DIVERSITY OF NATURALLY REGENERATED FOREST ECOSYSTEMS AND EVALUATION OF THE ECOLOGICAL (SOIL COVER) CONDITION ON THE LANDSLIDE SLOPES OF THE SKHALTA RIVER

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Abstract

Adjara is located in a mountainous, exceptionally small region, noted for its diverse and unique natural landscapes. In this area, intense land exploitation disrupts the already delicate balance of the geological environment, leading to the active advancement of natural geological processes. Consequently, the natural regeneration of forest ecosystems following a disaster is understood to be a complex successional process. Over35 years, the regenerated forest ecosystems on the landslide-affected slopes of the valley have been extensively studied. For this research, the systematic arrangement of the flora was analyzed, phytocoenology surveys were conducted, and assessments of soil fertility were completed. The flora of the naturally regenerated vegetation comprises 101 species, which are organized into 32 families and 84 genera. Species-rich families such as Asteraceae, Borraginaceae, Lamiaceae, Poaceae, Brassicaceae, Umbelliferae, Scrophulariaceae, Caryophyllaceae, and Leguminosae are identified. In the research site, as woody plants developed, cenotic relationships gradually emerged among species within the phytocenoses of the pine forest (Pineta; Pinus sosnovskyi), including Pinetum Ramnosum, Alnetum Pinetozum, Alnetum Ramnosum, and Alnetum Salixsosum. Consequently, tiered differentiation occurred, a tree canopy was established, and a specific system for natural regeneration was formed. The chestnut, oak, mixed (polydominant), and beech sub-zones within broad-leaved forests are primarily characterized by typical forest soils. It has been demonstrated through studies that the pH (KCl) of soil samples obtained from regenerated forests is 5.8, indicating a weakly acidic soil reaction. The strong buffering properties of the soil absorption complex are indicated by its high calcium content (336 mg/100g) and magnesium content (43.8 mg/100g). Low levels of total humus and nitrogen content are observed in the soil. The natural forest soil, with a neutral reaction (pH 7.1), is characterized by richness in calcium (378.7 mg/100g) and magnesium (50 mg/100g). Both soils possess a significant reserve of mobile phosphorus and potassium content. In comparison to the regenerated forest soil, the natural forest soil contains 1.65% more humus and 0.132% more total nitrogen. In the vicinity of the surveyed slopes, amid the presence of the derivative-type cascade Skhalta hydroelectric power station, an investigation was conducted on the soil's multi-elemental composition to evaluate the current ecological conditions and identify any toxic elements. Nickel (Ni), mercury (Hg), lithium (Li), antimony (Sb), selenium (Se), thallium (Tl), and vanadium (V) were detected below the detection limit in the 0–40 cm layer of soils. The concentrations of manganese (Mn), cadmium (Cd), lead (Pb), and molybdenum (Mo) in both soil samples exceed the permissible limits. This could be attributed to the proximity of the Skhalta Hydroelectric Power Plant (HPP) to the slopes, where its reservoir is fed by water from the Chirukhi River discharged through the derivation tunnel. Crushed rocks were deposited and spread on the surrounding slopes during the construction of the tunnel, potentially increasing the levels of heavy metals in the soil.

Keywords: secondary ecosystems, forest, variety, soil fertility, multi-element analysis

I. Introduction

Adjara is situated in the Caucasus, a region renowned for its biodiversity and recognized by the International Union for Conservation of Nature (IUCN) as one of the world's 36 biodiversity hotspots. This designation highlights regions with the highest biological diversity and a significant number of endangered terrestrial ecosystems. Additionally, the Adjara floristic region is part of the list of 200 ecoregions globally recognized, located in the southwestern corridor of the Lesser Caucasus. This area is notable for its species richness, high endemism, taxonomic uniqueness, distinctive origins, and rare habitats. Our region is also among the 25 regions worldwide with a uniquely high level of biological diversity, emphasizing the urgent need for its protection.

Adjara, with its diverse natural landscapes, stands out as one of the unique regions in Georgia. This uniqueness arises from its varied natural conditions and the complex history of its flora and vegetation development. According to numerous researchers, Adjara boasts the richest relict flora of Kolkheti in Georgia. Within this relatively small area, a wide range of ecosystems has evolved, from the wetland habitats of the Kolkheti plain to the distinctive ecosystems of the high mountains, where relict and endemic species still thrive. During the Ice Age, South Kolkheti, including Adjara, served as a refugium for ancient plant species (relicts).

