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Petrology of the Rocks Composing the Shuakhevi HPP Engineering Structure

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Abstract

The petrology of the rocks in the Adjaristskali River basin in the territory of Shuakhevi HPP engineering buildings has been studied. The petrographic, mineralogical and geochemical features of the rock material of the Middle Eocene Burnati and Kintrishi suites have been studied using both traditional and modern methods. This research confirmed that the mentioned suites are composed of basalt, andesite-basalt and trachybasalt tuffs, tuff-breccias and lavas. These rocks have been investigated for the first time from a geochemical point of view. They were established to be rocks of tholeiitic and calc-alkaline composition of high-K shoshonite origin. The rocks of both suites are characterized by boninitic composition, which is typical for the geodynamic conditions of young island arcs; their origin is related to back-arc tectonic conditions.

Keywords: Shuakhevi hydropower plant, Adjaristskali River, petrology, geochemistry

Introduction

The study area is located in the Adjara-Trialeti folded zone of the Lesser Caucasus fold system in the Adjaristskali River basin (Gamkrelidze, 2000). The basin is composed of volcanic-sedimentary rocks from the middle Eocene Burnati and Kintrishi suites. The engineering structures of the Shuakhevi HPP are located in the territory of these suites.

Petrographic and mineralogical studies of the rocks of the mentioned suites were performed in the last century for geological surveying, and the results are presented mainly as archival materials. The studies included only macroscopic and microscopic studies of rocks and minerals and analysis of the chemical composition of the material—only silicate analysis. However, no other kind of analytical research has been conducted within the framework of the abovementioned suites.

During the implementation of the Shuakhevi HPP project, a detailed study of the rocks in the HPP building area was needed. Our goal was to perform a complex study of the Burnati and Kintrishi volcanogenic-sedimentary suites. During geological field work and engineering-geological research, rich factual material was obtained, which was studied using both traditional and modern analytical equipment and methods. In addition to detailed petrographic and mineralogical studies, geochemical research has also been conducted. As a result, this work presents a detailed petrological characterization of the rocks composing the Kintrishi and Burnati suites.

Study Area

The research area, which covers ≈170 km2, is located in the mid-stream of the Adjariskali River gorge (right tributary of the Chorokhi River) (Fig. 1). It is structurally located in the central (axial) and southern subzones of the Adjara-Trialeti folded zone of the Lesser Caucasus fold system (Gamkrelidze, 2000). The geological study of the territory was carried out mainly in the first half of the twentieth century and included regional geological, geomorphological, hydrogeological and petrographic issues (Meffert, 1933; Gamkrelidze, 1949; Beliankin & Eremeev, 1935; Beliankin et al., 1935). On the basis of studies conducted in the 1960s and 1970s (Laliev et al., 1970; Zirakadze, 1967, 1969, 1973), three suites were distinguished in the Middle Eocene volcanic formations: 1. Zekari (≈1500 m), 2. Kintrishi (≈600-700 m) and 3. Burnati (≈400 m). The mentioned volcanogens are calc-alkaline rocks represented by andesite-basaltic tuffs, limburgites, trachytes, trachyandesites and trachybasalts. In the upper parts, massive tuff breccias, lavas, lava breccias and tuffs are also found

(Lordkipanidze & Nadareishvili, 1964; Lordkipanidze & Zakariadze, 1974). Lordkipandze and Nadareishvili (1964) dated the mentioned suites to the Middle Eocene.

As a result of processing the literary materials found during the design of engineering structures of the Shuakhevi HPP, it was established that the petrography and mineralogy of the suites composing the territory of the project engineering buildings were studied only at the level of rock identification, and analytical studies were limited only to silicate analysis of rocks.

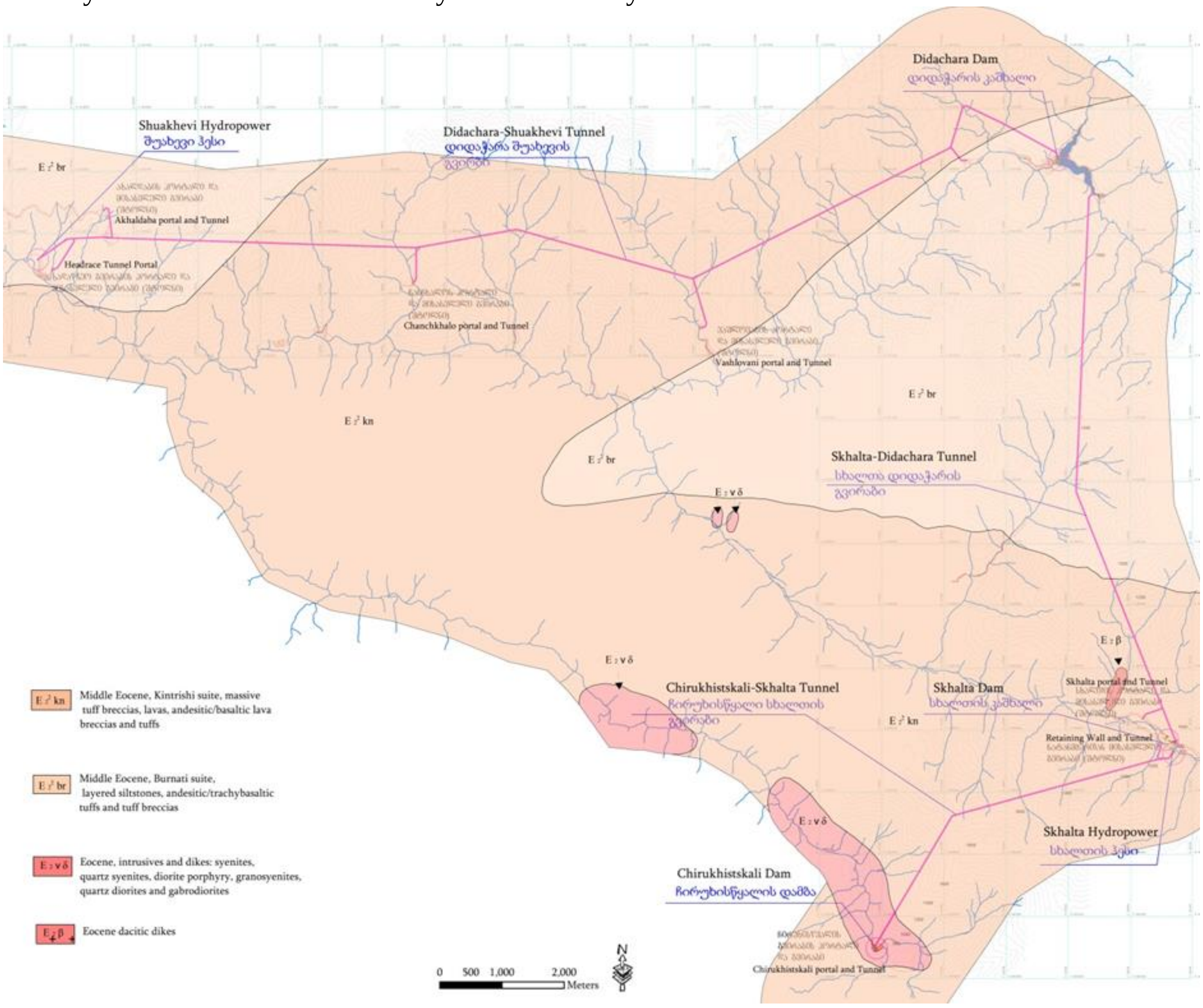

Figure 1. Geological map of the study area

Methods and Materials

The research methodology includes both traditional and modern analytical methods. Field work was carried out in the Adjaristskali River basin, as well as in its tributaries, the Skhalta and Chirukhistskali River valleys. Samples were collected from all key locations of Shuakhevi HPP engineering buildings (Table 1). During the field work, reference sections were selected, rock samples were collected, sampling was accomplished using GPS technologies, the points were plotted on geological and topographic maps of different scales, photographs of interesting areas of exposure were taken, informative charts were drawn on the spot, and deformation structures were measured using a geological compass. At the next stage, systematization/sorting/selection of collected and searched material was performed; at the Laboratory of Complex Geological Research of the Al. Janelidze Institute of Geology, thin sections were prepared. At the same institute, a microscopic description of thin sections was carried out using a polarizing microscope, and petrographic characterization was accomplished.

Table 1. Coordinates of sampling points selected for geochemical analysis from the territory of the Shuakhevi HPP engineering buildings

Sample №	Name	Coordinates	
		X	Y

1-18	Didadjara impounding reservoir	0279569	4615174
2-18		0279659	4615085
3-18		0279714	4615069
4-18	Northern portal of Skhalta tunnel, Adjaristskali basin, left bank	0279891	4614651
5-18		0280021	4614603
6-18		0279986	4614686
7-18	Didadjara impounding reservoir, the Ghorjomi and the Adjaristskali Rivers confluence	0279357	4615293
8-18	Left bank of Didadjara dam	0279357	4615293
9-18	Diakonidze tunnel gallery	0277819	4615130
10-19	Skhalta impounding reservoir	0281192	4605977
11-19		0280984	4605986
12-19		0280984	4605986
13-19		0280735	4606159
14-19		0281029	4605761
15-19	Chirukhi impounding reservoir	0276460	4602529
16-19		0276461	4602527
17-20	Didadjara Central tunnel (village Chanchkhalo)	0268899	4613369
18-20	Shuakhevi HPP building	0262935	4613648

For geochemical studies, the 18 most typical samples were chosen from several hundred samples. Analysis of major components, REs and REEs was performed at the Complex Laboratory of Geological Research of the Al. Janelidze Institute of Geology of Iv. Javakhishvili Tbilisi State University. The sample chips were finely powdered using a RETSCH RS200 vibrating mill. Major and trace element concentrations were determined by X-ray fluorescence (XRF) spectrometry using a SPECTROSCOUT X-ray spectrometer with a Cu-Rh X-ray tube.

Results

The samples for petrographic study were collected in the Adjaristskali River basin, as well as in its tributaries, the Skhalta and Chirukhistskali River valleys. Microscopically, the studied rocks were divided into two types. In particular, the main rock-building minerals of the Burnati suite are plagioclase (0.2-1 mm), pyroxene (0.2-0.8 mm in size) and hornblende (0.1-0.9 mm in size). Among the secondary minerals, calcite replaces plagioclase, and chlorite, which is an alteration product of hornblende, is notable. Zeolite and ore minerals also occur in the rock. The main rock mass is represented by volcanic glass. The rock is characterized by a porphyry structure. Petrographic characterization confirmed that the rocks composing the Burnati suite are tuffs and tuff breccias with andesite-basalt and trachy-basalt compositions (Fig. 2).

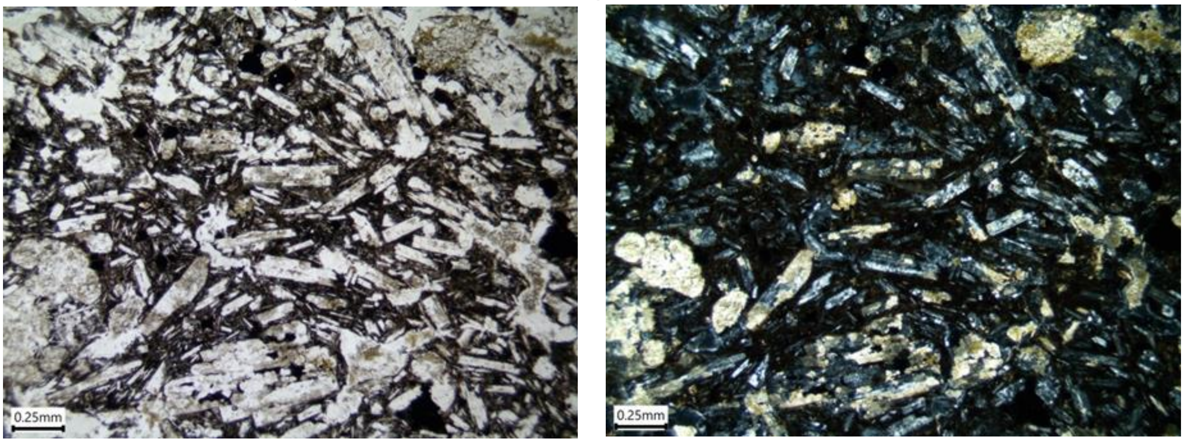

Figure 2. Burnati suite tuff of trachy-basalt composition, PPL and XPL

The main rock-building minerals of the Kintrishi suite are plagioclase (0.3-1.2 mm), which is sometimes fine grained, and pyroxene (0.3-0.6 mm). In addition to plagioclase chloritized hornblende (0.3-1 mm), andesites are notable. Among the secondary minerals, calcite, which substitutes for plagioclase, and chlorite, which is the alteration product of hornblende, are rather remarkable. Zeolite and ore minerals also occur in the rock. Volcanic glass represents the main mass of the rock. The rock is characterized by a porphyry structure. In andesites, volcanic glass is chloritized. In addition, in the rock, tuff fragments with andesite-basaltic compositions are observed. Petrographic characterization verified that the rocks composing the Kintrishi suite are tuffs, tuff breccias and lavas of andesite basaltic composition (Fig. 3).

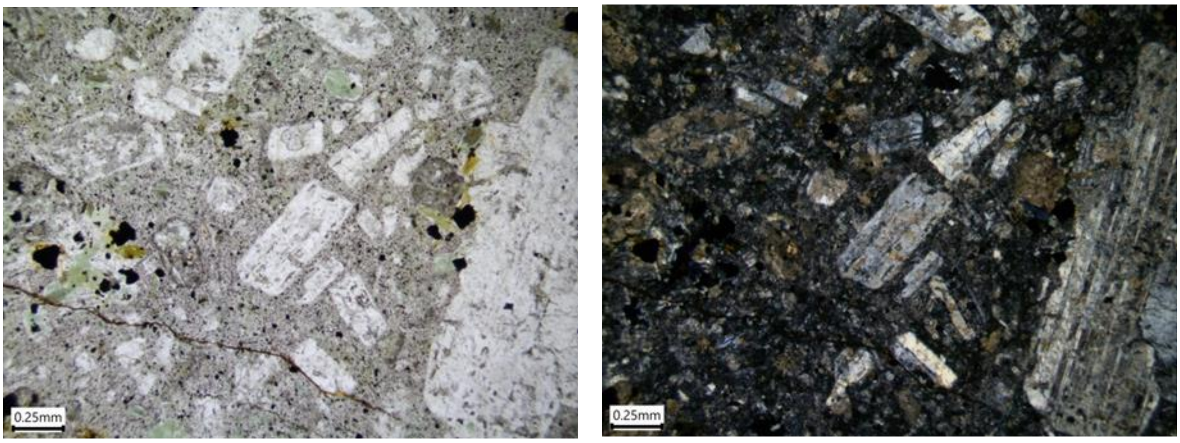

Figure 3. Kintrishi suite tuff-breccia of andesite-basaltic compositions, PPLs and XPLs

We conducted geochemical studies of tuffs, tuff breccias and lavas with andesite-basalt and trachybasalt compositions from the Burnati and Kintrishi suites (Table 2).

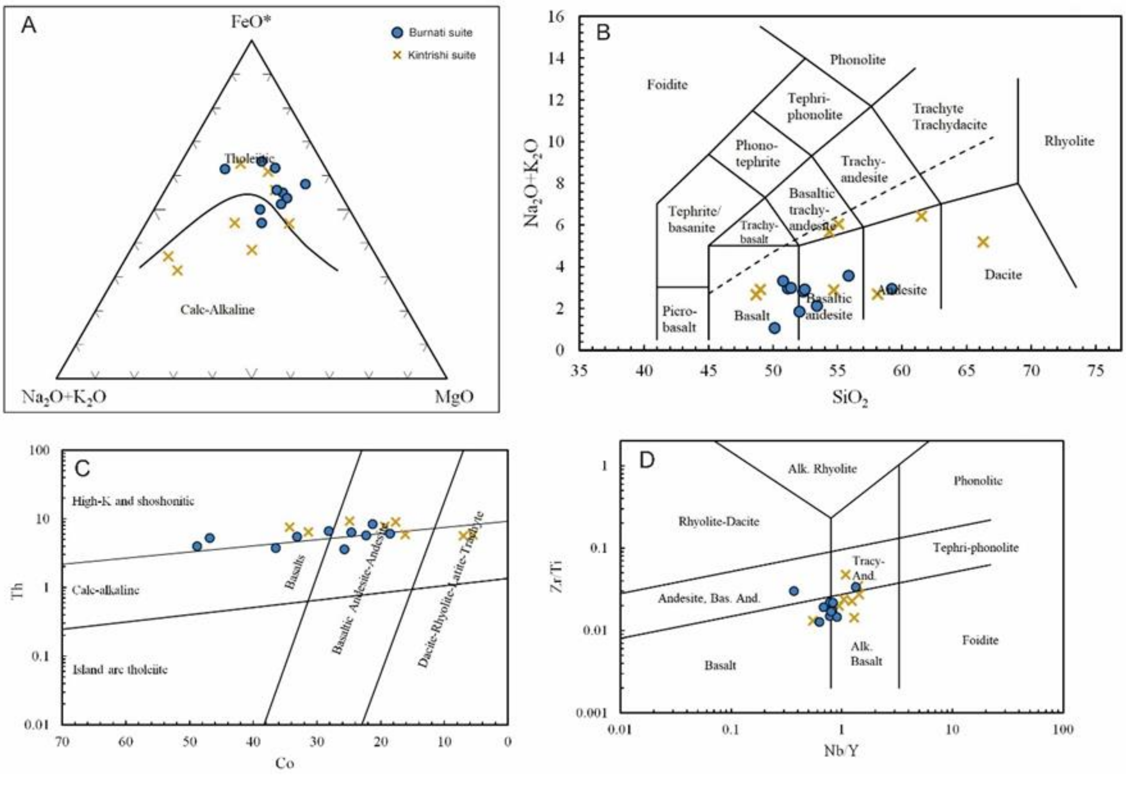

Figure 4. Classification discrimination diagrams: A – AFM (Irvine & Baragar, 1971); B - Na_2O+K_2O vs. SiO_2 (Le Bas et al. 1986); C - Th vs. Co (Hastie et al., 2007); D - Zr/Ti vs. Nb/Y (Pearce, 1996)

On the Na_2O+K_2O - FeO - MgO diagram (Irvine & Baragar, 1971; Fig. 4A), most of the figurative symbols representing the rocks of the Burnati suite are located in the tholeiitic field, and only two symbols plot in the calc-alkaline field; as for the rocks of the Kintrishi suite, their symbols are equally distributed in the tholeiitic and calc-alkaline fields. On the Na_2O+K_2O *vs* SiO_2 diagram (Le Bas et al. 1986; Fig. 4B), the symbols indicating the rocks of the Burnati suite were equally distributed in the basalt and andesite-basalt fields, while those of the Kintrishi suite were scattered in the andesite-basalt and basalt-trachyandesite fields; only in one case did the symbol fall into the dacitic field. On the Th *vs*. Co diagram (Hastie et al. 2007; Fig. 4C), the figurative symbols representing the rocks of both suites are located along the dividing line of the high-K shoshonite and calc-alkaline fields, with a well-defined increase in acidity. According to the Zr/Ti *vs*. Nb/Y diagram (Pearce, 1996; Fig. 4D), the Burnati suite rocks are equally distributed in the alkaline basalt and basalt field, and the Kintrishi suite rocks are equally distributed in the alkaline basalt and trachyandesite field.

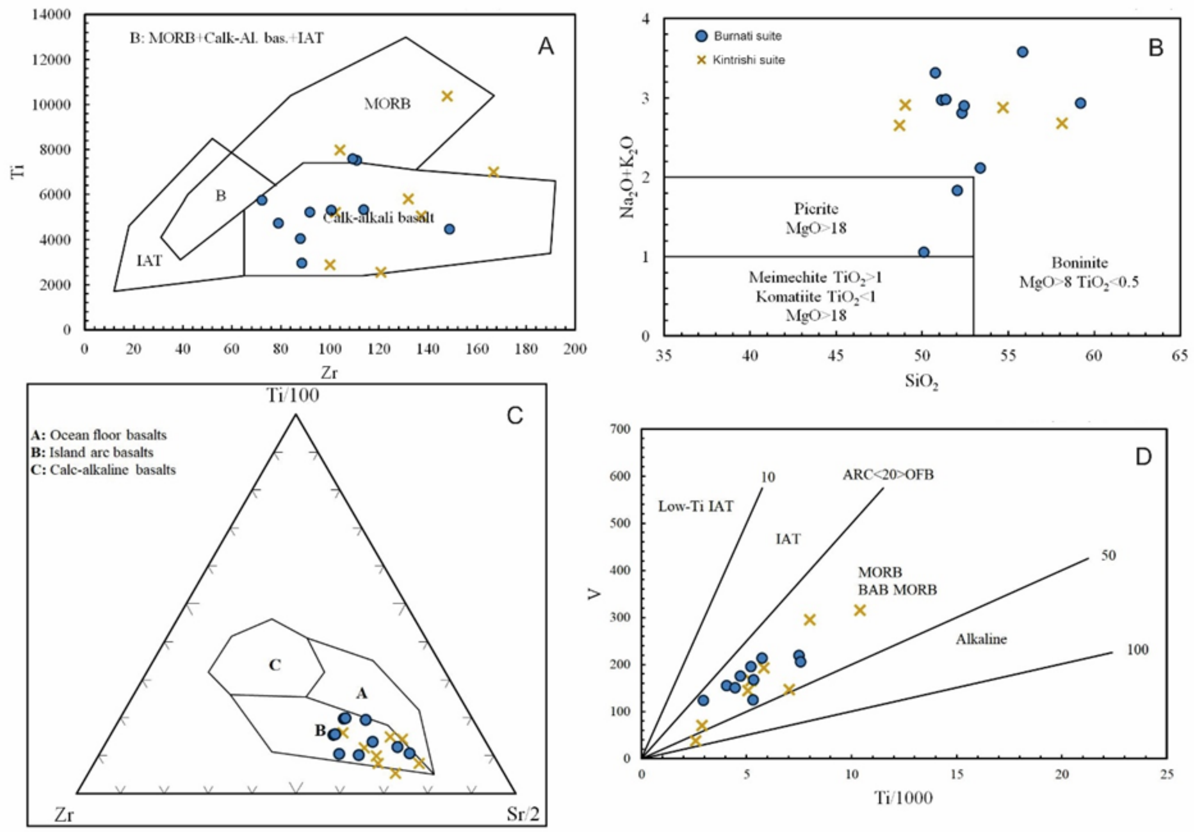

Figure 5. Tectonic diagrams: A – Ti vs. Zr (Pearce, Cann, 1973); B – Na_2O+K_2O vs. SiO_2 (Le Bas et al. *2007); C – Zr vs. Ti/100 vs. Sr/2 (Pearce, Cann, 1973); D – V vs. Ti/1000 (Shervias, 1982)*

On the Ti vs. Zr tectonic classification diagram (Pearce, Cann, 1973; Fig. 5A), the rocks of the Burnati and Kintrishi suites occur within the calc-alkaline basalts field. On the Na_2O+K_2O vs SiO_2 diagram (Le Bas et al. 2007; Fig. 5B), the rocks of both suites are also situated in the boninites field. Boninites are known to be characteristic of the geodynamic conditions of young island arcs. According to the Zr vs. Ti/100 vs. Sr/2 diagram (Pearce, Cann, 1973; Fig. 5C), the rocks of both suites are island arc formations, and according to the V vs. Ti/1000 diagram (Shervias, 1982; Fig. 5D), the rocks belong to the back-arc formations.

Table 2. Results of the XRF analysis of the volcanogenic-sedimentary rocks of the Adjaristskali River. Note: №1-18 – 9-19 and №18-20 Burnati suite; №10-19 – 16-19 and №17-20 Kintrishi suite

Symbol	1-18	2-18	3-18	4-18	5-18	6-18	7-18	8-18	9-18	10-19	11-19	12-19	13-19	14-19	15-19	16-19	17-20	18-20
SiO_2	41.08	41.46	41.20	40.93	42.08	40.77	42.02	40.16	44.77	54.86	48.24	51.69	43.02	49.63	39.20	42.89	48.14	51.95
TiO_2	1.25	1.26	0.96	0.87	0.68	0.89	0.79	0.89	0.75	0.43	1.17	0.48	0.87	0.84	1.33	1.73	0.97	0.49
Al_2O_3	15.08	15.18	14.90	13.96	15.98	15.56	16.16	15.47	12.54	15.68	17.06	15.59	15.80	15.15	16.02	18.07	14.12	16.75
Fe_2O_3	9.11	9.40	8.59	5.87	6.31	7.02	7.28	6.56	6.91	2.93	7.43	3.26	6.91	6.08	8.18	9.53	6.55	4.87
MnO	0.09	0.36	0.14	0.24	0.13	0.09	0.10	0.14	0.18	0.05	0.10	0.06	0.07	0.14	0.11	0.22	0.11	0.09
MgO	5.05	2.98	4.37	3.18	3.83	4.31	2.91	3.98	1.37	0.88	3.71	1.56	1.71	4.89	4.18	3.71	5.40	3.13
CaO	5.83	5.95	7.32	12.62	7.97	6.55	9.73	11.82	10.52	3.39	5.35	5.76	7.74	6.11	8.09	8.84	6.21	7.70
Na_2O	1.92	0.54	1.54	1.08	0.35	0.22	0.32	0.31	1.53	2.54	2.15	2.53	0.48	1.50	1.17	0.14	2.51	0.63
K_2O	0.47	1.68	0.85	1.59	1.32	2.03	1.16	0.54	1.34	1.75	2.88	2.86	1.79	0.78	1.16	2.20	2.78	1.94
P_2O_5	0.45	0.41	0.33	0.27	0.17	0.30	0.26	0.30	0.26	0.26	0.59	0.29	0.29	0.28	0.56	0.80	0.66	0.19
V	218.1	205.4	212.5	194.9	154.8	167.3	175.2	124.6	149.9	37.78	146.9	70.71	165.6	144.1	294.8	315.3	192.90	123.2
Cr	169.1	111.3	105.2	88.44	58.45	92.74	87.57	78.85	65.36	15.34	98.83	14.31	76.73	56.59	83.10	28.41	89.19	45.55
Co	46.82	48.85	36.48	22.27	33.16	24.61	25.69	28.19	21.30	5.54	24.89	7.02	16.14	17.64	34.32	31.39	19.38	18.55
Ni	86.41	89.35	72.43	40.29	41.16	63.62	52.78	42.16	38.92	1.83	44.56	2.65	27.96	31.83	32.50	36.45	41.15	22.58
Rb	6.63	26.45	12.67	29.31	21.07	29.83	17.75	7.21	23.89	22.97	52.94	40.86	30.82	11.17	25.63	40.40	50.53	26.69
Sr	385.1	387.7	331.1	686.2	264.60	347.90	510.40	473.60	463.40	686.20	696.80	474.90	343.50	651.90	753.00	896.60	1083.00	342.70
Y	14.89	18.28	11.88	9.91	9.16	13.02	9.36	13.42	11.43	5.03	14.39	5.28	9.67	8.84	15.31	18.89	10.14	13.64
Zr	110.9	109.2	72.31	91.71	87.93	113.8	79.00	100.6	148.8	120.6	166.60	99.99	102.20	137.20	104.10	147.70	131.80	88.48
Nb	11.61	16.54	7.51	8.19	7.13	10.84	7.47	9.19	15.25	5.45	15.05	7.39	9.07	12.70	8.35	24.39	12.48	5.06
Mo	0.64	0.66	0.63	0.62	0.59	0.61	0.62	0.61	0.63	0.53	0.64	0.54	0.60	0.60	0.64	0.70	0.63	0.59
Cs	5.73	5.86	5.77	5.50	5.73	5.87	6.46	5.40	5.79	4.96	6.02	9.72	5.30	5.16	5.86	6.72	6.14	5.63
Ba	210.5	337.70	211.20	314.70	160.00	201.20	275.70	233.90	295.30	515.80	368.70	420.10	129.70	293.00	207.00	575.30	886.70	782.60
La	9.19	32.52	9.43	8.57	26.19	21.35	18.32	110.80	9.36	9.16	9.63	9.28	8.90	26.85	26.78	42.23	23.13	21.94

Ce	46.20	65.12	39.32	18.62	52.93	40.96	30.12	152.10	93.97	81.52	65.21	59.94	30.81	53.68	45.44	87.61	38.29	24.92
Nd	104.4	53.43	82.37	42.69	62.10	60.59	74.03	20.05	51.59	42.07	106.50	56.42	86.90	64.70	102.7	150.5	95.95	61.32
Hf	2.70	1.39	1.29	1.27	1.19	1.22	1.28	1.25	1.27	1.03	3.13	1.07	1.22	1.20	1.35	3.18	1.29	1.14
W	1.61	1.65	1.59	1.55	1.47	1.49	1.56	1.54	1.55	1.25	1.58	1.30	1.51	1.47	1.64	2.78	1.57	1.40
Th	5.28	4.00	3.75	5.76	5.49	6.31	3.62	6.63	8.39	5.83	9.24	5.63	5.89	9.01	7.53	6.40	7.76	6.09
U	0.65	0.87	0.73	0.94	0.77	0.86	0.81	1.78	1.69	0.75	1.44	1.18	0.85	1.43	0.93	1.09	1.13	0.84

Conclusion

As a result of the research, it was established that

- The Burnati suite within the study area is composed of tuffs and tuff breccias of basalt, andesite basalt and trachybasalt, while the Kintrishi suite is composed of tuffs, tuff breccias and lavas of andesite basaltic composition;
- The rocks of both suites are characterized by similar geochemical characteristics; they have tholeiitic and calc-alkaline compositions, although the rocks of the Burnati suite are mostly characterized by tholeiitic compositions;
- According to the lithological composition, they are calc-alkaline rocks of high-K shoshonite origin;
- The majority of the rocks of both suites are characterized by boninitic compositions that are typical of the geodynamic conditions of young island arcs; their origin is related to back-arc tectonic conditions.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Some Questions about the Safe Operation of Short Road Tunnels

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Abstract

The article looks at the statistical data on fires in short tunnels. It notes that about a quarter of road tunnel fires are classified as strong ones. The analysis is made according to the standards of the USA, the leading industrial country in the world. Underground fire scenarios are analysed and it is shown that for descending ventilation flows, there occurs a strong back-layering on the fresh air jet. The reason for this is an algebraic summation of mechanically and thermally induced underground ventilation flows and the insufficiency of the generally accepted numerical value of critical velocity of 3.0 m/s in the case of a great tunnel slope and strong fires. Noteworthy among the fire-fighting measures are equipping the tunnel with measuring devices; training the tunnel service personnel and rescuers; imposing transportation regimes for heavy hazardous cargoes; information support and promotion of the issue.

Keywords: tunnel fire, critical velocity, fire safety standards, numerical modelling.

Introduction

More than 50 new road tunnels are planned to be built in Georgia in the next 3-5 years, some of which are relatively short tunnels. According to the building norms and regulations applicable in our country, tunnels less than 150 m long are ventilated only by natural traction; tunnels with lengths ranging from 150 to 400 m should also receive natural traction, but its sufficiency should be proven by a relevant assessment. Tunnels longer than 400 m need a mechanical ventilation system (Lanchava & Javakhishvili, 2021; Lanchava & Ilias, 2020; Lanchava, 1986). England has similar regulations: mechanical ventilation is not required for tunnels less than 400 m long, while according to the German RABT Standard, tunnels less than 700 m long do not require mechanical ventilation and are mandatory for tunnels longer than 700 m.

