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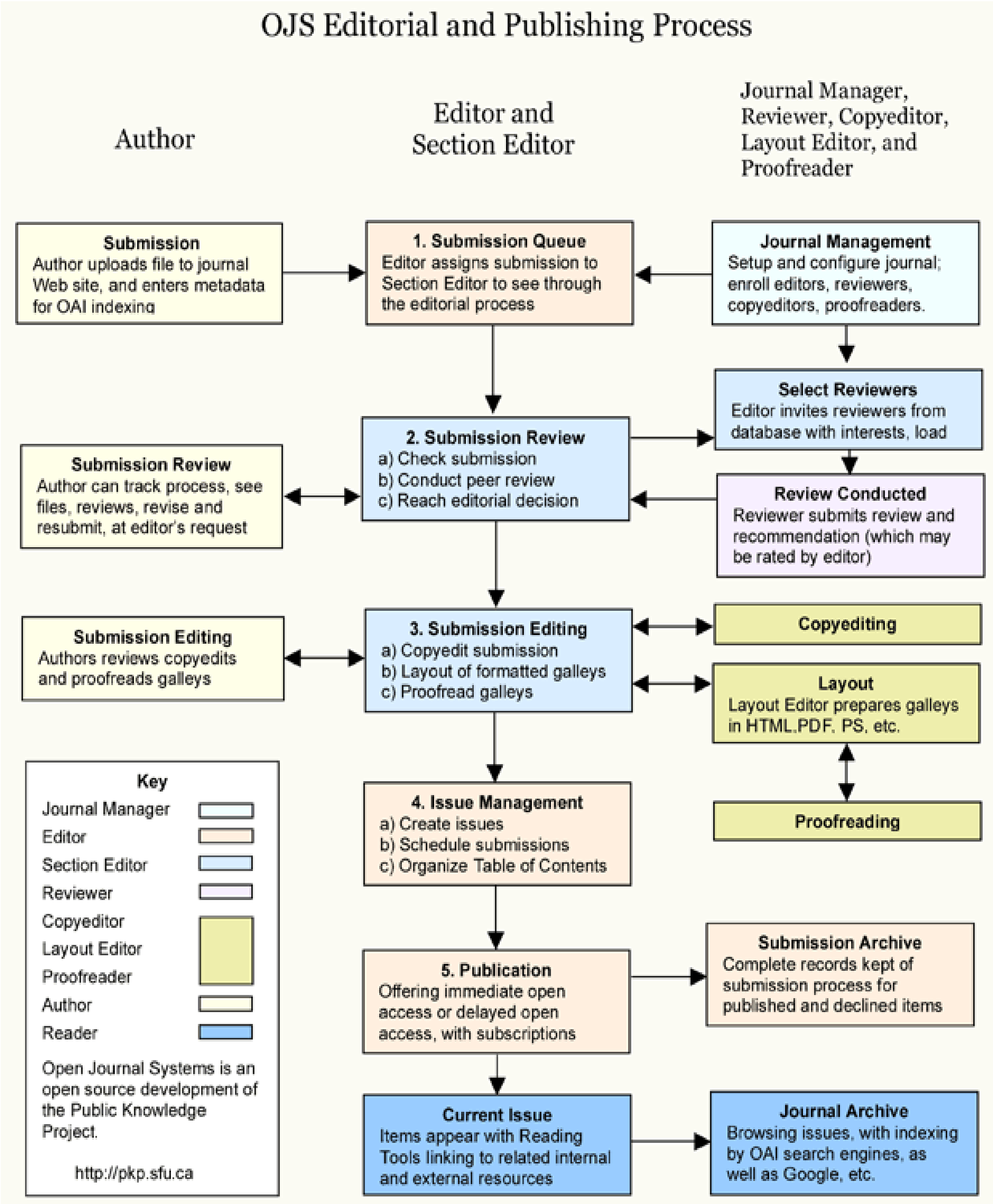

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Primary Temporal Analysis of Enguri Dam Displacement of Foundation under Loading

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ABSTRACT

The main aim of our research was the analysis of time distribution characteristics of the Enguri dam foundation displacement according to the periodic variation (loading) water level in the lake around the Enguri Arch Dam. The primary temporal analysis was carried out in 1974-1981 period. Modern methods of nonlinear analysis DFA (detrended fluctuation analysis), and MF-DFA (multifractal detrended fluctuation analysis) were used.
The results of our research are important and from investigation we can conclude that dynamic changes of dam foundation displacement, assessment of dam behaviour and water level change in the reservoir of the Enguri high dam. The analysis of the dynamics measures of the Enguri dam displacement shows us the pattern of nonlinear dynamics of the normal regime with start loading.

Key words: *Enguri Dam, displacement, temporal analysis*

Introduction

The location of the Enguri Dam was selected based on extensive engineering research. The influence of the dam and changes in the reservoir's water level on both the structure and the surrounding environment was studied. Construction began in the last century, and the 271-meter-high Enguri arch dam is one of the tallest dams of its kind in the world. Since construction began, state-of-the-art interdisciplinary geodynamic and geophysical monitoring has been organized in the dam area. Geological studies have documented that a fault branch of a major active fault beneath the Enguri Dam, the Ingirishi Fault, intersects the right wing of the dam's foundation. The presence of an active (or potentially active) fault at the foundation of a large dam is known to pose a serious threat to dam safety. It is logical that monitoring of the fault zone began long before construction of the dam and filling of the reservoir [1-5]. The main Ingirishi fault (Fig.1, Fig.2) crosses the foundation of the Enguri dam and, thus, poses a significant hazard to the dam.

The study area effectively serves as a natural large-scale laboratory for examining the effects of tectonic activity, anthropogenic influences, and environmental factors on fault-zone deformation. The combined impact of these processes is captured in the time series of fault-zone strain. The observed fault dynamics clearly reflect the interaction of two principal components: a tectonic strain component, which produces piecewise linear temporal displacements and is interpreted as the long-term trend, and a secondary component that generates quasiperiodic oscillations superimposed on this underlying trend.

Strainmeters and demographs are located in the dam body and tunnels, which measure the displacement of the dam when the water level in the reservoir varies.

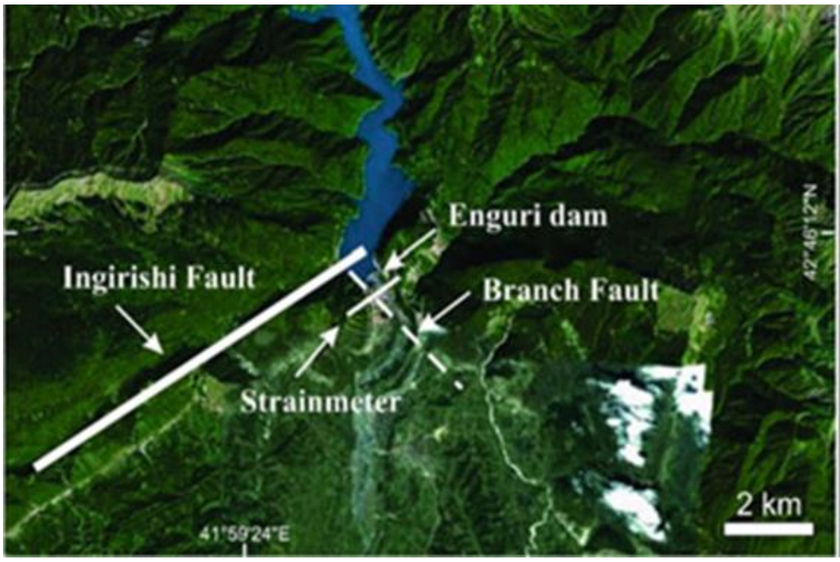


Fig. 1. Satellite image of the Enguri dam and reservoir area, locations of the Ingirishi fault and crossing the dam foundation.

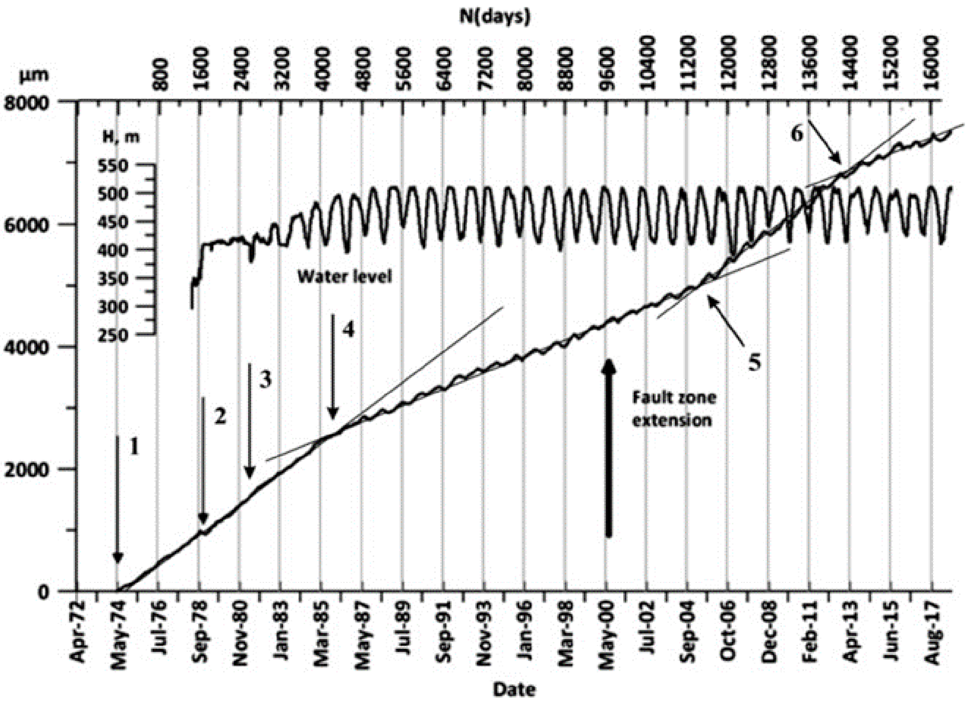


Fig. 2. The upper curve shows the variations of water level height at the Enguri lake from 1978 to 2017; the lower curve shows data from the strain-meter. Data are from 1974 to 2017 versus time. Arrows 1, 2, 3, 4, 5, 6 correspond to the start of 6 periods of fault zone extension, see Table 1 for details. We can see of fault compaction by approximately 90 microns, as a consequence of a quick, 100-m increase in water level in 1978. The upper horizontal axis shows the number of days after the start of the strainmeter monitoring. The thin, straight lines show six periods of the fault's main trend with different extension rates

The data (Fig. 2) also show that the water load reduced the initial displacement rate recorded before the lake refill, since the total accumulated deformation value in 2017 was only 7000. The decrease in accumulated deformation is explained by the orientation of deformation caused by the water load, which is favorable for the compaction of faults.

Table 1. Subdivision in periods of fault zone extension

Number of periods	Periods	Number of days in the period; in brackets the same from zero day (May 1974) to the end of a given period	Tectonic component of strain rate α μm/year	Pattern of lake impounding (man-made component of strain)
1	May 1974–Apr 1978	1500 (1500)	230	Before lake impounding
2	May 1978–Jan 1981	1300 (2800)	250	WLinthelakeraisedto100m
3	Feb 1981–May 1985	1400 (4200)	250	Irregular load-unload regime
4	Jun 1985–Sep 2004	7000 (11200)	160	Regular quasi-periodic regime
5	Oct 2004–Feb 2013	3200 (14400)	230	Regular quasi-periodic regime
6	Apr 2013–Mar 2018	2000 (16400)	150	Regular quasi-periodic regime

Methods.

