geographical point, not chronologically. There is information about the following lives of Akhaltsikhe Sapasha (Chrdili Province): Artanuji, Akhaltsikhe, Akhalkalaki, Adjara, Great Artaan, Small Artaan, Mamirvan, Oltis, Livana, Fanak, Potskhovi, Fertekreki, Chrdili (Childiri), Shavsheti, and Khertvisi. Moreover, Peter's Liva is not verified in the Chrdili Vilayet. This is explained by the fact that with the truce of 1639, this area (from Kvishkheti to Atskuri, i.e. Borjomi valley) no longer belongs to Ottomans and is still part of the Kartli Kingdom ["Jaba Davtar", p. 81].

It is interesting how to belong the small Artaani to the province of Livy, i.e., the Chrdili of Kola. This issue is unclear due to the fact that the same nahiyas (Khojevan, Sheti, Mzvare) of the mentioned Livy, often with the same villages, are included in both defters of Chrdili and Karsi. This strange case wasn’t considered a chancellery mistake by Abuladze. the "double" affiliation is also confirmed by the report of Katib Chelebi ("Jaba Davtari", p. 72). Today it is very difficult to explain how the same administrative unit was managed by different governorates. Today it is very difficult to explain how the same administrative unit was managed by different governorates. This issue can be resolved by finding new records; however, in our case, the territorial affiliation of the small Artaan Liv, or Kola, was determined by the Chrdili province.

According to the big defter (XVI century) of the Upper Adjara Liva, this one included almost the entire basin of Achariskali (middle and upper parts). Administratively, it was divided into two nahiye: Zemo and Kvemo Adjara. The territory of Liva mostly coincides with the borders of modern administrative units (Shuakhevi and Khulo municipalities), although there are differences between them. In particular, the eastern border of Liva had passed on the top of the Arsian ridge, and the upper part of Kvabliani and Ghrmanistskali did not enter within the border. (as well as modern Adjara) (Nikolaishvili & Sartania, 2011).

Even in the short story of Adjara Liva (XVI century) there are only reports about the nahiyes of Kvemo and Kvemo Adjara. It seems that, territorially, it coincides with the data of the extensive defter of Livy of Upper Adjara.

According to the 1728 "Tbilisi Vilayeti Big Defter", the territory of the vilayet was quite extensive and included almost the entire territory of present-day eastern Georgia, except Kakheti. The western parts of modern Azerbaijan and the northern parts of Armenia also entered the mentioned vilayet. This makes us think that the defter describes the whole Kartli at that time.

The issue about the name of the vilayet is also interesting. The Ottoman name "Gurjistan" meant the whole of Georgia, and that's what they called the territories they conquered as well.

Since by the 18th century there was already an administrative unit under the name of the province of Gurjistan, the newly joined territory (Kartli) could not be given the same name due to its large territorial coverage because it could not be merged with it. That’s why the newly conquered territory (Kartli) was separated as an administrative unit, and its name comes from its important center (city) - Tbilisi.

From the administrative point of view, Tbilisi Vilayet was divided into 5 livas (Table 3). From here, only 2 nahiye of Gori Liva came into Meskheti: Petre and Gujarati. A comparison with the 1595 "Gurjistan Vilayet defter" showed us that during the 16th-18th centuries, certain changes occurred in the administrative arrangement of the territory of Georgia conquered by the Ottomans, in particular, in the 16th century, the Borjomi Valley had a higher administrative status and was included in the Georgian Vilayet under the status of Peter's Liva. At the beginning of the 18th century, the Borjomi valley (already with the status of 2 nahiyes) was included in the Gori Liva of Tbilisi Vilayet, although the territory of the nahiyes did not change. Defter of Petre and Kashveti nahiyes of 1574 corresponds to Davtri Petre and Gujarat nahiyes of 1728.

It should also be noted that, according to the 1728 decree, the exact determination of the territory and intra-territorial division of the vilayet turned out to be quite difficult since there are many inaccuracies in it. A more detailed study of the issue is necessary.

Table 3. Administrative Unites of Tbilisi Vilayet, 1728

Livas	Nahiyas
Tbilisi	Tbilisi, Avlabri, Sabaratiano, Dmanisi, Baidar, Kaikuli
Gori	Satsitsiano, Mukhran, Saamilakhvro, Shavi Aragvi and Ksni Eristavi, Trialeti, Petre, Gomareti, Gujarati
Somkhiti	Armenia, Tashir, Fanbak
Akhcha kali	Akhcha kali
Kazaki	Anchi, Javad, Ahsabad, Terki

Today, it is very difficult to determine why the Borjomi valley was transferred from one province to another. This is a matter for the future, but some consideration can be given to moving it to a lower administrative status.

It is known from historiography that from the 16th century to the 18th century, Borjomi Valley was gradually almost completely deserted. Part of the population died in the fight against the invaders, and part of them moved to other parts of Georgia. Georgian material cultural monuments were significantly destroyed; the economy was disrupted. This is discussed in many scientific works (Abuladze, 1983; Berdzenishvili, 1985; Kudjadze, 1969; Makalatia, 1957). Therefore, the cancellation of Peter's Livy should have been a completely logical decision.