The diversity and distinctiveness of Adjara's vegetation are evident in the Acharistskali River valley and its surrounding areas. The natural ecosystems here exhibit regular variation based on vertical zonation, slope exposure and steepness. Forest ecosystems are systematically distributed throughout the area, each occupying its unique eco-topological zone characterized by distinct ecological conditions.

Active human intervention in nature has triggered natural processes everywhere, and the mountain region of Adjara is no exception. Adjara is situated in a vulnerable zone and is considered one of the most challenging regions in the country in terms of natural processes. Unplanned and excessive consumption of local natural resources has led to landslides, destroying forests around villages, causing slope deformation, and resulting in the fragmentation, degradation, and destruction of vegetation. The natural renewal of ecosystems in these areas is a long and difficult process.

The most critical factor for slope stability and landslide development in mountainous Adjara is the saturation of slope rocks with excess atmospheric precipitation. This wetting disturbs the already weak static balance and triggers gravity processes [4]. There is limited information on the natural renewal of ecosystems in Adjara that have been damaged by these natural processes [5,6]. Therefore, studying the naturally regenerated forest phytocenoses on the slopes of mountainous Adjara, as well as the natural forests on adjacent slopes, is essential. This is especially relevant in the context of the derivation-type hydro power plant being constructed in the valley. Such studies are crucial for assessing the current ecological situation and for timely and competently determining preventive measures to address existing and anticipated ecological problems [12].

The purpose of the research was to examine the current ecological condition of natural and regenerated phytocenoses, determine the systematic structure of the flora, and conduct a geobotanical diagnosis of the phytocenoses. Additionally, the research aimed to evaluate soil fertility at the study locations and analyze it using multi-element analysis.

The study focused on the renewed forest ecosystems following the natural disaster in the Skhalta River valley (Khulo municipality), the natural forests on the surrounding slopes, and the soils developed under them. The Skhalta River, a left tributary of the Acharistskali, originates on the western slope of the Arsiani ridge at an altitude of 2220 meters above sea level. It has a length of 29 kilometers and a basin area of 223 m^2, and is fed by snow, rain, and underground water.

II. Methods

The main research method was traditional route expeditions. We conducted numerous floristic and geobotanical descriptions and performed a reconnaissance survey of the study area to understand the vegetation background. Using phytocenological diagnostics, we identified xenotypes through the Relevé method. Traditional method sofphytocenological research were employed for geobotanical descriptions [8, 10, 11].

We determined some agrochemical indicators of natural and regenerated forests oils that would allo wus to judge the level of soil fertility. Agrochemical analysis of soils were carried using classic, widely tested methods: Soil Ph was determined potentiometrically with a laboratory pH meter (Metter Toledo) in both aqueousand salt (KCl) extracts; Mobile P_2O_5 and K_2O were measured photometrically by Oniani's method in a single extract obtained by adding 0.1N H_2SO_4 to the soil; exchangeable CaO and MgO were analyzed titrimetrically using the trilonometric method; total Humus was determined by the Turin method, which involves oxidizing soil organic matter (containing carbon) with 0.4N $K_2Cr_2O_7$ in H_2SO_4, followed by titrationof the remaining bichromate with 0.1N Mori'ssalt $(NH_4)_2Fe(SO_4)\cdot 6H_2O$ using diphenylamine - $C_{12}H_{11}$ Nasan indicator; total Nitrogen was measured by the Kjeldahl method, which involves oxidizing humus carbon to carbon dioxide and converting amine (NH_2) nitrogen to anammoniacal form during soil digestionin concentrated H_2SO_4. To completely separate ammonia, the solution is made alkaline with 40% NaOH, causing the formed NH_3 to be transferred to 0.1N H_2SO_4 under boiling conditions. At this point, NH_3 combines with H_2SO_4 toform $(NH_4)_2SO_4$. The remaining free H_2SO_4 is then titrated with a 0.1N NaOH solution using Congo redasan indicator until a weak pink coloris achieved [1, 2].

Multi-element analysis of the soil was conducted using the modern method of instrumental research known as plasma atomic emission spectrometry (on instrument ICPE-9820). For this analysis, we prepared comparison (standard) solutions in advance, including on esolution that represented the internal standard, ytrium (Y):

I – ytrium standard solution - concentration 0,1ppm;

II standard solution - concentrations 5ppb and 25ppb;

III standard solution - concentrations - 2ppm ans 5 ppm.