In addition, according to many standards, including the RABT and PIARC standards, a ventilation system must be designed for 30 MW fires, and the emergency ventilation system must be capable of mitigating the harmful effects of fires. For natural gas, an approximately 25 MW underground fire scenario demonstrated that the maximum heat release rate is attained in approximately 5 s. Given that most tunnel fires are controlled by ventilation, this power would be sustained until almost complete combustion of fuel. The modelling results also demonstrated that for short tunnels with natural ventilation, the smoke generated during combustion spreads towards the portals at a velocity of 2.5 m/s, which is very close to the generally accepted value of the critical velocity of 3.0 m/s and somewhat indicative of its numerical value.

The issue of fires is a hot topic worldwide, as the general increase in the number of tunnels, which means more intense road traffic, increases the risk of fires. Following major tunnel fires in the world, the European Union has given particular consideration to the Trans-European Transport Network, in which the safety of existing and future tunnels is a top priority. For tunnels of the network longer than 500 m, the European Parliament and the Council of Europe issued Directive EC 2004/54 on the required minimum level of safety. The total length of such tunnels in EU countries is more than 1000 km. The EU countries strongly recommended extending the requirements of the Directive to tunnels that are not part of this transport network, with the organizational and technical requirements for tunnels at a minimum.

December 2021 was marked by the European Commission’s proposal for a new Regulation on TEN-T guidelines (COM 2021/821), putting the Black and Aegean Seas on the list of newly harmonized transport corridors. Consequently, the abovementioned road tunnels under construction in Georgia should be considered part of the common European Transport Network.

The abovementioned tunnels are commonly built-in mountainous conditions, and the most difficult sections of roads are now traversed through them; however, in the future, with the construction and commissioning of new tunnels, freight turnover and traffic intensity will increase further. An increase in traffic will immediately increase the risk of fires.

US fire standards

According to Paragraph 11.1 of the U.S. National Fire Protection Association Standard 502, "Emergency ventilation systems and tunnel operating procedures shall be developed to maximize the use of the road tunnel ventilation system for the removal and control of smoke and heated gases that result from fire emergencies within the tunnel" (NFPA 502, 2011).

For tunnels less than 240 m long, Paragraph 11.1.1 of the said Standard provides for safety planning based on engineering analysis, taking into account natural factors, mode of transportation, traffic patterns and other similar indicators and does not provide for not considering the need for emergency ventilation. The standard is one of the best standards in the world, and it is worth considering it, especially if we do not have a similar standard in Georgia.

The NFPA-502–7 test standard was introduced in 1972. In 1980, the NFPA Committee revised the document as a recommended practice and added a chapter on air ventilation, which was introduced in practice at the 1981 NFPA Annual Meeting, a conference-like event.

The 1987 edition included a minor amendment regarding the fire water supply.

The 1996 edition included a chapter on the total revision of tunnels, as well as requirements for reviewing the use of new materials in tunnels.

The 1998 edition was revised in cooperation with the Motor Vehicle and Highway Fire Safety Committee. Specifically, practically all the chapters were critically revised, and a new Chapter 7 was added to include research results related to ventilation fire safety testing in the U.S. Memorial Tunnel. This tunnel was no longer in operation at that time and was categorized as an abandoned tunnel. It is located in West Virginia. Following the strong fires in European tunnels, to study air flows and smoke movement, temperature distribution and concentration of toxic gases during fires, the mentioned tunnel was equipped with all types of ventilation systems and measuring equipment, and fires of different powers were tested (Santoianni & Gonzales, 1996). More than 3 million data points were obtained, which were analysed and are presented as graphs and tables in 9 volumes.

The 2001 edition focused on emergency lighting and the optimal spacing of emergency exits. Some important editorial corrections were made. This edition clarifies the rule for applying the standard depending on the tunnel length.

The 2004 edition includes additional requirements for concrete and reinforcement, emergency lighting and emergency exit spacing. Appendix A of the same edition presents the results of new studies from around the world.

The 2008 edition added specific fire testing requirements for tunnel structural members and clarified the classification of road tunnels; additionally, it discussed proper ventilation, a safe environment, and the transportation of hazardous cargo. Annex E also provided a discussion on fixed fire extinguishing systems.

The 2011 revision provides more reasonable requirements for tunnel systems (safety) by tunnel categories. Chapter 9 on water extinguishing systems was added. The document also added materials on system control and periodic testing and updated the appendix on design factors for saving life and material assets.

Analysis of the statistical and factual data of tunnel fires

According to statistical data of long-term observations of tunnel operation in England and France (Beard & Carvel, 2012; Perard, 1996), Germany (Bauberhorde Highways Department, 1992), Sweden (Ruckstuhl, 1990) and Italy (Arditi, 2003), traffic accidents in tunnels are less frequent than those in open highways. This can be explained by the strict control of tunnels, less weather impact, better night lighting and greater attention of drivers when travelling through tunnels, being in an unusual environment—under the ground.

In addition, underground fires have more severe consequences than open environments because in open environments, the products of combustion—heat, toxic gases and smoke—are more easily dispersed. In tunnels, on the other hand, diffusion processes are limited, and there is a need to control them through ventilation.

According to French statistics, there are typically 1 or 2 fires per kilometer of tunnel for every 100 million passenger vehicles that pass through the tunnel. Similarly, for every one hundred million heavy-duty vehicles—the trailers that will pass through the tunnel—under the same conditions, i.e., per 1 kilometer of tunnel length, according to the statistical average, 8 fires will occur, including 3 strong (up to 100 MW) fires, the consequences of which will be disastrous for human life and tunnel infrastructure.

Based on these statistics, for example, in the Elbe Tunnel (Germany), where 37 million vehicles travel in both directions per year, the probability of a fatal fire is much greater than in the Chakvi-Makhinjauri Twin Tunnels in Georgia, where a maximum of 200,000 to 300,000 vehicles travel in one direction per year; however, considering the total length of the tunnels and the total number of vehicles, as well as the increase in freight traffic that is bound to occur due to heavy vehicles as a result of the Silk Road popularization, the risk of fatal fires in our country will significantly increase, and the country must be ready to prevent it.

We provide an example of just one fire in a medium-length road tunnel to show that despite a high level of preventive safety, fires cannot be completely avoided, and tunnel services must be prepared to mitigate and completely eliminate the harmful effects of expected fires: in the Mont Blanc Tunnel connecting France and Italy, which is 11.6 km long, there have been 18 fire incidents since 1965, i.e., when it was commissioned (Lacroix, 2001). The mortality of these fires was the same as that on March 24, 1999.

A large truck carrying margarine entered the tunnel on the French side at 10:46 pm. After 7 minutes, the driver noticed white smoke from his vehicle and stopped the truck 6.3 km from the portal. Immediately after stopping, the trailer caught fire and emitted black smoke, which started to propagate towards the portal on the French side. The driver immediately ran in the opposite direction. Before the emergency closure of the tunnel, 1 motorcycle, 9 cars, and 18 different heavy vehicles entered the tunnel on the French side after the burning truck, and 8 trailers and several cars entered the tunnel from the Italian portal. None of the latter were injured, but none of those who entered from the French side survived, resulting in 39 victims (including 27 car drivers). After the fire had raged for 53 hours, a 900 m long tunnel section collapsed, and 34 cars were destroyed. Ventilation or communication between the portals was insufficient.

This fire could have been easily avoided if normal operating conditions had been provided. Later, there was friction between the tire and the truck body. The heat generated dissipated as the truck drove in the open environment, but due to the reduced heat transfer to the environment in the tunnel, the tire overheated and ignited.

Using the example of the above case, we can visualize the mechanism of the emergency situation, which is very close to the classical definition: there was a deviation from the normal course of a naturally occurring process, an accumulation of an abnormal situation until reaching its culmination, and then relief and damping.

Fire protection of tunnels less than 400 m long is a problem because they usually do not have a mechanical ventilation system. Tunnels up to 700 m long, due to the traction induced by fire, have a greater probability of ventilation system collapse than longer tunnels. The fire traction in this case will increase due to the low aerodynamic resistance of the tunnel and hence the easy provision of an air supply sufficient for complete combustion (Lanchava et al., 2007; Lonnermark & Ingason, 2008). A similar opinion about fire intensification is given in (Ingason, 2010; Bajwa et al., 2009). In particular, at ventilation flow velocities between 2 and 4 m/s, the fire intensification effect is associated with more intense natural ventilation as the fire attempts to better ventilate, i.e., to obtain oxygen for combustion. For clarity, we should note that the length of the tunnels in the mentioned works is not limited, but only the velocity range is defined. The velocity of the flow caused by the natural traction induced by vehicle traffic will be approximately within the specified range in short tunnels.

Special attention should be given to fires in short tunnels resulting in human deaths. Although we do not yet have long or very long tunnels in Georgia, the issue of short tunnels is very important, as confirmed by world experience and evidenced by the following examples: the Newhall Pass Tunnel (USA) between Los Angeles and San Francisco (166 m long): the accident occurred on October 12, 2007, when a truck collided with a sidewall and another truck travelling at high speed collided with it, immediately causing a major fire, which was strengthened by natural traction induced by wind.

Twenty-three people were injured as a result of the accident. Despite the shortness of the tunnel, it took 24 hours to bring the fire under control.

An unnamed tunnel on the B 31 Highway (Germany), 200 m: the accident occurred on Christmas Day in 2005, when a passenger car collided with an oncoming vehicle and a fire broke out, in which four young people aged 18-23 were burnt and five others died of their injuries (Ingason, 2010).

The Viamala Tunnel (Switzerland), 700 m: The accident occurred on September 16, 2006, when a bus and two cars collided. A fire broke out immediately, and two more cars caught fire. Nine people died, and 5 were seriously injured. The Cabin Creek Hydro Power Plant (USA), 150 m: On October 2, 2007, a chemical used to purify water spontaneously ignited. Five people died as a result of the inhalation of toxic compounds (Bajwa et al., 2009).

Numerical modelling of the critical velocity

In longitudinal ventilation, the critical velocity in the emergency ventilation strategy is accepted as the decisive factor in preventing back layering. Back-layering is the propagation of combustion products on a fresh air stream. This phenomenon mainly occurs on the descending ventilation flow when there is reverse air movement in the part of the air-supply tunnel where the fresh air should be. This is caused by the high temperature of the combustion products, which results in less density and floating due to buoyancy. This is a very dangerous occurrence in terms of saving lives by evacuation.

The critical velocity is the minimum velocity to eliminate back-layering that must be assigned to the ventilation flow. The critical velocity depends on the fire strength, tunnel geometry, type of ventilation system used in the tunnel, and other factors. Since the dynamic pressure induced by fire and the similar pressure induced by jet fans are algebraically summed, to avoid smogging the clean jet portion of the tunnel, the clean air jet must have a velocity higher than the critical velocity. Therefore, with a longitudinal ventilation system, a jet moving at a critical velocity will drive out smoke and other harmful combustion products from the hearth of the fire to one side only, and there should be fresh air on the other side.

Many works, including the abovementioned US Standard (NFPA 502, 2011; Santoianni & Gonzales, 1996; Beard & Carvel, 2012), indicate that a 3.0 m/s critical velocity is sufficient to prevent back-layering in transport tunnels during fires, which, in our opinion, is incompatible with the scenarios of underground fires, which are realized through numerical simulations (Lanchava & Ilias, 2020; Lanchava et al., 2017).

Using the Clapeyron equation in our work, it was determined that the dynamic pressure induced by a fire at a temperature of 1000℃ in tunnels is 121.6 kPa, which exceeds the atmospheric pressure and is 6 to 8 times greater than the maximum static pressure of the most powerful fans. In this case, the air density drops to 0.277 kg/m3. Consequently, in the case of strong fires, it will be practically impossible to control the ventilation flow with fans, and the air direction and supply will be determined by the depression induced by the fire (Lanchava et al., 2022a; Lanchava et al., 2022b; Lanchava & Ilia, 2017). This statement is valid considering that mechanically (with the use of fans) and thermally (by fire) induced ventilation flows are algebraically summed up.

This statement contradicts the idea of critical velocity. Therefore, we carried out an experimental numerical simulation of a tunnel up to 100 m long. The purpose of the experiments was to demonstrate the steady increase in critical velocity as the fire power increased, as well as the unreasonableness of relying on the given concept in the attempt to avoid back-layering in accordance with the numerical modelling.

The velocity profiles obtained from the numerical simulations are shown in Fig. 1. To illustrate the increase in critical velocity, two jet fans are used to create a descending ventilation flow. The cross-sections are given depending on the distance from the lower portal as follows: Figure N1 - lower portal; Figure N2 - distance of 20 m from the lower portal; Figure N3 - distance of 60 m from the lower portal; and Figure N4 - distance of 80 m from the lower portal. The numbers of the curves correspond to the time intervals from the beginning of the experiment: 1 - τ= 60 s; 2 - τ= 80 s; 3 - τ= 100 s; and 4 - τ= 120 s. A negative velocity value in all velocity profile graphs indicates the movement of the ventilation flow towards the lower portal, and a positive value indicates the movement of the ventilation flow towards the upper portal.

Curve 1 in Plot 1 of Fig. 1 shows that before the fire starts, the air flow moves toward the lower portal, and the velocity epure has a classical shape. Two jet fans are running simultaneously at the upper portal. As soon as a fire starts, the situation changes immediately (curves 2, 3 and 4): now, the air direction and intensity are more strongly determined by the dynamic pressure induced by the fire, and the impact of the fans tends to decrease. It should be noted that all the velocity profile plots presented show that the pressure change propagates at the speed of sound, causing the corresponding results to change at the same rate.

Based on the above, it is necessary to distinguish the following cases: 1. When it is possible to develop life-saving emergency ventilation designs based on the available classical knowledge; and 2. When the available knowledge is no longer sufficient to realize similar projects, new study results are needed to develop a new approach to the problem.

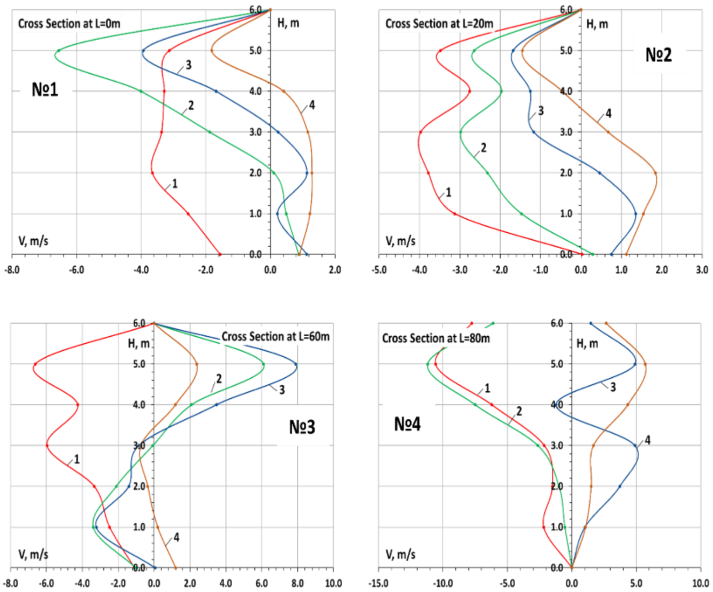

Figure 1. Velocity profiles of the descending ventilation flow with two operating jet fans. The curves correspond to time intervals: 1 - τ= 60 s; 2 - τ= 80 s; 3 - τ= 100 s; 4 - τ= 120 s.

Conclusion

Based on the results of the modelling of fires in short road tunnels and the analysis of statistical indices, it can be concluded that short tunnels, which are allowed to operate without a mechanical ventilation system as per effective standards, need an emergency ventilation system, which will be triggered in the case of fire.

Training of tunnel maintenance personnel and rescuers should be based on scenarios of fires of various strengths with time-varying rates of heat, smoke and carbon monoxide generation. Much attention should be given to strict observance of traffic safety rules; overtaking moving vehicles in tunnels should be prohibited in all instances and should be achieved. At the same time, we consider it advisable to establish a schedule for the movement of hazardous cargo and mandatory inspection of the relevant vehicles before they enter a tunnel.

Competing interests

The author(s) declare that they have no competing interests.

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Risks of Sustainable Environmental Management for the Purpose of Developing Regional Tourism (on the Example of the Lankaran Natural Region)

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Abstract

Currently, reconstruction and redevelopment of inhabited areas is taking place in the natural area of Lankaran, and the area of construction work is also increasing in new, previously undeveloped areas, primarily due to the intensive development of the tourism and recreational industry. The high-quality functioning of the territory is unrealistic without taking into account the factors and patterns of manifestation of landslide processes, the dynamics and forecast of their development. During the study, a pattern of expansion of landslide processes was identified and the intensity of their manifestation was analysed. To study landslide processes, in addition to expeditionary geological-geomorphological, landscape work and stock materials, remote sensing data was used. When conducting landslide hazard analysis, high-resolution satellite images (CNES/Airbus, Maxar Technologies (GeoEye-1), and medium-resolution Sentinel-2A and 2B satellite images were mainly used. Visual and semiautomatic decoding (classification with training) was carried out in the ArcGIS environment. The compiled map for assessing the recreational potential of landscapes is recommended to use as monitoring and timely response to the state of the landscape-geological-geomorphological situation in the Lankaran natural area.

Keywords: landslide processes, anthropogenic impact, landslide hazard, ArcGIS technologies, recreation

Introduction

In recent decades, recreation has taken a significant place within the economy in the development of the regions of Azerbaijan. The main condition for the development of recreation is the assessment of resource potential, taking into account the numerous areas of its use (Tarikhazer, 2020). Natural and recreational resources are the geological and geomorphological structures of a territory, lithology, seismicity, landscapes, climate, mineral springs, water areas, etc., and are distinguished by limited self-healing capabilities (Solovova, 2007).

The biological and landscape diversity of the natural region of Lankaran significantly distinguishes it from other regions of Azerbaijan — proximity to the Caspian Sea, humid subtropical climate, the presence of mineral springs (Istisu, etc.), relict plants (ironwood, boxwood, chestnut oak, etc.) and many others. In addition, this region is a growing area for citrus fruits, tea and rice. Consequently, the natural conditions and resources of this region are favourable for the development of such types of tourism as sanatorium treatment, health and educational tourism, and recreation. However, ensuring the long-term sustainable use of natural resources for the purpose of developing recreation is a problem. It is well known that the tourism sector causes significant damage to landscape complexes, which can ultimately lead to the development of a wide range of exogenous geomorphological processes (EGPs), specifically landslides (Mammadov & Tarikhazer, 2023; Tarikhazer et al., 2023). The relevance of this problem is that it is necessary to promptly develop plans for the technical and engineering protection of various objects to carry out monitoring work to predict the formation, reduction and even prevention of landslides, which will ultimately reduce risks and reduce material damage (Tarikhazer, 2020; 2019).

Landslide processes in the region under study are the most common but are also the most complex, long-lasting and multifactorial. In the natural region of the Lankaran Plateau in recent years, the largest number of landslide processes in developed or newly populated areas are associated with increased anthropogenic activities (e.g., cutting woody vegetation, pruning slopes, laying linear structures—roads, power lines, gas and water pipes, sewerage networks, expanding existing and establishing new settlements, increasing the area of household plots and crops, and excessive watering and overgrazing of livestock), which are carried out without considering the geological and geomorphological conditions of the area. Most of the numerous objects are located in low- and mid-mountain zones, and this requires increased attention to the conditions and areas of formation and potential development of landslides. Dangerous road zones include the Sadatli landslide section in the Jalilabad district, the Veri-Aliabad section in the Lerik region, the Goravench landslide section in the Lankaran region, the landslide section 17–19 km from the Lankaran–Lerik road (Fig. 1), the Gullutepe landslide section in the Masally region and many more.

In the regions of Azerbaijan located in landslide-prone zones, the number of settlements in the Lankaran region is 8%, and the number of people is 11.1%.

The main conditions and factors for the development of landslides in the Lankaran natural area are geological and geomorphological structures, relief and lithology, and climatic and anthropogenic factors.

Figure 6. Active landslide processes at 17–19 km of the Lankaran–Lerik highway (photo 07.03.2021)

Methods and Materials

In recent years, numerous studies have been conducted to assess landslide hazards in various regions of the world (Akgun & Bulut, 2007; Asadian et al., 2010; Guzetti et al., 2005; Lee& Jones, 2014; Metternicht et al., 2005). To study landslide processes, in addition to expeditionary geological-geomorphological, landscape work and stock material, and statistical and cartographic sources, we used remote sensing data. When conducting the landslide hazard analysis, high-resolution satellite images (CNES/Airbus, Maxar Technologies (GeoEye-1)) and medium-resolution Sentinel-2A and 2B satellite images were used. Visual and semiautomatic decoding (classification with training) was carried out in the ArcGIS environment.

Results

Geological and geomorphological conditions

The large orographic unit of the Lankaran natural region is the heterogeneous morphostructure of Talysh, which is part of the larger morphostructure of the Western Asian Highlands, which is a complex fold-block mountain system. In general, the relief of Talysh is in accordance with the prevailing physical-geographical conditions and geological structure. The formation of the main features of the relief is due to endogenous factors of morphogenesis. Volcanic activity played a significant role in the formation of the Talysh relief, which experienced its greatest development in the Eocene. The block structure of Talysh, caused by discontinuous tectonics, is manifested in the step-by-step nature of its relief. The first stage, 800–900 m high, corresponds to the watershed of the Burovar ridge, the eastern slope of which is cut off by the pre-Talysh deep fault. The second stage, which rises above the first, with a height of 1400–1600 m, occupies the basin of the right tributaries of the river. Lankaranchay in its middle reaches.

İt is limited by a deep fault separating the Lerik synclinorium from the Astara Ridge from the southwest. The third stage, with heights of 700-800 m in the southeast and 2200 m in the northwest, corresponds to the high peaks of the Peshtasar Ridge. There is also a deep fault in the southwest. The fourth stage, at 2400 m high, corresponds to the Talysh Ridge, which is limited from the northeast by a deep fault. Consequently, the morphostructures of the ridges of the Talysh Mountains have a block structure, determined by the features of their relief.

According to the structure of the surface, Talysh is divided into two parts: mountainous, where denudation processes predominate, and lowland, where accumulative processes predominate. The Talysh Mountains descend stepwise to the Lankaran lowland, from which they are separated by a deep fault. The structure of the Talysh relief is closely related to the altitudinal zone. There is no high mountain belt here and is represented by individual peaks of the Talysh and Peshtasar ridges in the watershed strip with heights of 2400–2450 m. Here, the slopes of the river valleys are steep, and their bottoms have large slopes. The mid-mountain belt occupies altitudes of 1400–2200 m and is characterized by deep incision of river valleys. The river valleys are narrow and steep, and erosion terraces have developed. The low mountain belt covers a significant part of the territory and is characterized by significantly flattened relief. The river valleys that cross it are wide and flat-bottomed, accompanied by a series of accumulative and erosion-accumulative terraces. Here, intermountain basins are characterized by large thicknesses of continental sediments filling them.

The main mountain ranges of Talysh extend in the northwestern (Pan-Caucasian) direction and are represented by the Talysh, Peshtasar, and Burovar ranges and the intermountain basins separating them—Yardimli, Dyman and Gosmalyan.

The Talysh Ridge is the highest (Kemurkey Mountain, 2493 m; Gyzyurdu Mountain, 2433 m) and longest (length, 100 km; width, 10–15 km). Its relief is rugged and characterized by intense erosional dissection. To the northeast, at a distance of 7–10 km in the northwest direction, the Peshtasar Ridge extends (maximum height of Tylykh, 2342 m). Due to long-term development, the watershed part and the slopes of the ridge are intensively dissected. On the extreme northeastern periphery of the mountainous Talysh, which is more than 70 km long, is the Burovar ridge, which is intersected by the valleys of the river. Bolgarchay, Vilyashchay, etc. The heights of the ridges range from 600–1000 m.

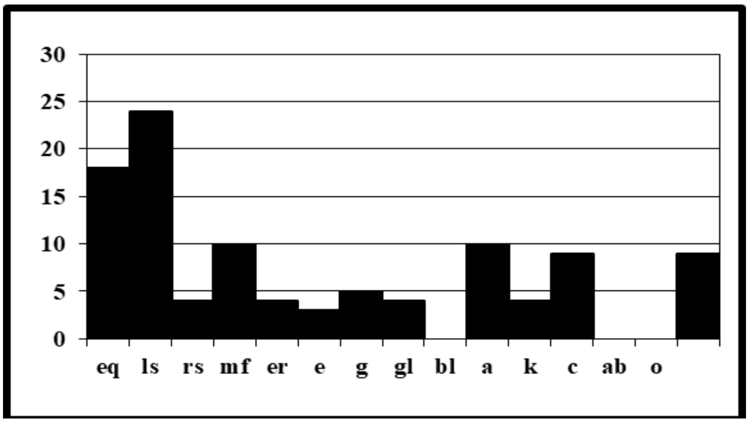

Figure 7. Structure of modern dangerous geomorphodynamic processes within the boundaries of the Talysh Mountains; Processes: eq — earthquakes; c — caves; ls — landslides; k — karst; rs — rockslides; gl —glacial (exaration and accumulation); mf — mudflows; bl — badland; er — erosion; a — avalanches; e — eolian; ab — abrasion; g — gullying; o — other processes.

Within Talysh, intermountain basins of erosional, erosional-tectonic and volcanogenic-tectonic origin have developed. Within their boundaries, the river valleys are wide and are characterized by better preservation of terrace levels of accumulative genesis. The most expanded sections of river valleys correspond to intermountain basins, where rivers, after forming an erosional base, filled the bottom with loose sediments and then cut into their own sediments and formed their own valleys with a series of nested terraces. Landslides are also widespread. The slopes of river valleys are terraced and complicated by landslide processes. Landslides developed on the northeastern slopes of the Peshtasar ridge and in the zone of its transition to the Yardimli intermountain depression. The Yardimli Basin, most of the northeastern slopes of the Burovar Ridge, which is composed of sandy-clayey deposits, is characterized by the widespread development of landslide processes, giving the areas of landslide development a typical landslide landscape.

The Gosmalyan intermountain basin is located in the upper reaches of Konjavuchay. The relief is intensively dissected and characterized by good terracing, with a strong accumulation of proluvial and colluvial deposits. In the northwestern part of the Talysh Range, a large geomorphological element is the Dyman intermountain basin, in which the rivers are wide and terraced. The central part is filled with alluvial-proluvial deposits, into which the river valleys are shallowly cut.

Here, at an altitude of 1480 m, the source of the upper reaches of the Vilyashchay River is concentrated.

The eastern part of the study region is occupied by the Lankaran Lowland, which is limited from the west by the steep northeastern slope of the ridge foothills of the Burovar Range. Along the Burovar ridge, a narrow intermittent strip stretches a zone of deluvial-proluvial deposits, forming alluvial cones, deluvial plumes, etc.

The change in the landscape belts of Talysh from humid subtropical regions in the low mountains and adjacent plains to semidesert regions in the northwestern part of the Talysh and Peshtasar ridges (landscape inversion) determines the vertical azonality of the manifestation of exogenous geomorphological processes (EGP) of relief formation. Consequently, the development of the EGP depends on the altitudinal zone of the relief, the latest and modern tectonic movements (seismicity up to 8 points), slope exposure, climatic conditions, etc. (Fig. 2).

Climatic conditions. Relief and the Caspian Sea have a great influence on the distribution of precipitation in the study area. The difference in precipitation distribution is very large, reaching 1100–1200 mm. The greatest amount of precipitation falls in the foothills of the southeastern part of Talysh (1700 mm). If 1400 mm of precipitation falls in the foothills of Talysh, then in the middle mountains, it decreases to 200–300 mm. In mountain depressions (especially in the Deman and Diabar depressions), up to 300 mm of precipitation falls. The reason for the uneven distribution of precipitation is the mountains.

Table 3. Changes in climate elements by landscape type in the Talysh Mountains

Types of landscapes	Absolute height (m)	Amount of solar radiation (kkal/sm2)	Number of hours of sunshine	Average annual precipitation (mm)	Average annual temperature (C^0)	Average annual evaporation (mm)
Dry steppe landscapes of low mountains	200>	120–130	2000–2200	300–450	14–14,7	800–1000
Forest landscapes of low mountains	200–700	132–136	<2000	400–1200	12–14	600–700
Forest landscapes of the middle mountains	700–1800–2000	130–135	2000–2200	600–1600	8–12	600–800
Mountain xerophyte landscape of the middle mountains	2000–2500	125–135	2200–2400	300>	6–8	400–600

The number of sunny hours in the Talysh Mountains is 2200–2400, and in low-mountain and mid-mountain areas, it is 2000–2200. The distribution of total solar radiation is 128–132 kcal/sm2 at the peak of Kemurgoy-Gyzyurdu 140–144 kcal/sm2. The radiation balance decreases from 35 kkal/cm2 during the year to 10 kkal/sm2 towards the high part of the middle mountains (Table 1).

The average annual relative humidity for the region is 70–80%. The maximum relative humidity is observed in the foothills (Table 2).

Table 4. Relationship between moisture conditions and differentiation of landscape types

Landscape types	Absolute height in meters	Average annual precipitation (in mm)	Average annual evaporation (in mm)	Humidification coefficient	Humidification type

Dry steppe landscapes of low mountains	200>	450	1000	0,45	Arid
Forest landscapes of low mountains	200–700	1200	700	1,7	Extreme Humidity
Forest landscapes of the middle mountains	700–1800–2000	1600	800	2	Extreme Humidity
Mountain xerophyte landscape of the middle mountains	2000–2500	300	600	0,5	Arid

In the region under study, landslide processes become more active during periods of heavy rainfall. For example, from November 7 to November 10, 2015, heavy rains occurred in the Lankaran-Astara zone. In total, 69–122 mm of precipitation fell here (44–72% of the average monthly average). The amount of precipitation in the summer months and early autumn is sometimes 3–4 times greater than the amount of precipitation in the winter and autumn periods, and this increase mainly falls on the share of rainfall precipitation. Therefore, it is no coincidence that landslide processes occurred precisely during this period. As noted by Madatzade and Shikhlinsky (1968), showers are observed in both lowland and mountainous zones. The differences between them lie not in the intensity but in the frequency of rainfall. In the mountainous areas of the Lankaran Plateau, an inversion of atmospheric precipitation has developed: in the mountains, showers are observed less frequently—especially the most prolonged and intense ones—and in lowland areas—much more often (Fig. 3).

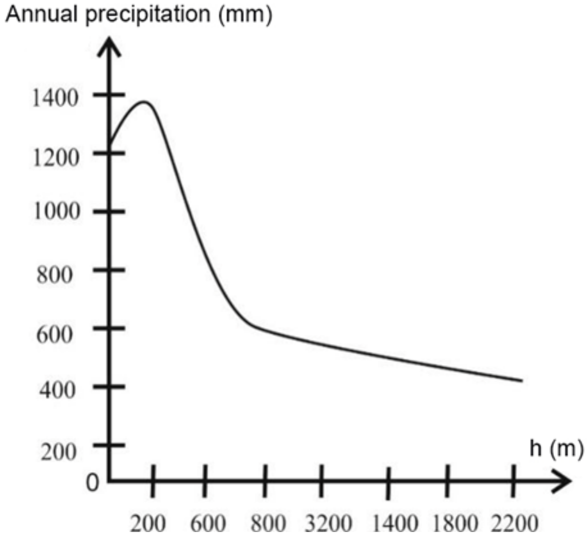

Figure 8. Change in the annual amount of precipitation with height in the central part of Talish (according to A.A. Madatzade, E.M. Shikhlinsky (1968)

The role of climatic factors in the development of landslide processes is undeniable. To reveal the role of climatic factors, a graph (Fig. 4) of the development of landslides in the Lankaran natural area was constructed by month. The maximum number of landslides is observed during periods with the greatest frequency of maximum precipitation, i.e., if the maximum frequency of precipitation occurs in spring and autumn, then the maximum occurrence of landslides occurs during the same period.

In addition, a graph of the frequency of landslide processes in the Lankaran natural area was drawn (Fig. 5). The statistical analysis of the landslides revealed that for the period of 2010–2022. On average, 6 of the most dangerous landslides occur annually.