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Conclusion

As it is clear from the above-mentioned differences, the territorial similarities are not so small, but not many. Here it is important to find out which defters match each other—long or short notebooks. It is much more informative, matching according to extensive definitions, which gives us an opportunity to discuss several social-economical and onomastical features in a dynamic perspective. According to extensive data, we have territorial matching in the following geographical areas: Didi Artaan, Fanak, Petre, and Machakhli Livas. Because this coincidence includes different historical-geographical provinces (Artaani, Tori, Machakhela), it also gives us the possibility to find similarities and differences between these provinces. However, it is also clear that these provinces have different areas. The borders of big Artaani and Fanak are the largest areas (3432 km2), where according to the 1595 register, there are 200 villages and 86 villages. Petres Liva has a relatively small area (944 km2), where we see only 8 villages and 41 villages. The area of Machakhli Liva is much smaller, although according to the 1835 register, the number of villages is more here (21 villages).

Despite the small area of territorial coincidences, it provides a good opportunity to discuss the onomastic and social-economic situation from a dynamic perspective. If we compare the matching geographical area by the decades of 1574 and 1595, we will see an interesting picture. In 1574, there were 120 families in this area; between them, 114 were Christians and 6 were Muslims, and after 20 years, this picture changed significantly: the total number of families decreased to 36, and 34 of them were Christians and 2 were Muslims. What caused the population decline is difficult to say. However, the economic structure has not changed. The population had continued to grow agricultural crops (wheat, barley, millet, etc.) as before. Despite the decrease in population, it is strange that taxes have increased slightly. This side in 1574 used to pay 380 akhchas, but in 1595 it was increased to 500 akhchas. The reason for this could be inflation or increased taxes to accelerate the process of Islamization.

Because we do not have a territorial overlap according to the above-mentioned defters, and it is difficult to talk about the change of the demographical and economic picture, but the general trend would be clear: it is an indicator of the irreversible process of the transition of the confessional issue from Christianity to Islam, which was also a factor in reducing the consciousness of ethnic belonging.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

D.S. and N. M. contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. were involved in planning and supervised the work. A.A. and D. N. performed the analytic calculations. A.A. translated this paper from Georgian into English. D.N. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

Acknowledgements

The authors cordially thank the Shota Rustaveli Science Foundation for support, under whose financial aid it became possible to accomplish the present work within the project "Mapping and to analyze Georgian cultural heritage of south-west Georgia according to old Turkish Population census books", Grant #HE-18-448, 26.07.2018). The authors also cordially thank members of the project (Avtandil Ujmajuridze, Darejan Kirtadze, Manana Kvetenadze, Tedo Gorgodze). The authors also thank Zaza Shashikadze for translating some parts of these documents and sharing this data.

Funding

This research [#HE-18-448] has been supported by Shota Rustaveli Science Foundation

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Vakhushti Bagrationi. Description of the Kingdom of Georgia. Tb., 1941

Occupied Territories of Sachkhere Municipality

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Georgian Geographical Journal, 2024, 4(2) 84-91

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Kekenadze, V. Occupied Territories of Sachkhere Municipality. *Georgian Geographical Journal* 2024, 4(2). 84-91
https://doi.org/10.52340/ggj.2024.04.02.10

Abstract

The civil war of the 1990s, the weakness of coordination of the newly formed law enforcement agencies of the Republic of Georgia made it easier for the Russian Federation to achieve its aggressive anti-legal goals in two large historical regions of Georgia - the Autonomous Republic of Abkhazia and the northern part of Shida Kartli (Tskhinvali, Java, Znauri, Kornisi).The Russian-backed separatist forces managed to escape from the control of official Tbilisi by forming their own illegal territorial associations. It is widely known that the activities of the separatist forces are much more active on the side of Shida Kartli than on the direction of Imereti, therefore, most of our citizens do not know that the so-called South Ossetia, the Russian Federation has occupied an important territory in the northeast of the Sachkhere municipality of Zemo-Imereti. Historically, as well as geographically, this area is practically not studied. Based on the current situation, it is practically impossible to study this territory directly in the field, but we tried to obtain several important information from local forced migrants (Vitaly Bakhturidze, Mevludi Kusiani). Which gives us a basis for important conclusions when summarized together with archival materials.

Keywords: History, Geography, Occupied, Cartography, Border

Introduction

While the historical and geographical research of occupied territories of Sachkhere Municipality special attention has been paid to historical toponymy (villages, old villages and microtoponymy), retrospective of orthographic and hydrographic naming. For this we studied old and new maps, where this territory is given, precision. Our attention was payed to the fact that toponyms of the municipality, especially orthographic units on maps and scientific literature is found with different names, also in Sachkhere section names of some mountains are not written at all, when all of them are equally important. First, we decided to solve this problem, learnt in detail and marked on the map historical and modern toponyms. For this we separated on the map village, old village, microtoponym, road,historic road, pass, churches, places of old churches, castles, hydrographic network and etc.

Based on all these it can be said that on our map there are given all the toponyms of research territory as well as historic and modern ones. It should be mentioned that in the process of research works of Vakhushti Bagrationi were very helpful, also notices of Giuldenshtedti and Russian versions maps of XIX century. We used and compared to each other cartographic works of Alexandre and Ivane Javakhishvili.