For estimating long-term correlations of the dam strain time series during load-unload of reservoir we used the methods DFA (detrended fluctuation analysis), and MF-DFA (multifractal detrended fluctuation analysis).

In time-series analysis, detrended fluctuation analysis (DFA) is a technique used to assess the statistical self-similarity of a system's components. The DFA scaling exponent encapsulates comprehensive information about temporal correlations and is particularly effective for identifying long-term correlations in non-stationary time series. DFA has been widely applied across numerous disciplines, including geophysics, geodynamics, meteorology, biology, bioinformatics, and economics. This scaling approach yields a straightforward quantitative measure of a signal's correlation structure and, compared with many conventional methods, offers the distinct advantage of reliably detecting long-range correlations in non-stationary data [6–9].

DFA consists of two steps:

(1) the data series B(k) are shifted by the mean B and integrated (cumulatively summed), $y(k) = \sum_{i=1}^{k}[B(i) - B]$, then segmented into windows of various sizes Δn;

(2) in each segmentation the integrated data is locally fit to a polynomial $y_{\Delta n}(k)$ (originally, and typically, linear) and the mean squared residual $F(\Delta n)$ (''fluctuations''):

$$F(\Delta n) = \sqrt{\frac{1}{N}\sum_{k=1}^{N}(y(k) - y_{\Delta n}(k))^2} \ ,$$

where N is the total number of data points. Note that $F(\Delta n)$ can be considered as the average of the summed squares of the residual found in the windows. The n-th order polynomial regressor in the DFA family is denoted as DFAn, with unlabeled DFA often referring to DFA1.

Multifractal detrended fluctuation analysis (MF-DFA) is used to detect variability and uncertainty in empirical time series data.

MF-DFA is the most effective method for detecting multifractality in time series. It takes the mean of the time series in each interval as a statistical point, which is then used to calculate volatility functions. It then determines generalized Hurst exponents based on the power law of the volatility functions. A key advantage of MF-DFA over other approaches is its ability to detect long-term correlations in non-stationary time series. The reaserch describes the key steps and formulas underlying the analysis.

The first step of the MF-DFA is to construct the "profile", $Y(j)$ by integration after subtracting from the time series, $R(i)$ its average, $\bar{R}$:

$$Y(j) = \sum_{i=1}^{j} (R(i) - \bar{R}), i = 1, \dots, N.$$

The second step of the MF-DFA is to divide the profile $Y(j)$ into $N_s = int\left(\frac{N}{s}\right)$ non-overlapping segments of equal length s.

The exponent *h(q)* is called a generalized multifractal Hurst exponent and is related to the classical monofractal Hurst exponent *H*.

For the MF-DFA analysis we use the generalized Hurst exponent, which has no upper limit and expressed as:

$$H = \begin{cases} h(q) & - \quad for\ stationary\ time\ series \\ h(q) - 1 & - \quad for\ non-stationary\ time\ series \end{cases}$$

The estimation of H represent fundamental base, as we want to know the long-term dependence of a time series.

Results.

For our primarily research of Enguri dam foundation displacement under compare with water variation the second period (May 1978–Jan 1981) was investigated (which shows on Fig.2 (arrow 2, 3)).

Nonlinear DFA analysis of Enguri dam foundation displacement data for 1978-1981 was carried out. The results of DFA analysis of displacement, show the long-range correlation of scaling features, changes in dynamical structures, and the regularity of the system. DFA analysis was carried out for polynomial fitting p=2, 3, 4, 5 (see Fig. 3).

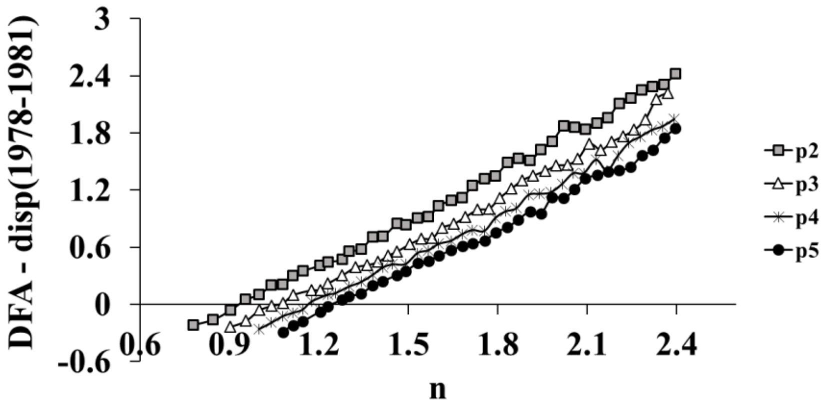
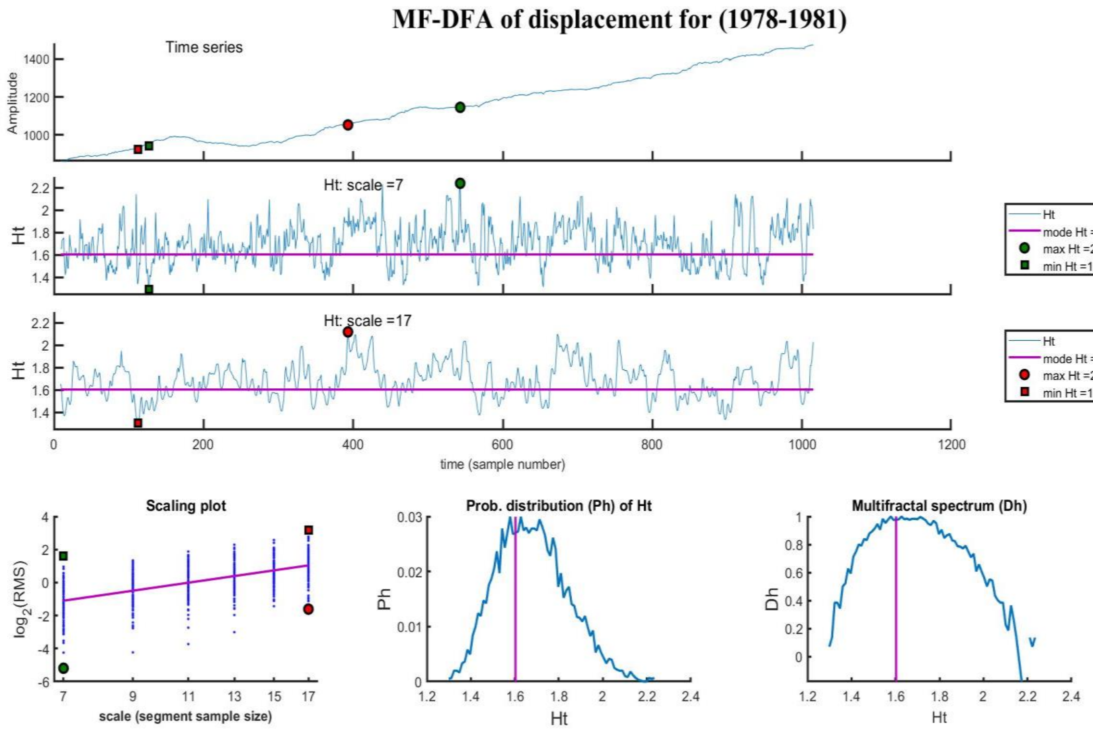


Fig. 3. DFA analysis of Enguri dam foundation displacement for 1978-1981.

From the DFA analysis of Enguri dam data sets, we can see how the structure of the dynamics changes with increasing polynomial approximation, order is disrupted, and mutual correlation weakens.

Multifractal Detrended Fluctuation Analysis (MF-DFA) of long-term correlations of the power law of non-stationary Enguri dam foundation displacement data in 1978-1981 was carried out. The variation of the multifractal characteristics was carried out for polynomial fitting with p=2, 3, 4, 5 (Fig. 4)

Values of Ht, the q-order of generalized multifractal Hurst exponent time signal, were calculated. The local generalized multifractal exponent (Ht) can now be computed from the local fluctuation of real time series signal (Fig. 4) estimated as well as the logarithmic function (Ht). From Fig. 4 we can see a non-stability, that under variation at the orders of scale s =7 and s =17 changed maximum and minimum of Ht, but Ht mode is constant ($mode\ Ht \approx$ 1.6). This changes in dynamic structure of time series clearly observed, where the plot of Ph-probability distribution of Ht and Dh- multifractal spectrum represents the relationship in the form of parabola and shows an increase in the thresholds at the $mode\ Ht \approx 1.6$.



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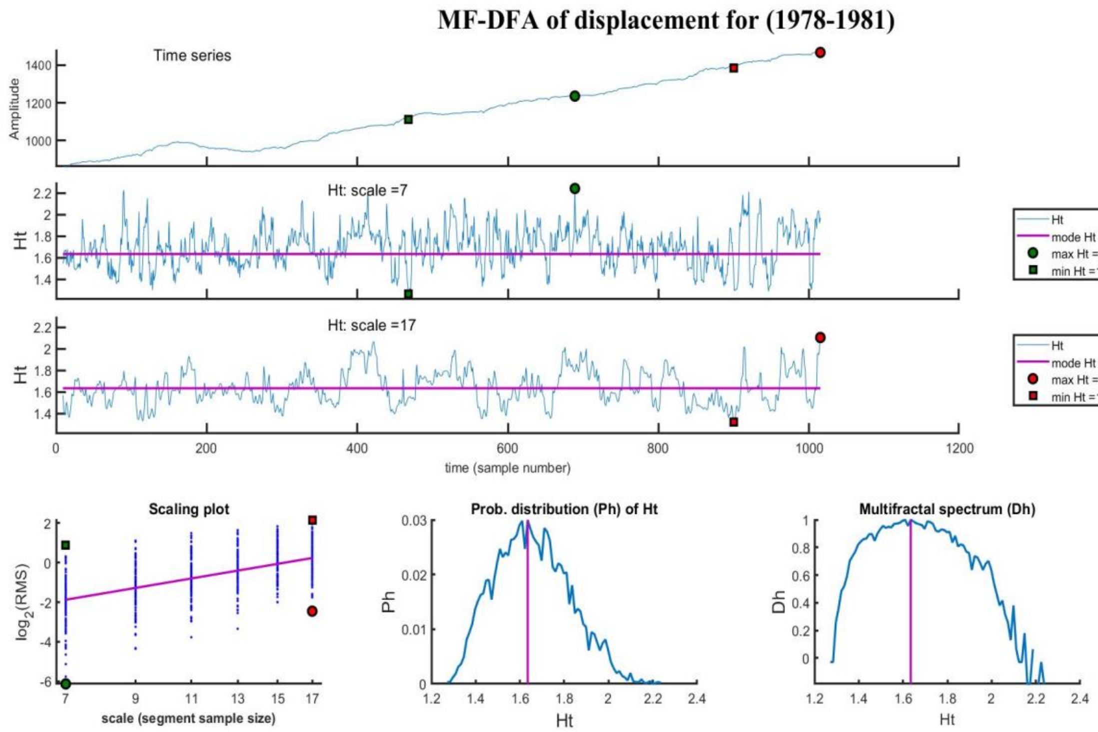