The multi element standard solutions include: $Al, Sb, Ba, Pb, B, Ca, Cd, Cr, Co, Fe, K, Cu, Mg, Li, Mn, Mo, Na, Ni, P, Si, Ti, V, Zn, As, Be, Se, Tl$
Inductively coupled plasma spectrometryis a method of atomic emission spectrometry that uses inductively coupled argon plasmaas a source of atomic excitation. The method works by causing excitationan dionization, where each element emits a quantum of light at a specific wave length. Quantitative analysis involves measuring the amount of electromagnetic radiation, while qualitative analysis is based on the wavelength of the radiation. This method allows for simultaneous qualitative and quantitative analysis. Currently, it is the most widely used high-sensitivity method for element alanalysis of liquid and solid substances, with a correlation coefficient of at least 0.99 [9, 14].

III. Results

The wild flora of the regenerated forest comprises 105 species, grouped into 36 familie sand 88 genera [7]. In contrast, the wild flora of the boreal forests developed on the slopes suffered from landslide consists of 202 species, organized into 61 families and 152 genera.

The distribution of species into major taxonomic units is clearly illustrated in the diagrams.

The species diversity of the regenerated forest flora is significantly lower compared to the natural forests on the surrounding slopes (Table 1). In natural forests, the families distinguished by species richness are:*Asteraceae* - 32; *Lamiaceae*- 15; *Brassicaceae* - 9; *Rosaceae* - 9; *Dryopteridaceae* - 9;

Borraginaceae - 8; *Caryophyllaceae* - 8; *Scrophulariaceae* - 7; *Apiaceae*– 7. In regenerated forests, the families distinguished by species richness are: *Asteraceae*- 23; *Lamiaceae* - 8; Borraginaceae - 8; Brassicaceae - 7; Poaceae - 7; Scrophulariaceae - 4; Leguminosae - 4; Caryophyllaceae – 3. A significant portion of the wild flora consists of perennial herbaceous species, accounting for 69.5%, while annual herbaceous species make up 16%. Woody plants comprise 9.5% of the total.

highest taxa	Family	Genus
Pteridophyta	5	4
gimnospermae	3	3
Angiospermae	26	81
Dicotyledones	24	73
Monocotyledones	2	8
all	34	88

Для изменения диапазон

Diagram 1: *Regenerated forest wild flora*

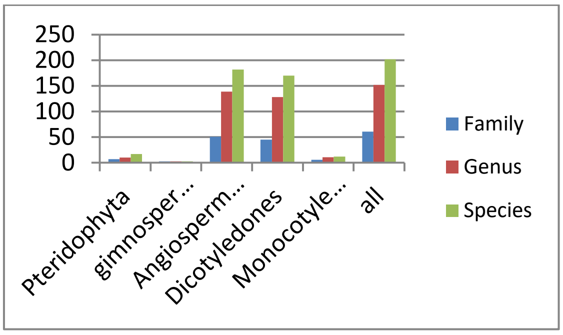

Diagram 2: *Natural forests wild flora*

Table 1: *Flora species of natural and regenerated forests*

	The families distinguished by species richness in natural forests		The families distinguished by species richness in regenerated forests	
	family	Number of species	family	Number of species
1	Asteraceae	32	Asteraceae	23
2	Lamiaceae	15	Lamiaceae	8
3	Brassicaceae	9	Borraginaceae	8
4	Dryopteridaceae	9	Brassicaceae	7
5	Rosaceae	9	Poacaea	7
6	Borraginaceae	8	Umbelliferae	6
7	Caryophyllaceae	8	Scrophulariaceae	4
8	Scrophulariaceae	7	Leguminosae	4
9	Umbelliferae	7	Caryophyllaceae	3
10	*Poaceae*	6	Rosaceae	3

The natural forests of the valley are polydominant and broad-leaved, with chestnut, oak, and beech as the dominant species. Typical phytocenoses include beech-larch-chestnut-leafy forests Fageto-Carpineto-Castanetumlaurocerasosum (Castanea sativa + Fagus orientalis + Carpinus caucasica – Laurocerasusofficinalis), hornbeam-chestnut-Cherry-laurel, Castaneto - Carpinetumlaurocerasosum (Castanea sativa + Carpinus caucasica - Laurocerasus officinalis), chestnut rhododendron, Castanetumrhododendronosum (Castanea sativa – Rhododendron ponticum), oak forest with rhododendron-Cherry-laurel, Quercetumrhododendronoso - laurocerasosum (Quercus hartwissiana + Rhododendron ponticum - Laurocerasus officinalis), beech forest with rhododendron, Fagetumrhododendrosum (Fagus orientalis – Rhododendron ponticum), chestnut-hornbeam-beech forest with blackberry, Castaneto-Carpineto-Fagetumrubosum (Fagus orientalis + Carpinus caucasica + Castanea sativa – Rubus caucasicus), Alder-grove with blackberry, Alnetumrubosum (Alnus barbata– Rubus caucasicus), Alder-grove braken blackberry, Alnetummatteuccioso-rubosum (Alnus barbata, Matteucciastruthiopteris, Rubus caucasicus). Natural regeneration of dominant species in forests is satisfactory in low-frequency groves (0,5-0,6), but weak in high-frequency groves (0,7-0,8).