It follows from Fig. 5 that the highest frequency of landslides is observed in 2015–2017. The trend line (dynamics) proves this, i.e., in recent years, landslide processes have been intensifying; however, we consider the main reason to be geological and geomorphological factors, as well as increased anthropogenic impacts. However, despite this, the role of climate factors cannot be denied. Climatic factors do not form the landslide itself, but they are a kind of trigger.

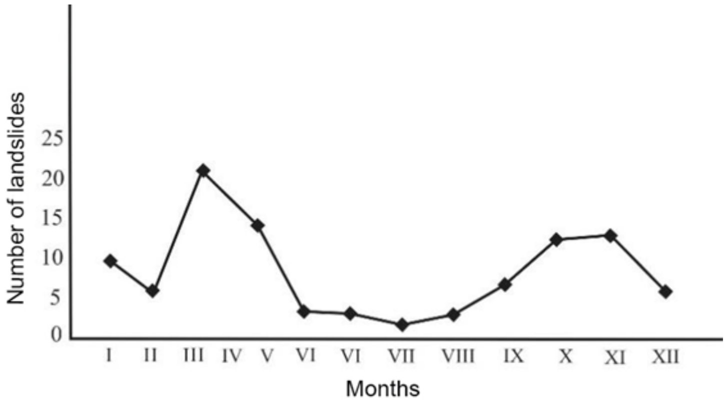

Figure 9. Distribution of landslides in the Lankaran natural area

Anthropogenic factors

It is known that during the anthropogenic development of a territory, it is of no small importance to assess the stability of the relief, its individual forms, or the risk of the occurrence of exogenous geomorphological processes (EGPs), in this case, landslides, which pose a danger to human life and the functioning of tourist and recreational complexes. Common types of anthropogenic impacts include cutting and overloading of slopes, artificial watering and waterlogging of constituent rocks due to leaks from water pipelines and excessive watering of lands (Gulieva et al., 2014). Naturally, they are confined to the most urbanized territories and linear infrastructure facilities. For example, unplanned deforestation during the construction of tourist facilities such as the Lankaran Springs Wellness Resort and Hirkan Park Hotel led to the formation of landslide processes on the slopes of the mountains of the Lankaran natural region. Slopes cut as a result of laying road surfaces such as Lankaran–Lerik, Lerik–Yardimli, and Degedi–Pelikesh in the Astara region (Fig. 6) also led to the formation of new centers for the development of landslides.

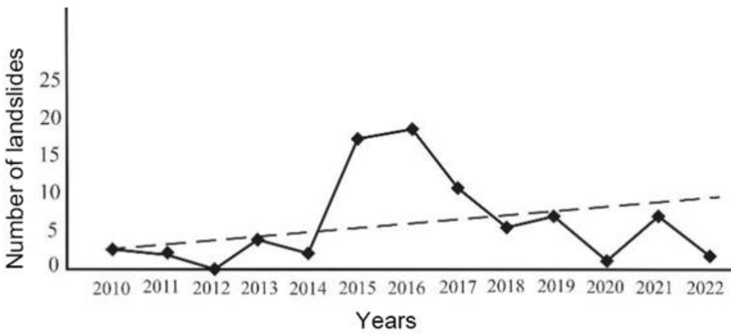

Figure 10. Frequency of landslides in the Lankaran natural area

When analysing the landslide hazard and creating a map for assessing the recreational potential of landscapes, high-resolution satellite images (CNES/Airbus, Maxar Technologies (GeoEye-1)) and medium-resolution Sentinel-2A and 2B images were used. Basically, visual and semiautomatic decoding (classification with training) was carried out in the ArcGIS environment (Fig. 7).

In the Talysh Mountains, the lowest landscape zone begins with forest, followed by mountain steppes and mountain-dry steppe landscape zones. Therefore, the main reason for this event is that, on the one hand, the highlands and internal depressions here are under the influence of the arid climate of the Iranian Plateau, and on the other hand, the mid-mountain Peshtasar ridge, which creates a barrier landscape in the Talysh Mountains and retains moisture generated by humid northeastern winds. Thus, moist air masses coming from the Caspian Sea pass over the narrow Lankaran Plain and on their way into contact with the steep slopes of the Talysh Mountains, resulting in a large amount of precipitation (1400–1600 mm). Air masses moving in the western and southwestern directions gradually lose moisture, and the amount of precipitation in the highlands sharply decreases. The reason for the formation of landscape inversion in Talysh is orography and associated climatic conditions. This led to the formation of unique landscape types at corresponding altitudes (Guliyeva, 2018).

Figure 11. Landslide on the Degedi–Pelikesh road, Astara district (photo May 28, 2023)

From the analysis of the landscape map, field research and other literature, it is clear that if the forests on the northern slope are dense and highly dense and occupy a large area, then the forests on the southern and western slopes are less dense, occupying a relatively large area. a small area and, in some places, even replaced by forest and shrubs.

One of the most important factors determining landscape differentiation in the study area is the formation of river valleys, gorges, and landslides. During your field survey, we observed active landslides on the right bank of the Alasha River, including between the villages of Sors, Aliabad and Shingedulag.

Conclusion

In this study, we analysed all the factors contributing to the development of landslide processes in the natural Lankaran area. The main factors are the geological and geomorphological structure, seismicity and anthropogenic factors. The remaining factors, namely, climate, are a trigger in the formation of landslide processes.

To reveal the role of climatic factors, a graph of the development of landslides in the Lankaran natural area was constructed by month. The maximum number of landslides is observed during periods with the greatest frequency of maximum precipitation, i.e., if the maximum frequency of precipitation occurs in spring and autumn, then the maximum occurrence of landslides occurs during the same period. In addition, a graph of the recurrence of landslide processes in the Lankaran natural area was compiled. The statistical analysis of the landslides revealed that for the period of 2010–2022. On average, 6 of the most dangerous landslides occur annually.

A map was constructed to assess the recreational potential of the landscapes of the Lankaran natural region, from which it follows that most landslides are confined to the plain-mountain contact zone, low mountains and middle mountains. Monitoring work has shown that in the study region, the number of landslides is increasing every year. Based on the results obtained, ArcGIS technology has advantages over traditional (cartographic) methods for studying landslide processes.

Based on the above, we believe that the current environmental situation can lead to a decrease in the productivity of natural ecosystems and further restoration potential in the future. This can subsequently lead to a decrease in the attractiveness of landscapes due to their powerful transformation. Currently, there is already an increase in environmental tension in the region. It is obvious that it is necessary to switch to a new system of environmental management, which, in the future, will ensure the long-term environmentally sustainable functioning of the Lankaran natural area with the aim of developing tourism.

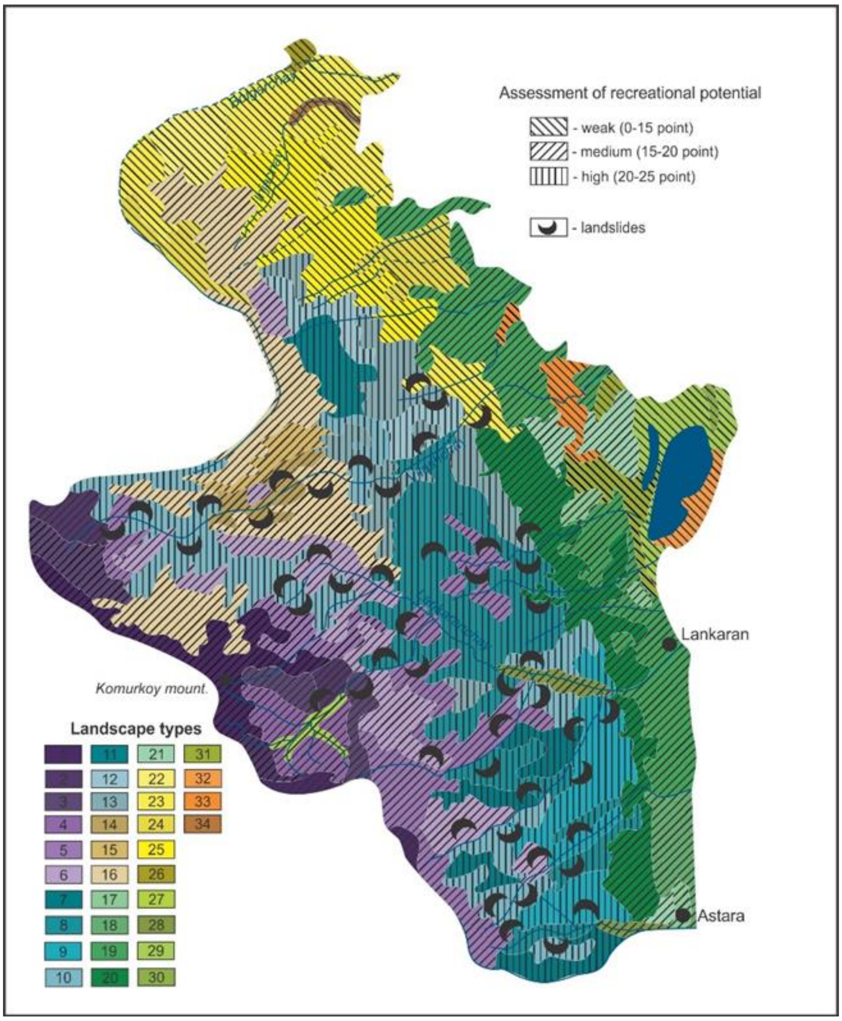

Figure 12. Map of estimation of the recreational landscape potential of the Lankaran region (taking in account the landslide hazard of the territory); Legend A. Temperate-humid mountain-forest landscapes; I. Intrazonal xerophytic mountain landscapes (1–6); II. Hyrcan type humid subtropical forests of low and medium highlands (7–13); B. Landscapes of medium and low mountains with a temperate-humid climate; III. Forest-steppe, steppe and mountain-meadow landscapes of low and medium highlands (14–16); C. Landscapes of temperate-humid accumulative plains; IV. Forest, shrub-meadow and forest-steppe landscapes of accumulative plains (17–21;); D. Lowland arid and semiarid landscapes; V. Dry-desert, desert landscapes of the arid lowland (22–25); VI. Lowland arid-forest, forest-shrub and shrub-steppe landscapes (26); VII. Dry desert and xerophyte-desert landscapes of denudasion-accumulative plains (27); VIII. Intrazonal landscapes of accumulative plains (28–31); E. Semidesert landscapes of arid and temperate-arid subtropical plains; IX. Semidesert landscapes of accumulative plains (32–34)

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Analysis of Spontaneous Exodynamic Processes in the Dghviora River Basin Taking into Consideration the Perspectives of the Shovi-Glola (Georgia) Tourist Agglomeration

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Abstract

River Dghviora originates from the much-modified cirque of the vanished glacier on the northern slope of the Shoda-Kedela mountain range, parallel to the Central Caucasus. The glacial and erosive-glacial relief of the nival zone is developed here, with clearly defined troughs, moraines, individual erratic boulders. At relatively low hypsometric levels, alpine and subalpine landscapes are represented. The building rocks of the valley, along with the slope of its bed and climatic conditions, are the main factors of the formation and development of exodynamic processes. The material coming from Dghviora river, and its parallel valleys flows into the Chanchakhi valley and forms a large withdrawal cone at the confluence, on which the village of Glola is built. From here, destructive mudflows arise during heavy rains, because of which this and other settlements are damaged. In July 2020, because of heavy rains, due to the overflow of Rioni, Chanchakhi, its abovementioned and other tributaries, destructive mudflows were formed, which destroyed the infrastructure, highways and bridges of the villages of region Zemo Racha. The purpose of the article is to analyse the mechanism of occurrence of natural processes and to assess their impact on the tourist agglomeration of Shovi-Glola, as well as to predict the further development of these processes as much as possible and to present preventive measures.

Keywords: Exodynamic processes; rockslides; mudflows; threats to tourism

Introduction

The Racha region covers the upper part of the Rioni River basin, from the Tvishi Narrows to the crest of the Central Caucasus. This includes the entire ethnographic Racha and partly the northwestern section of Samachablo (the headwaters of the Jejora River). The area covers an area 100 km in length and 50 km in width, and the depth of the vertical incision ranges from 500 to 1200 m. Absolute heights vary from 350 m (Tvishi Narrows) to 3780 m (Pasi Mountain). The region is distinguished by a complex and diverse geological and geomorphological structure, as the entire stratigraphic spectrum, starting with Palaeozoic crystalline rocks and ending with Quaternary alluvium, is exposed here, and the complexity of the relief is conditioned by the large amplitudes of the absolute and relative heights of its surrounding ridges and the genesis and morphology of the related relief landforms. Fragmented by Rioni and its tributaries, the cavity is bounded in the northeast by the southern slope of the main Caucasus Range, in the northwest by the Lechkhumi Ridge (Mt. Samertskhle, 3560 m) and its southwestern branches, and in the southeastern border by the Racha Ridge (Mt. Khikhamta, 2240 m). The Dghviora River is also a left tributary of Chanchakhi, the left tributary of the upper waist of Rioni, which originates on the northern slope of the Shoda-Kedela ridge, parallel to the Central Caucasus. The rocks forming the valley-Jurky and Lower Cretaceous shales, clay shales, sandstones, limestones, and Quaternary deluvial, proluvial and partially alluvial layers, together with the slopes of the valley, inclination of its bed and climatic conditions, are the main factors for the creation of exodynamic processes: mountain torrents, rock avalanches, stone falls, and debris cones. The material coming from Dghviora and its parallel valleys flows into the Chanchakhi valley and forms a large debris cone near the estuary. The Dghviora valley originates from the highly deformed cirque of the vanished glacier, where alluvial centers have appeared. From here, destructive mudflows arise during heavy rains, because of which the village of Glola and other settlements are damaged. In July 2020, because of heavy rains, due to the overflow of Rioni, Chanchakhi, its abovementioned and other tributaries, destructive mudflows were formed, which destroyed the infrastructure, highways and bridges of the villages of Zemo (Upper) Racha (Tsereteli, 1965).

Spontaneous Exodynamic Processes in the Dghviora River Basin

The Chanchakhi River basin is located on the southern slope of the Greater Caucasus. The glacial and erosive-glacial relief of the nival belt is developed here, with clearly defined troughs, moraines, and individual erratic blocks. At relatively low hypsometric levels, alpine and subalpine landscapes are represented. The depth of erosive dissection is more than 1000 m in some places, and the inclination of the slopes is 40-600. The absolute height of the highest peak of the Shoda-Kedela range, Shoda, is 3609 m. This high-elevation, deep-valley, erosional-denudation terrain developed on Jurassic and Lower Cretaceous sedimentary rocks. The presence of relatively mild forms of the relief relates to the erosive processes occurring in the Liassic, strongly dislocated micaceous sandstones and with the erosion processes occurring in the shale clays. The shape of the valleys is mostly V-shaped, and where clay shales dominate, the rivers form glacial-carved valleys (Tsereteli, 1965). At relatively low altitudes, denudation relief occurs with the active development of mudflows and landslide events. In the Lower Cretaceous sediments, intense tectonic movements produced folded structures. It is dominated by young and old faults of three latitudinal directions, which are complicated by paraclases and rupture dislocations of different directions, which are well defined in the terrain. The geological formations on the northern wing of the Upper Racha syncline are mainly composed of thick-layered marls of Upper Jurassic age, carbonate shales, and interlayers of limestones. Quaternary eluvial, deluvian, colluvial, alluvial, Proluvian and fluvioglacial layers form relatively young sediments (Fig. 1).

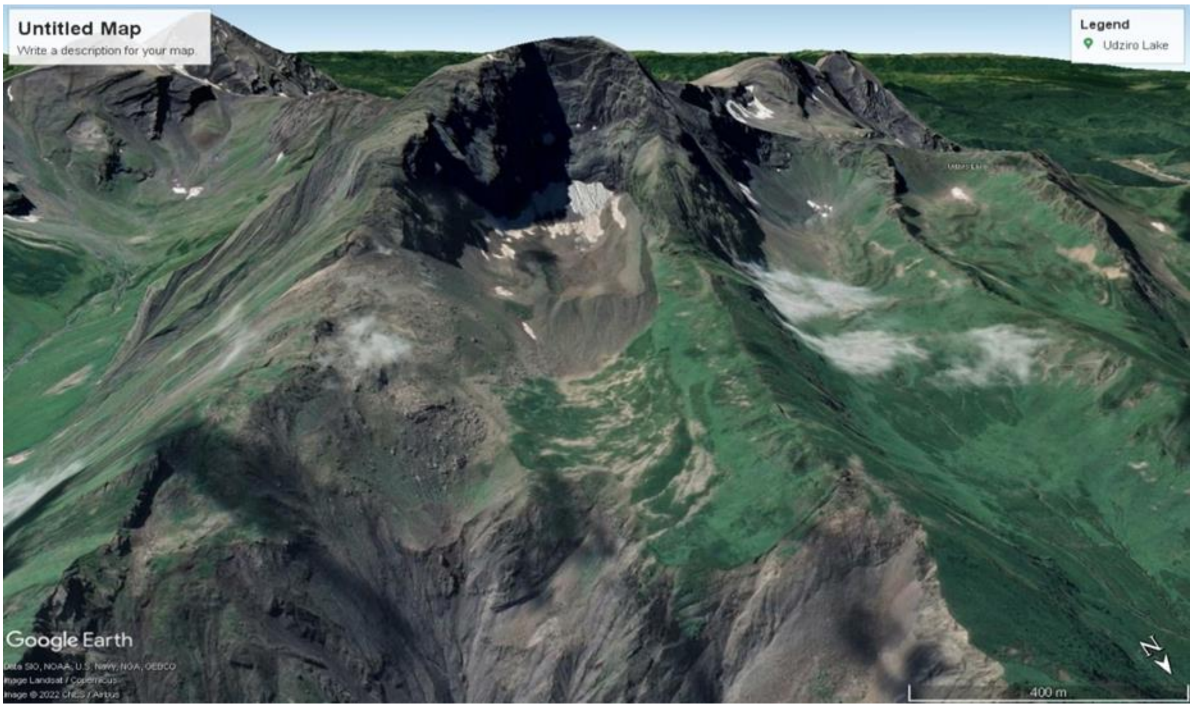

Figure 13. The head section of Dgviora river in the Chanchakhi basin. Source: Google Earth

The upper part of the Chanchakhi River from the left side joins the Dghviora River, whose basin is very peculiar and at the same time typical in terms of the manifestation of natural exodynamic processes in Upper Racha and in the Caucasus (Map oh mudflow hazards in Transcaucasus and Dagestan, 1989; Cernomorets, 2006; Dokukin et al., 2015). There are two channels near the mouth of the Dghviora River—old and new—developed later. The river originates from the northern slope of the Shoda-Kedela ridge near the summit at an altitude of 2640 m above sea level. The head of the river is a bursiform valley bounded by steep (60-700) slopes, which is probably a deformed glacial cirque (Figs. 2 and 3). Tectonic and rock lithology are among the most important factors influencing the relief of a valley (Adamia & Gujabidze, 2004; Tsereteli et al., 1985; Ovsyuchenko et al., 2011;

Arefev et al., 2006). According to the tectonic division into districts of Georgia, Lower Cretaceous clay shales and marly shales are intensively folded here. In the sandstone and limestone distribution zone, the relief is sharply dissected and represented by steep ridge and scarp slopes.

The area of the river basin does not exceed 6 km2, the length is 5 km, and the average slope of the riverbed varies between 15-17^0 in the middle and lower parts (Fig. 3). Fluvioglacial, proluvial and

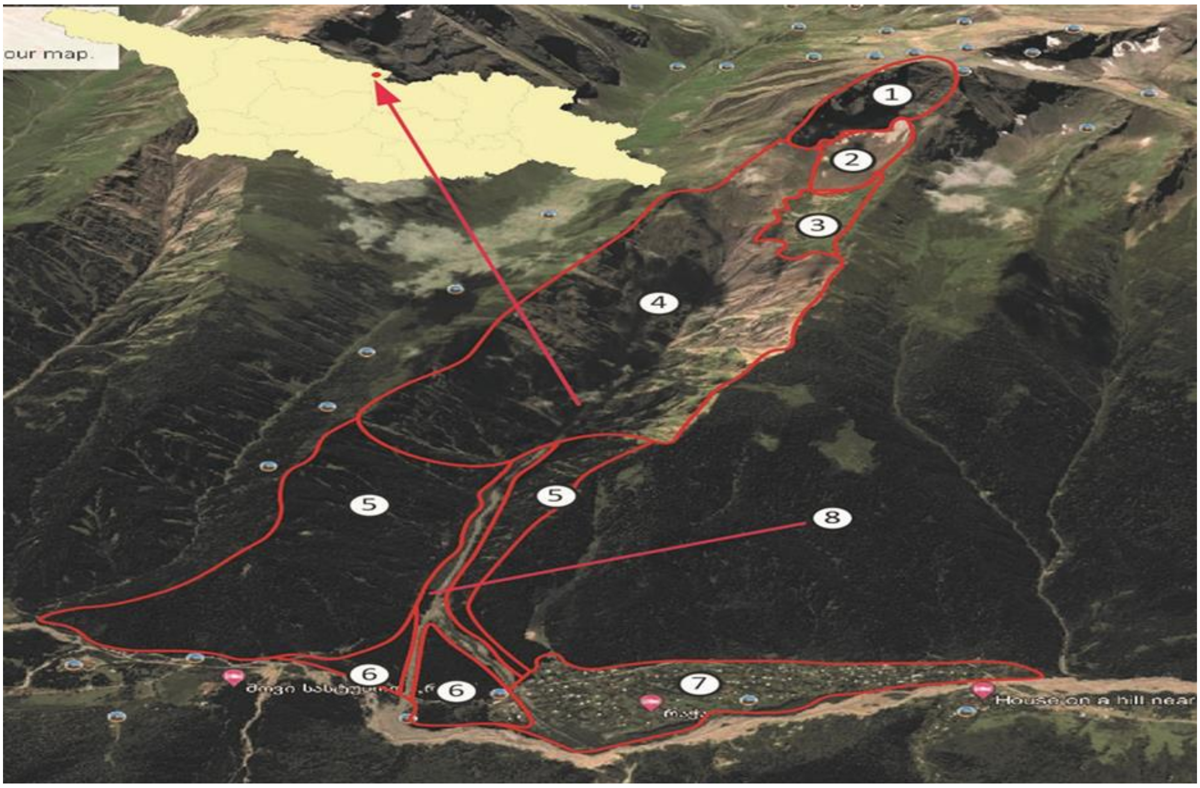

Figure 15. Scheme of the main geomorphological elements of the Chanchakhi river basin (Georgia, south slope of the Greater Caucasus range): 1. Old glacial cirque, 2. Moraine sediments, 3. Fragment of Old Trog 4. Wide erosive area 5. Relatively stable slopes, 6. Alluvial fan (cone), 7. Terrace-step of polygenetic origin 8. False terraces along the right side of the Dghviora river channel. Source: Google Earth

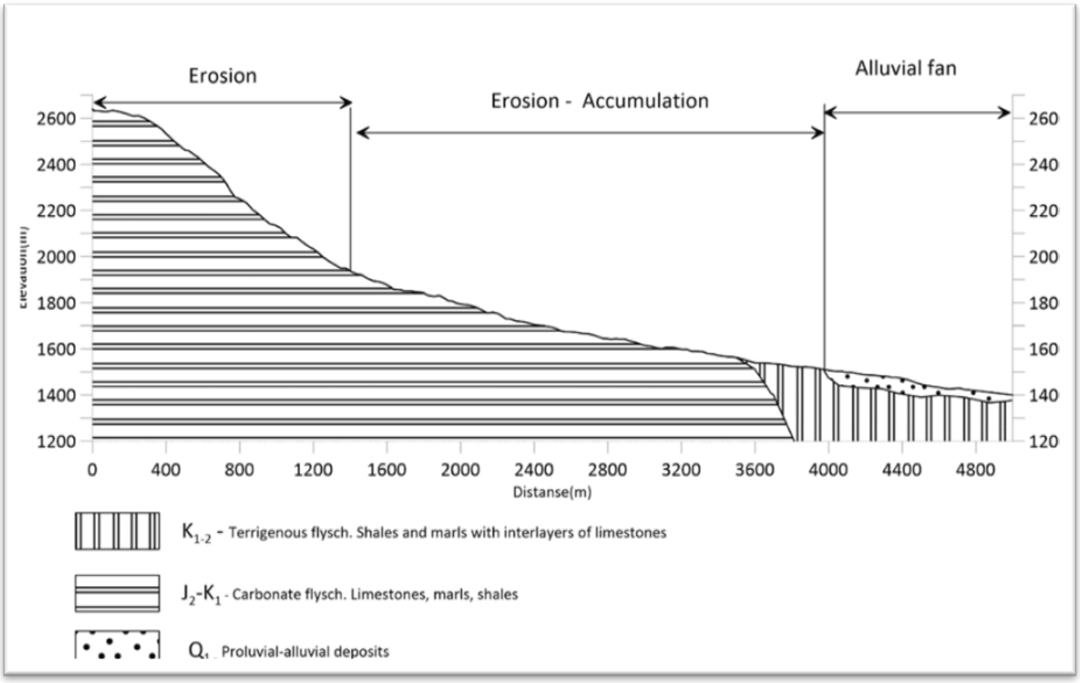

Figure 14. Profile along the Dgviora river gally

partially alluvial sediments accumulate in the riverbed in different layers. As a result, mudslides, landslides, rock avalanches, and snow avalanches are actively occurring here.

Figure 17. The head and bed of the Dghviora river

The Dghviora River basin developed because of a complex combination of erosive-denudational, glacial, tectonic, and climatic factors and lithological features of the basin-forming rocks. At the head of the river, there is a deep fault in the northeastern direction, which is complicated by numerous local faults in different directions, which significantly weakens the strength and stability of the rocky rocks against depletion, denudation and erosion (Abutidze et al., 2010). Additionally, a clearly defined cirque is formed here, which is followed by a small trough of a tub-like shape below. Over time, its area decreases, which is related to the erosive processes of the river, particularly reverse erosion. This process gradually consumes the rest of the trough. It should be noted that the Holocene layers slightly below the cirque moraine layers are probably preserved.

Figure 18. Typical composition sediments on the right bank of river Dghviora

According to the 2010 report of the National Environment Agency of Georgia (Abutidze et al., 2010), fossilized ice masses appear under loose sediments, which weakens the stability of the ground when thawing in warm weather, which becomes a contributing factor to the formation of mud flows. Below the trough, on a 50-60^0 inclined slope made of eroded rocks, large boulders can be found, the mass of which in some cases reaches tens of tons. Interestingly, at the bottom of the abovementioned steep slope, two water streams join and episodically; due to rock avalanches from above, impounded lakes appear in the valley. As a result of their breakthrough by the accumulated water, mud-flow torrents are released. After the confluence of the watercourses, the riverbed is continuously covered with depleted material. In the middle of the river, both slopes of the narrow gorge are erosive-denudational at 1 km and consist of Lower Cretaceous shale clays and marly clays, which are also among the main sources of mud-flow streams (Fig. 2). Further down, in the direction of the flow of the river, almost to the confluence, at 3 km, both. The slopes of the valley are covered with thick dark coniferous forest and are practically free from erosion. The right bank of the river is bordered by a 35-40 m wide pseudoterrace made of colluvial and fluvioglacial material, which consists of several steps. Its height varies from 3-4 m to 8-10 m. It occupies insignificant areas on the left bank of the river (Fig. 3). The thickness of the deposited mass in the bed itself should be at least 12-20 m.

Two streams, which flow from the steep and weathered slopes of the Shoda-Kedela Ridge, join each other in the upper part of the river and form the main stream of the Dghviora River (Fig. 4). Disintegrated material, mainly in large fractions, falls from the head, and slopes accumulate there, periodically blocking the flow of the river and temporarily creating lakes. Over time, this natural dam is breached by excess water, and a torrent is formed. The width of the river floodplain reaches 50-60 m in this section, and the inclination of the bed is 15-200. The accumulated material consists of several fractions: single large boulders of 1.5-2 m in size, small boulders of 20-30%, and small pebbles of up to 70%.

In its new bed, at 1.2 km upstream of the confluence with Chanchakhi, riv. Dghviora has cut its accumulation material in several places. The bottom of one of the trenches (height 1,717 m above sea level, thickness 120 cm, width 250 cm) begins with a sand fraction (less than 0.5 cm), which occupies 15% of the trench volume. Then, a slightly larger fraction of less than 5 cm (12%) was observed. These layers are as follows: 5-10 cm fraction - 9%; 10-20 cm fraction - 12%; 20-35 cm fraction - 20%; and 15 cm layer with 10 cm interlayers of pebbles, sand and clay - 12%, fine gravel coarse material or less processed 35-50 cm - 20% (Figure 5).

In the middle of the river, 120 m above the bridge, a granulometric polygon (20 m²) was set up to record the horizontal distribution of the solid sediment fractions of the river. The polygon consists of the following fractions: 0.5 m thick sand, clay and fine pebbles—25%, 5 cm thick sand fraction—13%, 5-10 cm sand and gravel fraction—11%, 10-20 cm thick sandy-pebble layer with inclusions of 15-20 cm boulders—10%, 20-35 cm thick boulders—8%, 35-50 cm thick boulders—11%, and 70 cm thick boulders—22% (Fig. 6).

At the estuary of the Chanchakhi River, the Dghviora River has created a powerful extraction cone, the length of which reaches 700 m, and the width reaches 60-70 m. As a result of the washing of the alluvial-proluvial layers of the cone by the riv. Chanchakhi, a 6-7 m high bare plateau escarpment was

Figure 19. Granulometric polygon in the bed of Dghviora river

formed, where the structure of the material is clearly visible. Boulders from 0.4 m to 1.0-1.4 m long are clearly visible here. Their amount ranges from 10-15%, and the remaining mass (55-60%) is made up of clayey and marly shale with a sandy filler, as well as a pebble-gravel fraction (20-25%). The surface of the extraction cone is covered with large and medium-sized boulders. While passing the catastrophic floods, the material from the Dghviora River completely or partially blocks the bed of the Chanchakhi River. As a result, the right bank of the river is intensively washed away, where a 10-12 m high and 50-60 m long exposure was formed. Rough moraine material appears here. The size of the boulders varies from 0.4-0.7 m to 1.8-2.5 m.

The Dghviora River, at the confluence of the Chanchakhi River, creates a modern powerful detrital cone. Today, two beds are marked on its surface: one old and the other partially artificially expanded. The new confluence of the Dghviora River has moved at 450 m from the location of the old confluence with the Chanchakhi River. The expansion of the new bed occurred after the event when, in the early 2010s, a catastrophic mud flow with a volume of 2 million m³ passed through the Dghviora River basin, which damaged residential houses and other buildings. The new riverbed begins 700 m above the old mouth. The bottom of the old bed along its entire length was quite quickly covered by perennial vegetation, a circumstance to be considered for the safety of the village of Glola. With a 2-3% reproducibility, only one branch of the estuary cannot deal with the catastrophic flow when passing extreme runoff. However, the flow may enter the surrounding coniferous forest and lose energy. It is necessary to clear the bottom of the old branch of the river from dense vegetation to a length of 600 m to ensure the maximum permeability of the flood flow. The modern detrital fan of the Dghviora River is joined to a lower 2 km long inclined terrace step of polygenetic origin on which the village of Glola is located. The terrace is Quaternary in age, and the relatively plain areas surrounding Glola are also Quaternary in age, apart from the bedrock outcrops. Therefore, it is not surprising that in highly mountainous, highly fragmented terrain, people choose more comfortable, relatively flat terrain for settlement.

Changes in the Dghviora riverbed have saved the important village of Glola from the ever-increasing threat of mudslides. Before the relocation, the continuously cultivated bed of the Dghviora River passed through its territory.