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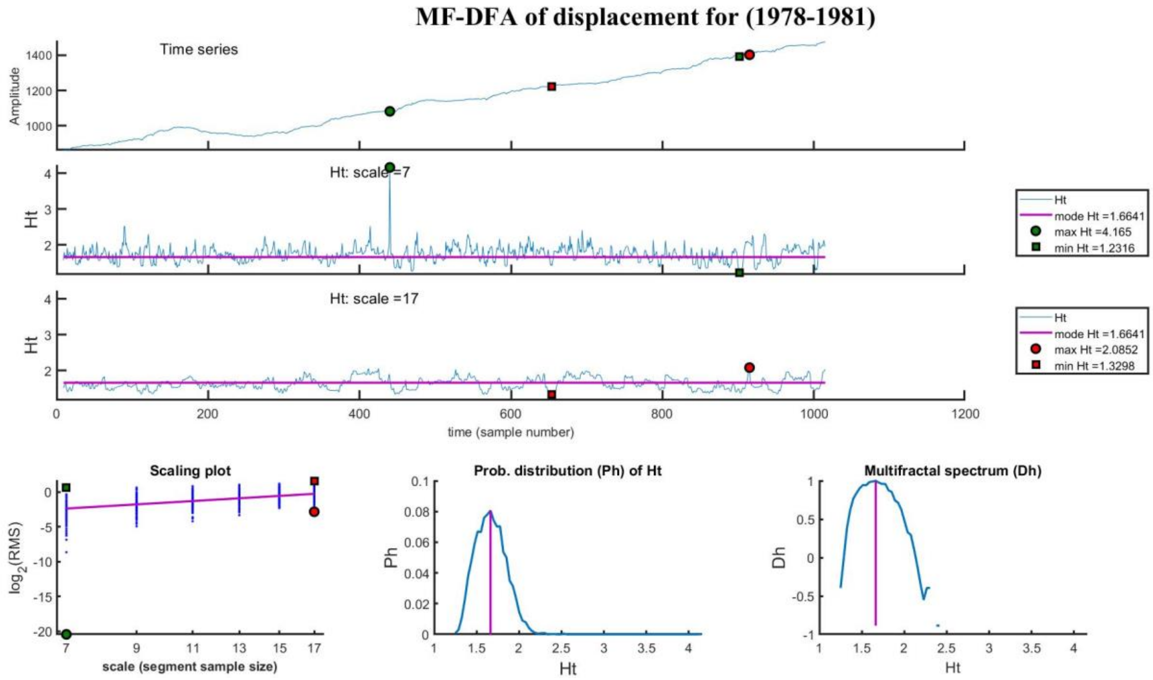
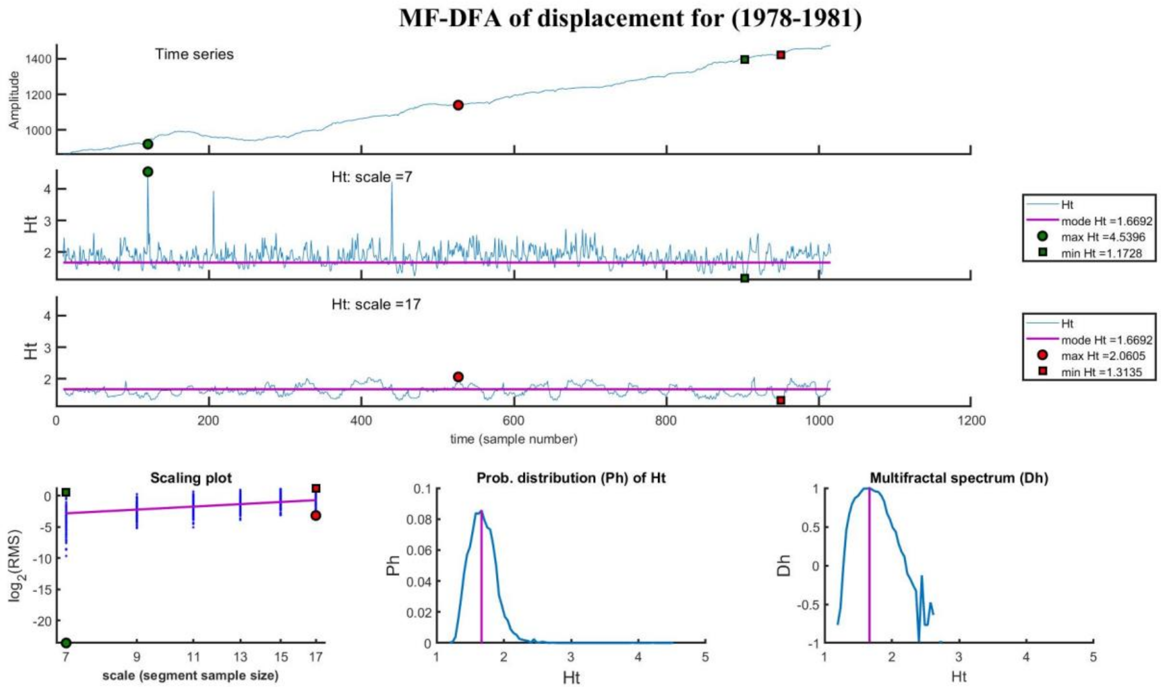


c)



d)

Fig. 4. The MF-DFA analysis of the Enguri dam foundation time series displacement in 1978-1981: a) for polynom =2; b) for polynom =3; c) for polynom =4; d) for polynom =5. Ht: q- generalized multifractal Hurst exponent time signal. Percent of output variable: Ph - probability distribution of Ht, Dh- multifractal spectrum.

From Fig.4 we can see the scaling functions Ht, Ph, Dh, which are depend on q-order Hurst exponent. The q-order Hurst exponent Ht for the time series is multifractal. MF-DFA analysis consists of several steps: to first convert Ht to the q-order mass exponent and thereafter convert signal to the q-order singularity exponent (Ht) and q-order singularity dimension Dh; The plot of Dh shows us multifractal spectrum.

The initial MF-DFA results indicate that the dynamics of dam foundation displacement began to change with the onset of reservoir impoundment during the period 1978–1981. This analysis enables an assessment of the dam's response to reservoir filling and the influence of this process on foundation displacement, as well as an evaluation of the associated risk of potential damage

Conclusion.

This article presents a preliminary analysis of Enguri Dam foundation displacement data, during the period 1978–1981. Nonlinear analysis methods DFA and MF-DFA revealed a clear pattern of dam deformation dynamics. These results are important for studying the behavior of the Enguri Dam. Analysis of the Enguri Dam displacement time series allows us to establish patterns in nonlinear dynamics under normal conditions and under water loading. Significant deviations from the multifractal characteristics obtained above should be analyzed in detail to determine whether the anomaly is significant for dam stability. The results of this study will form the basis for further research into dam behavior and will help scientists avoid a catastrophe caused by dam failure and foundation displacement.

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ჩვენი კვლევის შედეგები მნიშვნელოვანია და შეიძლება გამოყენებულ იქნას ენგურის კაშხლის წყალსაცავში წყლის დონის ვარიაციის დროს კაშხლის საძირკვლის გადაადგილებაში დინამიკური ცვლილებების დასადგენად და მუშაობის შესაფასებლად.
ენგურის კაშხლის დინამიკური გადაადგილების პარამეტრების ანალიზი ნორმალურ რეჟიმში საწყისი და დატვირთვის ქვეშ ავლენს არაწრფივი დინამიკის სურათს.

საკვანძო სიტყვები: ენგურის კაშხალი, გადაადგილება, დროითი ანალიზი.

Первичный временной анализ смещения основания плотины Энгури при нагрузке

Е. Мепаридзе, А. Сборщиков, Т. Челидзе

Резюме

Основная цель нашего исследования заключалась в анализе характеристик временного распределения смещения основания плотины Энгури в зависимости от периодических изменений (нагрузки) уровня воды в озере вокруг арочной плотины Энгури. Первичный временной анализ проводился в период 1974-1981 годов. Использовались современные методы нелинейного анализа DFA (детрендовый флуктуационный анализ) и MF-DFA (мультифрактальный детрендовый флуктуационный анализ).
Результаты нашего исследования важны и на их основе можно сделать вывод о динамических изменениях смещения основания плотины, оценке поведения плотины и изменение уровня воды в водохранилище платины Энгури.
Анализ динамических показателей смещения плотины Энгури показывает нам закономерность нелинейной динамики нормального режима при начальной нагрузке.

Ключевые слова: плотина Энгури, смещение, временной анализ

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Seismic Surveys and Seismicity Refinement in Kvibisi Village, Borjomi District, Considering Local Parameters

**Malkhaz G. Gigiberia, Vakhtang G. Arabidze,
Jemal K. Kiria, Nugzar I. Ghlonti**

ABSTRACT

To obtain objective information about the engineering-geological properties of rock massifs, it is necessary to conduct a wide range of studies, including geological, geotechnical, hydrogeological, geophysical and, above all, seismoacoustic studies. The physical basis of engineering seismic acoustics is the close dependence of the parameters of elastic waves on the features of the structure, properties and condition of the investigated rock massifs.
This work is devoted to the role of engineering geophysics, particularly seismic, in the construction of significant structures. As an example, specific projects and methods used for their implementation are given.

Key words: *engineering geophysics, seismicity, rock massifs.*

Introduction

The works carried out by us included the construction of seismic profiles and refinement of seismicity [1-15], taking into account local parameters, in Kvibisi village, Borjomi district, within the territory of Borjomi Plant No. 2.

Experimental Studies: Construction of Soil Seismic Profiles

Seismic profiling (using the refraction method) was conducted, relevant seismogeological cross-sections were constructed, and the propagation velocities of elastic longitudinal (P-waves) and transverse (S-waves) were determined. Additionally, the values of the corresponding physical–mechanical parameters were assessed.

The report presents cross-sections of four seismic profiles with a total length of 276 m, each 69 m long (Fig. 1.1). Table 1.1 provides the starting and ending coordinates of the seismic profiles in the UTM system, together with absolute elevations.

Table 1. Starting and ending coordinates of seismic profiles

№1 indicates the first geophone, i.e., the beginning of the profile, while №24 denotes the 24th geophone, i.e., the end of the profile. H represents absolute elevations.

GPH №2	X	Y	H, m
1-1	368867.43	4636255.37	777
1-24	368875.56	4636200.80	777
2-1	368859.34	4636266.63	777
2-24	368927.52	4636272.03	777
3-1	368929.15	4636270.89	777
3-24	368994.94	4636281.90	778
4-1	368925.21	4636192.11	780
4-24	368993.39	4636197.52	780

Fig. 1. Study area and schematic layout of seismic profiles.

Geophysical Investigations (Seismic Profiling)

In the study area, seismic profiling was conducted using the refraction wave method, on the basis of which the propagation velocities of elastic longitudinal and transverse waves were determined, and the corresponding cross-sections were constructed.

The refraction wave method makes it possible to determine the thicknesses of both near-surface and deeper layers, as well as the propagation velocities of elastic waves within them. The method is based on determining the arrival times of longitudinal and transverse wave fronts from an elastic wave source to geophones arranged along a single line.

The following physical–mechanical parameters were determined:

Table 2.

Vp m/sec	Longitudinal wave velocity
Vs m/sec	Transverse wave velocity
Vs/Vp	Velocity ratio
ρ gr/cm^3	Density
μ	Poisson's ratio
Ed Mpa	Young's dynamic modulus
Gd MPa	Shear dynamic modulus
Kd Mpa	Dynamic modulus of universal compression
D Mpa	Total deformation modulus
τ Mpa	Tensile strength limit

Parameters 1–3 and 5–8 were calculated based on well-established theoretical relationships, while parameters 4, 9, and 10 were derived using available empirical correlations.