Figure 1: *Natural vegetation of the valley*

Figure 2: *Naturally regenerated vegetation of the valley*

Naturally regenerated forests are pine forests (Pineta; Pinus sosnovskyi). Coenoses featuring alder grove on well-moistened soils in *the relatively leveled areas of the slope.* In pine groves, individual occurrences of Spruce, Silver-fir, hornbeam and Yew-tree can be found. We have described typical phytocenoses: *the pine grove with buckthorn sub forest Pinetum Ramnosum (Pinus Sosnovski-Ramnusimeretina); Alder-grove-pine forest, Alnetum Pinetozum (Pinus Sosnovski+Alnusbarbata); Alder-grove with buckthorn sub forest Alnetumramnosum (Alnus barbata+Ramnusimeretika); Alder-willow grove Alnetumsalixsosum* (Alnus barbata+Salix alba); In pine forests with low regeneration frequency, the natural regeneration of pine is satisfactory. However, the following species exhibit weak natural regeneration: *Piceaorientalis, Abies mordmaniana, Taxus bacatta, Alnus barbata, Ramnusimeretina.*

The soils of broad-leaved forests, including chestnut, oak, mixed (polydominant), and beech forests, represented by typical fulvous forests oils. In contrast, regenerated forest soils are characterized by being loamy, stony, and low inhumus.

Soil samples were collected from the surface at a depth of 0-20 cm for agrochemical analysis and to assess fertility levels. Upon arrival at the laboratory, the samples were spread on dense paper and allowed to air dry for 3-5 days. The soil was then cleaned of impurities, ground, sieved through a 1 mm diameter sieve, and stored in a hermetically sealed labeled container for analysis. The agrochemical indicators of the soils are detailed in Table 2. It is evident from these indicators that the main quality parameters of the regenerated forest soil (sample No. 1) are inferior to those of the natural forest soil. This includes its active reaction and the quality of basic nutrients, humus and nitrogen. The regenerated forest soil has average or below-average concentrations of essential plant nutrients, including phosphorus, potassium, calcium, and magnesium.

Table 2: *Some agrochemical indicators of natural and regenerated forest soils*

№	Samplinglocation	sampling depth, cm	pH		mobileformsofnutrients, mg/100 ginthesoil				Total, %	
			H_2O	KCl	P_2O_5	K_2O	CaO	MgO	humus	nitrogen
1	soilfromtheregeneratedforest	0–20	4.85	3.47	59.10	29.4	21.56	11.90	3.68	0.13
2	naturalforestsoil	0–20	6.58	5.69	72,30	44.6	78.47	46.21	5.62	1.90

To perform the multi-element alanalysis, an aqueous extract of the soils was prepared with a soil-to-water ratio of 1:25. The analysis results were compared with the maximum allow able concentrations of heavy metals established by the environmental quality standards approved by the Republic of Georgia. This comparison was made to prevent adverse effects on the environment and human health due to environmental and anthropogenic factors [3].

The conducted studies allowed us to judge the content of microelements and some heavymetals in the research soils in relationt to their maximum permissible concentrations (MPC)

(Table 3). The content of copper and lead in the natural forest soil exceeded the permissible concentration. As for the soil of the regenerated forest, there was an excess of concentration of several elements in relation to MPC. The seelements are: copper; manganese; zinc; plumbum.

Table 3: *Multi-element analysis of aqueous extracts from soil Concentration of microelements, mg/kg*

№	Sampling location	As	B	Ba	Co	Cu	Mn	Mo	Zn	Cr	Cd	Pb
1	Soil from the regenerated forest	0.00086	0,320	0.00112	0.450	4.465	1.348	0.326	5.983	1.476	0.113	2.866
2	Natural forest soil	0.00079	0.292	0.00103	0.414	3.850	0.127	0.312	4.738	1.397	0.102	2.527
MPC		0,001	0,5	0,0025	0,5	3,0	0,2	0,35	5.0	3.0	0.2	2,5