The village is located on the southern slope of the main watershed of the Caucasus, 25 km from Oni, at an average of 1,275 meters above sea level; it opens to the west to the Rioni valley, and the other three sides are surrounded by mountains covered with coniferous forests. Notably, this area is an important section of the northern border zone of Georgia (Fig. 7).

According to the classification by Jaoshvili (1996), Glola belongs to the seventh type of rural settlement in Georgia, which brings together small settlements scattered on mountain slopes that feature extensive agriculture, mainly based on animal farming. Such settlements often develop into agglomerated layouts, with Glola and Shovi also forming this kind of agglomeration.

Glola is a historical village – sources link an episode of its history with Queen Tamar. Vakhushti Batonishvili also provides a brief description of Glola (Vakhushti, 1973). The past importance of the village was mainly related to its location. For a long time, it represented a crossroad in the Middle

Figure 20. Rural agglomeration Glola-Shovi, emerging as a tourism cluster. In the center of the image, you can see the result of the shifting of the bed of river Dghviora to the east, which saved the settled part of village Glola from the danger of a catastrophic mudflow. Source: Google Earth

Ages where caravan routes from Georgia’s lowland and Lower Racha passed on their way to Upper Racha and Svaneti, as well as to Ossetia through Mamisoni, Notsara and other crossings on the Caucasus. This gave Glola—in particular, its lower roadside part, Saglolo—the role of a traffic distributor.

Starting in the nineteenth century and along with changing trade routes, Glola largely lost its function as a transport hub. Instead, with the development of the Shovi resort, Glola acquired the function of the resort's economic hinterland, along with its traditional agricultural role. Shovi is a climate and balneological resort located adjacent to Glola village at 1,520-1,565 meters above the sea in the Chanchakhi River valley, with a pulmonological, allergic and gastroenterological healing profile, healthy air and picturesque landscape that proved very popular between the 1920s and 1980s. (Sharashenidze, 1940). Since the 1990s, the situation has changed—the Shovi resort has lost its social purpose (healthcare for workers), and the state could no longer finance it, leading to a decline in both the resort and Glola village. The depopulation processes characteristic of Racha villages also developed here. Between the 2002 and 2014 state censuses, the population of Glola decreased by 27.5% to 279 residents.

In recent years, signs of revitalization of Shovi have appeared with its adaptation to the conditions of the market economy, activation of the process of commercialization of resort activities and resulting revival of health tourism, which has also been reflected in Glola - the village reacquired the function of providing accommodation for vacationers in the Shovi area. In addition to private apartments for rent, several family hotels (guesthouses) operate here, and a very comfortable and relatively expensive ($120/night) tourist cottage has opened. Activities serving tourism in the resort area—trade, supply, services, and transportation—have been stimulated. It is important for local prospects that Glola also features its own resources for tourism development – a healthy mountain climate (Gavasheli, 1978), coniferous forests, mountain trails for trekking and horseback riding tours, "Glola boulders" – granite moraine formations included in the “Red Book of Georgia” – as well as mineral waters and remains of cultural heritage.

Some authors writing about problems in rural areas consider the development of new, additional functions—e.g., industry, communications, energy, and tourism—for these locations to be one of the most effective means of stopping their depopulation and ensuring support (Delgado, 2019). In this regard, Glola can improve the services of the Shovi resort (in case of its restoration after the disaster of August 2023) and develop its own recreational activities, especially if we take into account the launch of the Gomi-Oni Road in the near future.

Conclusion

Along with natural factors, human agricultural activity plays an important role in the changes in the environment of Racha, which is manifested in the cultivation of agricultural lands (ploughing the slopes in accordance with the slopes, cutting down forests and growing annual crops in their place, etc.) and, as a result, soil damage (Salukvadze, 2022). Accordingly, agricultural activity in this zone has both extensive and intensive growth prospects. Natural exodynamic processes pose a constant threat to the regional communications and tourist infrastructure of the village of Glola. The prospects for tourism, including international tourism, in this dynamic, natural environment are directly related to ensuring security. Accordingly, for the prediction of environmental threats, regulation and protection measures against natural disasters have become even more important. Thus, to stop the critical decrease in the population in Glola and the surrounding area, it is necessary to activate tourism, which in turn requires ensuring the safety of the environment. Accordingly, for the prediction of environmental threats, regulation and protection measures against natural disasters have become even more important, and a positive and successful example of this is the change in the bed of the Dghviora River. To ensure the high security of the village of Glola and the surrounding area, it is necessary to clear the bottom of the old branch of the river from dense vegetation to a length of 600 m so that the flood flow can pass unhindered. It is also necessary to install an early warning system for natural processes at the headwaters of the Dghviora River (Tsreteli et al., 2018).

The 2023 Shovi disaster revealed high risks of natural hazards in this area and serious consequences for resort businesses, such as the failure to consider them. On August 3, at approximately 4:00 p.m., a glacial mudflow descended on the territory of the Shovi resort, resulting in the destruction of its built-up area and casualties—the tragedy claimed the lives of 32 people. The main area of the resort was covered by sediment, the total volume of which, according to initial calculations, reached one million m3. Cottages built in a manner that neglected natural risks near the banks of the Bubistskali River were destroyed, and the very existence of the resort came under question.

Competing interests

The authors declare that they have no competing interests.

Authors’ contributions

M.G. and G.L. conceived of the presented idea and wrote the manuscript. G.K. performed the analytic calculations and created the maps and design. G.K. contributed to the analysis and interpretation of the results and the writing of the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Holiday Climate Index in Kvemo Kartli (Georgia)

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Abstract

Weather and climate are two main factors that determine the bioclimatic resources of a territory and, accordingly, the degree of its suitability for the organization and development of the resort and tourism industry. Early studies used a variety of climate indices for tourism. In recent years, the so-called Holiday Climate Index (HCI), which is a combination of five climate elements (air temperature maximum, relative humidity, cloud cover, precipitation and wind), has been gaining popularity. Determination of HCI values for various locations in Georgia began in 2020 (Tbilisi, Kakheti region, 13 high-mountain points, etc.). In this work, an analysis of data on the long-term average values of the Holiday Climate Index (HCI) for 8 settlements in the Kvemo Kartli region of Georgia (Bolnisi, Gardabani, Dmanisi, Tetri Tskaro, Marneuli, Tsalka, Manglisi, Rustavi) is presented. The intra-annual distribution of HCI values was studied; correlations between individual stations were determined based on average monthly and seasonal HCI values; it was found that the regression equations for the intra-annual variation of average monthly HCI values for all points of Kvemo Kartli have the form of a ninth-order polynomial; categories of average monthly and seasonal HCI values in the specified settlements of Kvemo Kartli were determined; a comparison was made of the statistical characteristics of average monthly HCI values in 8 points of Kvemo Kartli with the indicated characteristics in Bolnisi, Gardabani, Marneuli, Rustavi (height of stations above sea level H < 1 km) and in Dmanisi, Tetri Tskaro, Tsalka, Manglisi (H > 1 km), and a corresponding analysis of the repeatability of HCI categories was conducted. It is shown that the bioclimatic conditions in Kvemo Kartli are favourable for the development of the resort and tourism industry for all months of the year. A visual map of the distribution of mean monthly HCI categories on the territory of Kvemo Kartli has been constructed.

Keywords: climate, bioclimate, resort and tourism industry, cartography

Introduction

The organization and development of the resort and tourism industry in the region directly depend on its geographical location, topography, vegetation, presence of natural disasters, weather and climate, etc. Weather and climate are two main factors that determine the bioclimatic resources of an area. Thus, the study of these resources, which are necessary for the organization and development of the resort and tourism industry, plays a major role and requires significant effort.

The study of the resort and recreational resources of Georgia was founded in the 20 s of the last century, when the “Research Institute of Balneology and Physiotherapy” was created. As a result of many years of field, stationary and practical studies of the institute, a trilingual atlas about the resorts and resort resources of Georgia was created and published (Vadachkoria et al., 1987). This atlas was awarded the State Prize of Georgia. It should be noted that this work (Vadachkoria et al., 1987) provided an impetus for the further development of multilateral research into the resort and tourism potential of Georgia.

Past studies have used many climate indices for tourism (Matzarakis, 2006; Matzarakis et al., 2021a, b; Amiranshvili et al., 2011, 2015a, 2018, 2022, 2019; Bolashvili et al., 2016; Amiranashvili & Kartvelishvili, 2008; Lanchava et al., 2021; Rutty et al., 2021; Kartvelishvili et al., 2023). The most widely known index used both in the past and in the present is the Tourist Climate Index (TCI), proposed by Mieczkowski (1985).

In southern Caucasus countries, the monthly TCI was first calculated in Georgia for Tbilisi (Airanashvili et al., 2008) and then for many other locations in the Caucasus (Armenia, Azerbaijan, North Caucasus, etc.) (Amiranashvili et al., 2014, 2015b, 2017, 2018a, 2018b; Rybak & Rybak, 2016; Kartvelishvili et al., 2019).

The study by Mushawemhuka et al. (2020) presents the first TCI calculations for Zimbabwe. Tanana et al. (2021) evaluated the climate comfort of Argentina as an intangible resource for tourism.

Despite the wide application of the TCI, it has been subject to substantial critiques (Scott et al., 2016). The four key deficiencies of the TCI include the following: (1) the subjective rating and weighting system of climatic variables; (2) it neglects the possibility of the overriding influence of physical climatic parameters (e.g., rain, wind); (3) the low temporal resolution of climatic data (i.e., monthly data) has limited relevance for tourist decision-making; and (4) it neglects the varying climatic requirements of major tourism segments and destination types (i.e., beach, urban, winter sports tourism).

To overcome the above limitations of the TCI, the Holiday Climate Index (HCI) was developed to more precisely assess the climatic suitability of tourism destinations. The word "holiday" was chosen to better reflect what the index was designed for (i.e., leisure tourism), as tourism is much broader by definition ("Tourism is a social, cultural and economic phenomenon which entails the movement of people to countries or places outside their usual environment for personal or business/professional purposes") (Javan, 2017; Rutty et al., 220; Hejazizadeh et al., 2019). In the same works, comparisons between the HCI and TCI were made.

A comparison of the Holiday Climate Index and Tourism Climate Index at several locations in Georgia and the North Caucasus (Amiranashvili et al., 2020; Amiranashvili & Kartvelishvili, 2021; Amiranashvili et al., 2021) is presented. The article by Amiranashvili et al. (2018b) compares the values and categories of the TCI and HCI in Tbilisi. The long-term average HCIs for 12 Kakheti locations (Akhmeta, Dedoplistskaro, Gombori, Gurjaani, Kvareli, Lagodekhi, Omalo, Sagarejo, Shiraki, Telavi, Tsnori and Udabno) are presented in Amiranashvili & Kartvelishvili (2021). For 6 stations in this region (Dedoplistskaro, Gurjaani, Kvareli, Lagodekhi, Sagarejo and Telavi), detailed analyses of the monthly, seasonal and annual HCIs over the 60-year period (1956-2015) were carried out. Comparisons of monthly HCIs and tourism climate indices (TCIs) for four points in the Kakheti region (Dedoplistskaro, Kvareli, Sagarejo and Telavi) based on data from 1961 to 2010 were carried out. The results of the comparative analysis of the Tourism Climate Index and the Holiday Climate Index, as well as the ratings of the components of these indices for six points in the North Caucasus (Kislovodsk, Pyatigorsk, Essentuki, Zheleznovodsk, Teberda and Nalchik), are presented in (Amiranashvili et al. 2021).

It was found that there is a high degree of correlation between the HCI and TCI. However, considering that the TCI is calculated for the so-called "average tourist" (regardless of gender, age, physical condition), the value and category of this index are lower than the HCI values and categories. In general, based on our estimation, the HCI more adequately determines the bioclimatic state of the environment for the development of various types of tourism than does the TCI (Amiranashvili et al. 2020, 2021; Amiranashvili & Kartvelishvili, 2021).

Using the Holiday Climate Index (HCI: Urban), this research (Williams, 2021) examines long-term tourism climate records in Tokyo between 1964 and 2019. The findings suggest greater climatic variability and a decrease in the favourability of Tokyo's tourism climatic resources in all three summer months. According to these findings, adaptation and mitigation strategies are recommended, and a Japanocentric tourism climate index is proposed.

Carrillo et al. (2021) noted that the TCI and HCI are good indicators of the environmental conditions for leisure activities in the Canary Islands. Using the Regional Climate Model, it is shown that by 2030-2059 and 2070-2099, tourism performance is expected to improve significantly in the winter and off-season but deteriorate in the summer months, including October, in the southeast, which is where hotels are currently located.

The aim of this study (Araci et al., 2021) is to assess the future HCI performances of urban and beach destinations in the greater Mediterranean region. For this purpose, HCI scores for the reference (1971-2000) and future (2021-2050, 2070-2099) periods were computed. HCI: The urban results showed that the Canary Islands have suitable conditions for tourism during almost all four seasons and all periods, which will have certain implications when other core Mediterranean competitors lose their relative climatic attractiveness. The HCI:Beach results for the summer season showed that Las Canteras, Alicate, Pampelonne, Myrtos, Golden Sands and Edremit all pose very good to excellent conditions without any Humidex risks for the extreme future scenario (2070-2099).

Detailed information on the variability of the monthly values of the Holiday Climate Index in Tbilisi in 1956-2015 is presented in Amiranashvili et al. (2020). It also presents data on the interval forecasts of HCI variability in Tbilisi for the next few decades.

Amiranashvili et al. (2021) performed a detailed analysis of monthly, seasonal and annual HCI values during a 60-year period (1956-2015) for 13 mountainous locations in Georgia (Bakhmaro, Bakuriani, Borjomi, Goderdzi, Gudauri, Khaishi, Khulo, Lentekhi, Mestia, Pasanauri, Shovi, Stepantsminda, and Tianeti) and compared HCIs and TCIs of monthly values for three points in Georgia (Goderdzi, Khulo and Mestia) based on data from 1961 to 2010. The variability data of the HCI in 1986-2015 compared to those in 1956-1985 and the trends of the HCI in 1956-2015 are also presented. Using Mestia as an example, the expected changes in the monthly, seasonal and annual HCIs of 2041-2070 and 2071-2100 were assessed. Some results of this work were used in (Kartvelishvili et al., 2023; Fourth National Communication of Georgia, 2021).

It should be noted that the scale of various bioclimatic indices (including TCI and HCI) is quite consistent with data on public health in various regions of Georgia (Amiranashvili et al., 2012, 2018, 2021), as well as on the spread of the COVID-19 virus in Tbilisi (Amiranashvili et al 2022).

This work is a continuation of previous studies. This study develops a long-term average HCI for 8 stations in the Kvemo Kartli region of Georgia (Bolnisi, Gardabani, Dmanisi, Tetri Tskaro, Marneuli, Tsalka, Manglisi, Rustavi), which is known for its historical attractions and resort and tourism resources.

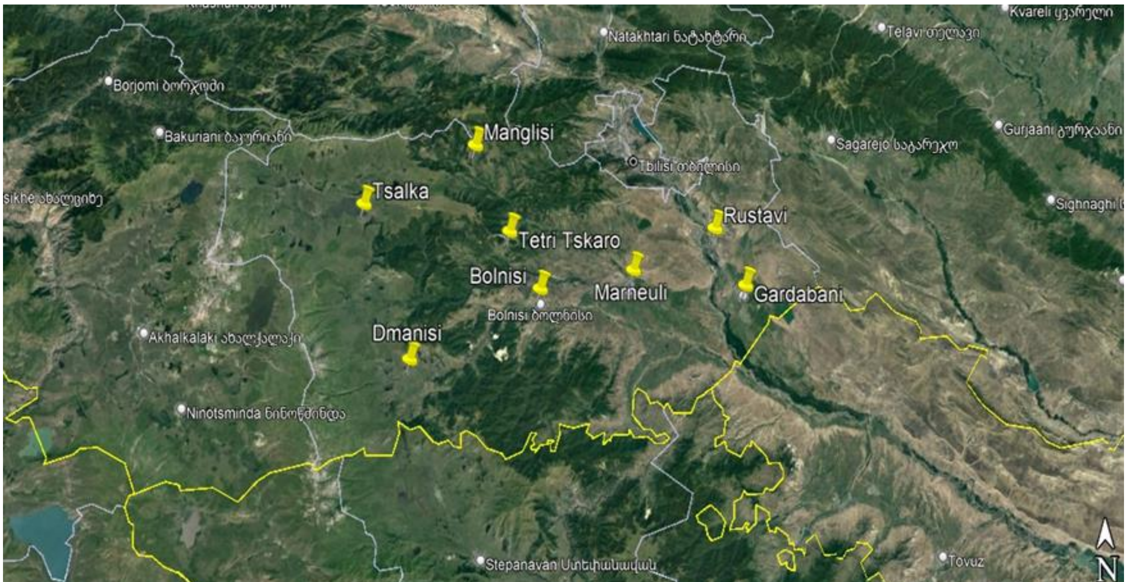


Figure 21. Locations of the 8 meteorological stations in Kvemo Kartli

Methods and Materials

Study Area

Kvemo Kartli region of Georgia (below - Kvemo Kartli). Kvemo Kartli is in the southeastern part of Georgia. The area is 6 436.2 km^2, the population is 442.8 thousand. pers., (including of urban - 197.5 thous. pers.), the capital of the region, Rustavi (population - 132.3 thous. pers.).

The natural-geographic conditions of Kvemo Kartli, as well as natural, cultural and historical monuments, create an opportunity for the development of tourism in the region. The prospective directions of tourism are horse-riding, hunting tourism, eco-tourism, cognitive tourism, family tourism, ethnographic tourism, agro-tourism, medical-rehabilitation tourism, etc. In Kvemo Kartli, tourists can see settlements dating back to the first millennium BC. The discovery of a prehistoric settlement and human remains in Dmanisi is considered a major archaeological discovery. According to experts, a hominid lived in Dmanisi 1.8 million years ago. Therefore, Dmanisi can be considered the earliest settlement in Europe and Asia. Kvemo Kartli has more than 650 historical monuments, 300 of which are included in various tourist routes.

Methodology

Studies of 8 locations in Kvemo Kartli (Bolnisi, Gardabani, Dmanisi, Tetri Tskaro, Marneuli, Tsalka, Manglisi, and Rustavi) were carried out. Fig. 1 shows a map of the arrangement of the indicated meteorological stations.

Table 1 presents information about the coordinates and heights of these 8 meteorological stations, whose data were used in this work. These stations are located 300 to 1458 meters above sea level.

Table 5. Coordinates and heights of the 8 meteorological stations in Kvemo Kartli

Location (Abbreviation)	Latitude, N°	Longitude, E°	Elevation (H), m, a.s.l.	Period of observation
Bolnisi (Boln)	41.45	44.55	534	1956-2015
Gardabani (Gard)	41.45	45.10	300	1956-2015
Dmanisi (Dman)	41.33	44.20	1309	1961-1990
Tetri Tskaro (T-Tsk)	41.55	44.47	1151	1961-1990
Marneuli (Marn)	41.48	44.80	432	1938-1960
Tsalka (Tsal)	41.60	44.08	1458	1956-2015
Manglisi (Mang)	41.70	44.38	1194	1961-1990
Rustavi (Rust)	41.55	45.02	332	1949-1960

In this work, the Holiday Climate Index (HCI) is used. The following five climatic variables are used for HCI identification: air temperature maximum, relative humidity, cloud cover, precipitation and wind (Scott et al., 2016; Amiranashvili et al., 2020a; Amiranashvili & Kartvelishvili, 2021; Amiranashvili et al., 2021a).

The rating scheme and HCI categories (Scott et al., 2016; Amiranashvili et al., 2020a) are presented in Table 2.

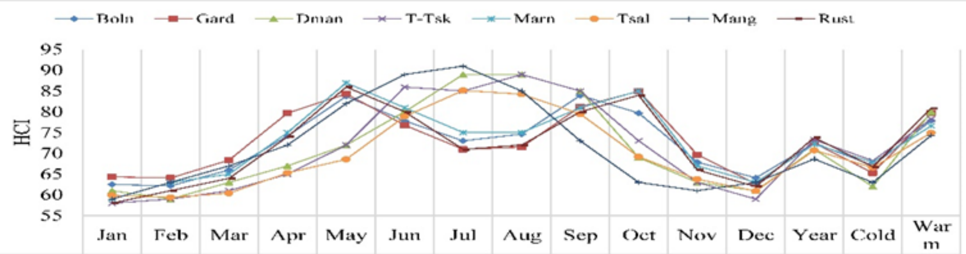
Table 2. HCI's Category

HCI Score	Category (Abbreviation)	HCI Score	Category (Abbreviation)
90÷100	Ideal	40÷49	Marginal (Marg.)
80÷89	Excellent (Excellent)	30÷39	Unfavourable (Unf.)
70÷79	Very Good (Very Good)	20÷29	Very Unfavourable (V_Unf.)
60÷69	Good	10÷19	Extremely Unfavourable (Ext_Unf.)
50÷59	Acceptable (Acceptable)	9÷-9; -10÷-20	Impossible (Impos.)

In this work, the monthly mean data of the indicated meteorological parameters from the Georgian National Environmental Agency (Bolnisi, Gardabani, Tsalka), famous reference books on the climate of the USSR (issue 14; Marneuli, Rustavi) and the Scientific and Applied of Georgia Climate Reference (2020) (Dmanisi, Tetri Tskaro, Manglisi) were used. Based on these data, the HCI monthly average values were calculated. Analysis of the HCI data using standard statistical analysis methods was carried out (Kobisheva & Narovlianski, 1978). The following designations are used: Mean – average values; Min – minimal values; Max – maximal values; St Dev – standard deviation; C_v – coefficient of variation, % (C_v = 100· St Dev/Mean); R^2 – coefficient of determination; R – coefficient of linear correlation; α – level of significance; H – altitude of the weather station at sea level, meter or km.

Results

The results are presented in figures 2-3 and tables 3-8. The long-term mean HCI real values at 8 locations in Kvemo Kartli are presented in Fig. 2.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Cold	Warm
Boln	63	62	66	74	84	78	73	75	84	80	68	64	72	67	78
Gard	64	64	68	80	84	77	71	72	81	85	70	63	73	65	80
Dman	61	59	63	67	72	80	89	89	85	69	63	61	71	62	80
T-Tsk	58	59	61	65	72	86	85	89	85	73	63	59	73	68	78
Marn	59	63	65	75	87	81	75	75	81	85	67	63	72	68	77
Tsal	60	59	60	65	69	79	85	84	79	69	64	61	71	67	75
Mang	59	63	67	72	82	89	91	85	73	63	61	63	69	63	74
Rust	58	61	64	74	86	80	71	72	80	84	66	62	74	67	81

MONTH/SEASON

Figure 22. Mean HCI values at 8 locations of Kvemo Kartli

As shown in Fig. 2, the mean monthly HCI changed from 58 (Tetri Tskaro, Rustavi, January, Acceptable) to 91 (Manglisi, July, Ideal). The variability of HCI values for individual items is as follows:

Bolnisi (62, February–84, May, September), Gardabani (63, December–85, October), Dmanisi (59, February–89, July, August), Tetri Tskaro (58, January–89, August), Marneuli (59, January–87, May), Tsalka (59, February–85, July), Manglisi (59, January–91, July), and Rustavi (58, January–86, May).

Table 3. Linear correlation coefficients between the monthly means and seasonal values of the HCI at the separate stations (R min = 0.41, α = 0.15; R max = 0.98, α = <0.001)

Location	Boln	Gard	Dman	T-Tsk	Marn	Tsal	Mang	Rust
Boln	1	0.94	0.68	0.73	0.97	0.65	0.58	0.96
Gard	0.94	1	0.49	0.53	0.93	0.44	0.41	0.95
Dman	0.68	0.49	1	0.96	0.62	0.97	0.84	0.58
T-Tsk	0.73	0.53	0.96	1	0.70	0.98	0.82	0.66
Marn	0.97	0.93	0.62	0.70	1	0.62	0.60	0.98
Tsal	0.65	0.44	0.97	0.98	0.62	1	0.83	0.57
Mang	0.58	0.41	0.84	0.82	0.60	0.83	1	0.53
Rust	0.96	0.95	0.58	0.66	0.98	0.57	0.53	1

The data analysis in Fig. 2 (Table at the bottom of the figure) shows that the linear correlation coefficients between the mean monthly and seasonal HCI values at the separate stations change as follows (Table 3). Bolnisi: 0.58 (Manglisi) - 0.97 (Marneuli); Gardabani: 0.41 (Manglisi) – 0.95 (Rustavi); Dmanisi: 0.49 (Gardabani) – 0.97 (Tsalka); Tetri Tskaro: 0.53 (Gardabani) – 0.98 (Tsalka); Marneuli: 0.60 (Manglisi) – 0.98 (Rustavi); Tsalka: 0.44 (Gardabani) – 0.98 (Tetri Tskaro); Manglisi: 0.41 (Gardabani) – 0.84 (Dmanisi); Rustavi: 0.53 (Manglisi) – 0.98 (Marneuli).

Table 4. Coefficients of regression equation of the intra-annual motion of HCI monthly mean values for 8 points of Kvemo Kartli

Equation of regress., coefficients	HCI = a·X9+b·X8+c·X7+d·X6+e·X5+f·X4+g·X3+h·X2+i·X+j, (X-Month)										
	a	b	c	d	e	f	g	h	i	j	R²
Boln	-1.50E-04	8.56E-03	-2.06E-01	2.72E+00	-2.15E+01	1.05E+02	-3.12E+02	5.48E+02	-5.12E+02	2.53E+02	0.993
Gard	3.85E-05	-2.32E-03	6.18E-02	-9.41E-01	8.91E+00	-5.31E+01	1.94E+02	-4.05E+02	4.31E+02	-1.10E+02	0.999
Dman	-5.14E-05	2.89E-03	-6.97E-02	9.45E-01	-7.91E+00	4.21E+01	-1.41E+02	2.84E+02	-3.03E+02	1.87E+02	0.996
T-Tsk	-1.39E-04	8.16E-03	-2.04E-01	2.83E+00	-2.39E+01	1.26E+02	-4.06E+02	7.71E+02	-7.65E+02	3.54E+02	0.989
Marn	-2.23E-06	1.48E-04	-1.67E-03	-4.61E-02	1.36E+00	-1.43E+01	7.49E+01	-2.01E+02	2.57E+02	-5.93E+01	0.990
Tsal	1.36E-05	-8.02E-04	1.97E-02	-2.62E-01	2.05E+00	-9.78E+00	2.82E+01	-4.60E+01	3.68E+01	4.90E+01	0.996
Mang	-4.59E-06	2.98E-04	-8.73E-03	1.49E-01	-1.59E+00	1.07E+01	-4.35E+01	1.02E+02	-1.22E+02	1.13E+02	0.999
Rust	-6.21E-05	3.65E-03	-8.88E-02	1.15E+00	-8.69E+00	3.82E+01	-9.50E+01	1.24E+02	-7.08E+01	6.88E+01	0.993

The distributions of the mean monthly values of the TCI for 8 locations in Kvemo Kartli according to the ninth power of the polynomial ($R^2 \geq 0.989$) are described. The coefficients of the equation of the regression of the intra-annual motion of the mean monthly HCIs for these points are presented in Table 4.

Table 5 shows the distribution types of the mean monthly HCIs at 8 locations in Kvemo Kartli.

Table 5. Intra-annual distribution types of HCI monthly mean values at 8 locations in Kvemo Kartli

Location	Distribution type	First extremum (Max)	Second extremum
Bolnisi	Bimodal	May	Sep
Gardabani	Bimodal	May	Oct
Dmanisi	Unimodal, flat	Jul, Aug	

Tetri Tskaro	Bimodal	Jun	Aug
Marneuli	Bimodal	May	Oct
Tsalka	Unimodal	Jul	
Manglisi	Unimodal	Aug	
Rustavi	Bimodal	May	Oct

According to this table, a generally bimodal distribution of HCIs is observed (5 locations from 8 locations). For the Gardabani, Marneuli, and Rustavi stations, the first and second extrema of the HCI distribution occur in May and October, respectively; for the Bolnisi station, they occur in May and September; and for the Tetri Tskaro station, they occur in June and August.

Table 6. Categories of HCI monthly means and seasonal values at 8 locations in Kvemo Kartli during the cold period

<table>
<tr><th>Location</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Cold</th><th>Year</th></tr>
<tr><td>Bolnisi</td><td rowspan="3">Good</td><td rowspan="2">Good</td><td rowspan="8">Good</td><td rowspan="2">Excellent</td><td>Good</td><td rowspan="3">Good</td><td rowspan="8">Good</td><td rowspan="6">Very Good</td></tr>
<tr><td>Gardabani</td><td>Very Good</td></tr>
<tr><td>Dmanisi</td><td rowspan="2">Acceptable</td><td>Good</td><td rowspan="6">Good</td></tr>
<tr><td>Tetri Tskaro</td><td rowspan="2">Acceptable</td><td>Very Good</td><td>Acceptable</td></tr>
<tr><td>Marneuli</td><td>Good</td><td>Excellent</td><td rowspan="4">Good</td></tr>
<tr><td>Tsalka</td><td>Good</td><td rowspan="2">Acceptable</td><td>Good</td></tr>
<tr><td>Manglisi</td><td rowspan="2">Acceptable</td><td>Very Good</td><td>Good</td></tr>
<tr><td>Rustavi</td><td>Good</td><td>Excellent</td><td>Very Good</td></tr>
</table>

For Dmanisi, a unimodal distribution of HCIs with plateaus from July–August was observed; for Tsalka and Manglisi, unimodal distributions with maxima occurred in July and August, respectively.

Table 7. Categories of HCI monthly means and seasonal values at 8 locations in Kvemo Kartli during the warm period

<table>
<tr><th>Location</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Warm</th><th>Year</th></tr>
<tr><td>Bolnisi</td><td>Very Good</td><td rowspan="2">Excellent</td><td rowspan="2">Very Good</td><td rowspan="2">Very Good</td><td rowspan="2">Very Good</td><td rowspan="5">Excellent</td><td>Very Good</td><td rowspan="5">Very Good</td></tr>
<tr><td>Gardabani</td><td>Excellent</td><td rowspan="2">Excellent</td></tr>
<tr><td>Dmanisi</td><td rowspan="2">Good</td><td rowspan="2">Very Good</td><td rowspan="3">Excellent</td><td rowspan="2">Excellent</td><td rowspan="2">Excellent</td></tr>
<tr><td>Tetri Tskaro</td><td rowspan="4">Very Good</td></tr>
<tr><td>Marneuli</td><td>Very Good</td><td>Excellent</td><td>Very Good</td><td>Very Good</td></tr>
<tr><td>Tsalka</td><td rowspan="2">Good</td><td>Good</td><td>Very Good</td><td rowspan="2">Excellent</td><td>Excellent</td><td>Very Good</td></tr>
<tr><td>Manglisi</td><td>Very Good</td><td rowspan="2">Excellent</td><td>Ideal</td><td rowspan="2">Excellent</td><td>Good</td></tr>
<tr><td>Rustavi</td><td>Very Good</td><td>Excellent</td><td>Very Good</td><td>Very Good</td><td>Excellent</td><td>Very Good</td></tr>
</table>

In Tables 6 and 7, the mean monthly and seasonal HCI values at 8 locations in Kvemo Kartli during cold and warm periods are presented.

As shown in these tables, the categories of the mean monthly and seasonal HCIs at 8 locations in Kvemo Kartli change from acceptable to ideal.

Table 8 shows the statistical characteristics of the monthly mean HCIs at 8 locations in Kvemo Kartli (all stations); at Bolnisi, Gardabani, Marneuli, and Rustavi (H < 1 km); and at Dmanisi, Tetri Tskaro, Tsalka, and Manglisi (H > 1 km).