Seismic Profiling Methodology:

Seismic profiling was carried out using 10 Hz geophones spaced at 3-meter intervals. Seismic wave generation was achieved by striking a special plastic plate with a 10 kg hammer.

The measurements were conducted in both Z-Z and Y-Y orientations. A five-shot point system was used, which included:

- Two shots at the beginning and end of the profile,
- One shot in the middle of the profile,
- Two shots positioned off the ends of the profile.

Wave registration was performed using a 24-channel engineering seismic station manufactured by **GEOMETRICS**. Data processing and interpretation were conducted using the licensed **SeisImager** software from the same company.

Subsequently, the recorded data were analyzed, and the corresponding seismic sections were constructed (see Figs. 2–5).

Analysis of Conducted Works and Results

Seismic profiling (using the refraction wave method) was conducted in the study area, and corresponding seismogeological cross-sections were constructed. The propagation velocities of elastic longitudinal (P-wave) and transverse (S-wave) waves were determined. Additionally, the values of the relevant physical-mechanical parameters were assessed.

The report presents cross-sections of 4 seismic profiles, each 69 meters in length, with a total length of 276 meters (see Fig. 1.1). Table 1.1 shows the starting and ending coordinates of the seismic profiles in the UTM system along with absolute elevations.

Based on the values of the geophysical parameters, three distinct layers with different properties were identified on the seismic profiles. In our assessment, and considering the geological data from the surrounding areas and the elastic wave velocity values, these correspond to:

- **Layer 1** – Clay and clayey soils of varying consistency, occasionally containing hard pebbles, gravel, and cobble inclusions. The range of longitudinal and transverse wave velocities is: **V_p = 221–377 m/s; V_s = 148–252 m/s**. This layer corresponds to layers SGE1 to SGE5 described in the geological investigation report.
- **Layer 2** – Pebbly-gravelly deposits with a firm clay-sand matrix. The range of longitudinal and transverse wave velocities is: **V_p = 728–985 m/s; V_s = 287–377 m/s**.

This layer corresponds to layer SGE6 in the geological investigation report.

- **Layer 3** – Weathered and fractured alternation of foliated and thin-bedded argillites and medium-bedded sandstones. The range of longitudinal and transverse wave velocities is: **V_p = up to 2776 m/s; V_s = 1364–1423 m/s**.

This layer corresponds to layer SGE7 in the geological investigation report.

The resulting seismic cross-sections are shown in Figures 2 through 5, and the relevant physical-mechanical parameters have been calculated accordingly.

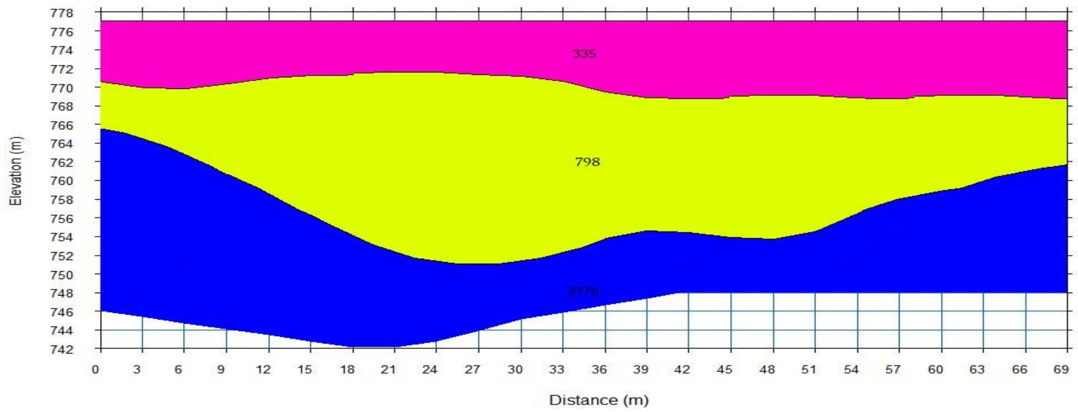

Fig. 2. Seismic section №1.

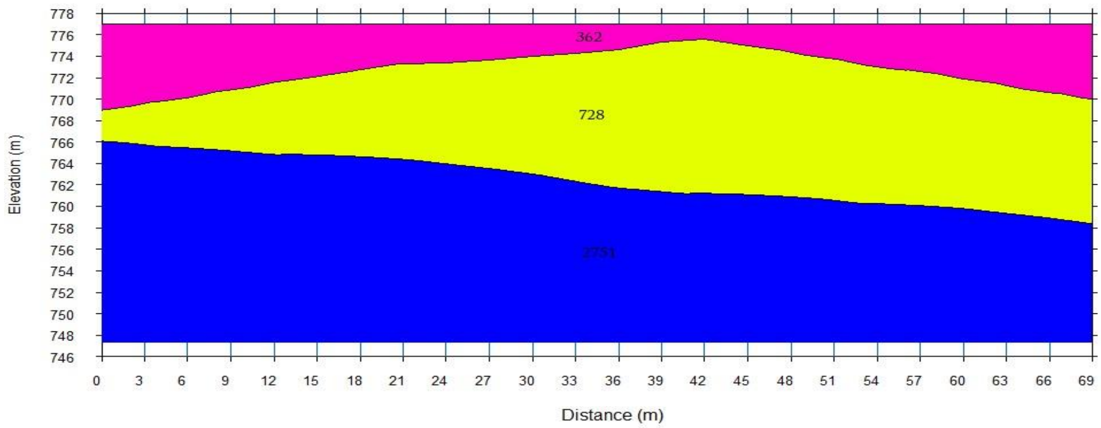

Fig.3. Seismic section №2.

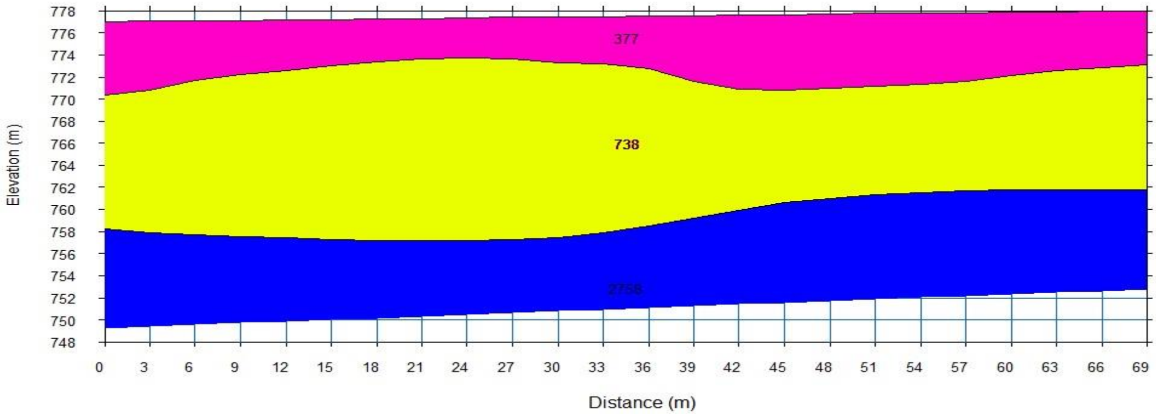

Fig.4. Seismic section №3.

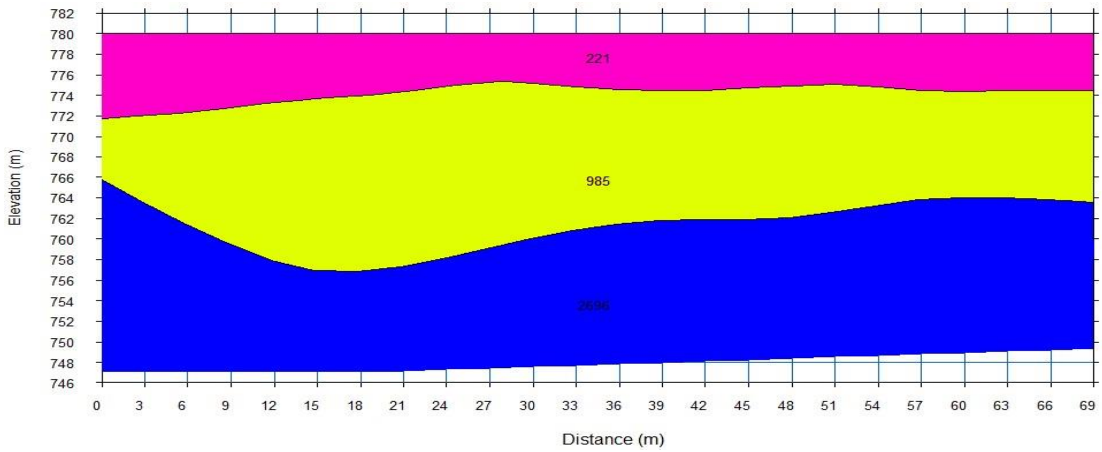

Fig. 5. Seismic section №4

Based on geophysical surveys, soil categories were assessed using the average shear-wave velocity in the upper 30 meters of the ground (Vs30). Averaged shear-wave velocities were obtained for the study area, and the corresponding soil categories were determined according to both Georgian national standards and international standards (IBC2006, Eurocode 8, ASCE7). For this area, the average shear-wave velocity in the upper 30 meters (Vs30) was found to be 382 m/s.

According to the national standards of Georgia, each profile area corresponds to Soil Category II, while under international standards, the classification is as follows: Eurocode 8 – Class B, IBC2006 and ASCE7 – Class C.

The detailed velocity values and corresponding soil categories for each profile area are presented in Table 2.

Table 2.

Prof. N	Vs30 (m/s)	DN 01.01-09 (Georgian Standard)	IBC2006 (International Standard)	ASCE (American Standard)	Eurocode 8 (European Standard)
1	365	II	D	D	B
2	401	II	C	C	B
3	401	II	C	C	B
4	361	II	D	D	B

Clarification of the Seismicity of the Study Area

The seismicity of the construction site was determined using the method of seismic stiffness, which involves adjusting the seismicity by comparing the acoustic stiffness of the reference soil to that of the investigated soil. The calculation is performed using the following formulae [2.2, 2.3, 2.4]: I=I0+ΔI, Where: **I** is the adjusted seismic intensity, $\mathbf{I_0}$ is the intensity of the reference soil, determined by seismic microzonation, **ΔI** is the intensity increment, calculated by the formula:

ΔI=1.67·log(V0·ρ0Vi·ρi)+exp(−0.04·h2), Where: $\mathbf{V_0}$ and $\mathbf{\rho_0}$ are the velocity of shear (or longitudinal) waves and density of the reference soil, $\mathbf{V_i}$ and $\mathbf{\rho_i}$ are the respective values for the investigated soil, **h** is the depth of groundwater below the foundation level.

According to the engineering-geological report, groundwater was detected and stabilized in five geological boreholes:

- Borehole #3 – stabilized at 12.0 m,
- Borehole #4 – 12.2 m,
- Borehole #7 – 13.3 m,
- Borehole #9 – 9.3 m,
- Borehole #11 – 13.7 m.

Groundwater was not detected in the remaining boreholes. The average groundwater depth across the construction site is **h = 12.1 m** (minimum **h = 9.3 m**).