In the process of research except historical –geographic parts, we presented issued of medical geography. which refers to the local balneological resort Lesevs, but there is almost no information about it in the literature that we have learnt. As an example of this it will be enough the ways of treatment of psoriasis by Lesevs mud and treating skin and gastrointestinal tract by local acid waters. Readers also will get information about the notices of local respondents, which refer to many important issues. Research will help the readers who are interested in local history and geography.

Methods and Materials

The Vakhushti map is of greater importance for restoring the historical and geographical picture of the region, but it is very scarce and due to its scale, does not give a complete picture, nevertheless, its role as a source is immeasurably great. It was the map of Vakhushti and his works that helped us to correctly read many toponyms on the map with Russian terminology and incorrect translation. It should be noted that the Russian map is immeasurably great in restoring the toponymy of the historical settlements of early Georgia in the 19th century (Map of the Caucasus region XIX-XX, 1905). The materials found on the map of Russia were significantly supplemented and enriched with old historical names by the historical map of Ivane Javakhishvili (Javakhishvili, 1923), a map compiled in 1931-1932 (Javakhishvili, 1932). edited by Alexander Javakhishvili and others. Comparison of the materials shown on the mentioned maps helped us a lot in restoring a retrospective picture of the toponymy of the occupied territory of the Sachkhere municipality. Comparison of the materials given on the mentioned maps helped us a lot in restoring a retrospective picture of the toponymy of the occupied territory of the Sachkhere municipality. Based on the information received, we tried to create an approximate historical and geographical map of the country, which shows villages, microtoponyms, mountains, passes, rivers (with small streams), minerals, historical roads, balneological resorts, churches, parishes, etc. The article also talks about some issues of medical geography (treatment of psoriasis and various skin diseases with the mud of the Lesevi resort, etc.). Much attention is paid to historical demography (settlement and the number of Ossetian and Georgian surnames, the history of settlement). Particular attention is paid to the Ossetian and Georgian toponymy. The materials presented above are discussed in synthesis with historical events.

Results

The territory of the modern municipality of Sachkhere is geographically represented in a very diverse space, here you will find both complex terrain and mountainous areas, as well as floodplains and wide-open plains. The security of the municipality in the eastern and northern directions during the historical period was determined by the abundance of orographic objects located here. On the eastern side, the mountain system of the Likhsky ridge is isolated, which contributed to its relatively better protection. It is a historically known fact that the Likhi ridge was an obstacle to the advance of the enemy, who entered Eastern Georgia, into Western Georgia. The eastern line of the municipality is crossed by the following mountain system of complex geographical structure: Alkhashenda, Ribisi (modern Lebeuri), Biliurta (Obolis), Kardanakhumi, Rustavi, Shaharadeti, Lokhoni, Peranga, Mshvildauri (Shvildis), Dziri, Kortokhi, Edishvari and MtaVakisa.The mentioned mountains were an almost insurmountable barrier for the enemy advancing from east to west of Georgia. Strengthening the three passes located here, if necessary, was very convenient in terms of geographical location and a great advantage against the enemy encountered.

The same can be said about the northern part of the municipality, which is characterized by an even more complex geographical structure due to its mountainous terrain. Along the entire border line in the direction of Racha there are mountains: Veltkegi, Ketsebi, Didgora, Khikhamta, Sabvi, Phoni, Pepeleti (Sabugrao), Dagverila, Sirkhlabirti (Tsitelikle). In the specified geographical area, there were six difficult passes, the protection of which, if properly fortified, created a very advantageous strategic advantage in the fight against the enemy. In written historical sources we find several important references to the occupied villages: Vakhushti Bagrationi, Johan Anton Kurt Guldenstedt (Guldenstedt, 1962) and Beri Egnatashvili. Vakhushti Bagration mentions the area above the village of Chali: “However, before Chalida there were no buildings; Garna was built first, where you can see churches and nadabars” (Vakhushti Bagrationi, 1997) As we see, Vakhushti describes exactly the territorial area that is the subject of our study.

The northeastern part of the Imereti-Kartli border, east of Mount Peranga, was historically part of the Kingdom of Kartli. Describing this area, Vakhushti Bagrationi notes that above the floodplain it is completely deserted, and there are only nosebleeds and swamps. This lack of population must have been the reason why Ossetians moved here in the 18th-19th centuries and created Ossetian villages, which subsequently became the basis for the administrative classification of this territory as the administrative district of South Ossetia, and not to the Sachkhere municipality, while the territory is geographically it is an integral part of Sachkhere. Moreover, in the 1922 project to create the South Ossetian Autonomous Region, Sachkhere was considered as the administrative center of the region instead of Tskhinvali, although this project was later rejected. The fluctuation of the mentioned administrative division was corrected during the restoration of independent Georgia in the 90s of the last century, and this territory was assigned to Sachkhere, although today it is an occupied territory (Kekenadze & Katsitadze, 2014).