Table 8. Statistical characteristics of the monthly mean HCIs at 8 locations in Kvemo Kartli (all stations); at Bolnisi, Gardabani, Marneuli, and Rustavi (H < 1 km); and at Dmanisi, Tetri Tskaro, Tsalka, and Manglisi (H > 1 km).

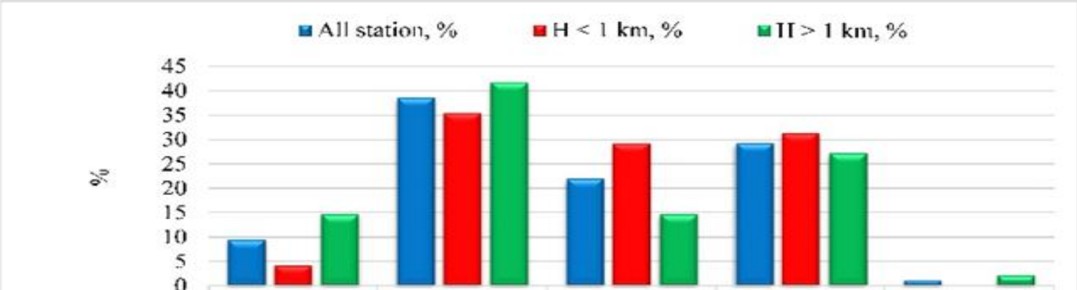
Location	All station		H < 1 km		H > 1 km	
Variable	HCI	Category	HCI	Category	HCI	Category
Min	58	Acceptable	58	Acceptable	58	Acceptable
Max	91	Ideal	87	Excellent	91	Ideal
Mean	72	Very Good	73	Very Good	71	Very Good
St Dev	9.8		8.5		11.0	
Cv,%	13.6		11.7		15.5	

As follows from this table, the HCIs for stations with H < 1 km change from 58 (Acceptable) to 87 (Excellent), and for stations with H > 1 km from 58 (Acceptable) to 91 (Ideal). For both groups of stations, the average HCIs are in the "Very Good" category (73 and 71, respectively).

Fig. 3 shows the repetition of the monthly mean HCI category at 8 locations in Kvemo Kartli (all stations); at Bolnisi, Gardabani, Marneuli, and Rustavi (H < 1 km); and at Dmanisi, Tetri Tskaro, Tsalka, and Manglisi (H > 1 km).

Therefore, as shown in Tables 6 and 7 and Fig. 3, in Kvemo Kartli, there are favourable conditions for the development of tourism and resorts throughout the year.

Notably, the research results of this work, in addition to scientific interest, also have practical applications for planning the development of the resort and tourism industry in the Kvemo Kartli region.



	Acceptable	Good	Very Good	Excellent	Ideal
All station, %	9.4	38.5	21.9	29.2	1.0
H < 1 km, %	4.2	35.4	29.2	31.3	0.0
H > 1 km, %	14.6	41.7	14.6	27.1	2.1

Figure 23. Repetition of monthly mean HCI category at 8 locations of Kvemo Kartli (All station) and at Bolnisi, Gardabani, Marneuli, Rustavi (H < 1 km) and at Dmanisi, Tetri Tskaro, Tsalka, Manglisi (H > 1 km)

Finally, in Fig. 4, a map of the distribution of mean monthly HCI categories in the territory of Kvemo Kartli (in Georgian) is presented.

This map was constructed in accordance with previously reported methods (Rekacewicz, 2005; Rekacewixz &Stienne, 2013). Such maps are very visual and are intended for a wide range of people who want to receive information about various data, phenomena, events, etc., presented in an easy-to-understand form. The bioclimatic conditions of Kvemo Karli are related to the resort and tourism potential of this region.

Note that a similar map has been prepared for the Atlas of the Kakheti region (ready for publication) from the series Geographical Atlases of Georgia.

The indicated map (Fig. 4) will be included in the Atlas of the Kvemo Kartli region (forthcoming) from the same series of geographical atlases of Georgia.

In both cases, the methodology for constructing maps (Rekacewicz, 2005; Rekacewicz & Stienne, 2013) under Georgian conditions was used for the first time.

Discussions

In recent decades, due to the unprecedented rate of increase in air temperature, climate change on our planet has become a particularly urgent problem. At the same time, changes in air temperature and other climate elements have significant spatial and temporal heterogeneity on both global and regional (even the territory of small countries with complex terrain) scales.

This problem of climate change is also very relevant in Georgia due to the diversity of climatic regions in its territory. Moreover, changes in the thermal regime of the atmosphere increase people's vulnerability to external factors.

The negative impact of the environment on human health can be mitigated by the development of resorts and the tourism industry, which allows people to undergo treatment, health and rehabilitation activities and to actively relax. Therefore, in recent years, special attention has been given to the development of this sector of the economy and, accordingly, to the identification of new bioclimatic resources in existing and promising resort and tourist areas.

Therefore, studying the impact of climate change on the variability of various thermal indices, including the TCI and HCI, is important.

The conducted studies once again confirmed the presence of a variety of climatic and bioclimatic conditions in Georgia, as well as the characteristics of their temporal variability. It is concluded that it is necessary to conduct a detailed study of climate change (as well as bioclimate) not only on a regional but also on a local scale.

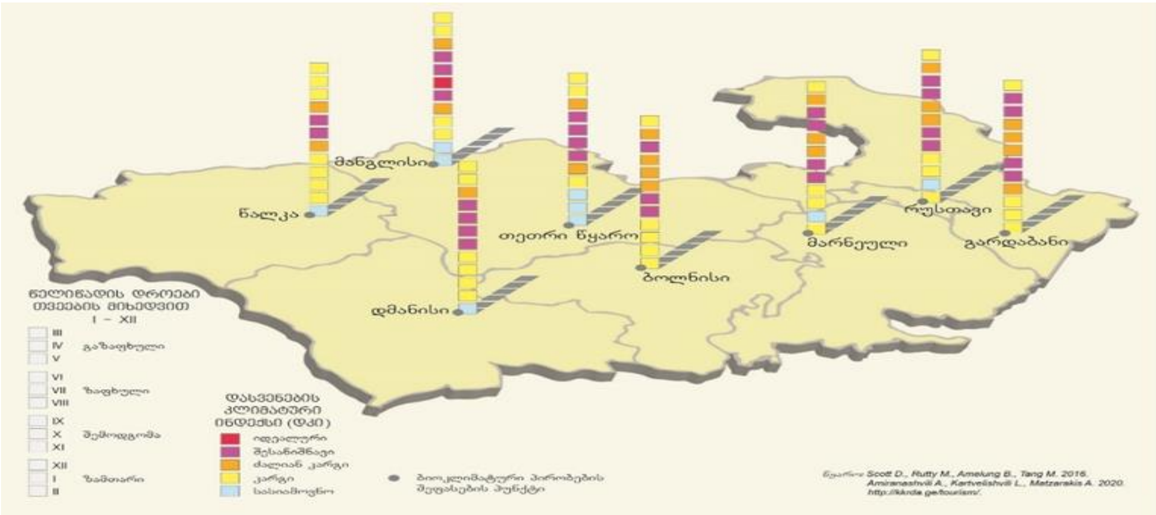


Figure 24. Map of the distribution of mean monthly HCI categories on the territory of Kvemo Kartli. Designations on the map. ბიოკლიმატური პირობების შეფასების პუნქტი - Point of assessment of bioclimatic conditions. Name of points: (წალკა - Tsalka, მანგლისი - Manglisi, დმანისი-Dmanisi, თეთრი წყარო - Tetri Tskaro, ბოლნისი-Bolnisi, მარნეული - Marneuli, რუსთავი - Rustavi, გარდაბანი-Gardabani). წელიადის დროები თვეების მიხედვით (I-XII) - Times of the year by month (I-XII): გაზაფხული (III-V), ზაფხული (VI-VIII), შემოდგომა (I-XI), ზამთარი (XII-II) - Spring (III V), Summer (VI-VIII), Autumn (I-XI), Winter (XII-II). დასვენების კლიმატური ინდექსი (დკი): იდეალური, შესანიშნავი, ძალიან კარგი, კარგი, სასიამოვნო - Holiday Climate Index (HCI): Ideal, Excellent, Very Good, Good, Acceptable.

Conclusion

In recent decades, due to the unprecedented rate of increase in air temperature, climate change on our planet has become a particularly urgent problem. At the same time, changes in air temperature and other climate elements have significant spatial and temporal heterogeneity on both global and regional (even the territory of small countries with complex terrain) scales.

This problem of climate change is also very relevant in Georgia due to the diversity of climatic regions in its territory. Moreover, changes in the thermal regime of the atmosphere increase people's vulnerability to external factors.

The negative impact of the environment on human health can be mitigated by the development of resorts and the tourism industry, which allows people to undergo treatment, health and rehabilitation activities and to actively relax. Therefore, in recent years, special attention has been given to the development of this sector of the economy and, accordingly, to the identification of new bioclimatic resources in existing and promising resort and tourist areas.

Therefore, studying the impact of climate change on the variability of various thermal indices, including the TCI and HCI, is important.

The conducted studies once again confirmed the presence of a variety of climatic and bioclimatic conditions in Georgia, as well as the characteristics of their temporal variability. It is concluded that it is necessary to conduct a detailed study of climate change (as well as bioclimate) not only on a regional but also on a local scale.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

A.A. and N.B. conceived of the presented idea. L.K. and G.L. performed the analytic calculations. G.T. constructed the map and edited the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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Mapping of Erosion by Wind with RS Data and GIS (case study of Dedoplistskaro Municipality, Georgia)

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Abstract

Wind erosion plays a significant role in the degradation of agricultural land. When formulating strategies for mitigating wind erosion, it is crucial to possess precise quantitative data pertaining to the possible soil loss. Various types of equations and models are developed for this objective. This article used the WEQ to quantify the mean annual soil loss resulting from wind erosion on agricultural soils within the Dedoplistskaro Municipality in Eastern Georgia. The area of eastern Georgia experiences a higher degree of wind erosion because of its specific meteorological characteristics. The agricultural soils in the study area have been identified based on the land use classification provided by the ESA in 2021. The climate data for the research area has been obtained from the GWA and MODIS open-access satellite images. The WSD was used as the primary data source for the computation of the soil erodibility index. To evaluate the impact of vegetation cover, the LAI was chosen, which was derived from the yearly average NDVI data acquired using Sentinel 2. The width of open plots was determined by applying satellite-based Land Use and Land Cover (LULC) open access data as well as data acquired from the Ministry of Agriculture and Environmental Protection of Georgia. This data specifically pertains to windbreaks and plots that were occupied by perennial crops. The mathematical computations were executed via the web platforms GEE and ArcMap 10.8. Subsequently, a raster file depicting the probable soil loss resulting from wind erosion on the agrarian soils within the Dedoplistskaro municipality was obtained.

Keywords: Wind, Erosion, WEQ, RS, GIS, Georgia

Introduction

Agricultural soil plays an important role in food production and agricultural development. Agricultural soil, including arable land, perennial crops, and pastures, is used for agricultural purposes. The physical and chemical features of agricultural soil determine its suitability for different crops. These soils are usually rich in organic matter, nutrients, and beneficial microorganisms that promote plant growth. Agricultural soil fertility is critical for maintaining high yields and ensuring a continuous food supply.

The use and protection of agricultural soil include various measures aimed at optimizing its productivity and sustainability. These measures include tillage, irrigation, crop rotation, nutrient application, and erosion control.

Erosion (water and wind), nutrient depletion, and thus soil degradation are common challenges for intensive agriculture. For example, 42 million hectares of European soils suffer from erosion by wind (Klik, 2004). The implementation of erosion control measures such as contour ploughing, terracing, and windbreaks can help prevent soil erosion and preserve valuable topsoil.

In Georgia, agricultural soil plays a crucial role in supporting the agricultural sector and rural communities. With diverse landscapes and climate zones, Georgia has a wide range of agricultural soils that are vital for food production and economic development. However, as in many regions of the world, erosion by wind remains one of the main challenges in Georgia, which, among other factors, may affect the productivity and sustainability of agricultural soils. Erosion by wind occurs when strong winds carry topsoil particles away, causing loss of important nutrients and organic matter and deterioration of the soil structure. Erosion by wind is particularly common in areas with little rainfall and dry climates, where soil moisture is limited, and vegetation is poor.

The lowlands of eastern Georgia are particularly affected by erosion by wind, which has a semiarid and continental climate characterized by hot summers and little precipitation. The combination of dry conditions, open plains, and exposed soil surfaces increases the risk of erosion by wind. In addition, the spread of certain agricultural practices, such as extensive cultivation, overgrazing, and inadequate soil conservation measures, further increases the vulnerability of agricultural soils to erosion by wind (Ministry of Agriculture of the USSR of Georgia, 1981).

A total of 21.1% of the arable land in Eastern Georgia is damaged by wind. Quantitatively, this number is 102.5 thousand hectares throughout the country (Gogichaishvili, 2019). According to previous studies, this number is quite high. According to data from the 1970s, 172,000 hectares of arable land in eastern Georgia suffer from erosion by wind. The outer Kakheti Plateau, Sagarejo, Gurjaani, and Sighnaghi Municipalities, and Dedoplistskaro municipality are the most affected by wind (Ministry of Agriculture of the USSR of Georgia, 1973).

Recognizing the importance of erosion by wind as a threat to agricultural soils, there are efforts in Georgia (The parliament of Georgia, 2023) to implement soil conservation measures and reduce its impact. These measures include the adoption of conservation agricultural practices, such as minimum tillage and contour ploughing, to reduce the risk of soil disturbance and erosion. Agrosilvopastoralism and the cultivation of windbreaks contribute to the formation of vegetative barriers that protect fields from strong winds and prevent soil erosion. Appropriate land management techniques such as crop rotation, contour farming, and terracing are also encouraged to reduce erosion by wind and maintain soil health.

In addition, awareness campaigns and educational programs are being implemented among farmers and landowners to promote sustainable soil management practices. These initiatives aim to promote the importance of soil conservation, the risks associated with erosion by wind, and the adoption of erosion control measures.

It is crucial for the government of Georgia, agricultural organizations, and interested parties to cooperate in the development of comprehensive soil conservation strategies. This includes conducting research on the development and impact of erosion by wind, implementing monitoring systems, and providing support and incentives to farmers to implement sustainable land management practices. For example, we can cite the Resolution of the Government of Georgia (No. 146, March 24, 2022) on the approval of the rules for restoration, planting, maintenance, protection, and supervision of windbreaks (Government of Georgia, 2023).

These models, accompanied by field and laboratory studies (Zou et al., 2015), are actively used in research on erosion caused by wind. These models serve different levels of research, and such research helps those responsible for monitoring and predicting the development of appropriate conservation policies. Erosion by wind models varies in complexity (Tatarko et al., 2013) depending on the number of variables included in the model. Therefore, the selection of the model depends on the objectives of the research and the scale of the obtained result (local, regional, or global). It is also important to have the data available to calculate the variables needed for the model. All erosion models have limitations that lead to some level of inaccuracy in the results obtained. At the initial stage of modelling development, these inaccuracies were much greater; however, the demand for quantitative data was so great that their use did not stop, and over time, along with the refinement of models, the inaccuracies were eliminated. Developments in the implementation of geophysical models in geoinformation systems (GIS) have made the process of erosion by wind modelling more flexible (Rousseva et al., 2016)

A quantitative assessment of the risks of erosion by wind is important for the proper implementation of these measures. The first established erosion by wind prediction model was the erosion by wind equation (WEQ) (Woodruff & Siddoway, 1965), which calculates the potential soil loss in the study area through factors affecting the development of erosion by wind (climatic, soil erodibility, topography, vegetation). This research aimed to calculate the soil loss due to erosion by wind on the agricultural soils of Dedoplistskaro Municipality. To achieve the set goal, we must implement the following tasks:

a) Modelling of the main factors affecting erosion by wind in the study region (climate, soil erodibility, topography, vegetation cover, bare plot length) using open data satellite images and GIS analysis.

b) Calculation of the possible loss of soil caused by erosion by wind by collecting the data obtained from the research area and by corresponding arithmetical calculations.

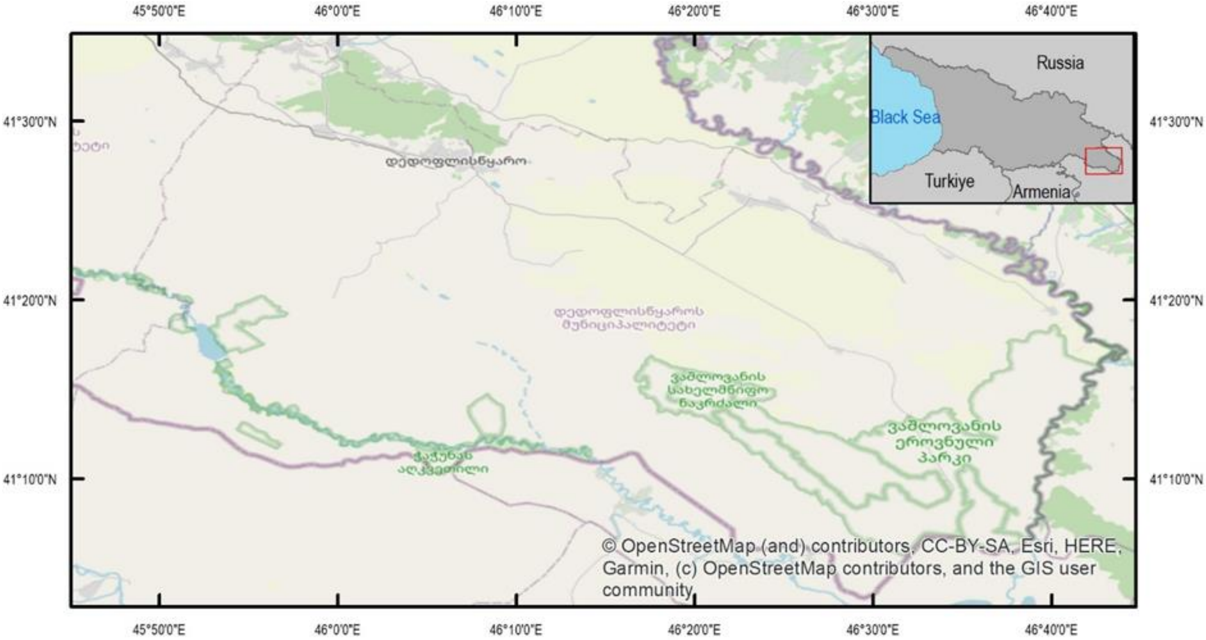

Figure 25. Study area – Dedoplistskaro Municipality

Methods and Materials

Study Area

Dedoplistskaro municipality is in the extreme southeastern part of the country (Fig. 1). The municipality is the second largest in the country by area (2532 sq. km). The study area is the only place in Georgia where a semidesert landscape has developed. Therefore, the hydrographic network of the study area is poor. In addition to the two main rivers (Alazani and Iori), there are mainly periodic rivers. There are 4 main climate types in the study area (Climate Types, 2018): a moderate warm steppe climate with hot summers and precipitation with two minimums per year, a transitional climate from moderate warm steppe to moderate humid climate, a moderate humid climate with moderately cold winters and hot summers and a moderate humid climate with moderately cold winters and prolonged warm summers. The study area is characterized by a wide distribution of fertile soils. According to Figure 2, these are *Kastanozems*, *Leptosols*, *Vertisols*, and *Solontz. Kastanozems*, which are brown or grayish in colour, are common in the dry steppes of Georgia. The Vertisols in the study area are relatively younger and belong to the Upper Tertiary and Quaternary Ages (Matchavariani & Kapanadze, 2019).

Considering the abovementioned natural factors, the study area is particularly vulnerable to droughts (Tatishvili et al., 2022). Studies based on data from the Dedoplistskaro meteorological station have confirmed that rainfall erosivity has increased in recent decades under the influence of climate change (Tsitsagi et al., 2018).

Methods

The erosion by wind equation (WEQ) is an empirical model used to estimate erosion by wind and sediment transport potential.

The WEQ is calculated by the following equation:

$$E = f(C * I * K * L * V) \quad (1)$$

where E is the estimated mean annual soil loss (t ha -1 yr -1); C is a climatic factor, which is calculated based on the mean annual wind velocity and soil moisture; I is the soil erodibility index (t ha -1 yr -1), which quantitatively determines the sensitivity of the soil to erosion by wind; K is the surface roughness factor; L is the unsheltered distance along the prevailing wind (m); and V is the vegetation cover factor, which represents the proportion of the land surface protected by plants. f is a mathematical notation of the functional relationship between erosion by wind and other variables.

All the data were processed in ArcMap 10.8.1, and the corresponding raster layers were created based on equation 2.

$$E = 0.0015 * r2.718^{\frac{V}{4500}} * \left(I^{1.87} * K^2 * \left(\frac{C}{100}\right)^{1.3}\right) * L^{0.3} \qquad (2)$$

The climatic (C) factor. Studies have shown that the movement of soil particles is directly related to the wind velocity and effective moisture, which in turn depends on the temperature and precipitation. Areas with higher wind velocities and durations are more prone to erosion by wind. Higher values indicate greater potential for erosion by wind. The C factor is determined by the following equation:

$$C = \frac{386u^3}{(\mathrm{PE})^2} \qquad (3)$$

where u is the mean annual wind velocity (m/s). (PE) is the precipitation-effectiveness index of Thornthwite (1936), and 386 is a constant used to adjust local values to the common base. Later, Thorn White introduced the concept of potential evapotranspiration (PET) (Allaby, 2023).

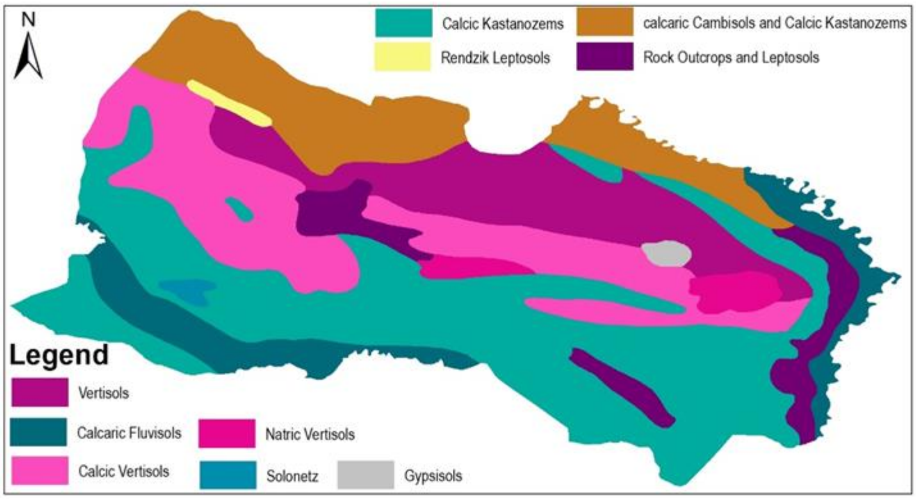

Figure 26. Soils in the study area (Soils, 2018)

In the present study, when determining the C factor, we used the Global Wind Atlas (GWA 3.0) (DTU, 2023) as a source of data on the mean annual wind velocity (Fig. 3A). GWA is a free web-based application. PET data (Fig. 3B) were obtained by processing the MODIS images (Running, 2017). The MOD16A2 V.6 product is an 8-day composite dataset with 500 m pixel resolution. We used 20-year average values of MODIS-based PET data. After equalizing the pixel resolution of the raster file obtained from the wind atlas and the MODIS raster file, both raster layers were placed in equation (2) through ArcMap's Raster Calculator, and finally, we obtained a new raster layer representing the C factor (Fig. 5A).

The soil erodibility index ($\mathcal{I}$) is related to the percentage of nonerodible surface soil aggregates larger than 0.84 mm in diameter (Chepil, 1942). It considers soil properties such as texture and organic matter content. Clay soils are generally more prone to erosion than sandy soils. Soils rich in organic matter and with good structure are more resistant to erosion by wind.

The $\mathcal{I}$ factor is calculated by the following equation (Mandakh et al., 2016):

$$\mathcal{I} = \frac{0.31S_A + 0.17S_i + 0.33\frac{S_A}{CL} - 2.59OM - 0.95CaCO_3}{100} \qquad (4)$$

where S_A is the sand content (%), Si is the silt content (%), CL is the clay content (%), OM is the organic matter (%), and $CaCO_3$ is the calcium carbonate content (%). As a rule, the abovementioned data were obtained through field and laboratory studies. The present study is regional in scope, and in this case, fine-scale data can be used. Data on the above soil characteristics were obtained from the World Soil Database (FAO, 2023). The abovementioned database is a global inventory of soils that provides information on the morphological, chemical, and physical properties of soils with a resolution of 1 km. The database did not contain information on organic matter content but instead provided information on soil organic carbon. Using formula 4, we calculated the content of organic matter in the soils of the study area.

$$OM = SOC * 1.72 \qquad (5)$$

where SOC is the soil organic carbon content (%). The layer obtained from the mentioned database was placed in equation (4) through the ArcMap raster calculator, and finally, we obtained a new raster layer representing the $\mathcal{J}$ factor (Fig. 5B).

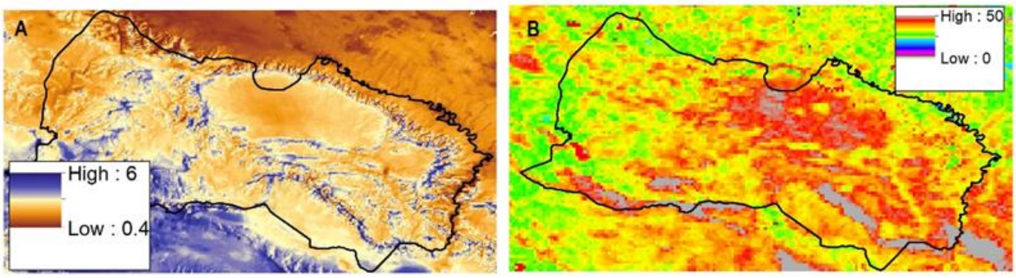

Figure 27. A – Mean annual wind velocity based on Wind Atlas; B – PET based on MODIS

The roughness factor (K) describes the effect of soil surface roughness on erosion by wind. Steep slopes are known to be more prone to erosion than gentle slopes. Calculating the same K factor for terrain influence is a rather complicated procedure. In large-scale studies, when the study area is small, it is possible and mandatory to conduct appropriate measurements. In regional studies, K is considered constant and assigned a value of 1.

For the length of the unsheltered plot, the same L factor represents the distance along the prevailing erosion by the wind direction. Windbreaks, forests, and buildings are perceived as protective barriers. To calculate the L factor, we used the ESA land use map (Zanaga et al., 2021) and aerial images.

Studies have shown that the protective function of trees of medium height extends to 20 metres, that of buildings extends to 10 metres, that of orchards extends to 5 metres, and that of vineyards extends to 1.7 metres. Through the land use layer, vineyard cadastre, and orthophotos, the distribution areas of each of the abovementioned classes (trees, orchard, cultivation, vineyard) were determined, and after placing the abovementioned distance buffer, we obtained a new polygon, which we assigned a value of 1. In the remaining area, according to the prevailing wind direction (on the Kartli Plain from west to east, on the Kvemo Kartli Plain from the east, on the Iori Plateau from the west, and on the Alazni Plain from the southeast), the length of the plots was measured. The prevailing wind direction in the study area is western. We received data about windbreaks from the Agency for Sustainable Land Management and Land Use (Land Agency).

The vegetation factor (V) quantifies the effectiveness of vegetation in reducing erosion by wind. A higher vegetation cover results in a lower wind velocity at the surface, thereby reducing the wind erosion potential. Research has shown a correlation between the normalized difference vegetation index (NDVI) and wind velocity (Mao et al., 2013). Based on past studies (Mandakh et al., 2016; Carlson & Ripley, 1997), we used the leaf area index (LAI) to calculate this factor, which was calculated according to the following equation:

$$LAI=2.745*NDVI-0.201 \quad (6)$$

$$NDVI=((NIR-R)/(NIR+R)) \quad (7)$$

where NIR is the near-infrared band and R is the red band of the electromagnetic spectrum. To calculate the NDVI, we used Sentinel-2 10-m resolution satellite images from April-October 2022 (the growing season). Using the appropriate algorithm in the Google Earth Engine (GEE), we calculated the average values of the mentioned images, and by substituting them into equation (6), we obtained the LAI.

Finally, we used WGS84 and UTM38 for all the data. After changing the projection, the raster files representing all the factors were placed in equation (2), and using the ArcMap Raster Calculator, we obtained the final raster image. Each pixel in this image contains information about the estimated soil loss due to erosion by wind.

Papers reporting something other than experiments, such as a new method or technology, typically have different sections in their body, but they include the same Introduction and Conclusion sections as described here.

Results

As mentioned above, climatic factors are crucial in the assessment of erosion by wind. In this case, the wind velocity is the main influencing factor. As Fig. 4a shows, 42% of the study area has an average annual wind velocity of 0-2 m/s, and more than half of the area is in the zone with an average annual wind velocity of 2-5 m/s.

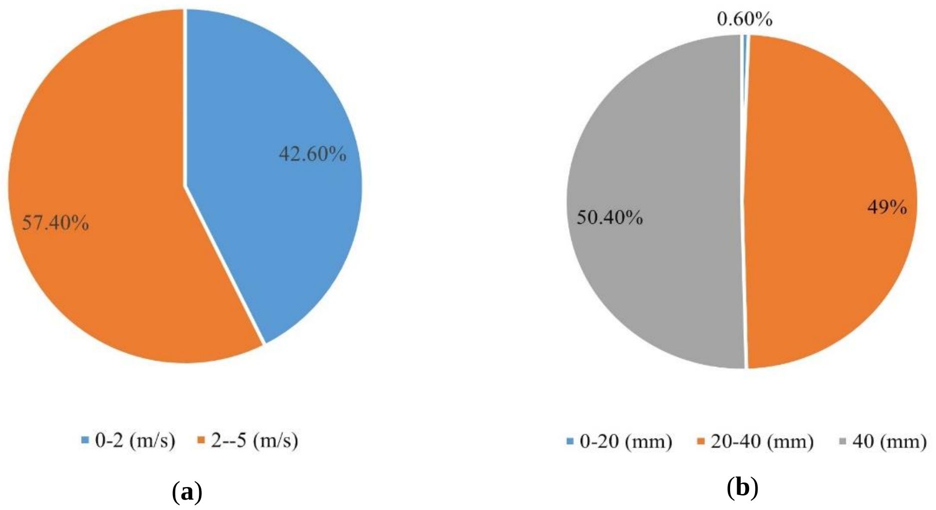

Figure 28. Distribution of territory (percent) based on wind velocity (a) and PET (b)

The second least important climatic factor is soil moisture, which in turn is determined by precipitation and air temperature regimes. According to the MODIS PET data, the values in half of the study area are greater than 40 mm (Fig. 5b), and in the other half, they are 20-40 mm. Only a small part of the territory is within 0-20 mm. Considering both abovementioned factors, the C factor values (Fig. 5A) were spatially distributed in such a way that high values were recorded in the eastern and southwestern parts of the municipality. Relatively low values of the C factor are recorded in areas where there is mostly agricultural land.