Taking these values into account, the intensity increment is calculated as:

ΔI=1.67·log[(600±100)·(1750±50)/((429±64)·(1911±61))]+exp(−0.04·9.32) =0.3517±0.1324≈0 intensity)

Conclusions

Based on the method of acoustic stiffness used on the construction site, the obtained increment in seismic intensity is: For reference intensity $\mathbf{I_0 = 8}$, ΔI = 0.3517 ± 0.1324 (maximum value 0.48 < 0.50), 0 intensity, no full additional intensity grade is added, **Final adjusted seismic intensity** for the construction site is **I = 8**.

Using this method, the **calculated design horizontal acceleration** on the construction site is **0.274 g** (**2.688 m/s²**).

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ბორჯომის რაიონში სოფ. ყვიბისში სეისმური კვლევები და სეისმურობის დაზუსტება ლოკალური პარამეტრების გათვალისწინებით

მ. გიგიბერია, ვ. არაბიძე, ჯ. ქირია, ნ. ღლონტი

რეზიუმე

ქანების კლდოვანი მასივების სანჟინრო-გეოლოგიური თვისებების შესახებ ობიექტური ინფორმაციის მისაღებად საჭიროა კვლევების ფართო კომპლექსის ჩატარება, რომელშიც შედის გეოლოგიური, გეოტექნიკური, ჰიდროგეოლოგიური, გეოფიზიკური და უპირველეს ყოვლისა სეისმოაკუსტიკური კვლევები. საინჟინრო სეისმოაკუსტიკის ფიზიკურ საფუძველს წარმოადგენს დრეკადი ტალღების პარამეტრების მჭიდრო დამოკიდებულება საკვლევი კლდოვანი მასივების აგებულების, თვისებებისა და მდგომარეობის თავისებურებებთან.
ეს ნაშრომი შეეხება საინჟინრო გეოფიზიკის, კერძოდ სეისმიკის როლს მნიშვნელოვანი ნაგებობების მშენებლობაში. მაგალითის სახით მოვიყვანთ კონკრეტულ პროექტებს და მათი განხორციელებისათვის გამოყენებულ მეთოდებს.

საკვანძო სიტყვები: საინჟინრო გეოფიზიკა, სეისმურობა, კლდოვანი მასივები.

Сейсмические исследования и уточнение сейсмичности с учетом локальных параметров в селе Квибиси, Боржомский район

М. Гигиберия, В. Арабидзе, Д. Кириа, Н. Глонти

Резюме

Для получения объективной информации о инженерно-геологических свойствах скальных массивов необходимо проведение широкого комплекса исследований, включающего геологические, геотехнические, гидрогеологические, геофизические и, прежде всего, сейсмоакустические исследования. Физической основой инженерной сейсмоакустики является тесная зависимость параметров упругих волн от особенностей строения, свойств и состояния исследуемых скальных массивов.
Настоящая работа посвящена роли инженерной геофизики, в частности сейсмики, в строительстве значимых сооружений. В качестве примера приведены конкретные проекты и методы, использованные для их реализации.

Ключевые слова: инженерная геофизика, сейсмичность, скальные массивы.

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Construction of Seismic Profiles and Seismic Hazard Assessment Considering Local Parameters on the Reconstruction Site Located on Ilia Chavchavadze Street, Dusheti

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Jemal K. Kiria, Nugzar I. Ghlonti

ABSTRACT

Obtaining objective information on the engineering and geological properties of rock masses requires a broad range of studies, including geological, geotechnical, hydrogeological, and geophysical ones. The physical basis of engineering seismic acoustics is the close relationship between elastic wave parameters and the structural features, properties, and condition of the rock masses being studied.
This article examines the role of engineering geophysics in the construction of critical structures. Specific projects and their implementation methods are presented as examples.

Key words: *engineering geophysics, seismicity, rock massifs.*

Introduction

We conducted a series of works that involved the construction of seismic profiles and clarification of seismic hazard considering local parameters on the reconstruction site located at Ilia Chavchavadze Street #27, in the city of Dusheti.

Experimental Studies: Construction of Soil Seismic Profiles

Seismic profiling was carried out using the refraction wave method [1-13], obtaining data up to a depth of 30 meters. Additionally, the physical and mechanical parameters of the rocks were assessed based on the propagation velocities of elastic waves (both longitudinal and shear waves). A seismic profile 38 meters in length was constructed.

Figure 1 shows the study area and the location of the seismic profile. The corresponding start and end coordinates of the seismic profile, along with the absolute elevations in the WGS-84 coordinate system, are presented in Table 1.

Table 1. Start and end coordinates of seismic profiles with corresponding absolute heights. 1s indicates the start of the profile, and 1e indicates the end of the profile.

GPH #	X, m	Y, m	H, m
1s	475165	4659307	887
1e	475145	4659275	884

Fig. 1. Study area and schematic layout of seismic profiles.

Geophysical Investigations (Seismic Profiling)

Seismic profiling using the refraction wave method is one of the key techniques for investigating rock properties in solving engineering seismological problems. Our main objective was to study the structure of the given area and to determine the physical-mechanical parameters based on the velocities of longitudinal (P) and transverse (S) elastic waves.

For this purpose, the field seismic method of refracted waves was selected. The refraction wave method allows for the determination of the thicknesses of surface and deeper layers, as well as the velocities of elastic wave propagation within them.

The method is based on determining the arrival times of the first P and S waves from an elastic wave source to geophones arranged in a straight line. This makes it possible to calculate the velocity of the longitudinal wave.

Thus, the objective of the investigation was to determine the rock structure down to a depth of 30 meters and to define the following physical-mechanical parameters within the identified structural elements:

Table 2.

Vp m/sec	Longitudinal wave velocity
Vs m/sec	Transverse wave velocity
Vs/Vp	Velocity ratio
ρ gr/cm^3	Density
μ	Poisson's ratio
Ed Mpa	Young's dynamic modulus
Gd MPa	Shear dynamic modulus
Kd Mpa	Dynamic modulus of universal compression
D Mpa	Total deformation modulus
τ Mpa	Tensile strength limit

Note: Parameters 1–3 were obtained through field investigation, parameters 5–8 were calculated based on known theoretical relationships, while parameters 4, 9, and 10 were derived using available empirical correlations.

Seismic profiling was conducted using 10 Hz geophones spaced 2 meters apart. Seismic waves were induced by striking a special plastic plate with a 10 kg hammer. Both geophones and impacts were oriented along Z-Z and Y-Y axes. A five-shot point system was used, which included two shots at the beginning and end of the profile, one shot in the middle, and two off-end shots placed at a significant distance from the profile. This configuration enabled the acquisition of information down to a depth of 30 meters. Depending on the type of wave, the orientation of the impact was adjusted.

Wave recordings were made using a 24-channel engineering seismic station, model GEODE, manufactured by the American company GEOMETRICS. The direction of the impact varied depending on the wave type. Subsequently, interpretation was carried out using the licensed SeisImager software, also developed by GEOMETRICS. Seismogram analysis was performed, a geological cross-section was constructed, and the corresponding physical-mechanical parameters were evaluated.

Seismic profiling using the refraction wave method was carried out in the study area. A 38-meter-long seismic profile was acquired, providing subsurface information to a depth of 30 meters. Figure 1 shows the study area and the location of the seismic profile. The starting and ending coordinates of the profile, along with absolute elevations in the WGS-84 system, are presented in Table 3 below.

Table 3

GPH #	X, m	Y, m	H, m
1s	475165	4659307	887
1e	475145	4659275	884

Based on geophysical parameters, different engineering-geological elements (layers) have been identified, and the distribution of P-wave (VP) and S-wave (VS) velocities within them has been determined. The corresponding physical-mechanical parameters were also obtained. According to the constructed geophysical cross-section, three distinct layers are observed based on their physical properties (due to the lack of detailed engineering-geological information, identification is based on geophysical data and local visual observations, and is therefore somewhat conditional):

- **Layer 1** – Loose material, dry, decompressed;
- **Layer 2** – Clayey, highly decompressed;
- **Layer 3** – Clayey, presumably water-saturated.

Seismic Profile #1

Layer 1 extends from the surface down to a depth of 1.8–2.5 meters with the following seismic velocities: VP = 227 m/s; VS = 142 m/s.

Layer 2 lies beneath Layer 1 and varies in thickness from 0.5 to 7.0 meters. Its seismic velocities are: VP = 691 m/s; VS = 318 m/s.

Layer 3, observed down to a depth of 30 meters, is located below Layer 2 and has the following seismic velocities: VP = 876 m/s; VS = 433 m/s.

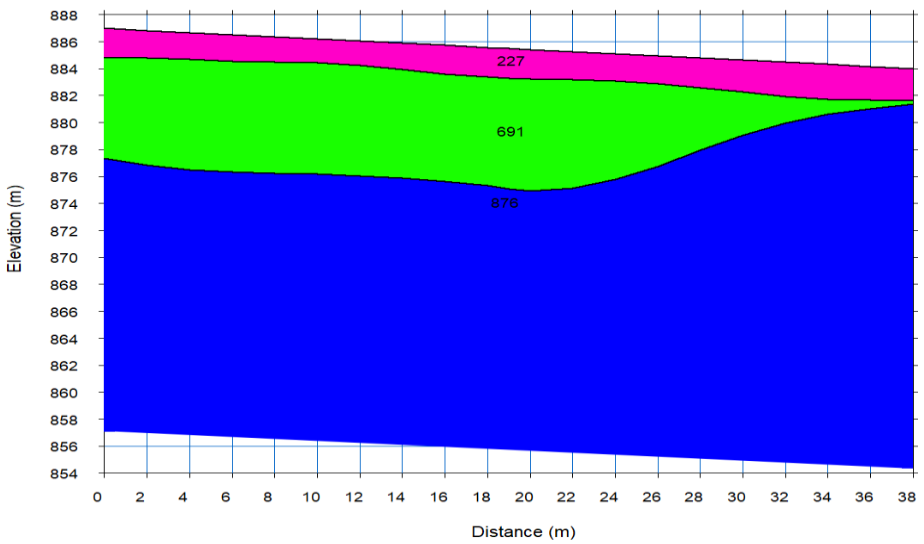

Fig. 2. Seismic section №1.

Layer N	Parameter	Parameter description	Values	Capacity, m
1	**Vp m/sec**	Longitudinal wave velocity	227	2
	Vs m/sec	Transverse wave velocity	142	
	Vs/Vp	Velocity ratio	0.63	
	ρ gr/cm^3	Density	1.25	
	μ	Poisson's ratio	0.18	
	Ed Mpa	Young's dynamic modulus	60	
	Gd MPa	Shear dynamic modulus	25	
	Kd Mpa	Dynamic modulus of universal compression	308.01	
	D Mpa	Total deformation modulus	0.37	
	τ Mpa	Tensile strength limit	-	
2	**Vp m/sec**	Longitudinal wave velocity	691	4
	Vs m/sec	Transverse wave velocity	322	
	Vs/Vp	Velocity ratio	0.47	
	ρ gr/cm^3	Density	1.65	
	μ	Poisson's ratio	0.36	
	Ed Mpa	Young's dynamic modulus	470	
	Gd MPa	Shear dynamic modulus	171	
	Kd Mpa	Dynamic modulus of universal compression	5600.50	
	D Mpa	Total deformation modulus	10.09	
	τ Mpa	Tensile strength limit	2.45	
3	**Vp m/sec**	Longitudinal wave velocity	876	24
	Vs m/sec	Transverse wave velocity	438	
	Vs/Vp	Velocity ratio	0.50	
	ρ gr/cm^3	Density	1.75	
	μ	Poisson's ratio	0.33	
	Ed Mpa	Young's dynamic modulus	900	
	Gd MPa	Shear dynamic modulus	336	
	Kd Mpa	Dynamic modulus of universal compression	8961.87	
	D Mpa	Total deformation modulus	28.56	
	τ Mpa	Tensile strength limit	4.80	
Vs30, m/sec		Average transverse wave velocity up to 30 m depth	36	9

Conclusion

Based on geophysical surveys and the average shear-wave velocity in the upper 30 meters of soil (VS30, which was determined to be 369 m/s for the construction site), the soil categories were determined according to both Georgian standards and international standards (IBC 2006, Eurocode 8, ASCE 7). It should be noted that, according to Georgian standards, the soil corresponds to Category II, while according to international standards, it was classified as follows: Eurocode 8 – Type B, IBC 2006 and ASCE 7 – Class C.