Geographical boundary. The border of the Kartli kingdom often crossed the Likhi ridge here, and the geographical border was replaced by a political border. According to Vakhushti, the Kartl-Imereti border will pass above Lich - near Korbouli, along the Dzirula River, so that it will enter its borders from the left bank... (Vakhushti Bagrationi, 1997). Beri Egnatashvili speaks about this section of the

Kartl-Imereti border, who describes the situation of the 16th century, which some scientists consider to be a transfer of its modern borders into the past, but, in our opinion, it was this border that should have become the dividing line between Kartl-Imereti from the beginning of time, not the 18th century. According to Beri Egnatashvili, the Sachkhere section of the Kartli-Imereti border looks like this: „Tsedisi pass and Kudaro,and behind Mount Chali is Ertso, and behind Mshvildauri and Peranga are Goradziris-Akat, Lichi, Godora, Kefiskhevi and Chkheri Castle" (Berdzenishvili, 1966). As we saw above, the messages of Vakhushti and Beri coincide with each other. These two researchers are contemporaries of each other. According to Güldenstedt, the upper country, the upper region of Khvrili, i.e. northeast from Sachkhere to the Likhsky ridge, looks like this: „this is a large part of the imperial slopes of the intersecting ridge, extending south from the Alps (Caucasus ridge). The east, i.e. the part located along Kartli and on the crest of the ridge, is called Saabashion (Life of Kartli, 1955).

Historical roads passing through the occupied territories of Sachkhere were studied by N. Berdzenishvili. The roads were as follows: 1) Sachkhere-Chikha-Zana-Khvi-Tamarasheni-Tskhinvali; 2) Sachkhere – Chikha – Chala -Darka – MtaPeranga – Kornisi – Tsorbisi – Erkneti – Avnevi - Dvani-Breti; 3) Sachkhere – Chikha – Chala – Darka – MtaPeranga – Gomarta - Khtana – Ozhora – Tigva - Atotsi (Berdzenishvili, 1966).

When mapping the boundaries of the principalities, we encountered a slight misunderstanding: whether the territories of modern villages: Perevi, Jriya, Kardzmani, Tedeleti, Jalabeti, Khakhieti, Choisi should be included in the Saabashidzeo estate, whose possessions these territories are directly separated from. On the one hand, our assumption that this territory was part of the Principality of Saabashidzeo was supported by the general geographical confusion of Güldenstdet presented above. None of the mentioned villages appear on the map of Vakhushti Bagration, which suggests that these villages did not exist then. The historical sources we have traced also do not tell us anything about the ownership of the territory. It is worth noting that we decided to include this territory in the Saabashidze estate due to the fact that these villages and territory are not part of the headquarters of ShidaKartli - Samachablo, which borders it in the east. Geographically, this territory belongs more to the Sachkhere municipality; they are sharply separated from the villages of the Yavan region by mountains: Sirkhlabirti, Alkhashenti, Ribisi, Biliurta, Kardanakhumi, Rustavi. These villages are geographically adjacent to the territory of the municipality of Sachkhere (formerly Saabashidzeo) (Kekenadze, 2014).

Due to the lack of old materials, the study of the historical demography of the occupied territories is possible only at the end of the 19th century. Since 1886, periodic demographic censuses began in the Russian Empire, and later in the 20th century in the USSR. Population censuses provide information about the number of residents of a particular village, ethnic and religious composition, etc. As we mentioned above, according to Vakhushti, in the 18th century the population no longer settled in this territory; we do not have any information that would confirm the presence of any settlement here before 1886, although in the 1886 census we already find one settlement is the village of Tedeleti, whose population is entirely Russian.

This part of Abashidze's Satavado especially suffered from Ossetian attacks, as local empirical information tells us, it was as a result of the Ossetian invasions that the previous settlements in this area, which Vakhushti calls Nadaburi and Nasoflari, were to be destroyed. The local population apparently took refuge in the nearby mountains, where villages appeared: Chitaeti (Chitadzes), Lomureti (Lomuridze), Davaeti (Davadzes) and others.The princes of this part of Saabashidzeo are called Abashidze Mtachale precisely because they did not live in Bari, in the valley of the Kvirili River. The generally accepted rule in this area was to transfer individual surnames to the name of the village, which suggests that the toponym Tedeleti recorded here may come from the Ossetian surname Tedelevi. There is also no empirical data about this toponym (Kekenadze, 2017).

According to the 1886 census, the village of Tedeleti is included in the Sachkhere district of Shorapni-Mazri. The composition of the population is as follows: total households - 28; people – 110; woman – 117; The total number is 227 people. The majority of the population are Ossetians, all Orthodox Christians. Neither the prince nor any of the clergy is registered in Tedeleti. There are 25 houses, 17 horses, 28 oxen and 28 carts.

In June-August 1918, an anti-government uprising broke out in the Sachkhere region, ethnic Bolshevik forces organized an armed uprising under the command of OsiKharebov and the Georgian Bagrat Khvedelidze (Kekenadze, 2013). The newly created independent Georgian government under the leadership of General Konstantin Ishkhneli was able to prevent the exit of the Ossetian and Georgian Bolsheviks. The villages of the Tedeleti district are mentioned here, since, apparently, at that time the village of Tedeleti was presented as the administrative center of the region.