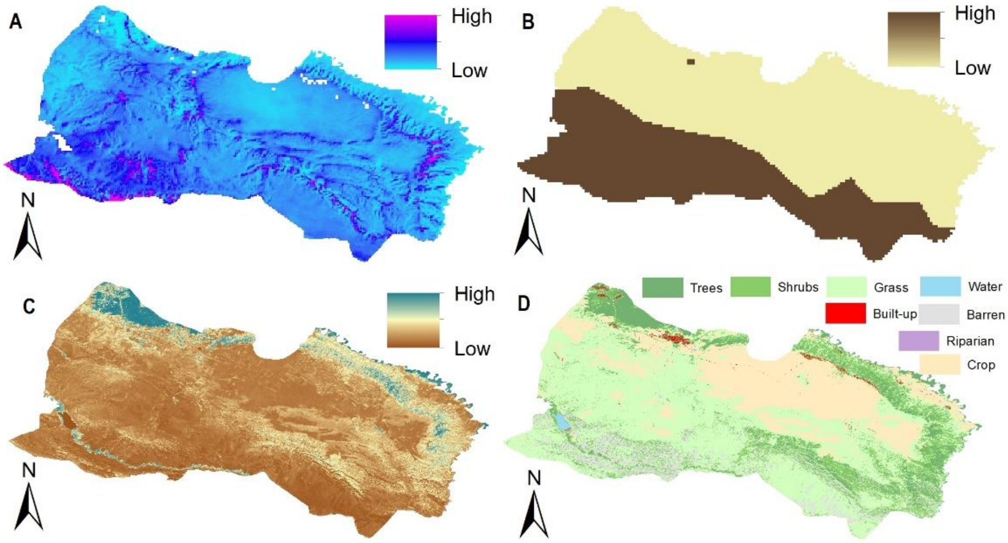

Figure 29. A – C factor; B – ℐ factor; C - V factor; D – LULC in the study area

The results obtained by processing the global data showed that 2 values of the ℐ factor were present in the study area. According to Figure 5B, the research area is almost equally divided. A relatively low value of factor *I* is recorded in the northern part, and a relatively high value is recorded in the southern part.

Table 1. Physical and chemical characteristics of the soil in the study area

ID	*Depth (cm)*	*Texture*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*SOC (%)*	*$CaCo_3$ (%)*
28044	0-20	Clay loam	33	31	36	1.93	0
28045	0-20	Clay loam	33	31	36	1.93	0
28046	0-20	Sandy clay loam	61	19	20	0.744	0

The results obtained by processing the global data showed that there are three types of soil in the study area. The table shows the soil ID in the global database, the depth, and the physical and chemical characteristics of each type. As shown in Table 1, ID 28044 and 28045 are characterized by a clay loam texture, while 28046 is a sandy clay loam. Accordingly, in the case of the first two soils, the percentage of clay is 36%, and in the third, it is only 20%. An important variable in determining soil erodibility is organic carbon, the content of which, in the case of ID 28046, is almost 2 times less than that of the other two variables. By placing the mentioned data in the formula, we have 2 values of the $\mathcal{I}$ factor. According to Figure 5B, the research area is almost equally divided. A relatively low value of the $\mathcal{I}$ factor is recorded in the northern part, and a relatively high value is recorded in the southern part.

The creation of protective barriers is crucial for controlling erosion by wind, especially in areas occupied by annual crops. Considering the protective barriers in the study area, the width of the unsheltered plots in the direction of the prevailing wind was determined. Figure 6a shows that the width of the unsheltered plots between the protective barriers is especially large in the central and southwestern parts of the study area. According to Figure 6b, 62% of the arable lands in the research area are unheated plots, the width of which is more than 500 meters in the direction of the prevailing wind, and 20% of the plots are within the range of 100-300 meters.

Vegetation cover has a decisive role in the process of erosion by wind. Plant height and leaf area reduce wind velocity, preventing soil particles from being blown up. In Dedoplistsakro municipality, high LAI values (2 or more) are associated with areas covered by forest (Figure). Riparian vegetation in the Alazni and Iori floodplains is associated with medium LAI values (1-2), while arable land has low LAI values (0-1).

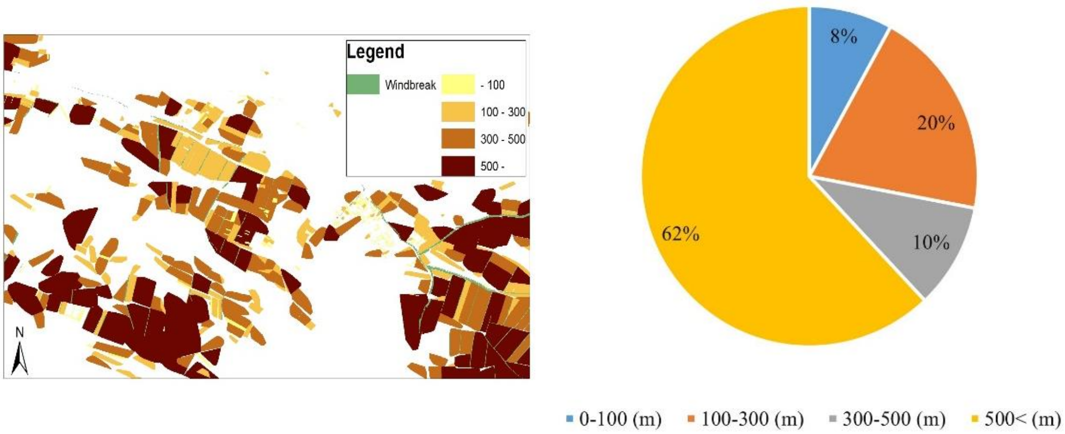

Figure 30. a-Unsheltered land width (m), b-spatial distribution (percent) of unsheltered land plots

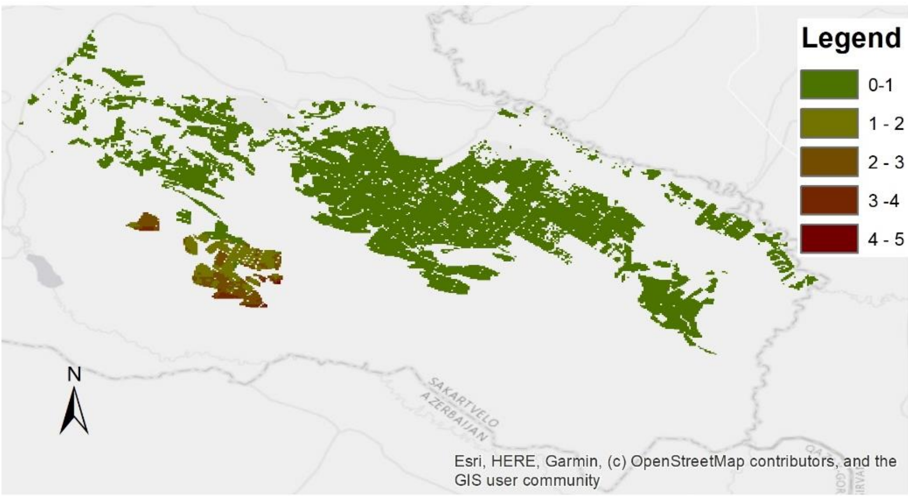

Figure 31. Average annual soil loss in the study area (t ha -1 yr -1)

The functional relationship of the geophysical variables discussed above showed that the maximum values of annual soil loss in the study area are fixed in the southwestern part of the municipality (Fig. 7), while relatively low values are fixed in the main part of the study area.

Discussions

The purpose of this study was to quantify the average annual soil loss on the agrarian soils of Dedoplistskaro municipality. The analysis of the main factors of erosion by wind mechanisms revealed that the study area is relatively vulnerable to erosion by wind. This result is confirmed by the resolution of the Government of Georgia, where the country's municipalities are divided into categories according to the average annual wind velocity. The Dedoplistskaro municipality belongs to the first category. In this case, one circumstance is worth noting, namely, the first category of municipalities according to the government's decree were assigned to those where the average annual wind velocity was 9.9 m/s. According to the data used in our research (GWA), a maximum average annual wind velocity of 5 m/s was recorded in the research area. The reason for this difference may be as follows. The data mentioned in the resolution of the Government of Georgia (Government of Georgia, 2023) are based on data from past observations. On the other hand, the results of past research indicate that the average annual wind speed in the research area is within 0-4 m/s (Soils, 2018). Currently, wind velocity is not measured at most meteorological stations in the country. Therefore, global data were selected for the study. Here, we assume that the improvement of the observation network in the country will confirm that the global mean annual wind data in the study region are underestimated.

The intermittency of the Dedoplistskaro meteorological station data prompted us to use MODIS open-access data. In this case, the high values of PET (30-48 mm) in the study area are due to local climatic conditions. The study area is characterized by high temperatures (especially in summer) and a low amount of precipitation (this is where the dry pole of the country is located). Such a ratio of temperatures and precipitation determines the high values of PET. Other studies also prove that there has been an increase in temperature in recent decades, especially in eastern Georgia (Elizbarashvili et al., 2017). For more concreteness, studies have shown that the study area has the highest average annual amplitude of ground surface temperature in the country (Tavartkiladze & Kikava, 2021).

These conditions, in turn, affect soil depletion, and the depleted and dried soil surface is easily split by the wind. According to global data, three soil types are represented in the study area. Based on their physical and chemical features, clay loam soils are characterized by lower erosivity than sandy clay loam soils.

The Dedoplistsakaro municipality is the main region of grain crops in Georgia. Accordingly, a large area of the municipality is occupied by arable land. These lands are completely free of vegetation in early spring and late autumn when strong winds are characteristic of the region. Of course, there are windbreaks in the research area (unpublished data from the Land Agency - 1550 ha); however, their condition and functionality are separate topics of discussion. Therefore, it is logical that the width of the unsheltered plots in the study area is quite large. As repeatedly mentioned, the study area is a region of intensive agrarian practices, and there are few forested areas to which to connect; additionally, the study area is mainly in river floodplains and protected areas. Trees and plants on agrarian soils are the aforementioned windbreaks.

Conclusion

In eastern Georgia, in the municipality of Dedoflitskaro, during the assessment of erosion by wind, it was revealed that the study area is quite vulnerable. The main difficulty in the study was the availability of data needed for model parameters, so the study is based on open-access data, including GWA, MODIs, ESA LULC, and WSD. High-accuracy data are also used in the study; for example, windbreaks in the study area are recorded in the field via GPS planning. The combined results showed that although the average annual wind speed (0-4 m/s) is recorded in the research area, low soil moisture, lack of vegetation, and large width of uncovered plots create favourable conditions for the activation of erosion by wind.

In the future, it is recommended to include relatively high-resolution data, especially for soils, to obtain more detailed and valid results.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

M.T. developed the theory and performed the computations. L.M. aided in interpreting the results and worked on the manuscript. A.T. and L.M. contributed to the design and implementation of the research, to the analysis of the results, and to the writing of the manuscript. All authors discussed the results and commented on the manuscript.

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Dynamics of Atmospheric Microcirculation Processes in Certain Regions of Georgia

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Abstract

There are many microregions on Earth in which the study of developed hydrometeorological processes is important and has great practical value. Such regions include various caverns, highways, open quarry work areas, hydropower plant construction area. A special theoretical approach to study of local events in such areas for their modelling is given in the presented paper. The mathematical basis of this approach is presented; sample examples and calculation procedures are given. The presented materials and obtained results are important for conducting further studies, have practical value and are recommended to be taken into account when carrying out various activities in the local area of similar terrain.

Keywords: Microcirculation processes, wind speed, turbulence flow, atmosphere disturbances, von Karman vortex

Introduction

Atmospheric processes are highly heterogeneous and anisotropic in space and time. The main reason for this is the uneven distribution of energy from the sun to the Earth's surface. In the lower layers of the atmosphere, the heat regime is provided by longwave radiation reflected from the Earth's surface. The heterogeneous surface causes the rays to reflect at different angles, which in turn causes an uneven distribution of the heat field. An uneven heat field causes an uneven distribution of atmospheric pressure to establish so-called permanent "barrier centres". These centres provide air motion mainly from west to east ("leading" flow) (8-12) m/s and other zonal flows. These processes are peculiar everywhere, especially in difficult physical terrain, such as Transcaucasia and Georgia. The wind speed is a three-dimensional vector. The vertical stiffness is small compared to the horizontal stiffness and can only reach 10-20 cm/s or greater under intense convective motion. Such convective movements, however, often occur on uneven, mountainous terrain (Tatishvili et al., 2019a). Therefore, in the mountainous terrain layer, it is not acceptable to have zero divergence of the wind, as is allowed for a straight surface. Experimental measurements of wind vertical velocity are associated with principal difficulties; therefore, it is necessary to evaluate these measurements using theoretical methods (Khvedelidze et al., 2018).

There are several microregions in the territory of Georgia whose climatic conditions sharply differ from the climate, with changes in climatic parameters and impacts on weather conditions in the outer region. Thus, it is necessary to investigate, explain and justify the nature of changes in wind speed, air flow turbulence and climatic parameters on different construction tracks, radiation regimes and environmental pollution assessments for different time intervals. Actions of the mentioned type were ongoing and are still ongoing in Transcaucasia, particularly in Georgia. The Transcaucasia Road, open pit works in the Chiatura and Kaspi regions, and the construction of hydroelectric power stations in various regions. When performing such studies, the spatial change in the turbulent flow of atmospheric air, first in the ground layer, should be studied. It is known that additional orographic turbulent currents and regular oscillatory disturbances are formed in mountainous areas (Khvedelidze et al., 2018). A change in the microrelief of the Earth's surface, even on a small scale, causes local circulation of the air flow. It becomes clear what impact such long-term construction, which we have already mentioned above, will have. It is necessary to analyse the spatial-temporal change mode of meteorological parameters in these regions (Khvedelidze et al., 2023).

There are several microregions in the territory of Georgia whose climatic conditions differ sharply from the climate of the outer region. One of these microregions is the Svaneti Cavern. Zemo Svaneti plays a special role in diverse regions of Georgia. This is due to both its unique nature and centuries-old history, which has added a unique touch to the cultural heritage of this area. Zemo Svaneti is located on the southern slopes of the Central Caucasus. Most of the high peaks of this mountain massif are concentrated in this part of the Caucasus and include those of Shkhara (5203 m above sea level), Tetnuldi (4858 m), Ushba (4700 m), Tikhtingeni (4617 m), and Shkhilda (4368 m) (Khvedelidze, 2018).

The peaks covered with glaciers and permanent snow rise above the villages are scattered on the slopes and terraces, of which the center of the region, the village of Mestia, which is in the hollow region, stands out. The region of Mestia is bordered to the north by the ridge part of the main axial ridge of the Caucasus, which morphologically belongs to the Western Caucasus. This section is covered with a glacial coat. The district is bounded in the northwest by the Kodori ridge, which continues to the Jvari reservoir, and in the southeast, it is bounded mainly by Svaneti and in the southwest direction by the Odishi ridge, which flattens to the southwest.

The Lentekhi municipality is located on the southern slope of the Caucasus range and is one of the most mountainous regions in Georgia. The region is bordered to the southeast and south by the Lechkhumi range, to the west by the Kodori range, and to the north by the main watershed of the Caucasus. The Tskhenistskali River is the main hydrographic unit in the territory of the Lentekhi municipality. It is joined by the Kheledura River and Laskadura River in the town of Lentekhi, after which the Tskhenistsali River flows out of the Kvemo Svaneti cavern. Then, it connects the caverns of Kvemo Svaneti and Tsageri, has a submeridian direction and continues from Lentekhi township to Tsageri at 20 km. The Kvemo Svaneti cavern extends from west to east at 85 km. The area of Lentekhi municipality is 1344 km2. The largest settlement is the village of Lentekhi. There are 61 villages in the municipality (Khvedelidze et al., 2020).

Under quiet atmospheric conditions, in narrow deep canyons, under the influence of a periodically active specific heat source related to solar radiation, a convection boundary layer can form on the slope of the ridge bordering the canyon. As the height in the canyon increases to 200-250 m, the speed of the convection wind increases. After reaching the maximum, its magnitude gradually decreases to such an extent that, at some level, the direction of the wind reverses (inversion). This event should be qualitatively the same in different canyons. It is known that the inversion level, such as the wind speed, increases with increasing atmospheric instability. Under calm, less cloudy conditions, the wind flow on the mountain side, approximately half an hour after sunrise, occurs down the valley (Tatishvili et al., 2019b). When the slope warms up and the specific heat source is activated, the wind blows in the same direction for approximately one hour. After that, the direction of the wind, whose characteristic speed is (1-3) m/s, changes from downwards to upwards.

Methods and Materials

One of the most important contemporary problems from both scientific and industrial-practical points of view is to study the climatic features of local regions against the background of global climate change. The quantitative forecasting of precipitation (QPF) and other meteorological parameters: temperature, wind, pressure and etc on regional scales is still inadequate for many applications such as weather prediction, hydrology, flood and landslide forecasting. For this purpose, it is essential to reproduce precipitation accurately down to the size of small catchment areas. The most applicable is the Weather research and forecasting model (WRF) that is weather numerical forecasting and atmosphere simulation system created as for research as operational application. The model is elaborated USA National Center for Atmosphere Research (NCAR), Mesoscale and Microscale Meteorological Division (MMM), NOAA, NCEP, ESRL, AFWA, Naval Research Laboratory, CAPS, and etc (Ebert et al., 2003). It is used in following fields: real-time numerical forecasting, data assimilation, physical parameterization research, regional climatic simulations and etc. The Dynamical core of the model provides general circulation processes transformation influenced by Caucasus relief and proximity of The Black and Caspian Seas resulting in local weather. The specification of those processes is possible by optimal configuration selection of schemes describing physical processes. Besides ARW provides introduction of higher spatial-temporal resolution horizontal grid that focuses on target sub-region and significantly increases model resolution (from 15km to 5 km.) (Bianco, 2008). The WRF-ARW version 3.1 was running operationally on the NEA cluster during several months with two different model configuration combining different convective and microphysical schemes. All runs were initialized with 25-km NCEP GFS Model GRIB data results from regional NWP do not have the same quality for all areas within the domain. (Kutaladze et al., 2021). The results of model validation are not homogeneous inside domain and are highly dependent on the physical content of the synoptic process and complexity of relief.

Continuous operational data show that the weather in some local regions noticeably differs from that in surrounding areas. This circumstance is mainly related to the shape and the dynamic processes caused by the relief. Therefore, the definition of terrain influence parameters and their analysis are highly pertinent and important. A hydrodynamic approach was used to explain the developed microcirculation processes in the Svaneti cavern. The characteristic parameters of the relief of the region are estimated, and the orographic vertical velocity is calculated. By statistically processing long-term meteorological data, the climatic features of caverns and the nature of air flow dynamics can be determined. The results of the model calculations make it possible to clarify those features.

We use the following hydrodynamic equation for a vertical wind velocity compiler (Khvedelidze, 2018):

$$\frac{\partial \Omega}{\partial t} + u\frac{\partial(\Omega + l)}{\partial x} + v\frac{\partial(\Omega + l)}{\partial y} = -lD \qquad (1)$$

For the mountainous territory, the wind velocity vortex in the geostrophic approach may be written as follows (Khvedelidze, 2018):

$$\Omega = \frac{1}{\eta}[\Delta\Psi - (a\Psi_x + b\Psi_y)] \qquad (2)$$

where Ψ is the current function and u and v are the horizontal components of the wind velocity. $\eta = \frac{p_z}{p_0}$- ageostrophic parameter, p_z- pressure at the hill top, p_0- pressure at the bottom, $\Delta -$ Laplacian operator, $a = -\frac{\partial ln\eta}{\partial x}$; $b = -\frac{\partial ln\eta}{\partial y}$; parameters describing the influence of parallel and meridian orography, Ψ_x and Ψ_y current functions derived from the ox and oy axes, D-velocity divergence, and l- Coriolis parameter. From the above equations, we obtain the following equation:

$$\left(\frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y}\right)\left(\Delta\Psi + a\Psi_x + b\Psi_y\right) = l\eta(a\Psi_x - b\Psi_y) \qquad (3)$$

The solution of this equation is a flat wave, and after transformation, the following dependence is obtained:

$$am + bn = 0 \qquad (4)$$

This dependence theoretically confirms the regional problem noticed and recognized in synoptic practice, namely, that atmospheric processes in the Trans Caucasus mainly spread in parallel directions along mountain ridges (Khvedelidze, 2018; Tatishvili, 2017; Tatishvili et al., 2022).

This result is also valid for the local area, where the mountain massif can be approximated in the form of a geometric figure and the appropriate characteristic parameters can be calculated. Thus, the air flow at any selected local polygon is influenced by the up-and-down currents generated by the influence of the terrain, which must be considered. These currents principally determine the nature of local circulation and a number of features in local hollows.

After simple transformations, we obtain the equation for the orographic vertical velocity

$$W_h = \frac{1}{l\eta\rho}(p, \ln\eta)H = \frac{1}{l\eta\rho}\left(\frac{\partial p}{\partial x}b - \frac{\partial p}{\partial y}a\right)H \qquad (4)$$

The identification of a , b and W_k members must be realized for each local region.

Results

The complex topography of the region results in a considerable diversity of climatic zones. Hypsometric heights in the region cover a wide range—from 500 meters on the bank of the Cross Reservoir to 5203 meters on the peak of Shkhara. Accordingly, the climate in Upper Svaneti changes from the humid warm sea climate characteristic of the Colchis Lowland to the humid high mountain climate with permanent snow and glaciers; according to the modern classification, it contains 5 climatic zones. Naturally, all these zones, depending on the local conditions, react in their own way to regional climate change.

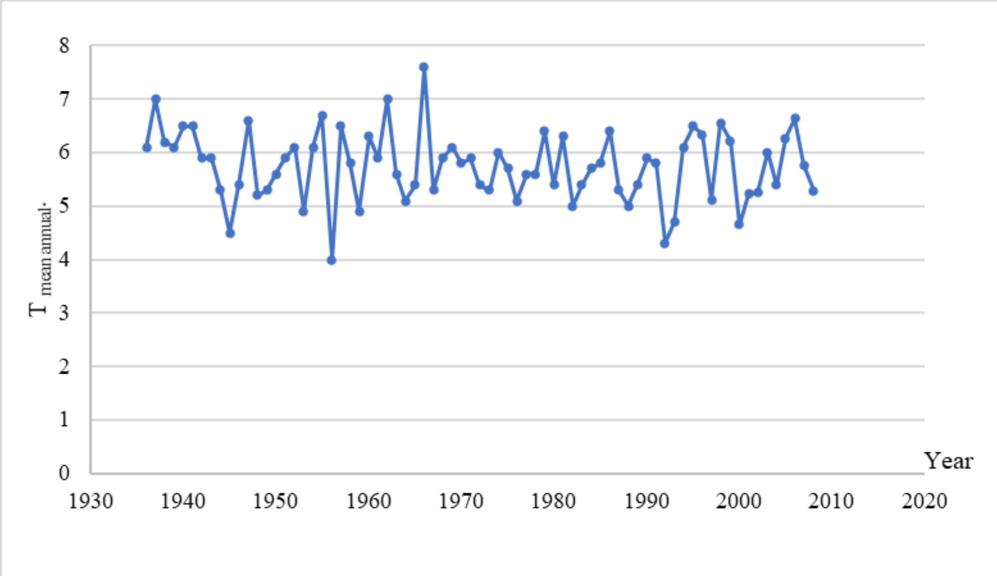

Figure 32. The average annual air temperature according to the Mestia weather station data (1938-2008)

The territory of Zemo Svaneti is characterized by a moderately humid mountain climate. Weather types within the district vary hypsometrically from a moderately humid valley-type climate to a harsh high mountain climate. Atmospheric precipitation is unevenly distributed in the district territory. The average annual amount reaches a maximum in the crown region and a minimum below Mestia in the Enguri River direction and reaches 800-1000 mm per year. The distribution of precipitation is mainly determined by orography.

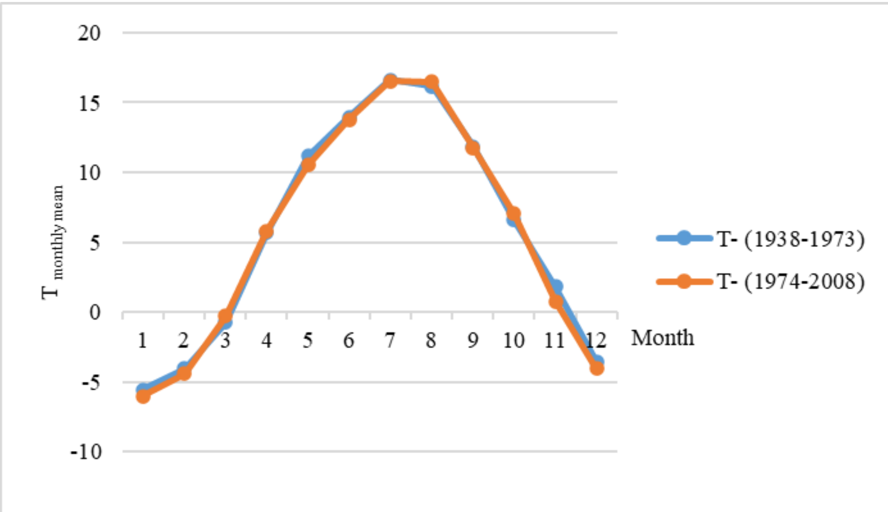

Figure 33. Distribution of the monthly mean air temperature according to the Mestia weather station data (yellow, 1974-2008; blue, 1938-1973)

The significant part reflecting the climate of Upper Svaneti (the middle zone) has been characterized by the Mestia weather station, which is located at an elevation of 1,441 m. Mestia has a humid climate with cold winters and long, cool summers. Based on observations from 1936-1960, the average annual temperature of this area is 5.7°C, and the average temperature of the coldest month (January) is -6.0°C. The average temperature of the hottest month (July) is 16.4°C, the absolute minimum is -350°C, and the absolute maximum is 35°C. The sum of the active temperatures (more than 10°C) is 2,039 degrees, the average annual relative humidity of the air is 75%, the annual precipitation sum is 918 mm, and the maximum of the monthly sum usually occurs in the month of October and reaches 95 mm, while the minimum occurs in February (61 mm). The average annual wind speed is equal to 1.1 m/s. North and southwest winds prevailed in the surrounding area.

According to the Mestia weather station data, the average air temperature for the coldest month (January) in 1938-2008 was -5.7°C, and that for the hottest month (June) was 16.6°C. For the course of the average annual temperature according to the last 10 years of data (after 1999), the average annual temperature reached its maximum of 6.6°C in 2006.

To determine the temperature dynamics, we divided the given period into two (35-year) parts: 1938-1973 and 1974-2008. The distribution of average monthly air temperatures for both periods is given in Fig. 2.

According to the data from the last 35 years, an increase in the monthly mean temperature is observed in March (0.10°C), August (0.30°C) and October (0.40°C). For other months, the average monthly temperature is either constant or decreasing.

According to the Mestia weather station data, the average air temperature in 1938-2008 for the coldest month (January) was -5.7°C. The hottest month (June) is 16.60°C in temperature. For the mean annual temperature, according to the last 10 years of data, it reached its maximum in 2006 (6.6°C).

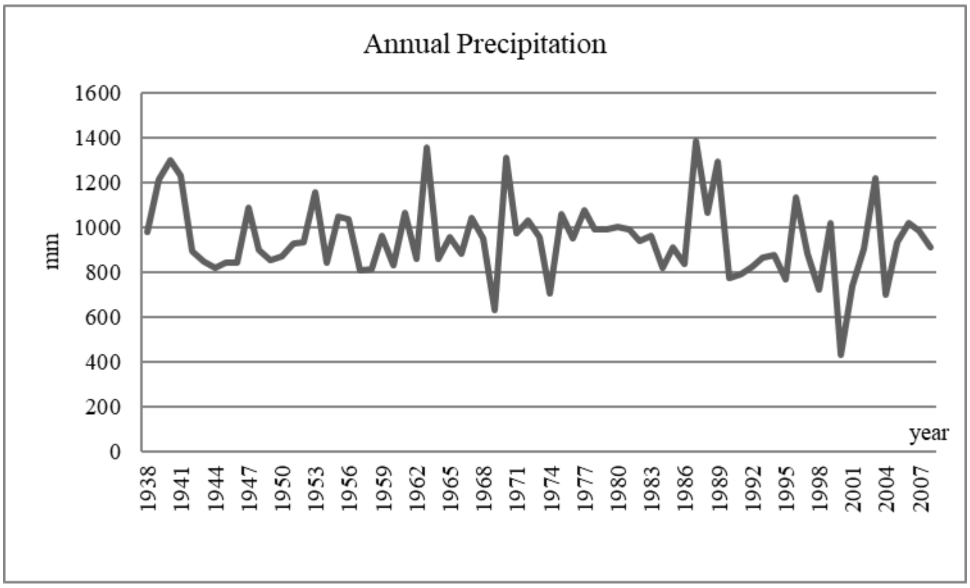

Figure 34. Distribution of the annual precipitation sum for the Mestia weather station (1938-2008)

Discussions

The peculiarities of the Mestia cavern in the Svaneti region are particularly interesting. This hollow occupies a significant area in the altitude zone of 1000-2000 meters. The cavern is characterized by cold winters and long cool summers. If for model calculations we conditionally assume that the hollow occupies (50/50) the area of a square kilometre, then the following values are obtained for the orographic parameters: a=7, 2.10-4 1/m, b=10-4 1/m; that is, a=7,2b. These parameters are inversely proportional to the wavelength of the invading air masses. Therefore, the wind in the cavern mostly blows (in the landward layer) from the west in a direction parallel to the main ridge. The orographic vertical velocity is small. The intruding air mass is surrounded by mountains covered with high glaciers on three sides; due to the low vertical speed, mass flow cannot occur over these mountains. The air stream is reflected from the mountains (a law of momentum constancy) and remains in the hole for a long enough time. This is the reason for the climatic peculiarity of Svaneti, which has a cold winter and long cool summer. From the given reasoning, the received theoretical modelling result substantiates the climatic specialness that is observed in caverns.

Conclusion

The existence of hollows over terrain significantly complicates weather prediction (Tatishvili et al., 2020; Tatishvili, 2017). The latent heating in a large complex of deep moist convection often produces a cyclonic vortex. These vortices can then initiate additional convection the next day. As a result, they represent a complex forecast challenge: for a numerical model forecast to make an accurate "day 2" forecast, it must make a correct prediction of the location and timing of the convection on day 1 (which is itself difficult); it must represent the vertical structure of latent heating that leads to the development of the cyclonic vortex; it must correctly capture the evolution of the vortex; and it must determine whether the lifting associated with that vortex will initiate convection again. When steady wind flows around an isolated obstacle, such as a mountain or a mountainous island, atmospheric vortex streets (AVSs) can be generated on the leeward side of the obstacle under favourable meteorological conditions. The AVS pattern exhibits a double row of counterrotating vortex pairs shedding alternately and resembles the classic von Karman vortex street; these types of vortex streets have significant weather and climate implications. Atmospheric vortex streets may modulate cloud and wind patterns over downstream regions and are an additional reason for forecasting uncertainty. To avoid all these complications together with numerical weather predictions, another model must be run: the microscale model, which depicts local atmospheric disturbance (Tatishvili et al., 2022.) This coupling became essential, as Georgia is a country with great tourism potential, including winter sport tourism. Detailed information on the wind stream velocity can aid in safe paragliding sport and rescue missions. Additionally, research outcomes may be important for early warning systems.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

M.T., Z.K. and I.S. conceived of the presented idea. I.S., N.Z., and N.N. performed the analytic calculations. M.T. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research and analysis of the manuscript.

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The Natural Resource Potential of landscapes in the Lechkhumi Region (Tsageri Municipality)

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Abstract

To study a region's natural capital, it is important to classify and describe local landscapes, which, depending on the area they are found in, have different characteristics and vary in terms of natural resources. The mountainous region of Lechkhumi (Tsageri Municipality) has been selected for this purpose. Along with relevant literary sources, the research draws on cartographic material, the landscape maps (1970, 1983) of Georgia and Transcaucasia, and the topographic map (1:50000) as well as on observation records made during the 2022 field expedition in Lechkhumi. Geo-informative system of Lechkhumi landscapes has been created by GIS technology. The large scale (1: 50 000) landscape map of Lechkhumi region has been made, where landscapes are shown on the level of landscape species. The paper describes the region's individual natural assets as well as the natural resources available in selected landscapes. Data on mineral, climate, agroclimatic, soil and forest resources are provided in the tables and diagrams. The synclinical depression in Racha with river terraces (Tskhenistskali, Rioni, Lajanuri) and humus-carbonate soils on the southern slope of the Lechkhumi Ridge (450-750 m above sea level) provide a favourable micro zone for the cultivation of grapevine species (Usakhelauri, Tsolikauri, Orbeli Ojaleshi red and Tskhvediani white) used in the production of the widely known naturally semi sweet Usakhelouri, Tvishi, Ojaleshi red and white wines.