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ქ. დუშეთში, ილია ჭავჭავაძის ქუჩის სარეკონსტრუქციო ობიექტის ტერიტორიაზე სეისმური პროფილების აგება, სეისმურობის დაზუსტება ლოკალური პარამეტრების გათვალისწინებით

მ. გიგიბერია, ვ. არაბიძე, ჯ. ქირია, ნ. ღლონტი

რეზიუმე

ქანების კლდოვანი მასივების სანჟინრო-გეოლოგიური თვისებების შესახებ ობიექტური ინფორმაციის მისაღებად საჭიროა კვლევების ფართო კომპლექსის ჩატარება, რომელშიც შედის გეოლოგიური, გეოტექნიკური, ჰიდროგეოლოგიური და გეოფიზიკური კვლევები. საინჟინრო სეისმოაკუსტიკის ფიზიკურ საფუძველს წარმოადგენს დრეკადი ტალღების პარამეტრების მჭიდრო დამოკიდებულება საკვლევი კლდოვანი მასივების აგებულების, თვისებებისა და მდგომარეობის თავისებურებებთან.
ეს ნაშრომი შეეხება საინჟინრო გეოფიზიკის როლს მნიშვნელოვანი ნაგებობების მშენებლობაში. მაგალითის სახით მოვიყვანთ კონკრეტულ პროექტებს და მათი განხორციელებისათვის გამოყენებულ მეთოდებს.

საკვანძო სიტყვები: საინჟინრო გეოფიზიკა, სეისმურობა, კლდოვანი მასივები.

Сейсмические исследования и уточнение сейсмичности с учетом локальных параметров в селе Квибиси, Боржомский район

М. Гигиберия, В. Арабидзе, Д. Кириа, Н. Глонти

Резюме

Для получения объективной информации об инженерно-геологических свойствах скальных массивов необходимо проведение широкого комплекса исследований, включая геологические, геотехнические, гидрогеологические и геофизические. Физической основой инженерной сейсмоакустики является тесная связь параметров упругих волн с особенностями строения, свойств и состояния изучаемых скальных массивов.

В данной статье рассматривается роль инженерной геофизики в строительстве ответственных сооружений. В качестве примера приведем конкретные проекты и методы их реализации.

Ключевые слова: инженерная геофизика, сейсмичность, скальные массивы.

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Intra-Annual Distribution of Landslide Recurrence in Georgia and its Relationship with Monthly and Cumulative Multi-Month Sums of Precipitation

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ABSTRACT

The correlation and regression relationship between the intra-annual distribution (%) of the number of landslides (LS) and the precipitation sums in the month when the landslide occurred and the accumulated sums for the month and 1...11 months before the landslide, P(1)…P(12), respectively, were studied. In particular, it was found that the intra annual distribution of landslides across the territory of Georgia is rather uneven. The highest number of landslides occurs in July and September (11.7% and 11.0%, respectively), while the lowest occur in January and November (5.3% and 5.6%, respectively). A moderate correlation is observed between the intra-annual distribution of LS with the intra-annual distributions of P(9)…(12). For the pairs LS – P(1) and LS – P(8), the correlation is low. For the remaining cases, the correlation is negligible. Linear regression equations between the parameters under study are presented.

Key words: *natural disasters, landslides, precipitation, correlation and regression analysis.*

Introduction

Landslides, as a type of natural disaster, often cause significant damage to the environment in many countries around the world [1–3], including Georgia [4–10]. In particular, [10] presents the results of a statistical analysis of data from the Geological Department of the Environmental Agency of Georgia on the annual number of activated and newly formed landslides (LS) for the period from 1995 to 2024. The number of landslides varies in the range from 56 to 1360 with an average annual value of 581. The trend in LS values has the form of a seventh-degree polynomial. In a subsequent study [11], an interval forecast of LS values up to 2030 was carried out taking into account the periodicity in the observation series. The mean predicted LS value for 2025–2030 was found to be 1582 ± 107, with a 68% confidence interval from 875 ± 107 to 2289 ± 232.

Landslide activation is caused by many natural and anthropogenic factors, including the influence of prolonged, intense, or extreme precipitation [12].

In recent years, a number of studies have been conducted in Georgia to identify the short-term (hours, days, months) [13–16] and long-term (years, climate scale) effects of precipitation on landslide and mudflow activation [17–20]. These studies used landslide and mudflow data presented in [7, 8], as well as ground-based, radar, and satellite precipitation data, taking into account their representativeness depending on the distance to the measurement point. A detailed review of these studies is presented in [21].

In our latest work [22] a detailed statistical analysis of the relationship between monthly and accumulated multi-month precipitation sums and the number of landslides in 12 regions of Georgia is presented. Landslide data with a known month and year of activation were used (a total of 788 landslide events from 1961 to 2022). For the analysis, the precipitation sum for the month of landslide activation (P1) was determined, as well as the accumulated precipitation sum for the month of activation and for 1 month (P2), 2 months (P3), …, and 11 months (P12) prior to landslide occurrence.

Specifically, the following results were obtained. The relationship between average precipitation values (threshold values) and monthly precipitation duration during the month of landslide activation and before landslide activation in Georgia and its individual regions was determined. It was found that, overall, in eastern Georgia (including the Samtskhe-Javakheti region), landslide activation occurs with significantly lower precipitation sums than in western Georgia. The average P1 values are 76 and 156 mm, respectively, and the P12 values are 684 and 1588 mm. The linear correlation between the number of landslides and the P1…P12 values across the regions of Georgia is low for P1 and moderate for P2…P12. The sum of precipitation associated with landslides exceeds the general long-term average monthly precipitation by approximately 16%. For Georgia as a whole, the dependence of the number of landslides on the P1 and P12 values has the form of a fifth-order polynomial (sequentially: slight increase – plateau – strong increase). For P1 values, the precipitation sum plateau, after which a strong increase in the number of landslides begins, covers the range from 62 to 149 mm, and for P12 – from 914 to 1588 mm (the number of landslides is ≈ 108–114).

This work is a continuation of the study [22]. Below are the results of the analysis of the relationship between the intra-annual distribution of landslide frequency in Georgia and monthly and accumulated multi-month precipitation sums.

Study area, material and methods

Study area is Georgia.

Data on the number of landslides with a known month of their activation were taken from the catalog [7]. Period of observation - from 1961 to 2022. Total - 788 landslide cases.

Data National Environmental Agency about monthly sum of atmospheric precipitations for 78 meteorological stations are used. List of meteorological stations, their coordinates and locations in [22] are presented.

In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods [23].

The following designations will be used below: R – coefficient of linear correlation; 1....12 - January .... December; LS(1)...LS(12) - the ratio of the number of landslides from January to December to their annual number, %; P(1)...P(12) - the ratio of the sum of precipitation in the month with landslide activation to their cumulative sum in the month and 1…11 months before the landslide, respectively, %;

The degree of correlation was determined in accordance with [23]: very high correlation ($0.9 \le R \le 1.0$); high correlation ($0.7 \le R < 0.9$); moderate correlation ($0.5 \le R < 0.7$); low correlation ($0.3 \le R < 0.5$); negligible correlation ($0 \le R < 0.3$).

Results and discussion

Results in Fig. 1-3 are presented.

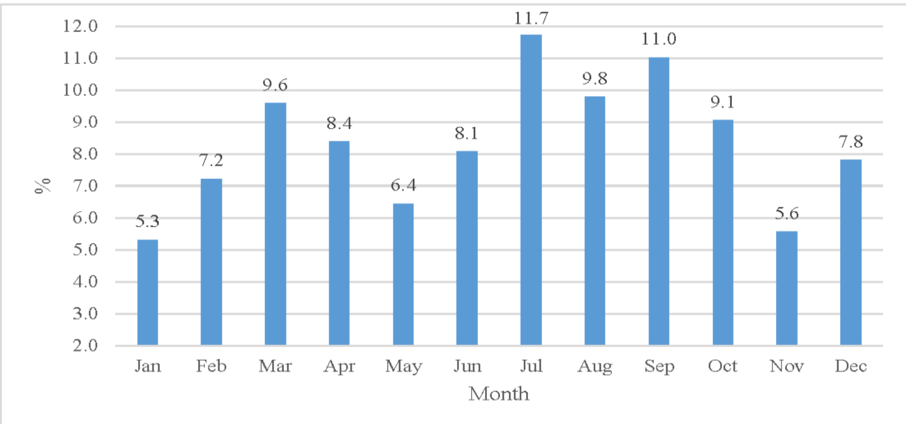

Fig. 1. Intra-annual distribution of landslide recurrence in Georgia.

In Fig. 1 intra-annual distribution of landslide recurrence in Georgia is presented. As this figure shows, the intra annual distribution of landslides across Georgia is quite uneven. The highest number of landslides occurs in July and September (11.7% and 11.0%, respectively), while the lowest occur in January and November (5.3% and 5.6%, respectively).

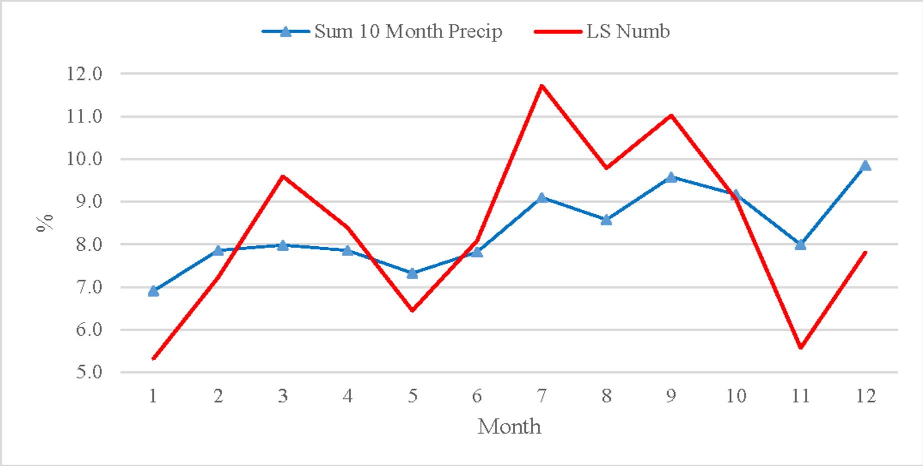

Fig. 2. Intra-annual distribution of the recurrence of landslides and P(10) in Georgia.

In Fig. 2 as an example intra-annual distribution of the recurrence of landslides and P(10) in Georgia is presented. The correlation coefficient between the specified distributions is 0.66 (Fig. 3, moderate correlation).