IV. Discussion

I. Floristic and Coenological Analysis of Natural and Regenerated Forest Ecosystems

Forest phytocenoses on the slopes affected by landslides develop primarily in zones at an altitude of 750–1000 meters, mostly on slopes with an eastern exposure, where they in habit slightly moistened areas. The natural form at ion of secondary phytocenosesis quite dynamic, influenced by local climatic and soil conditions. Over the years, as woody plants grow on the baresubstrate, a tiered structure of phytocenosis gradually forms (see Fig. 3 and Fig. 4). The primary layer of secondary natural forest phytocenoses is predominantly composed of pine (Pinus Sosnovski), within dividual representations in some places of alder (Alnusbarbata), spruce (Piceaorientalis), sochi (Abiesnordmaniana), willow (Salixalba), and horn beam (Carpinus caucasica). Depending on the intensity of plant growth influenced by local climatic and soil conditions, the sub-tiersoft hemainlayer have naturally formed. The over all density of the groves in most phytocenoses ranges from 0,5 to 0,6. Typically, the main forest exhibits unevendensity, which significantly impacts the floristic composition and structure of the understory and herbaceous cover in the lower levels. The understory is unevenly developed, featuring species such as Ramnusimeretina, Ilexcolchica, Rhuscoriaria, and Swidaaustralis. The herbaceous cover is primarily composed of perennial species, with relatively high projected coverage in open areas and gaps: Athyriumfilix-femina, Crepisfaetida, C. foetida, Hieraciumpilosella, Echiumvulgare, Fragariavesca, Brachypodiumsilvatica, Trifoliumcampestra,T. pratese, T. arvense, Poaannua, Mycelismuralis, Sambucusebulus, Plantagolanceolata, Tunicasaxifraga,Circiumimeretina, Teucriumnuchense, Clematisvitalba, Hipericumperforiatum, Eupatoriumcannabinum and other.

The natural regeneration of pine on the slopes of the renewed forest is progressing satisfactorily. However, species such as Piceaorientalis, Abiesnordmaniana, Taxusbaccata, Alnusbarbata, and Ramnusimeret in a exhibit weak natural regeneration. This indicates that while a system of natural renewal existsin secondary natural phytocenoses, the development of monoclimax ecosystems in the near future seems unlikely.

Figure 3: *Slopes affected by landslides 1989 affectedbylandslides*

Figure 4: *Secondary natural forests on the places*

II. Agrochemical Indicators of Soil.

The experimental study of the soils revealed that the natural forest soil has significantly higher fertility compared to there generated forest soil. Specifically, the pH in KCl suspensionis 3.47, indicating a moderately acidic reaction. The levels of mobile phosphorus and potassium are average (59.10 and 29.4 mg/100g of soil respectively). However, the concentrations of mobile Caand Mg which are important for the soil's buffering capacity, are below average (21.56 and 11.90 mg/100g). Additionally, the soils are deficient in total humus (3.68%) and total nitrogen (0.13%), which are crucial indicators of soil quality and fertility (Table 2).

In the natural forest sample (sample №2), the pH in KCl suspension is 5.69, placing it in the weakly acidic range. The soil is well-supplied with essential nutrients, including calcium (78.47 mg/100g) and magnesium (46.21 mg/100g). The content of mobile phosphorus in the natural forest soil is higher by 13.2 mg, and the mobile potassium content is higher by 15.2 mg compared to the regenerated forest soil. Consequently, the natural forest soil is adequately provided with these nutrients. A similar pattern is observed for total humus and nitrogen content, with these indicators being 1.94% and 1.77% higher, respectively, in the 1st sample compared to the 2nd sample.

III. Multi-element Analysis of Soil.

The content of mercury, lithium, antimony, selenium, titanium, thallium, and vanadium is below the detection limitin both regenerated and natural forest soil samples. Additionally, the levels of arsenic, boron, barium, cobalt, molybdenum, chromium, and cadmium do not exceed the permissible concentration in any of the samples.

The content of Cu (3.850 mg/kg) and Pb (2.537 mg/kg) in natural forest soil was higher than maximal permissible concentration (MPC). As for the soil of the regenerated forest, there was an excess of concentration of several elements at the same time, in relation to MPC. These elements are: Cu-4.465mg/kg; Mn-1.348mg/kg; Zn-5.983mg/kg; Pb-2.866 mg/kg.

The elevated concentrations of the mentioned metals are likely attributed to the proximity of the Skhalta HPP to the slopes. The water reservoir of the HPP is fedby the Chirukhi River, whichdischargeswaterfromthederivationtunnel. During the tunnel's construction, crushed rocks were placed and spread over the surrounding slopes, potentially leading to increased levels of these heavy metals in the soil.

The current situation under scores the need for systematic research and monitoring of soil chemical composition. This will help assess the current state of the soil and enable timely preventive measures to improve soil quality.

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