Keywords: Natural resources, Landscape map, Lechkhumi region, Tsageri Municipality

Introduction

Utilization of the environment of a region is related to its natural conditions and resources, as well as the peculiarities of the geographical location of the territory and the historical processes taking place there. Environmental conditions, in turn, impact the material and spiritual culture of the population, traditions, features of nature use and settlement style. All this is clearly reflected in the landscapes, as a single (entire) territorial system, which has a certain characteristic potential, e.g., it has the ability to provide people living in it with heat, water, the possibility of rest (recreation), etc. Meanwhile, for that purpose, it is necessary to reveal the resource potential of landscapes.

Lechkhumi (Tsageri Municipality) is located in the northeastern part of western Georgia on the southern slopes of the Caucasus. The hypsometric levels of the territory vary from 320 m (Tvishi Cliff) to 3170 m (Mount Tsekuri, Egrisi Ridge). In regard to climate, it is located in a subtropical humid sea climate zone and is distinguished by its variety and complexity of natural components and natural-territorial complexes (landscapes) as a whole. The peculiarity of the natural conditions and specificity of the geographical location have determined the peculiar structural characteristics and aspects of nature use of the landscapes of the region.

The landscapes in the region are useful for agriculture, livestock farming, and recreational purposes in accordance with natural conditions.

Methods and Materials

The research was based on the existing published literature and foundation material about the Lechkhumi region. These include Georgia (Saneblidze et al., 1970), the Transcaucasus Medium-Sized Landscape Map (Ukleba et al., 1983), topographic maps (scale: 1: 50 000, 1: 100 000) and statistical data. An important component was the field expedition research conducted in 2022. Based on the obtained material, the Lechkhumi electronic map was created (ArcGIS) on a cartographic basis and several thematic maps. Lechkhumi region landscapes have natural and socioeconomic environmental influences. Natural conditions and specific geographical locations created the peculiar structural character of the landscape of the region and aspects of natural use.

The Lechkhumi region, represented by the Tsageri Municipality, is a region distinguished by its diverse nature. Tsageri Municipality (1 town and 58 villages) is located in western Georgia on the southeastern slopes of the Caucasus Mountains, in the Tskhenistskali and Rioni River Basins, bordered on the west by Martvili and on the north by Lentekhi municipalities, on the east by Ambrolauri municipality, and on the south by the Tskaltubo and Khoni municipalities. Its area is 756 km2.

The region occupies the southern slopes of the folded mountains of the Caucasus. It is mainly composed of Jurassic and Cretaceous shale, sandstone, and limestone and is built from Palaeogene-Neogene rocks, and the river terraces and the bottoms of the basin are composed of alluvial layers.

Results

Lechkhumi is a region with many mountains and a shortage of land. Most of the time, 67. Six percent of its territory is occupied by mountains and foothills. Due to the relief complexity, extreme disintegration and strong inclination (45% of the territory is covered with slopes inclined by 20° and more), the resources of the land for agricultural activities are extremely limited. The agricultural lands occupy 17 146 ha, which is 21% of the whole territory (Government of Georgia, 2023).

Lechkhumi is bordered by the Egrisi and Lechkhumi Ridges in the north, the Askhi Massif in the west and southwest, and the Khvamli Massif in the south. In the east, the valley of the Askhistskali River borders it from the Racha Region. The Lechkhumi Ridge is built of lower Jurassic sediments, shale and sandstones (in the top part of the Lechkhumi Ridge); the Egrisi Ridge and the Jonouli River Basin are built of the Middle Jurassic Bajocian porphyritic suite; the Askhi Massif (northern and eastern slopes) and the western part of the Nakerala Ridge are constructed of lower Cretaceous quartz-arkosic sandstones and dolomitic limestones; the Khvamli and Askhi massifs – with Urgonian facies limestones; and the northern part of the Khvamli Massif, Tvishi Cliff and Lajanuri Cliff – with limestones and marls (Maruashvili, 2020). An important orographic unit is the Tsageri Depression, which represents the western part of the Racha-Lechkhumi Syncline. It is built of Palaeogene and Neogene marls, sandstones, clays and conglomerates. The Tsageri Depression, which is crossed by the Tskhenistskali River, starts from the Muri Cliff and continues south to the Saretskela Cliff. To the south of the Saretskela Cliff, the Tskhenistskali River redistributed again and formed the Zubi Depression in the porphyritic rock. The Tsageri Depression is separated from the Orbeli Depression in the east by the Mid-Lechkhumi Hill. To the east in the Cretaceous limestones, the Rioni River formed the Tvishi cliff. The limestone massifs are characterized by sharp erosive and karst landforms, while landslides are typical of depressions.

In regard to climate, Lechkhumi is located in a subtropical humid sea climate zone. The following climate subtypes are distinguished here: a) damp climate with moderately cold winters and hot and relatively dry summers; b) damp climate with moderately cold winters and long summers (lower belt of mountains); c) damp climate with cold winters and long summers (middle belt of mountains); d) damp climate with cold winters and short summers (1500-2000 m above sea level); and e) damp climate devoid of real summers (the summit zone of the Egrisi and Lechkhumi Ridges and the Askhi Massif).

The average annual air temperature is 11°, the average temperature in January is close to 0°C or is negative, the average temperature in July is 22.5°, and the absolute maximum temperature exceeds 40°. The sum of the active temperatures is 2700-3500°, while the vegetation period lasts for almost 7 months. The annual total precipitation at an altitude of 600-800 m above sea level is equal to 1100-1200 mm. A greater precipitation amount typically occurs in late spring and autumn. The lowest amount occurs in the second half of summer and the beginning of autumn, i.e., when it is most needed for vineyards and fruit. At this time, the humidity coefficient is 0.6-0.8. Therefore, watering is required during this period of the year.

During the active vegetation period, the amount of precipitation varies from 585-780 mm to 970-1298 mm. The annual precipitation is 1300 mm, and the highest precipitation is 122 mm in October. The number of days with snow cover ranges from 54-138. The maximum thickness of snow cover is 103 sm (Tsageri) – 138 sm (Lailashi). In the lower zone, the active vegetation process starts on 4-19 April and ends at the end of the third week of October and the beginning of November. In separate years, when the freezing period is too long or starts in early autumn, the vegetation period may decrease by 1 month (Gobejishvili, 2000; Elizbarashvili et al., 2004; Elizbarashvili & Elizbarashvili, 2021; agroclimatic resources of Georgia, 1978).

Lechkhumi, according to agro-climate zoning, belongs to the moderately humid region of the West Caucasus subdistrict of the West Georgian district (Table 1).

Table 6. Agro-climate characteristics of the Lechkhumi Region (Tsageri municipality)

Object	M. above sea level (m)	The sum of active temperatures (10^0>)	Absolute minimum temperature (average) (C^0)	Moisture rate	Annual sum of atmospheric precipitation (mm)	Duration of frost-free days
Tsageri	**760**	**3610**	**-18**	**1.3**	**1000**	**267 -186**
Lailashi	**980**	**2980**	**-22**	**1.5**	**1300**	**216 - 175**

In Lechkhumi, there is a dense network of mountain rivers, and the main rivers are Rioni and Tskhenistskali. The main right tributary of the Rioni is Lajanuri, while its other right tributaries are Utskherisghele, Minatskarosghele and Lakhepisghele. The right tributaries of the Tskhenistskali River are Janouli, Namkashuri, etc. The rivers are characterized by steep slopes and deep, sometimes canyon-like valleys. Mixed nutrients are characteristic of these plants because they are fed by rain, snow and underground waters. Some of the small rivers have karst regimes, and some have torrential characteristics. The flooding of rivers occurs in spring, while that of torrents occurs in summer-autumn. Among the most remarkable lakes are Akhalouri Lake, Mtsvane Lake (green lake), Babushkino Lake and Lajanuri Reservoir.

Here, humus-carbonate soils are common (Tsageri and Orbeli Depressions, eastern part of the Askhi Massif and the Khvamli Massif) and are alluvial (the bottom of the Tsageri Depression); other types of soils are dark gray forest soils (in the basins of the Lajanuri and Jonouli Rivers) and mountain-meadow soils (in the highest part of the Askhi Massif, in the summit zones of the Egrisi and Lechkhumi Ridges). In the mountain-meadow zone, we observe low mountain meadow-peat soils and peat soil, while higher (in the alpine zone) thin primitive mountain meadow soils are observed. Alluvial soils are common on the banks of large rivers. In valleys and on slopes where alluvial and humus-carbonate soils are widespread, there are favourable conditions for viticulture and fruit growing.

In regard to the economy, forest cover is of the greatest importance. It has a great role in soil protection, climate regulation, water regulation, anti-erosion and recreation in healthcare. The forests of the resort area are especially noteworthy. The most distinguished forests are so-called virgin forests that are preserved in their original form and biodiversity (Government of Georgia, 2023; Salukvadze et al., 2021).

Forests also have industrial potential. They provide the possibility to fully satisfy the population's needs for both firewood and timber for industrial purposes. Forests are mainly located on the slopes of the branches of the Main Caucasus Range (Fig. 1). Forests cover 56% of the entire territory of Lechkhumi (Targamadze & Chikhradze, 1973).

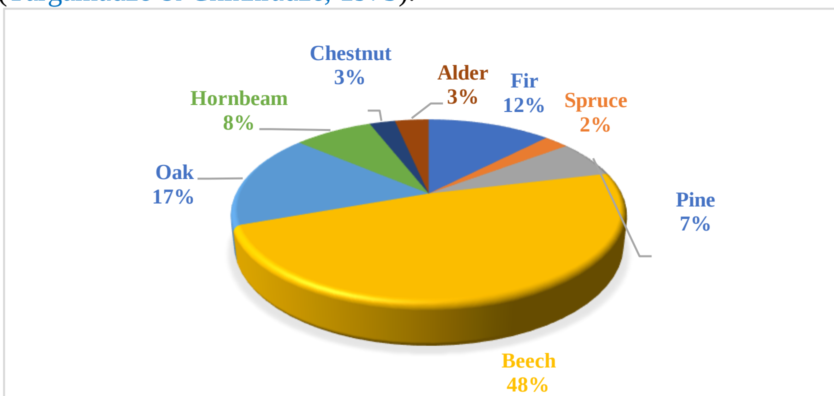

Figure 35. Dominant woody species of Lechkhumi Region

The forests are located at an altitude of 700-2200 m above sea level. Colchian-type forests are observed in the lower part. Here, we describe the relics of the Tertiary flora of Colchis (Pontic rhododendron, laurel, holly, box tree, etc.) as well as the vegetation cover characteristics of the dry climate of Eastern Georgia, including oak, oriental hornbeam, hawthorn, cornelian cherry, medlar, juniper, pine, etc. In the lower part of the valleys of the Rioni and Tskhenistskali and alongside their tributaries, we encounter alder trees and Colchian forests with evergreen undergrowth (Salukvadze, Tsitsagi, 2022). In the lower zone of the region, beech and hornbeam trees are dominant, while chestnut, oak and maple trees are also observed. Hazelnut, hawthorn, medlar, Pontic azalea, etc., are among the undergrowths. Among deciduous trees, oak, hornbeam, oriental hornbeam, and beech trees are dominant. For coniferous trees, spruce, fir and pine are present. Beech-oak forests and oak forests are observed in the limestone areas (Fig. 1). On the slopes of the Egrisi and Lechkhumi Ridges, the coniferous forests are followed by subalpine forests and meadows in the higher belt. Alpine meadows occupy only a small area. The massifs of Tsekuri, Sazamtro and Sakeria reach the subnival belt.

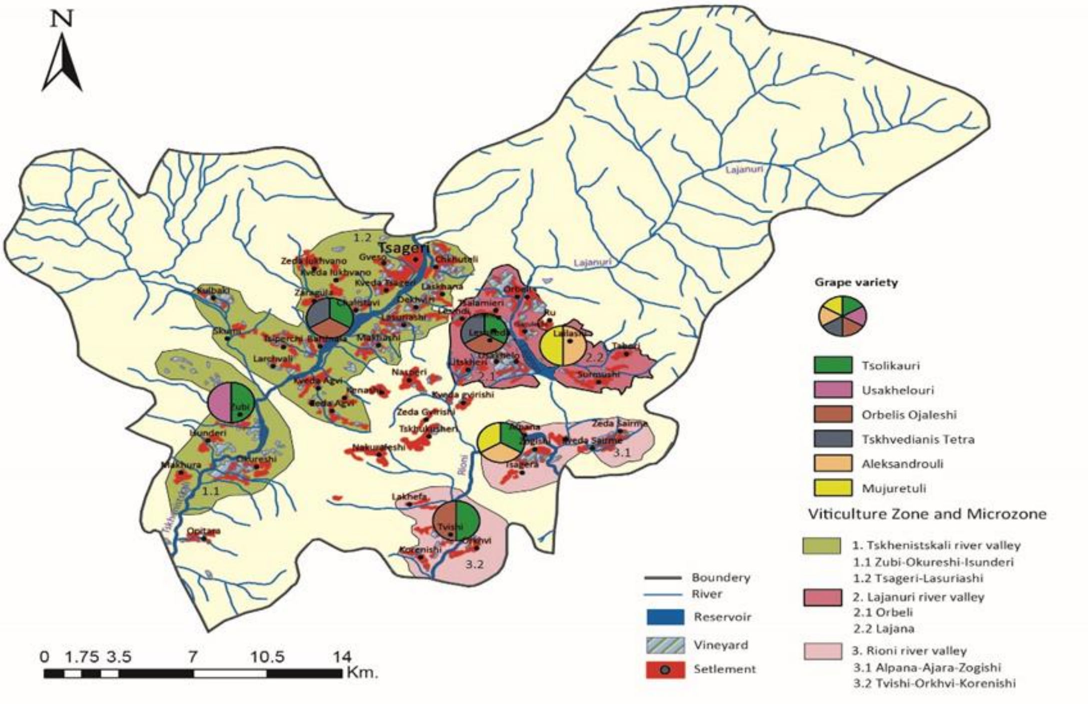

Figure 36. Viticulture Areas of Lechkhumi Region (Tsageri Municipality)

In Tsageri Municipality, the best mineral waters are the healing balneological waters of the Lashichala Resort and the mineral healing water of Dzughuri, which are mainly used for the treatment of diabetic patients. The mineral healing waters of Alpana, Akhalchala, Aghvi-Tsageri, Ladzgveria and Usakhelo are also prominent and are used for preventive arthrological, gastroenterological, gynecological, and neurological treatment. Due to the lack of relevant infrastructure, the potential of mineral water resources is underutilized.

In Tsageri, the hydroelectric power station Lajanurhesi has a capacity of 112.5 MW. The power station provides the energy supply for the region. Small hydroelectric plants can be built at different locations on rivers (Jonouli, Akhalouri).

In the 1980s-1990s, the area of arable land considerably decreased due to the following factors: as a result of the partial land reform, due to the privatization of public land, the infertile land was abandoned. Due to the significant steepness of the relief and erosive and landslide processes, certain arable lands have lost their fertility and are currently used for different functions. In particular, favourable agroclimatic conditions in Lechkhumi have promoted the development of viticulture, horticulture, and cereal farming, which have been carried out by the population since ancient times.

Arable lands occupy 1.5 thousand ha, pastures occupy 30.2 thousand ha, meadows occupy 14.8 thousand ha, and perennial crops occupy 0.3 thousand ha (Government of Georgia, 2023).

Lechkhumi is a homeland of nearly 30 species of vine (Devidze, 1961). The endemic vine species “Usakhelouri”, “Orbelis Ojaleshi”, and “Tskhvedianis Tetri” are represented here. From these unique vine species, known wines are produced. The vineyards mainly grow in the lower zone on the slopes along the Tskhenistskali and Rioni Rivers and their tributaries. The whole area of vineyards is approximately 233 ha. The vine species here are characterized by high sugariness and corresponding acidity and are distinctly different from one another in terms of their fragrance, colour and softness. The following well-known semisweet and table wines are produced: “Usakhelouri”, “Ojaleshi” and “Tvishi” (Table 2.). At different exhibitions, these wines have won several gold and silver medals. According to vertical zoning, industrial vineyards are mainly grown at heights of 400-600 m above sea level. The extreme limit of the vertical distribution is 750-900 m (Fig. 2.)

Table 2. Viticulture Areas of the Lechkhumi Region (Tsageri Municipality)

Viticulture Zone	Microzone	Villages	Grape variety	Type of wine
1. Tskhenistskali river valley	**1_1**. Zubi - Okureshi -Isunderi.	Okureshi,Zubi, Isunderi	Tsolikauri, Usakhelouri	Usakhelouri
	1_2. Tsageri - Lasuriashi	***Right bank of Tskhenistskali river:*** Tsageri,Gveso, Bardnala, Tsiperchi, Larchvali	Tsolikauri, Orbelis Ojaleshi, Tskhvedianis Tetra	Tvishi, Ojaleshi
		Left bank of Tskhenistskali river: Chkhuteli, Laskhana, Dekhviri, Lasuriashi, Makhashi, Kvemo Agvi		
2. Lajanuri river valley	**2_1**. Orbeli	Orbeli, Usakhelo	Orbelis Ojaleshi, Tskhvedianis Tetra, Tsolikauri	Usakhelouri, Tvishi, Ojaleshi
	2_2. Lajana	Lajana, Lailashi	Aleksandrouli, Mujuretuli	Quality red wine
3. Rioni river valley	**3_1**. Alpana - Ajara - Zogishi	Alpana, Ajara, Zogishi, Zeda Sairme, Kveda Sairme	Aleksandrouli, Mujuretuli, Tsolikauri	Quality red wine, Tvishi
	3_1. Tvishi - Orkhvi -Korenishi	Tvishi, Korenishi, Orkhvi	Green Tsolikauri, Orbelis Ojaleshi	Tsolikauri of Korenishi Kvevri, Green Tsolikauri of Orkhvi, Tvishi

We carried out comprehensive studies of landscapes in the territory of the region. Each type of distinguished landscape is estimated in terms of its natural conditions and potential possibility of resource usage. In the territory of Tsageri Municipality, we distinguished 23 types of landscapes. We will consider several of these landscapes as long as they have significant resource potentials (Fig. 3):

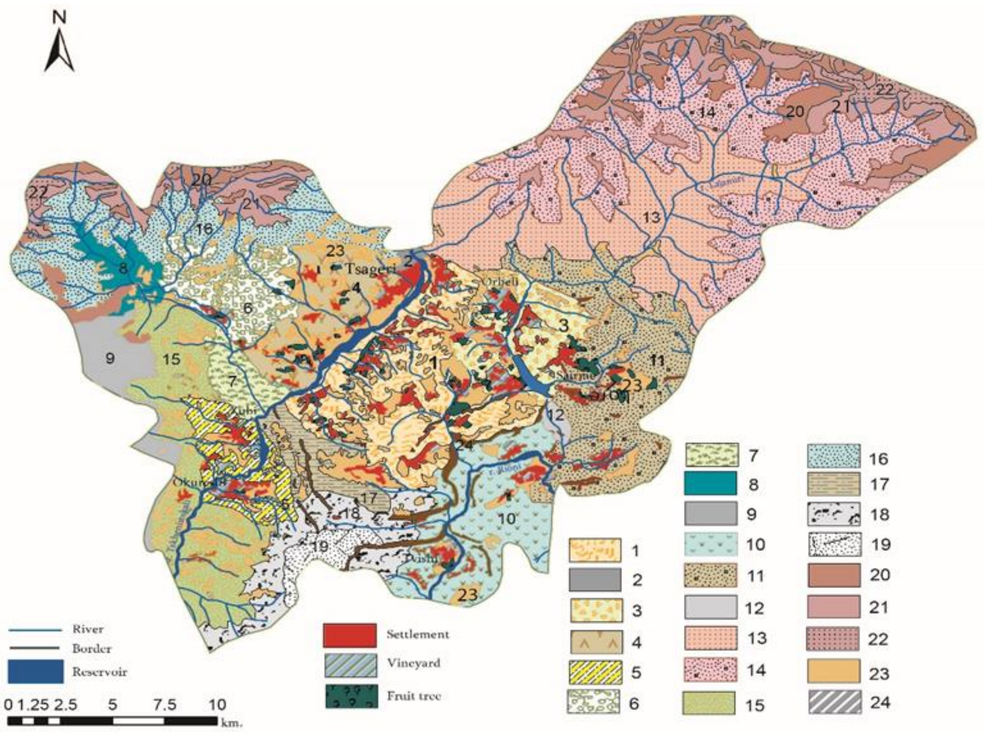

Figure 37. Landscape map of Lechkhumi Region (Tsageri municipality)

The Lechkhumi Landscapes:

1. Lowland erosive depression, with terrace steps, humus carbonate and alluvial soils, with secondary forest shrubs, with landslide processes, rockslides, with river fans, and agro-landscapes (corn fields, vineyards, orchards, and vegetable crops).

The Tsageri erosive depression is located in the western part of the Racha-Lechkhumi Syncline. The depression is presented as a section of the Tskhenistskali Valley between the Muri and Saretskela Cliffs and the basin of the right tributary Kvereshula of the Tskhenistskali River. The bottom of the depression is flat and is located at an altitude of 400-500 meters above sea level. It is distinguished by its typical erosion-accumulation terraces. The Tsageri Depression is composed of Oligocene and Miocene rocks, which are represented by clays, marls, sandstones, etc. Quaternary alluvium, represented by conglomerates and sandstones, is spread on the bottom of the depression. On the right bank of the Tskhenistskali River, the villages of Tsagera, Gveso, Bardnala, Tsiperchi and Larchvali are distinguished for viticulture and wine production. The terrace steps on the left bank of the Tskhenistskali River are flattened and are quite favourable for growing vineyards. On the left bank of Tskhenistskali, the following villages are known for their viticulture: Chkhuteli, Laskhana, Dekhviri, Lasuriashi, Makhashi, and Lower Aghvi. This area is the main viticulture center in the Tskhenistskali Basin, where the naturally sweet wine “Tvishi” is produced. Vineyards located on the right bank of the river produce more wine than those on the left bank. The Tsageri Depression is one of the microzones of Lechkhumi viticulture, where Tsolikauri, Orbelis Ojaleshi and Tskvedianis Tetra, which are promising grape varieties, are grown. Within the landscape, active landslides, erosion processes and rock avalanches are common.

2. Cliffs intruded into Cretaceous limestones, steep slopes, and outcropped surfaces devoid of soil and vegetation cover. The landscape includes Muri Cliff, north of Tsageri near the border of Svaneti, where the River Tskhenistskali passes from Svaneti to Lechkhumi. The Muri Cliff is a narrow cliff section of the Tskhenistskali valley at the northern end of the Tsageri Depression and intrudes into the Upper Cretaceous limestone layers of the Lechkhumi syncline.

3. Lowland erosive calcareous depression, humus-carbonate soils, intense landslides, altered secondary natural vegetation, agricultural beds, fragments of floodplain forest and shrubbery in some places, reservoirs, and swampy areas in some places.

The landscape includes the Orbeli Depression, Orbeli village and the villages of Lesindi, Spatagora, Usakhelo and Gagulechi located to the south. The Orbeli Depression is located 600-700 m above sea level. The terrain is composed of Oligocene and Miocene clays, sandstones, and marls. The Orbeli Depression has fewer terraces than the Tsageri Depression. Erosive and landslide processes are common. The Lailashi Plateau, which is located in the eastern part of the Orbeli Depression, is a large block landslide. In the southern part of the Orbeli Depression, the Lajanuri River has been blocked, and an artificial reservoir has formed. The natural conditions of the landscape are favourable for the development of viticulture. In this regard, the following grape varieties are common here: Ojaleshi of Orbeli, Tetra of Racha, Aligotte, Shardone, Tsitska, Tsolikauri, Tskhvediani Tetra, etc., and the species of Aleksandrouli and Mujuretuli are found in Lajana village. The Orbeli-Lajana viticulture-winery zone, which is located in the Orbeli Depression, is distinguished by its vineyards of the Ojaleshi variety and the production of the dark red wine “Ojaleshi”. The natural landscapes have been heavily transformed and mainly include anthropogenic-cultural landscapes, vineyards, orchards, corn fields, highways, and artificial reservoirs. The primary vegetation cover has greatly changed to secondary sparse forest and forest-shrubbery landscapes.

4. Low-mountain erosive depression, with dark grey forest soils, oak forests, and agricultural fields.

The landscape is spread around Lukhvano village, between the Jonouli River and Tskhenistskali River. It includes the erosive Lukhvano Depression, the basin of the Kvereshula (Lukhvanoskskali) River, and the right tributary of the Tskhenistskali River. It is composed of Oligocene and Miocene rocks. Landslides are common here, and lakes have formed as a result of landslide processes. Here, agricultural landscapes – orchards, corn fields and vineyards – are met.

5. Low-mountain erosive depression, with humus-carbonate soils, scattered pine groves (artificially planted), agricultural fields (mainly vineyards), rockslides, mudflows, and ravines.

The landscape includes the erosional depression of Zubi, which has developed in the outcropped porphyritic rocks formed under the Khvamli and Askhi Massifs. The valley of the Tskhenistskali River widens here. The Zubi Depression is the only way to reach the Askhi Massif from Lechkhumi. The Zubi-Okureshi viticulture-winery zone is located on both sides of the Tskhenistskali River, south of the Saretskela Cliffs. It has been known for producing high-quality wine since ancient times. In the villages of Zubi and Okureshi, from the naturally sweet grapes of the "Usakhelouri" vine species, the dark red semisweet wine Usakhelouri is made, which is known for its excellent quality. The soil and climatic conditions are favourable for the development of fruit growing. Among natural processes, landslides and rock avalanches are widespread here.

6. Low mountains with brown forest soils, with oak, and with Colkhian broad-leaved forest.

The landscape is spread in the upper part of the valley of the Jonouli River (the right tributary of the Tskhenistskali River) near the Akhalchala Resort. It is represented as a relief form of troughs, cirques, moraines, and large erratic boulders formed by old glaciers. The slopes of the Jonouly Valley are covered with mixed fir-spruce-beech forests and beech forests. Resort Akhalchala is located 1900 m above sea level, where mineral springs containing carbonic acid and iron are present.

7. Low-mountain flat-bottomed valley, with alluvial boulders, humus-carbonate and alluvial soils, broad-leaved forest with evergreen undergrowth, intensive landslides, terraced right and steep, terraced left slopes.

The landscape is spread across the valley of the Jonouli River above the Akhalchala Resort in the Akhalouri River valley, which collects water from the slopes of high mountain massifs of Tsekuri, Sazamtro, and Tsalmagi of the Egrisi Ridge. Glacial troughs are observed at a height of 2300 m. The lower parts of the slopes are covered with erratic boulders. This proves that in the past, the glaciers descended even further.

8. A low-mountain flat-bottomed valley with alluvial boulders, brown forest and dark gray podzolic soils, beech forest, spruce, and fir-beech forest with recreational resources.

The landscape is spread in the middle reaches of the Jonouli River (the right tributary of the Tskhenistskali River). This part of the valley is characterized by a wide and flat bottom that is significantly inclined in the direction of the river. Here, above the village of Kulbaki, limestone boulders are scattered and were brought down by a powerful landslide that moved from the northern edge of the Askhi Massif. The southern part of the Jonouli Valley is bounded by a slope of the limestone Askhi Massif, and the karst plateau is covered with karst funnels.

9. Steep slopes of the limestone massif, devoid of soil and vegetation. The landscape is presented as the eastern part of the Askhi Massif, the peripheral part of the Plateaus of Maidani and Sachikvano. In the north and east, it is bounded by a high limestone cliff, which stretches like a wall along the right side of the upper basin of the Jonouli River and the right bank of the Tskenistskali River. The cliff is extremely high. Its crest is several hundred meters above the base. The plateaus and ridges are dotted with karst funnels, karst wells and fissures.

10. low mountain karst limestone, valleys with steep and rocky slopes, oak forest, and oak-pine forest. The landscape presents the valley of the Rioni River (within Lechkhumi), which has formed in Cretaceous and Tertiary sedimentary layers. The narrowest and deepest part of the valley is the Cliff of Tvishi, which intruded into the Cretaceous limestones of the southern part of the Racha-Lechkhumi syncline. In its walls, at a great height above the level of the Rioni River, there are karst caves – the Verdzistava Cave on the right side and the Orkhvi Cave – on the left side. It is spread on the right bank of the Rioni Valley up to an altitude of approximately 600-700 m and is characterized by moderately cold, short winters and hot long summers. The annual amount of precipitation is 1000-1300 mm. Due to favourable climatic conditions, viticulture and fruit growing have developed since ancient times. It is the Usakhelouri-Tvishi viticulture microzone, where two types of semisweet wines, "Tvishi" and "Usakhelouri", are produced. On the right bank of the Rioni River, the landscape includes the villages of Alpana and Tvishi, while on the left side of the Rioni River, the villages of Orkhvi, Zogishi and Tsagera are located.

11. Low-mountain erosive depression, built with sands, clays, limestones, brown forest soils, oaks, oak-hornbeam forests, secondary meadows, and agrolandscapes.

The landscape is spread across the villages of Lailashi, Gagulechi, Tabori and Surmushi. Vineyards, fruit orchards and cereal crops (maize) are grown in the territory. The flora consists of oak and oak-hornbeam forests. Here, landslide phenomena are widely observed, among which the "Lailashi Landslide" is well known.

12. Erosive depressions with steep slopes, oak and pine forests, strongly transformed by anthropogenic factors, and cliffs intruded into Cretaceous limestone sediments.

The landscape covers the areas of the lower and upper sairme villages and includes the valley of the Lajanuri River in the southern region of the Lajanuri Reservoir at the junction of the Lajanuri and Rioni Rivers near the village of Alpana. The Lajanuri River is one of the largest right tributaries of the Rioni River within Lechkhumi. Within the boundaries of the landscape, its lower reaches have been formed in Cretaceous and Tertiary suites. The valley of Lajanuri is erosive along its entire length. There are deep eroded gorges with steep slopes. Steep rocky slopes undergo intense fragmentation, and rock avalanches occur there. The bed of the Lajanuri River has been blocked by large limestone boulders. Rock avalanches are generated due to the cracking processes occurring in limestones and the great inclination of slopes. The Lajanuri basin contains deciduous forest at up to 2000-2100 m; its lower belt is covered with oak, hornbeam and chestnut forests, while beech trees are observed in the upper belt. Coniferous forests are not present here. The landscape includes the Sairme Plateau, the absolute height of which reaches 800-900 m. Its relative height from the Rioni River is 400-500 m. The plateau is built of Cretaceous limestones and marls; karst funnels and wells have developed on the surface. The Rioni River follows the tectonic fault line in the Sairme area and creates the so-called "Narrow Pass of Sairme" in the Cretaceous and Eocene limestones. Similarly, in the Udabno area, in the marl limestones, a pyramidal, truncated cone and pole-shaped landslide relief, called "Sairme Pillars", has formed, which looks like a stone forest as a result of erosion. It is a unique geomorphological phenomenon in the form of landslides and erosion. Landslides are common here, and the "Sairme Landslide" is quite prominent.

Within the landscape, humus-carbonate soils, which are commonly used for fruit orchards and maize, are common, resulting in high yields under favourable terrain conditions. Vineyards are also met in some places.