During the general census of 1926, the picture completely changed, the district is administratively no longer on the Sachkhere side (in 1886 it was part of the Sachkhere police district of Shoropni-Mazri), but as part of the newly created (1922). It is connected with the Kudaro and Kemultinsky districts of the South Ossetian Autonomous Region. In addition to the village of Tedeleti, the following villages are already appearing: Sinaguri, Khafalgom (Khampalgom), Khakhieti (Kakheti), Jalabeti (part of Kudaro), Tsoisi (Choisi, Noisi), (part of Kemulto). As we can see, the villages in this area have grown significantly over the past 30 years. Their numbers and ethnic composition are interesting: Tedeleti - only 460 inhabitants, 229 men, 231 women, of which 97.6% are Ossetians, 3.2% are Georgians. As we see, unlike 1886, the ethnic Georgian population is now settling in the village; Sinaguri - only 67 inhabitants, 36 men, 31 women, 80.6% Georgians, 19.4% Ossetians; Khafalgom - a total of 172 inhabitants, 84 men, 88 women, the population is entirely inhabited by ethnic Ossetians; Khakhieti - only 96 inhabitants, 56 men, 40 women, entirely populated by Ossetians; Jalabeti - only 165 inhabitants, 81 men, 84 women, all Ossetians; Choice - only 50 residents, 30 men, 20 women.

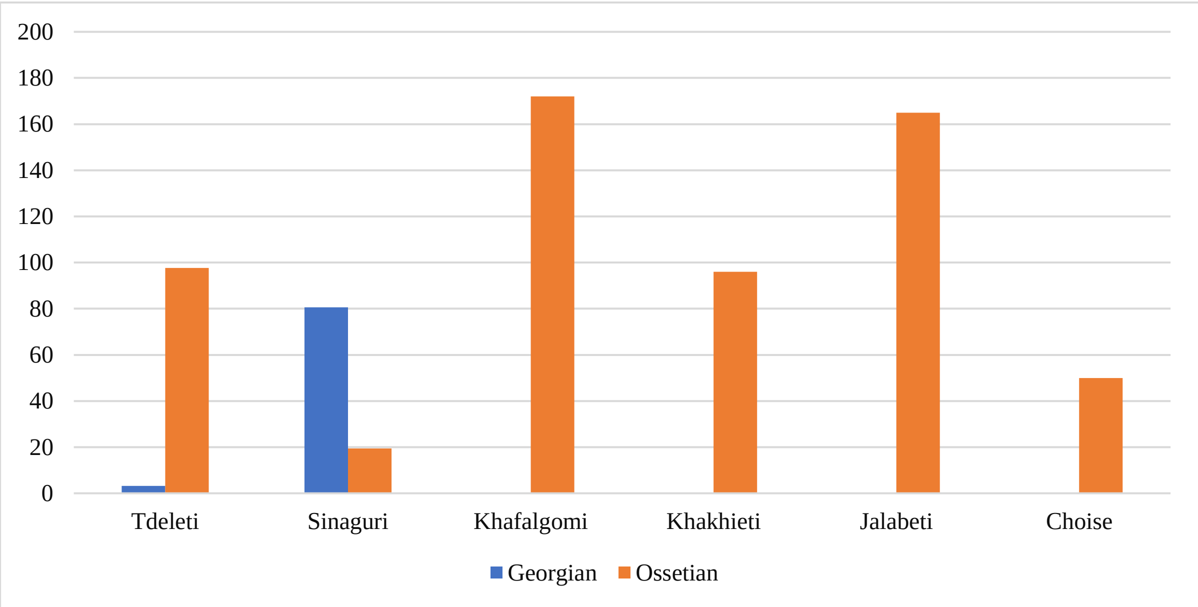

Figure 5.Ethnic groups in the villages of the study area based on 1926 census

In the 1939 census, the data from previous years was again changed: Hamfalgom - only 121 inhabitants, 58 men, 63 women (Zanian Village Council); Jalabeti - total 409 inhabitants, 235 men, 174 women; Zemo Kardzmani - total 345 inhabitants, 175 men, 170 women; Kvemo Kardzmani - total 107 inhabitants, 56 men, 51 women; Sinaguri - total 98 inhabitants, 51 men, 47 women; Tedeleti - total 527 inhabitants, 273 men, 254 women; Khakhieti - total 114 inhabitants, 57 men, 57 women (Tedeleti Village Council).

In the 1970 census, quite a lot of changes occur, completely new settlements appear: Tbeti, Perevi and Shua Kardzmani, of which Shua Kardzmani and Perev are completely populated by Ossetians and belong to the Dzhava district of the South Ossetian Autonomous Region. Sinaguri - a total of 164 inhabitants, 87 men, 77 women. Entirely populated by ethnic Ossetians; Tedeleti - a total of 316 inhabitants, 151 men, 165 women. Only the Ossetian population lives in the village; Jalabeti - only 139 inhabitants, 73 men, 66 women. The village is completely Ossetian; Khakhieti - only 108 inhabitants, 59 men, 49 women (Ossetian village); Perev - only 36 inhabitants, 15 men, 21 women (Ossetian village); Kvemo Kardzmani - only 140 inhabitants, 70 men, 70 women (the village is entirely represented by the Georgian population); Zemo Kardzmani - total 103 inhabitants, 45 men, 58 women (Ossetian village); Shua Kardzmani - only 71 residents, 33 men, 38 women (Ossetian village); Tbet - only 72 inhabitants, 31 men, 41 women.(the village is completely populated by Georgians), (Sinaguri village council); Hamfalgom - a total of 49 inhabitants, 19 men, 30 women (Ossetian village), (Tsoni village council).