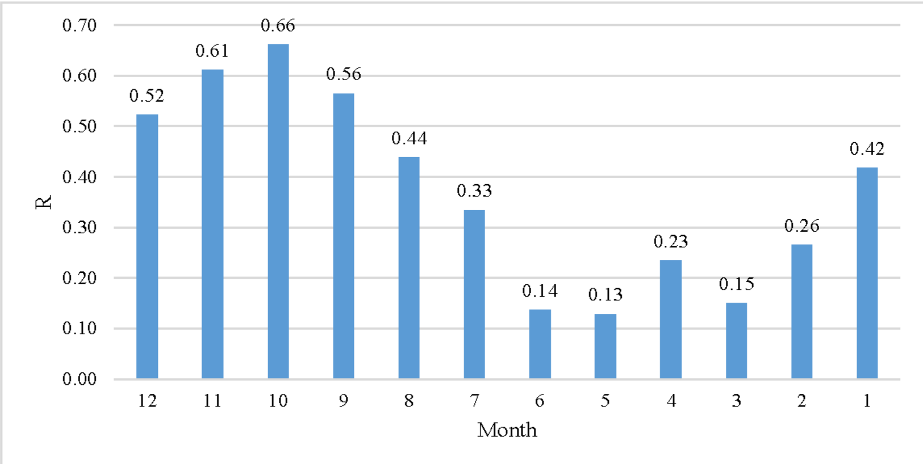

Fig. 3. Linear correlation between the intra-annual distributions of landslides and P(1)…P(12) in Georgia. Correlation coefficient values from 0.13 to 0.33 are negligible.

Fig. 3 also shows that a moderate correlation is also observed between the intra-annual distribution of LS with the intra-annual distributions of P(9), P(11), and P(12). For the pairs LS – P(1) and LS – P(1), the correlation is low. For the remaining cases, the correlation is negligible.

Linear regression equations between the intra-annual distributions of landslides (y) and P(1), P(8)…(P12), (x), in Georgia are as follows: P(1): $y = 0.3753x + 5.2062$; P(8): $y = 0.9013x + 0.8224$; P(9): $y = 1.2998x - 2.4986$; P(10): $y = 1.4601x - 3.8339$; P(11): $y = 1.3305x - 2.754$; P(12): $y = 1.0938x - 0.7817$.

Conclusion

In the near future, as new data accumulates, we plan to refine the results obtained in this study. We also plan to conduct research assessing the role of various factors (including precipitation) in landslide activation using artificial intelligence methods in both steady-state and dynamic modes.

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მეწყრული განმეორების შიდა წლიური განაწილება საქართველოში და მისი კავშირი ნალექების ყოველთვიურ და კუმულაციურ მრავალთვიან ჯამებთან

ა. ამირანაშვილი, ლ. ბროკა, თ. ჭელიძე, თ. ქირია,
დ. სვანაძე, თ. წამალაშვილი, ნ. ვარამაშვილი

რეზიუმე

შესწავლილი იქნა მეწყერების რაოდენობის (LS) წლიური განაწილების (%) და მეწყერის თვეში ნალექების რაოდენობის, ასევე მეწყერამდე ერთი თვისა და 1…11 თვით ადრე დაგროვილი რაოდენობის, შესაბამისად, P(1)…P(12) შორის კორელაციისა და რეგრესიის კავშირები. კერძოდ, დადგინდა, რომ საქართველოში მეწყერების წლიური განაწილება საკმაოდ არათანაბარია. მეწყერების ყველაზე დიდი რაოდენობა ივლისსა და სექტემბერში ხდება (შესაბამისად 11.7% და 11.0%), ხოლო ყველაზე მცირე - იანვარსა და ნოემბერში (შესაბამისად 5.3% და 5.6%). ზომიერი კორელაცია შეინიშნება LS წლიური განაწილებისა და წლიური განაწილების P(9)…(12) შორის. LS – P(1) და LS – P(8) წყვილებისთვის კორელაცია დაბალია. სხვა შემთხვევებში კორელაცია უმნიშვნელოა. წარმოდგენილია შესწავლილ პარამეტრებს შორის წრფივი რეგრესიის განტოლებები.

საკვანძო სიტყვები: სტიქიური უბედურება, მეწყერი, ნალექი, კორელაციული და რეგრესიული ანალიზი.

Внутригодовое распределение частоты оползней в Грузии и его связь с месячными и накопленными многомесячными суммами осадков

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Резюме

Изучена корреляционная и регрессионная связь между внутригодовым распределением (%) количества оползней (LS) и суммами осадков в месяце, когда произошел оползень, и накопленной сумме за месяц и 1…11 месяцев до оползня, P(1)…P(12), соответственно. В частности, получено, что внутригодовое распределение оползней по Грузии довольно неравномерно. Наибольшее количество оползней приходится на июль и сентябрь (11.7% и 11.0% соответственно), а наименьшее — на январь и ноябрь (5.3% и 5.6% соответственно). Наблюдается умеренная корреляция между внутригодовым распределением LS и внутригодовыми распределениями P(9)…(12). Для пар LS – P(1) и LS – P(8) корреляция низкая. В остальных случаях корреляция незначительна. Представлены уравнения линейной регрессии между исследуемыми параметрами.

Ключевые слова: стихийные бедствия, оползни, атмосферные осадки, корреляционный и регрессионный анализ.

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Modeling and Forecasting System of the Hydrological Fields in the Georgian Waters of the Black Sea and its Further Development

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ABSTRACT

This paper discusses current state and further development of the high-resolution marine regional modeling and forecasting system for the Georgian sector of the Black Sea and adjacent waters, which has been developed within the EU international scientific and technical projects ARENA (2003-2006), ECOOP (2007-2010). Its further expansion with the inclusion of impurity transport models in the system was carried out within the framework of Shota Rustaveli National Science Foundation grant (2013-2015). This system, based on a regional numerical model of the Black Sea dynamics and 2-D and 3-D transport models of the impurity, provides modeling of the main hydrological fields and the spread of oil and other impurities with a spatial resolution of 1 km. In the case of providing real input data, the system makes it possible to forecast the state of the sea for several days in advance. Further development of the existing regional modeling system is related to the development of a very high-resolution modeling subsystem for the Batumi-Poti-Anaklia nearshore water area and the inclusion of a wind wave forecast model in the subsystem. The purpose of the very high-resolution modeling subsystem is to specify and make more detailed marine forecast for the Batumi-Poti-Anaklia coastal waters (with a spatial resolution of 200 m), which are subject to the greatest anthropogenic load.

Key words: *forecasting system, mesoscale eddies, high-resolution model, system of equations, boundary conditions.*

Introduction

According to many experts, recent decades have been characterized by the intensification of human activity, which has led to a deterioration in the ecological state of the natural environment, including the hydrosphere. In this regard, the Black Sea is no exception. According to numerous studies the level of pollution of the Black Sea with oil products, marine litter, plastics and other pollutants is growing [1, 2]. Anthropogenic pressure on marine ecosystems increases sharply in areas of intense technogenic activity. Intensive use of the coastal and shelf zones of the Black Sea leads to an increase in anthropogenic load and deterioration of the ecological situation in these zones, to which many marine organisms react sharply [3, 4].

For Georgia, as a Black Sea country, the ecological safety of the coastal zone is especially important, since the contribution of the Black Sea in terms of the socio-economic situation of the country is very relevant. The most important part of the Georgian Black Sea sector is the Adjara (Batumi)-Poti-Anaklia nearshore water area, where economic activity is growing significantly: the flow of tourists is growing every year, the coastal infrastructure is developing intensively. In the coming years, the Black Sea transport function is expected to increase since the construction of Anaklia deep-water port is on the agenda.

In conditions of intense anthropogenic load, a very high-resolution coastal modeling and forecasting system, which provides a timely and detailed forecast of the state of the Georgian nearshore waters by identifying the pollution zones, acquires significant relevance.

As a result of participation in the EU International scientific and technical projects ARENA (2003-2006) and ECOOP (2007-2010), M. Nodia Institute of Geophysics developed a regional marine forecasting system for the southeastern part of the Black Sea, which includes the Georgian sector of the Black Sea and the adjacent water area. The regional system became one of the components of the Black Sea basin-scale monitoring and forecasting system. The main core of the regional system - the regional model of the Black

Sea dynamics (RM-IG) of M. Nodia Institute of Geophysics with 1 km horizontal resolution, was nested in the basin-scale model of the Black Sea dynamics of Marine Hydrophysical Institute (Sevastopol, Ukraine) with 5 km horizontal resolution. The RM-IG is based on the solution of the complete system of the ocean hydrothermodynamic equations with appropriate initial and boundary conditions. 2-D and 3-D numerical transport models of oil and other impurities based on non-stationary advection-diffusion equations are coupled with the RM-IG.

Finite-difference methods based on the two-cycle splitting method are used to solve the equations of the models included in the modeling system [5].

We were able to receive all necessary input data every day required for forecast calculations via the Internet during 2010-2021, which was provided within the framework of the mentioned EU projects. A detailed description of the methodology for calculating marine forecasts is presented in [6-8].

In the case of real input data the regional forecasting system makes it possible to calculate a 3-day forecast of the main hydrophysical fields - current, temperature and salinity with a horizontal resolution of 1 km in the Georgian sector of the Black Sea and in emergency situations to predict zones of pollution and concentrations of oil and other impurities.

The present paper discusses the further development of a high-resolution marine regional forecasting system for the Georgian sector of the Black Sea and adjacent waters by developing a very high-resolution modeling subsystem for the Batumi-Poti-Anaklia nearshore water area. In addition, examples of short-term forecasting of the main hydrophysical fields and oil slick transport are given to illustrate the functioning of the existing forecasting system.

Results and discussions

The computer implementation of the RM-IG is carried out on a computational grid that includes 30 vertical computational levels with uneven grid steps (the minimum grid step is 2 m near the sea surface, the maximum is 100 m). The number of grid nodes on each horizon is 215x 347 with the grid step 1 km. The time step is equal to 0.5 hours.

Numerous numerical studies conducted on the basis of the RM-IG under the conditions of real atmospheric forcing showed that the Georgian sector of the Black Sea and the surrounding water area are characterized by high dynamic activity, where the formation of various mesoscale and submesoscale vortex structures continuously occurs (i. g. [9-13]).

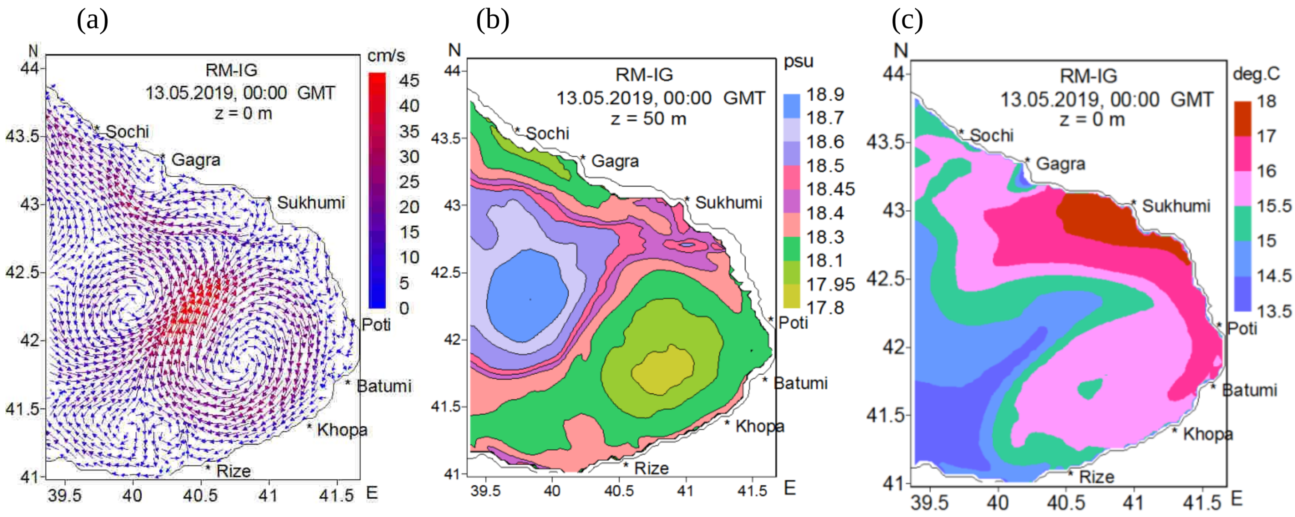

Fig.1. Predicted surface current (a), salinity (on z = 50 m) (b) and SST (c) on 13 May 2019, 00:00 GMT. The forecasting time period is 00:00 GMT, 10 – 13 May, 2019.