13. Middle mountains with brown forest soils, beech and hornbeam-beech forests.

The landscape is spread on the right and left banks in the middle reaches of the Lajanuri River. Within the landscape, the slopes of the Lajanuri Valley are devoid of terraces and have a wide bottom full of cobblestones. The landslides are mainly related to diluvium deposits. Mudflows are common during rains. The landscape is characterized by moderately warm summers and cool winters. Among the branches of agriculture, land farming and animal husbandry are mainly developed here. The forests are rich in mushrooms and fruit (crab apple, wild pear, dog rose, cornelian cherry, etc.).

14. Middle mountains with extremely steep slopes, dark grey forest soil, beech forests.

The landscape is spread in the valley of the Lajanuri head river. Here, mainly dark grey forest soil is present; a mix of beech, lime, elm and maple trees is observed at some places.

15. Middle mountains with brown forest soils, beech-hornbeam forests, pine forests (artificially planted), hornbeam forests and pine-hornbeam forests

The landscape covers the extreme western part of Lechkhumi and is adjacent to the limestone massif of Askhi. The dark grey forest soil is covered with beech-hornbeam, hornbeam and pine-beech forests. Man-made pine wood can also be found in the villages of Isunderi, Makhura, Chkumi and Kulbaki.

16. Middle mountains with karst relief, beech-dark coniferous and dark coniferous tree forests, and evergreen undergrowth. The landscape is spread in the extreme northwestern part of Lechkhumi, in the valley of the Jonouli River, and in the area of the head river, including the eastern part of the Egrisi Ridge. It is composed of a Mid-Jurassic porphyritic suite. The landscape is mainly beech-dark coniferous forests, dark coniferous forests (spruce and fir trees), and evergreen undergrowth (holly, cherry laurel, box tree, and Butcher's broom).

17. Middle mountains, built with limestones, with karst relief, humus-carbonate soils with beech and hornbeam-beech forests, with evergreen and deciduous undergrowth.

The landscape is spread in the northern part of the limestone massif of Khvamli, between the villages of Okureshi and Nakuraleshi. The Kvamli Massif is composed of monocline layers inclined toward the north. It presents a double cuesta. Within the landscape, the lower northern cuesta, i.e., the Upper Cretaceous cuesta, unlike the southern cuesta, is relatively less karstic. It is 450 meters lower than the southern cuesta. The northern part of the Khvamli Massif is covered with beech and hornbeam-beach forests, although the main vegetation cover there is leafy shrubbery.

18. The middle mountains are composed of Cretaceous limestone with karst reliefs: karst funnels, cliffs, caves, humus-carbonate soils, spruce-fir forests, and dark coniferous and beech-dark coniferous forests. The landscape is located on the Khvamli Massif between the villages of Okureshi and Korenishi. On the Khvamli Massif at 300-400 m above sea level, up to the upper boundary of the forest zone, dark gray soil is present (up to 1000-1200 m), and further (1400-2000 m), dark gray podzolic and podzolic forest soil is spread under the beech-dark coniferous and coniferous forests.

19. Subalpine meadow shrubland on a limestone massif with mountain meadow soil. The landscape is met by the Khvamli Massif. Here, mainly mountain meadow soil is spread. In the former shrubbery

and forest areas, which were later covered with meadow, secondary podzolic soils were present. The plants are used as natural hay meadows and pasture fields, while shrubbery prevents soil erosion.

20. High-mountain subalpine meadow-shrubbery on mountain meadow soils.

The landscape is located on the ridges of Egrisi and Lechkhumi. Under harsh weather conditions, mountain meadow soils are dominant on slopes. Subalpine tall herbaceous vegetation consists mainly of umbelliferous and complex flowering plants. Reach pasture fields are located in the upper part of the Lajanuri Valley, where subalpine meadows full of various high grasses are spread.

21. High-mountain alpine meadow-shrubbery on mountain meadow and peaty soils.

The landscape is spread on the Ridges of Egrisi and Lechkhumi. The alpine meadow territory is characterized by flattened relief, a high mountain climate and dense grass cover and is used as pasture fields in summer. The cover consisting of various grasses creates a dense meadow in the upper horizon of the soil that prevents the denudation of the hay meadows and pasture fields.

22. High-mountain subnival landscape with cliff vegetation and primitive mountain meadow soils (the Egrisi and Lechkhumi Ridges).

The landscape includes the highest peaks and summits of Egrisi and Lechkhumi Ridges. Here, mechanical erosion intensely occurs. The relief is characterized by a rocky surface. Washed-off soils and certain representatives of rock vegetation are observed in some areas of primitive mountain meadows.

23. After they were cut, secondary meadows at former forests met on the Egrisi and Lechkhumi Ridges, on the Askhi and Khvamli Massifs, and in former forests.

24. The reservoir.

Discussions

The goals of this research are to reveal the transformation of the environment of the Lechkhumi Region, which is affected by both natural and anthropogenic factors; to assess natural resources; to identify separate natural-territorial complexes (landscapes) as landscape types; and to create a geoinformational database. For that purpose, we had a scientific field examination in Tsageri Municipality (in 2022). Observations were made on the landslide and mudflow areas and the landscapes that had changed as a result of their activities. The materials obtained in the field immensely helped us to reveal the natural and anthropogenic landscapes of the region and define their boundaries. We distinguished natural and anthropogenic landscapes and created a geoinformation system of the landscapes of Tsageri Municipality. We also created a database on the basis of which we constructed a large-scale (1:50000) landscape map of Tsageri. During the study of the natural landscapes of the Lechkhumi Region, the potential of the landscapes was taken into account. It included identifying the set of resources that might be used for the purpose of protection and improvement of living conditions, economic growth, and complex development at present or in the future. In the case of landscapes, this means taking into account the set of properties on the basis of which and according to which a landscape can perform this or that (socioeconomic, ecological) function. It adequately reflects the degree to which a landscape participates in satisfying the diverse needs of society.

Conclusion

As a result of comprehensive studies of Lechkhumi by GIS technology, a large-scale landscape map (1:50 000) of the Lechkhumi (Tsageri Municipality) region was constructed. We distinguished 23 low-rank landscape entities—landscape types. The distinguished landscapes provide a clear image of the diversity and potential of the natural resources of the study region. It is noteworthy that most (67. 6%) of the landscapes is made of mountain landscapes. Certain parts of the distinguished landscapes are useful for agricultural activities; some parts can be used as forest resources, while others can be used for tourism and recreation. Most of the agricultural landscapes are located in considerably lower hypsometric zones (400-800 m) in the Tsageri Depression on either side of the Tshenistskalii River. The landscapes (#1, #3, #4, #5, #10, and #11) here play a special role in the development of viticulture and for fruit growing in Lechkhumi. The landscapes (#10,12) on the alluvial soils along the Rioni River are the most useful for fruit and vegetable growth and cereal farming. The landscapes in the high-mountainous subalpine (#19, 20) and alpine (#21) zones are the best pastures and meadows for mowing and are necessary for cattle breeding, with a total area of 24 000 ha. The pastures and hay meadows of Lechkhumi have great potential. These findings can aid in the development of livestock breeding in this region. The forest landscapes occupy the dead territory of Lechkhumi. They have high value in industry as well as in preserving ecology and biodiversity. Here, the landscapes of river-side forests (#2), low mountain forests (#9, #10, #11 landscapes) and middle mountain forests (#13, #14, #15, #16, #17, #18) are met. Among them, virgin forests occupy a considerable area. Great touristic and recreational potential has been unlocked in the landscapes (#6, # 13) around the balneoclimatic (Lashichala, Akhalhala) and balneological (Dzughuri) resorts, as well as in resort places (Kulbaki, Tabori, Surmushi) and other significant tourism and recreation objects.

Among the landscapes of Lechkhumi in the Tsageri, Orbeli and Zubi Depressions, the boundary landscapes of low mountains, middle-mountainous forests and high-mountainous meadows have changed. In many places, secondary meadows can be observed in former forests. The natural landscapes that existed in the past here include varieties of anthropogenic and natural-anthropogenic landscapes.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

E.S. led the writing of the article, distinguished the separate landscapes of the Lechkhumi Region as landscape types and compiled a large-scale landscape map with a diagram, Map: Viticulture Areas of Lechkhumi Region (Tsageri Municipality) and a table: Agro-climate characteristics of Lechkhumi Region (Tsageri Municipality); Viticulture Areas of Lechkhumi Region (Tsageri Municipality). T. C. compiled a geoinformational database of Lechkhumi landscapes in GIS and provided an electronic version of the landscape map of the Lechkhumi Region (Tsageri Municipality) and a map of the Viticulture Areas of the Lechkhumi Region (Tsageri Municipality).

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Linguistic-Historical Study of the Toponym Ureki

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Abstract

In this paper, we present a linguistic analysis of a toponym using a historical comparative method. We provide our interpretation of the toponym "Ureki" based on historical data. People have been interested in toponyms—place names and their origins—since ancient times. The majority of geographical objects did not have official names. People named them according to their natural characteristics, which played a significant role in their daily activities and livelihoods. Different categories of scholars, such as linguists, historians, geographers, ethnographers, and others, study toponyms of interest. The toponymy of any country reflects soil, water, plants, animals, birds, or any living or nonliving nature, organic or inorganic natural resources, or traces of the inhabitants of that area. A toponym is a geographical name of a place, a word taken from the linguistic material of the collective that created it, and usually contains information about the named object. The toponym is passed down from generation to generation, from era to era, and continues for thousands of years. In this interdisciplinary research, we aim to advance academic studies further by providing an etymological analysis of a toponym. In the article, we analyse a specific toponym, "Ureki," located in the northeastern part of Batumi, on the Black Sea coast, within the Ozurgeti municipality

Keywords: toponym, linguistics, etymology, ethno-linguistics

Introduction

It is known that the study of toponymy is one of the important opportunities to understand the historical life of a certain territory whenever people have lived there. Researchers from a variety of scientific fields (linguists, historians, geographers, ethnographers, etc.) will be interested in studying toponyms. First, in interdisciplinary studies in the last century, the academician Iv. Javakhishvili added that "...the researcher of toponymy should first of all take into account the specific circumstances of the location and property of this or that place and be surprised..." (Javakhishvili, 1950). Toponyms are not simply labels that identify certain points of space but rather portals of social change, history, and the use and perception of the environment; as such, they contain facts, reflect hidden landscapes, and have political power and significance (Reszegi, 2020). Toponymy is a branch of onomastics that studies the meaning and structure of geographical names (village, city, river, etc.) and their geographical distribution. Toponymy refers to a geographical object in objective reality. Most of the time, the reason for choosing this or that toponym specifies what it means (Akhvlediani, 2009).

Methods and Materials

Starting from the objectives of the research, we will first establish a connection with the given toponym and its significance in the context of scientific literature and languages or dialects. Critically, we will analyse existing scientific perspectives. In the process of searching, we will generalise the most specific and concrete knowledge with scientific literature data. Through scientifically grounded research with the opportunity for interpretation, we aim to minimise errors and extract relevant findings. While working on the article, we will focus on historical comparisons, descriptions, and analytical methods. The name "Kolcheti" was first mentioned by the ancient Greek historian Hesiod and the poet Pindar and later by the Greek geographer Strabo in the 8th century BC.

It is noteworthy that the first mention of Kolchis closely aligns with the historical context of the kingdom's foundation, specifically with the reign of King Aeëtes. Ancient scholars often refer to it as "Aia" in connection with the realm of Queen Medea. It is essential to note that the first appellation of Kolchis corresponds accurately to the official name of the state's ruler: "Kulcha || Kolchi." The old name "Kolcha" is derived from "Kulcha," and this toponym has its origins in this region. According to the wisdom of the scholars, the first name of a state should be established when the name "Kolchidi" did not yet exist, and at that time, someone else might have referred to this area with different names (such as "Gaia," "Aia": land, country).

Results

A toponym is a "living heritage" that preserves traces of ancient local culture. In addition to location information, it contains a whole range of identifying information. With the development of critical studies of place names, it has become clear that they can gain knowledge not only about natural factors, such as ethnopedology (the natural science of soils and landscapes) and plant coverage but also about anthropological factors. A place name can also be an indicator of historical situations—what a particular place was like in the past.

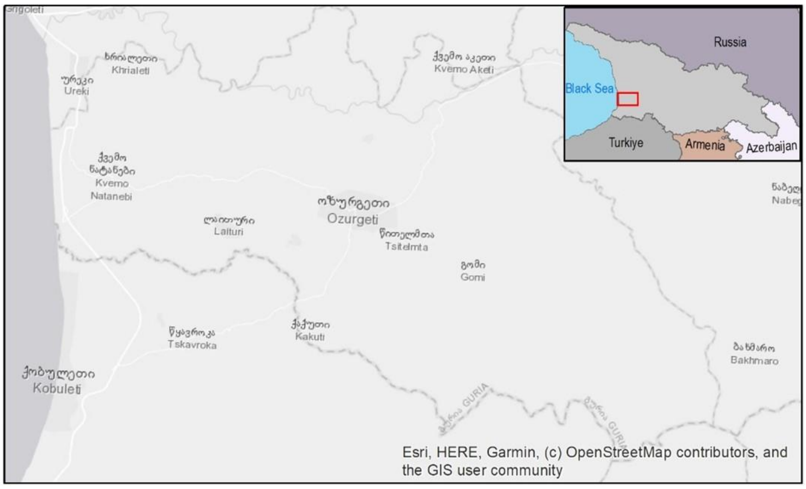

Figure 38. Study area-Ureki

Ureki is a township and sea resort in Ozurgeti municipality (Fig. 1). It is located on the coast of the Black Sea, 4 m above sea level, and 24 km from Ozurgeti. It is bordered from the north and south by the confluences of the Sefa and Supsi Rivers, and from the east, it is surrounded by Tsvermaghala Mountain.

Figure 39. Artefact from study area

There is an opinion that Urek means a wooded, inaccessible place where hunters have difficulty hunting. The microtoponym in mountainous Samegrelo, "Na-ek-ura," confirms the definition of Urek as a deep, impassable place. Archaeological investigations confirm that the coastal areas of Urek, i.e., "Nazurgebi," have been settlements since ancient times. It is known that bronze objects were found at different times at the mouth of the Supsi River, which is named after the treasure of Urek. There is a difference of opinion in dating: BC, AD XVIII, BC, XVII century (Koridze, 1965; Ramishvili, 1974), the first half of the II millennium BC (O. Japaridze), BC XV, BC, XIV century (T. Mikeladze). The hoarding of Middle Bronze Age weapons, which contained direct prototypes of Colchi axes, is notable. tools with signs of early bronze axes (axes with slats, axes, etc.), early hoes, etc. Different types of Colchian axes were also found in Urek and BC (XVI-XIV centuries). (Part of it is preserved in the St. Petersburg Museum of Ethnography and Anthropology; the main part is kept in the State Museum of Georgia named after S. Janashia; and a small part is kept in the Ozurgeti Historical Museum.) The hoard is important in terms of the origin and typological evolution of the Kolkhir bronze period (Tent, 2015).

In 1942, items from the Black Sea coast near Diuni were found, suggesting the presence of cultural relics of the same age as those of the 3rd and 4th centuries. These finds include pottery, animal bone fragments, and jewellery (Fig. 2). The Ureki are characterised by a remarkable archaeological and cultural layer that dates to the end of the 3rd century and the beginning of the 4th century. The main discoveries, except for silver hoard and Byzantine coins from the same time period, are related to the late antique style. The cultural layer found on the Black Sea coast in 1948 included various types of early mediaeval materials, including Georgian, Colchian, polychrome, and Hellenistic ceramic items. In 1948, silver hoards with the following characteristics were discovered in Ureki: a silver torque, a necklace, a brooch, two hairpins, and other items. That same year, the same museum received early mediaeval Colchian jewellery and a rare necklace. There is also evidence that early mediaeval Colchian rings and beads were discovered near Ureki.

In 1944, the discovery of magnetite began. German prisoners of war living in the Urek region mined magnetite for the Rostavi metallurgical complex. Among these German prisoners was a certain Eriks Anders, a scientist. He discovered that Urek's magnetite had a beneficial effect on human health, and this knowledge led to the liberation of the local population from certain diseases. A magnetic field of natural origin, an important geological feature, can be observed on the Ureki Peninsula.

In 1946, he found himself in Urek, BC. Treasures of the VIII-VII centuries (bronze Kolkhur axe, satevari, blade, segmented weapon, wormwood and absinthe, zod, and clay tolcha), which are also preserved in the State Museum of Georgia named after S. Janashia in 1949, 50 km long, were built from Kobuleti to Poti in the Guria maritime strip. Long Bichvinti pine grove (Ushveridze, 1986). It has been established and is no longer in dispute that Ureki ceramics contain an excess amount of magnetite, which indicates their local production. The existence of cultural layers from ancient times can also be observed. The intensity of the settlement can be explained by the presence of excess magnetite in the coastal sands.

There is an opinion that Urek means a wooded, inaccessible place where hunters have difficulty hunting. A microtoponym in mountainous Samegrelo, "Na-ek-ura," confirms the definition of Urek as a deep, impassable place. Archaeological investigations confirm that the Ureki coastline, or the "backbone" region, has been inhabited since ancient times. In one of his articles, Chikobava recognised it as a place name in Georgian science. St. Senaki (in the last century, a toponym was recorded near the city of Tskhakaya: O-reke-sh-i-, Sarekisi" (Chikobava, 1942) in the Maghrul-Georgian dictionary of P. Charaya].

The name Ureki, "Sareki" (gathering place), was a general name in the past, and it was called "Nadirtmosarek" (a gathering place for animals). Therefore, for example, the toponym of the former Makhinjauri village council (in the territory of present-day Batumi) has been confirmed: "Sarekelai" (the information is kept in the personal archive of Az. Akhvlediani), which probably meant hunting. The name "Sareki" for hunters is also located near Sachkheri (Gogatishvili, 1968), and this name seems to refer to that place. It is known that until the second half of the last century, there were impassable dense forests around Batumi, in which there were always many games. Here, in these forests, hunting was not so rare, the organiser of which, of course, would be some nobleman, in whose hunting estate there would be plenty of baziern, marekni, and others. The duty of the latter (Marekni) was to call the game in a certain area. The best hunting grounds were the places where Marekni rarely visited. The current Urek was considered such a place then. The same toponym is confirmed by the names of the Guria villages. Sarekela: Pasture Khulo, Mr. S., in the village of Furtio. "Sarekelai" is a rural district in Kortok (Shuakhevi mn.). cf. :sa - mkrev - el - a" - forest, village of Ghurta (Shuaakh, mn.). "Sa-re - ki" is a forest and a rocky place in Kidzinidze (a municipality) (Kamadadze, 1992). Sarekela, derg (dish), is a dish in Adjara in which butter is made from dairy products [11]. In this toponym, the root "rek" is isolated. It is not foreign to Georgian languages. Megr. Rekua: Rekva means ringing (Charaya, 1997), and "u" is prefixed in the toponym. In Rachuli, ringing a nut means hitting a nut with a stick (Kobakhidze, 1987). "Sareki" is found in Kizikur with two meanings: 1. Sarek: a latan tied to the hands in front of the wheels of the cart so that the buffaloes tied to the head of the cart can hold the cart while going uphill. At the same time, the cart's eye does not fall on Gava's legs, and 2. Sarek is a place from which those called to hunt at this time called the game Sakhundari, that is, Samkvdev (N. Saba) (Menteshashvili, 1943). In Tushur, Sarekelakh is Sarekela, which is reflected in the stone of the mill by Khvimir grains (Khubutia, 1969).

In Ureki, located in the Ozurgeti municipality, the term 'ureki mareki' is used. 'Ureki mareki' refers to the distribution of land, specifically the allocation of land to beneficiaries through the process of land redistribution. In Ureki, the local government is aware of this term. It is worth noting that 'ureki mareki' involves the regulated allocation of land to individuals, and discussions about such regulations have been heard from representatives of the Guria population. However, it is emphasised that in Ureki, a place characterised by such distinct land, the process of land redistribution may not be feasible, except in cases related to 'ureki mareki' (Dzneladze, 2011). 'Sareki' is the designated area where the allocation of land can take place, and where it cannot occur, it is Ureki.

The wisdom of local residents regarding their knowledge of the environment or other types of information is crucial to the development of future generations (see the article "The toponym 'Batumi – Etymology'", where it is discussed how the name of a lost plant was preserved in folk etymology- (Akhvlediani, 2023), as it prevents the loss of cultural knowledge that contributes to the cultural heritage of society. In the course of generations, the neglect of unique earth wisdom is regrettable, as it can lead to the disappearance of cultural knowledge. In the progression of societies, the neglect of indigenous knowledge can result in ignorance of the intricacies of the land and the principles of sustainable development, as seen through the eyes of the Earth's maps and environmental planning.

Conclusion

Periodically, many things may disappear, change the relief landscape, or become extinct with the animals, birds, plants, or human tribes living there, but the geographical names of the places can tell us a lot about the earlier world. Regarding toponyms, two main questions are asked: "Why was it named?" and How was it named?" The answer to the first question lies in the extralinguistic field and concerns the problems of motivation. The answer to the second question belongs to the linguistic field and provides for the determination of the linguistic means of nomination. According to our observations, we can consider the landscape and geographical list of the place "Ureki."

Competing interests

The authors declare that they have no competing interests.

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Phytotoponyms- Chronicler of Local Flora

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Abstract

Toponymy is a distinctive field of language vocabulary. Taking into account the conclusions obtained on the basis of its scientific study is the best way to fully understand the nature, landscape, historical past, migration of ethnic groups of a particular country, since the adventures of the country and the peculiarities of its nature are most succinctly conveyed by toponyms. In Kartvelology there are a number of valuable scientific works in the field of toponymy. We consider it necessary to include toponymy achievements in educational programs of general schools. It will be useful in many ways to make it interesting.

Keywords: Phytotoponyms, flora, Dzelkva, Georgia

Introduction

Students are particularly interested in place names derived from plant names. They know such toponyms well, list them with pleasure, ask questions, express their own opinions, and turn to folk etymologies. Properly selected, diverse material for phytotoponym analysis provides students with interesting information and knowledge in a number of areas (linguistics, botany, ecology, geography, traditional life, beliefs, etc.). The motivation behind the names of these phytotoponyms, along with the relationship between the designated geographical objects, can transform students' perception of their native environment, prompt them to consider the unfavourable state of ecology, and guide them towards necessary conclusions. We introduced the students to appropriate plants and their unique characteristics. This will facilitate a better understanding of various geographical objects and their respective locations. When discussing issues and presenting a proper presentation, it is necessary for students to get acquainted with certain terms, such as toponym, microtoponym, toponymy, phytotoponymy, name motivation, relict, endemic, "Red Book," and others. In this case, we are talking about phytotoponymy in detail, and we will give appropriate examples.

Phytotoponyms are toponyms that arose on the basis of plant names. The names of plants form the basis of phytotoponymy, which, in turn, represent a rich, diverse, and multi-layered area of the language's vocabulary. The use of plant names to designate territories dates back to ancient times. Phytotoponyms are the result of deep thinking, observation, and many years of experience with a particular ethnic group. The analysis of phytotoponyms determines numerous factors, such as the flora of a particular geographical area (even in the distant past), the economic and cultural existence of the population, religious destinations, the boundaries of ancient settlements, migrations, and internal migrations, among others. We draw attention to the fact that the Georgian language reveals rich and diverse possibilities in the linguistic design of phytotoponyms, which we make visible to students by giving relevant examples. This time, we will take the following presentation material (phytotoponyms) as an example: Dzelkviani is the administrative unit of Kutaisi municipality since 2014; Dzelkviana is one of the districts of Ofshkvit village, Tskaltubo municipality; Dzelkvebi is a plain place in the village of Zeda Kldeeti, Zestafoni Municipality; Dzelkva is a sowing place in Lanchkhuti municipality; and Dzelkvavenakhi is a vineyard in the village of Lower Sazano, Zestafoni Municipality.

When analysing phytotoponyms, it is necessary to discuss more than one issue in a certain order.

I. Linguistic analysis

First, we perform a linguistic analysis of the given material – phytotoponyms.

Dzelkva - simple noun, nominative case, singular; Dzelkv-eb-i - simple noun, nominative case, plural; Dzelkv-ian-a - derived name, dzelkv- stem, ian-a – complex suffix; Dzelkvavenakhi (< dzelkva+venakhi) - a complex name.

The stem of these names is divided into dzelkv-/dzelkva. This is the name of one of the trees (Georgian ძელქვა [Dzelkva], English "Caucasian elm" or "Caucasian zelkova"). Based on this, the motivation of the name of the given geographical objects is determined - the presence of the mentioned tree in these places.

Here, we will draw the students' attention to the unfortunate fact that, with one exception, there are no longer any Caucasian zelkova trees on the mentioned geographical objects.

II. Getting to know this plant

We try to show and introduce students to this tree from different angles: botanical description, distribution, use, origin of its international nomenclature name, ecology, etymology of the name, etc. For this, we actively use appropriate visual material.

"Zelkova is agenus of six species of deciduous trees in the elm family Ulmaceae, native to southern Europe, and southwest and eastern Asia. They vary in size from shrubs (Z. sicula) to large trees up to 35 m (115 ft) tall (Z. carpinifolia)".

Common species in Georgia is Zelkova carpinifolia (Pall.) K. Koch. It is a tree up to 25-30 m tall with grey-green thick dense bark, growing in moist forests, coastal plains and lower mountain belt. In Georgia, it is common in Samegrelo, Imereti, Guria and Kakheti (Babaneuri nature reserve). It is a relic of the Tertiary period and is included in the "Red Book" of Georgia (Gagnidze et al., 1975).

III. Distinctive properties and use of the plant

Caucasian zelkova (Zelkova carpinifolia) is a fast-growing, rare and beautiful ornamental tree. In many countries it can be found in parks and squares. Zelkova trees live for centuries.

Caucasian zelkova has hard, elastic, highly durable wood, which is superior to oak wood in terms of technical properties. It is a valuable building material, it withstands moisture. In Western Georgia, houses and wooden churches, as well as fences, were built from it. The wood was also used in carpentry and furniture production, they also made work tools.

IV.The name „Zelkova"in the International Botanical Nomenclature

The establishment of the name of Georgian origin (Zelkova) in the international botanical nomenclature has an interesting history: In 1771, a member of the Russian Academy of Sciences, I.A. Güldenstedt traveled to the Caucasus on a special assignment. In Georgia, near the city of Kutaisi, he noticed an unknown tree and called it Rhamnus ulmoides. Güldenstedt wrote in his diary: "...The bumps forced me to have a rest day on August 23rd. Here I saw a tree which I had never seen before, and which is here called Zelkva... I described it under the name of Rhamnus ulmoides." (Güldenstedt, 1962).

In 1788 P. Pallas described this plant and called it Rhamnus carpinifolia, in 1819 M. Biberstein called it Planera Richardi. In 1841, E. Spach named the genus Zelkova after the Georgian "Dzelkva", and named the species Zelkova crenata. In1892 L. Dippel called this species Zelkova carpirifolia. Today this species is presented in the international nomenclature of plants as such Zelkova carpinifolia (Pall.) C. Koch.

Here we provide students with information about who Johann Anton Güldenstedt was and for what purpose he traveled to the Caucasus.

Anton Güldenstedt (1745 - 1781) was a naturalist, a doctor of medicine, a true member of the Russian Academy of Sciences. He participated in the expedition of the Russian Academy of Sciences of 1768-1774, which served the subjects of the conquest of Russia. His two-volume work contains a faithful account of his journey.

V. Georgian scientists about Caucasian zelkova („Dzelkva")

This plant, common in the wild nature of Georgia, has always attracted the attention of Georgian scientists. They recorded the places where this tree grew, described it, wrote interesting information about the tree, for example: „ ...According to the legend recorded in Tsaisi, the Genoese, who discovered hot springs, erected three Zelkova in this place in honor of this, two of which are still alive today." (Chitaya, 2001).

„Zelkova is one of the oldest plants on our planet... This means that it was widespread in the past geological era. There must have been its large forests in the Caucasus as well… The fact that it was widespread in Georgia, apart from its fragmented area, is also confirmed by the fact that the remains of stone slabs from Shirak and Meskheti (Kisatibi fossils) are often found... Around Lanchkhuti there is a shrubbery, in Adjara there is no more of it, in Imereti - Ajametsky reserve we have more or less a good grove. Even more of them have been preserved in yards, under vineyard fences, in cemeteries... In the Terzholiy district, in the area of Ishkhneli, there is a unique stone pillar, the thickness of which reaches several meters... In the forest of Babaneuri there are several very large... Zelkova tree. One of them, a good man from Babaneur, Dimitri Gaurashvili, called this tree the head of the forest; He tried to save the tree. On his initiative, Babaneuri Dzelkviani was declared a nature reserve since 1965" (Ketskhoveli, 1980).

VI. Zelkova in Georgian beliefs

We are talking about the tree cult in Georgian folk beliefs. We note here that along with other iconic trees (oak, lime...) in Georgia, Dzelkova was also considered a sacred tree and was worshiped. We introduce the students to appropriate ethnographic material, including the ones we obtained during field work.

VII. Why is this tree called "Dzelkva"?

The dendronym ძელქვა (Zelkva) is a complex word and consists of 2 nouns: ძელი (dzeli) + ქვა (kva). „The name Zelkova derives from the native name of Z. carpinifolia in the Georgian language – one of the Kartvelian languages spoken in theCaucasus, as shown by the Georgian name, ძელქვა (dzelkva), from ძელი (dzeli) meaning 'bar' or 'pillar', and ქვა (kva) meaning 'rock', 'stone' The tree was often used for making rock-hard and durable bars for building and furniture ".

Thus, the semantics of this name is related to the strength and durability of the tree's wood.

VIII. The meaning of the name „Dzelkva"in Georgian. As a result of the research, it turns out that „Dzelkva"in Georgian is not only the name of Zelkova carpirifolia, but it refers to other trees as well: In dialects of the Georgian language, it can refer to Celtis caucasica (Kartl.) or Acer platanoides (Mtiul., Rach.). „Dzelkva"is confirmed in the old Georgian texts of the Bible, in the new Georgian translations of which we have Plane tree (rarely, maple, chestnut, elm, ash tree, white poplar) as equivalent to Zelkova. In the old Georgian dictionaries (XVII-XIX centuries), Plane tree and Zelkova are also presented as synonyms. (Compare also: „Of the valuable trees that grew in the valleys, we can point to... Dzelkva or planertree, which is already rare and superior in quality to all other local tree species" (CGS, 1866).

R. Eristavi (19th centuary) made a breakthrough in the definition of Zelkova and he wrote the name of this tree in his dictionary with international nomenclature (Eristavi, 1884).

Thus, "Dzelkva" in Georgian is: 1. The official (scientific) name of a certain plant genus (Zelcova) and one of its species (Zelkova carpirifolia); 2. The name of Plane tree (sometimes also of other trees) in old Georgian; 3. The name of some trees of another genus (Celtis caucasica, Acer platanoides) in dialects; 4. The general name of trees with strong wood in dialects.

Here, we remind the students of R. Eristavi's famous poem and explain that he was not only a poet and public figure, but also a scientist and lexicographer.

After the presentation, a field study is planned, where the students will see the pillar in nature. This can be Tbilisi Botanical Garden, Babaneuri Reserve or any of the above-listed places where you can still see this tree.

Conclusion

Teaching with project models turned out to be an effective way to learn about Georgia's toponymy. For a student, it means not only repetition and reconciliation of the knowledge acquired so far from different subjects, but also enrichment of this knowledge, and, what is especially important, the opportunity to see a number of issues in a new way.

The students realized after learning about and discussing the presented issues that phytotoponyms store valuable information and can be considered chroniclers of the local flora.

For the teacher, it becomes clear that finding and analysing appropriate toponyms when familiarising oneself with a number of issues makes the learning process more interesting and effective. Teachers across various subjects will utilize this resource.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

N.K. and D. T. conceived of the presented idea. N.K. took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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