According to the 1979 census, Shua Kardzmani disappears from rural settlements; we have no other significant changes. Sinaguri - total 204 inhabitants, 104 men, 100 women (Ossetians); Tedeleti - total 192 inhabitants, 102 men, 90 women (Ossetians);Jalabeti - total 114 inhabitants, 58 men, 56 women (Ossetians); Khakhieti - total 93 inhabitants, 51 men, 42 women (Ossetians); Perev - only 35 inhabitants, 20 men, 15 women (Ossetians); ZemoKardzmani - total 195 inhabitants, 104 men, 91 women (Ossetians); Kvemo Kardzmani - total 113 inhabitants, 63 men, 50 women (Georgians); Tbet - a total of 53 residents, 32 men, 23 women (Georgians) (Sinaguri village council); Hamfalgom - a total of 24 inhabitants, 10 men, 14 women (Ossetians) (Tsoni village council).

According to the 1989 census, significant changes took place in the ethnic composition, the Georgian population appeared in villages inhabited only by Ossetians. Sinaguri - total inhabitants 165, men 83, women 82. Georgians 53%, Ossetians 45%; Tedeleti - total inhabitants 146 people, 75 men, 7 women. Georgians 58%, Ossetians 41%; Jalabeti - only 53 inhabitants, 25 men, 28 women. The population is Ossetian; Khakhieti - only 61 inhabitants, 27 men, 34 women. Population - Ossetians; Perevi - only 27 inhabitants, 12 men, 15 women. Georgians 77%, Ossetians 21%; Kvemo Kardzmani - total of 148 inhabitants, 69 men, 79 women.Georgians 48%, Ossetians 51%; ZemoKartsman - total 157 inhabitants, 86 men, 71 women. Georgians 35%, Ossetians 51%; Tbet - a total of 58 residents, 26 men, 32 women. Georgians 74%, Ossetians 25% (Sinaguri village council); In Hamfalgom there are only 11 inhabitants, 6 men, 5 women. Ossuria (Zanian village council) (Geostat, 2024; Javakhishvili, 1923)

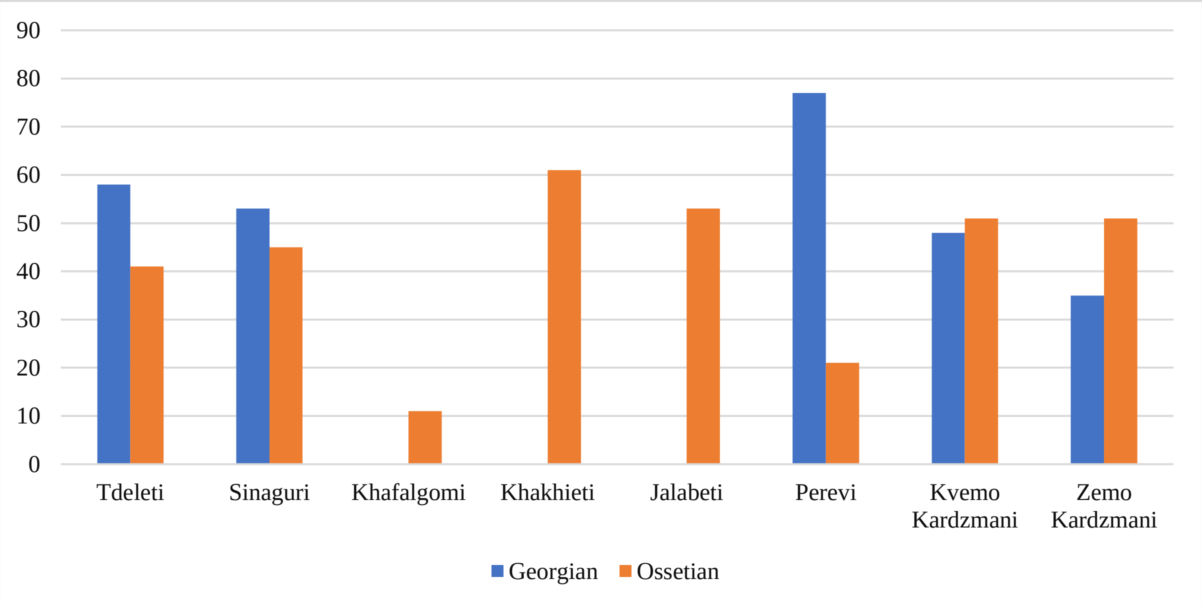

Figure 6. Ethnic groups in the villages of the study area based on 1989 census

In 1991, the Supreme Court of independent Georgia abolished the South Ossetian Autonomous Region, artificially created under the Soviet Union without any grounds, thereby restoring historical justice. Administratively, the villages confiscated in 1922 were returned to the Sachkhere district. Unfortunately, after the well-known events of the 90s, this territory was occupied by the Ossetian-Russian side. It should be noted that there was no armed confrontation between Georgians and Ossetians in the Sachkhere direction throughout the 90s.There was only one moment when the newly created Georgian Guard (the first Georgian Guard was created in Sachkhere under the command of Colonel Besiki Kutateladze) tried to take some action in the occupied territory of the Sachkhere region, which did not lead to any other clashes, except for minor incidents. A small incident was also related to a bunch of goods that were confiscated by the Ossetians and distributed to the Georgian population, but the local population, on their own initiative, took these goods back to the Ossetians. After the occupation of the 90s, only the village of Perevi remained under the jurisdiction of the Georgian side.

In the 2008 war, as well as during the events of the 90s, during the war, unlike ShidaKartli, there were no hostilities in the occupied territories of the Sachkhere municipality, although the Russian side occupied the village of Perevi, which was previously part of the South Ossetian autonomous region. According to the ceasefire agreement reached on August 12, 2008, the village of Perevi was to be handed over to the Russian army, but the Russian army still held this newly occupied territory along with the Akhalgori region. On October 14, 2010, during the thirteenth round of Karasini-Abashidze negotiations in Geneva, Russian representative Karasin stated: “The Russian Federation has prepared and will soon withdraw the Russian border checkpoint from the settlement of Perev, which is located on a geographically disputed territory.” Soon after the agreement, the village of Perevi was transferred to the jurisdiction of the Georgian side. It is in Perevo that a Russian checkpoint has now been established, through which communication with the occupied territories is carried out.

The fact that there was never an armed conflict between the local Ossetians and Georgians led to the peaceful coexistence of the Georgian population here in the Ossetian-occupied villages, but the Russian “peaceful” continent often blocked the road and did not allow the Georgian population to move freely. An example of the severity of the situation is the case of the family of Vitaly Bakhturidze, a resident of the village of Zemo Kartsman, whose two daughters were unable to cross the Russian checkpoint from the occupied territories due to the road being blocked. this is why they were unable to pass the national examinations and were forced to abandon higher education. There are quite a lot of similar cases among the local population, which leads to the fact that the Georgian population slowly leaves the occupied territories and moves to territories controlled by the Georgian side to live, although they still retain their property in the occupied territories. territory.

Currently, the following villages operate in the occupied territories of the Sachkhere municipality:Sinaguri, Jalabeti, Tedeleti, Zemo Kartsmani, Kvemo Kartsmani, Tbeti. Villages that became rural: Fatkudzhina, Khafalgom, Dzirischala, Kheldakheuli, Sadarno, Choisi, Lohoisa, Gvizga, Gomarta.We tried to present the following local microtoponyms on the map: Fizarta, MefiStadsomi, Pantevi, Mokhveula, DimitriasNamoslo, Pshanari, Magvlar, Skhliceri, SachinosAho, SandrosAho, Dimnalia, Ukvakhe, Silion spring. Mountains: Peranga, Lokhon, Shaharadeti, Rustavi, Varkhnis, Kardanakhumi, Topara, Biliurta (Obolis), Ribis (Lebeuri), Dagverila, Sirkhlabirti (Red Rock). Passes through: Peranga, Rustavi, Ertso, Sirkhlabirti, Dagverila. Minerals: Coal, oil, gold. During the flood, gold-bearing rocks were carried out of the Kakarak gorge; back in Soviet times, it was planned to develop a gold deposit in this area, but due to developments this was no longer carried out.

The Russian map, published in 1906, also shows coal ores north of the village of Tedeleti and mentions oil-bearing rocks in several places.George Tsereteli, a nineteenth-century artist, as well as magazines and newspapers of the time provide us with information about the oil available here.

Churches/Parishioners. St. George Gomarti, St. George Fitsarmti, Vahanmti Church, Makvlis Church, Pshanari Church.

Rivers and gorges: Kvirila, Givizga, Obolis water, Kartli gorge, Utsur gorge (Utsur waterfall is located here), Fizzarti gorge, Mariantuli gorge. All of these lakes contain large numbers of trout.

Ossetian toponyms: Darka (large village), Jria, Tedeleti, Sinaguri, Fatkudzhina.

Resort Lesev. In the occupied territory there is a balneological resort Lesev, famous for its healing mud and acidic waters. Since the second half of the 20th century, this place has already become widely known and a small boarding house was founded here. Lesevi mud was used to treat skin diseases; it was used to treat such serious diseases as psoriasis, lichen versicolor, etc. Currently, the sanatorium is not functioning, but residents of the neighboring village still transport this mud through various channels and use it for medicinal purposes. Displaced citizen Vitaly Bakhturidze recalls: “Viktor Bagaev had a boarding house in Les, where small wooden cottages were built for vacationers. Vacationers took both mud baths and were treated in local water baths, taking in acidic waters saturated with minerals. Here were the pastures and hayfields of the village of Kyrtsmani. From Vitaly Bakhturidze we also recorded the legend about the toponym Heldakheuli: according to legend, Queen Tamar is buried in Heldakheuli. The fighters from Heldaheuli will take an oath of silence on Fitzarmt, and then kill each other so that no one knows about the location of Tamar's grave.

Conclusion

We tried to get information given in historical scientific literature and in cartographic works about occupied territories of Sachkhere Municipality. After proper analysis we used information found by us, that finally gave us an opportunity to make interesting conclusions.

In this research great emphasis is made on retrospective cartography of the side, it can be mentioned that the aim to represent historical and modern toponymy of the side was mostly done successfully. On the map it is separately represented historical toponyms (old villages, microtoponyms), modern toponymy, (villages, microtoponyms and hydrographical network), churches old places of churches, historical and modern roads, passes, castles, etc.

Except retrospective cartography, we aimed at publishing specific issues of historical geography of the side, in which works of Vakhushti Bagrationi, who had been on the territory of Sachkhere Municipality and describes modern or past historic conditions. Also, valuable facts were found is specific historic sources and scientific literature. In this work much attention has been payed to the issues of historical demography. We showed the change of the local population from 1886 to 1989. After introducing our research to readers it will become clear the flexibility of inhabited places of the side at this period, also ethnic issues and specifics. Except wide demographic notice, readers will get information about administrative division, which village belongs to which region or a local community.

With historical notices given in the article we tried to show modern condition of the territory, for this reason respondents mentioned in the article helped us a lot, who left occupied territories without their own permission. Based on the information of this research we made historical –geographic map, that makes this work more conspicuous and visible.

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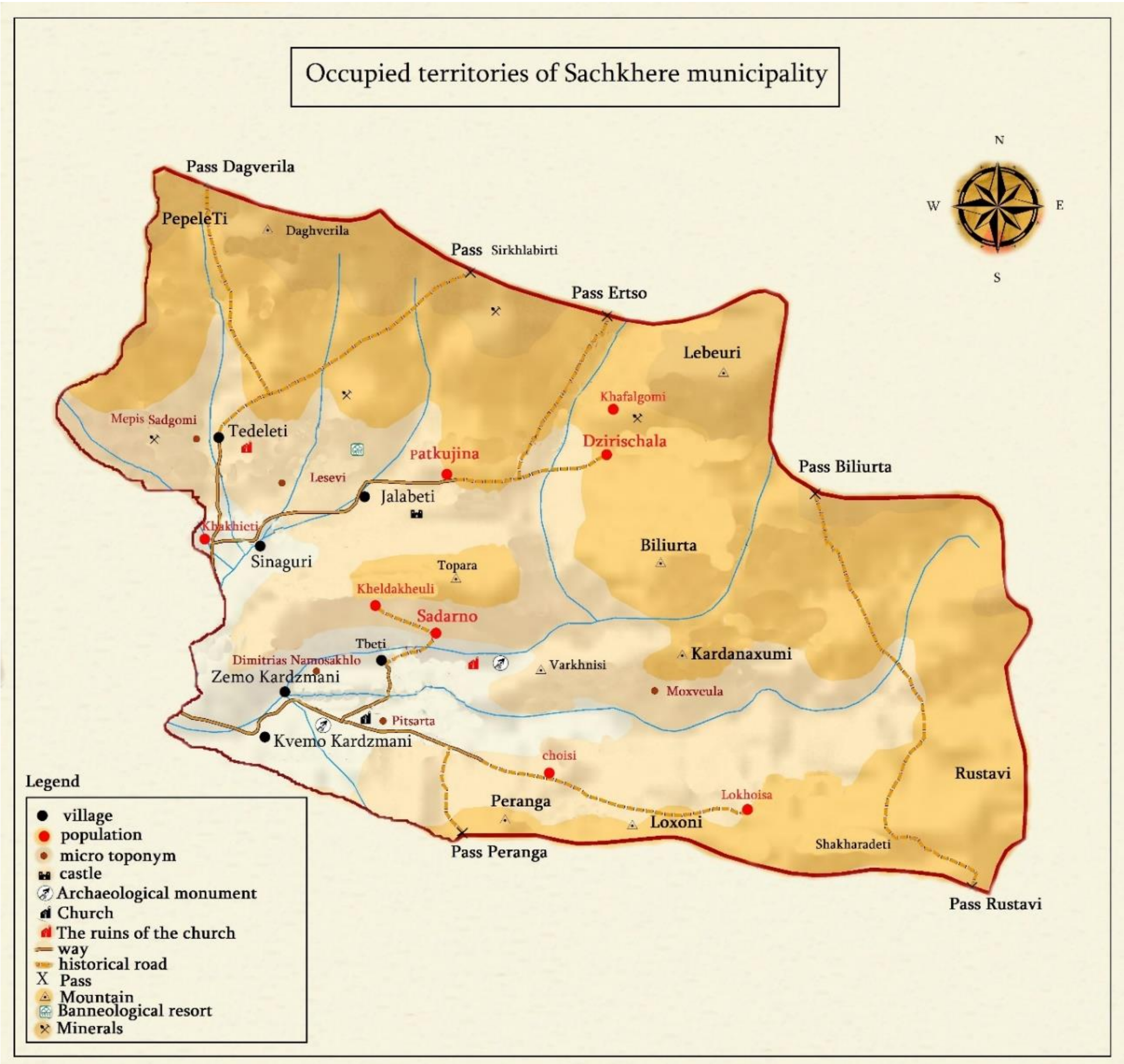

Competing interests

The authors declare that they have no competing interests.

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