As an example, in Fig.1 predicted sea surface current, salinity (on the depth of 50 m) and sea surface temperature (SST) fields are shown at t=72 hours (time is accounted from the initial moment of the forecast) corresponding to 00:00 GMT, 13 May 2019. The forecasting time period was 00:00 GMT, 10.05.-13.05 May 2019. In Fig. 1a is clearly shown that the circulation on May 13, 2019 was characterized by the formation of two main structural elements - an anticyclonic eddy in the southeastern part of the considered area and a cyclonic eddy located in the northwest direction from the cyclonic eddy. The formation of some submesoscale eddies is also observed here.

In Fig.2 geostrophic current field reconstructed using satellite altimeter data is shown for the same time moment ((http://dvs.net.ru/mp/data/main.shtml). Comparison of the predicted circulation field (Fig1a) with the geostrophic current (Fig.2) shows good agreement with each other. Note that the geostrophic approximation cannot reproduce the submesoscale eddies identified by the model. Comparison of salinity (Fig1b) and circulation fields (Fig.1a) shows a significant contribution of the flow field to the formation of the distribution of salinity: waters of the central part of the anticyclonic eddy are characterized with relatively low salinity, while in the central part of cyclonic eddy the salinity is relatively high. This feature of the salinity distribution depending on the circulation regime is well known from the previous studies [6-7]. From Fig.1c is well visible that waters near the Georgian shoreline were characterized by relatively high temperature and the temperature decreases away from the shore.

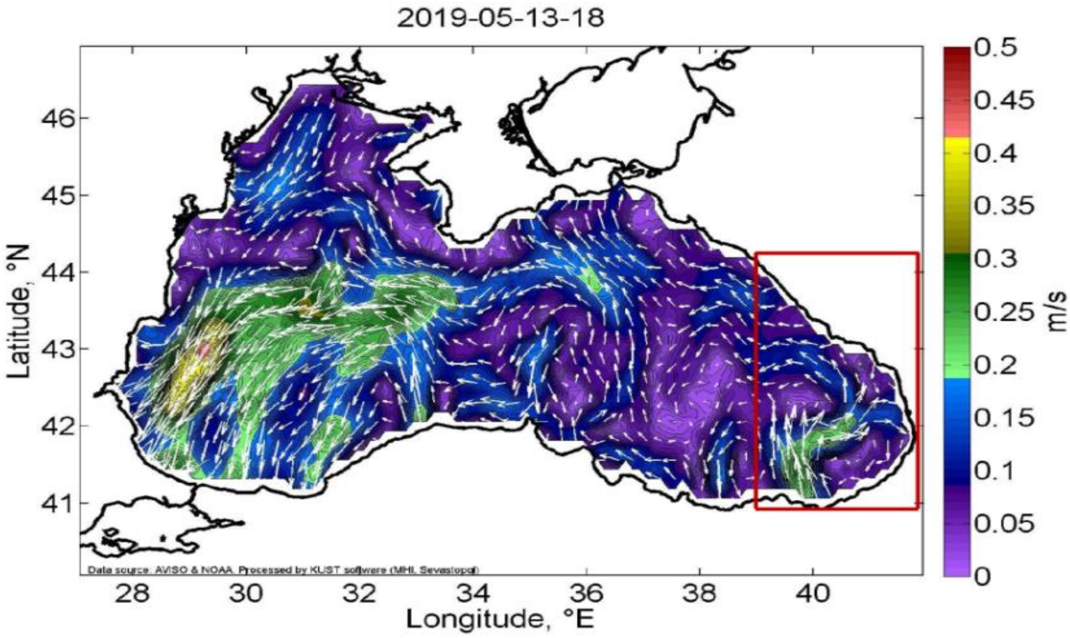

Fig.2. Geostrophic current field on 13 May 2019 reconstructed using satellite altimeter data. By rectangle the forecasting area is marked.

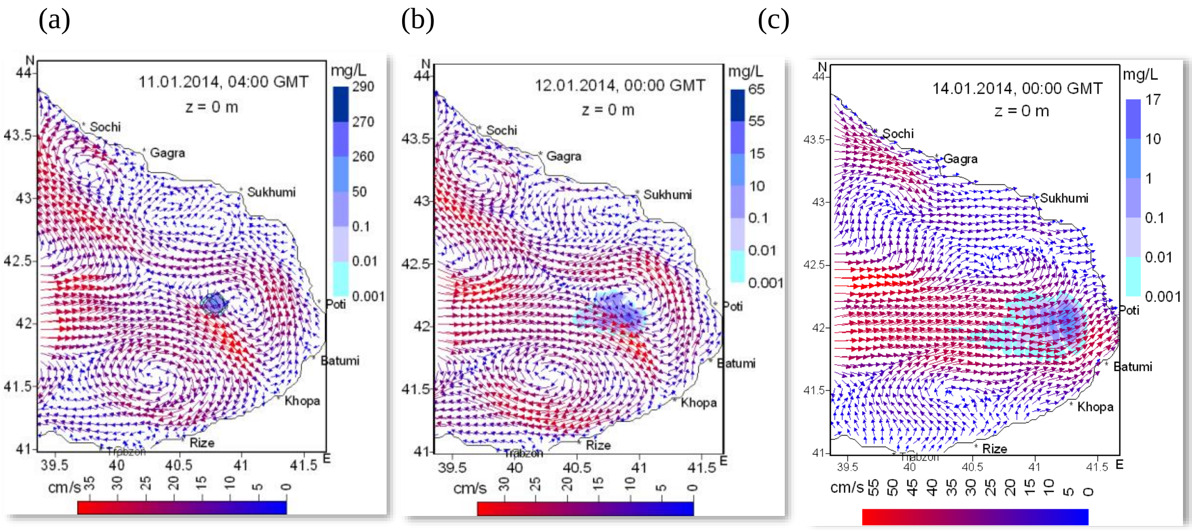

Fig.3. Predicted surface current fields and oil spill transport corresponded to the following time moments after oil flood: (a) - 4h, (b) - 24 h, (c) - (72). the forecasting period: 00:00 GMT,11-14 January 2014.

In Fig.3 predicted surface current fields and oil spill transport are shown, when the forecasting period was 00:00 GMT, 11-14 Jainuary 2014. In a numerical experiment, a hypothetical emergency oil spill into the sea occurred at a distance of about 70 km from the coast of Georgia. The oil spill occurred over four hours in the amount of 10 tons. The oil spill was considered as a point source. It is evident from the Fig.3 that the oil slick gradually expands and, under the influence of circulation, approaches the Georgian coast.

We consider further development of the regional forecasting system by developing a very high-resolution modeling subsystem (with a grid step of 200 m) for the Batumi-Poti-Anaklia nearshore area with sizes of about 54x177 km, which is subject of great anthropogenic load. The modeling subsystem will become a part of the existing regional modeling and forecasting system. Increasing the resolution of the numerical model is a very important factor for identifying unstable coastal submesoscale eddies that often form in this water area. It should be noted that the seabed topography in this area is characterized by the presence of underwater canyons [14], which are practically impossible to take into account in a model with a resolution of 1 km. In addition, a very high resolution of the model will allow us to more adequately reflect the contribution of rivers to coastal processes.

A spectral model of the forecast of the sea surface waves will be developed, which will be included in the modeling subsystem for the Adjara-Poti-Anaklia adjacent water area.

Fig.4 shows the forecast area, where the forecast is calculated with a spatial resolution of 1 km, and the Batumi-Poti-Anaklia water area, where the forecast should be calculated with a resolution of 200 m.

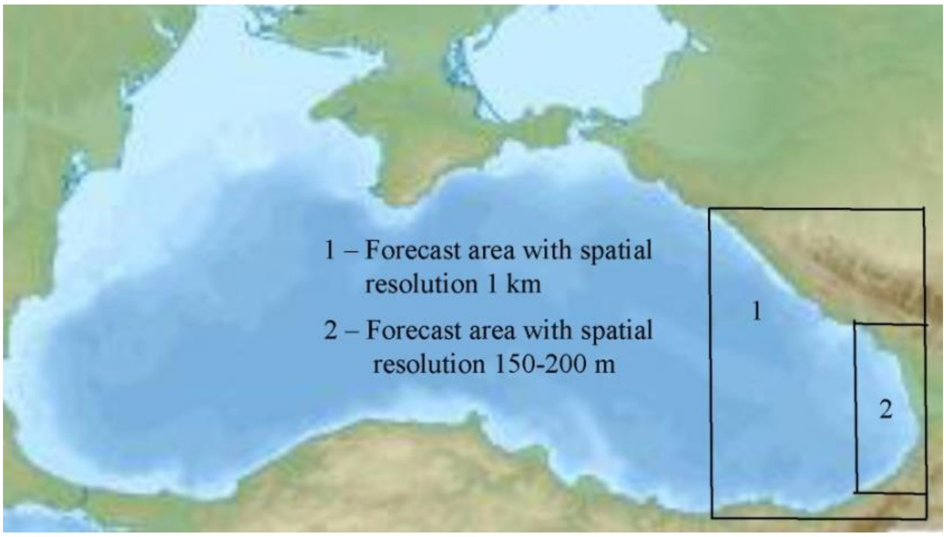

Fig.4. Regional and coastal forecast areas in the southeastern part of the Black Sea.

Fig. 5 shows the structure of the new advanced version of the marine regional forecasting system after including a very high resolution modeling subsystem into existing regional forecasting system. As shown in Fig. 5, the components of a forecasting subsystem will be the following very high-resolution models with grid step of 200 m :

- A 3-D numerical model of coastal dynamics, which will be nested in the RM-IG with 1 km resolution.
- A 2-D numerical model of oil slick transport.
- A 3-D numerical model of spreading of non-conservative impurities.
- Surface gravitational wind wave model.

The main core of the coastal forecasting subsystem will be a new very high-resolution version of the sea dynamics model, which will be obtained by adapting the RM-IG to the Adjara-Poti-Anaklia water area and increasing the spatial resolution from 1 km horizontal grid step to 200 m grid step. At the same time, the coastal forecasting subsystem will be expanded with the task of forecasting sea surface waves. It is planned that the wind wave model will be based on the spectral wave energy balance equation. It should be noted that the well known SWAN (Simulating Waves Nearshore) model in the literature is based on the same equation, which quite fully describes the formation and transformation of wave motion in coastal areas and is widely used to calculate wind waves in a number of coastal areas [15-17].

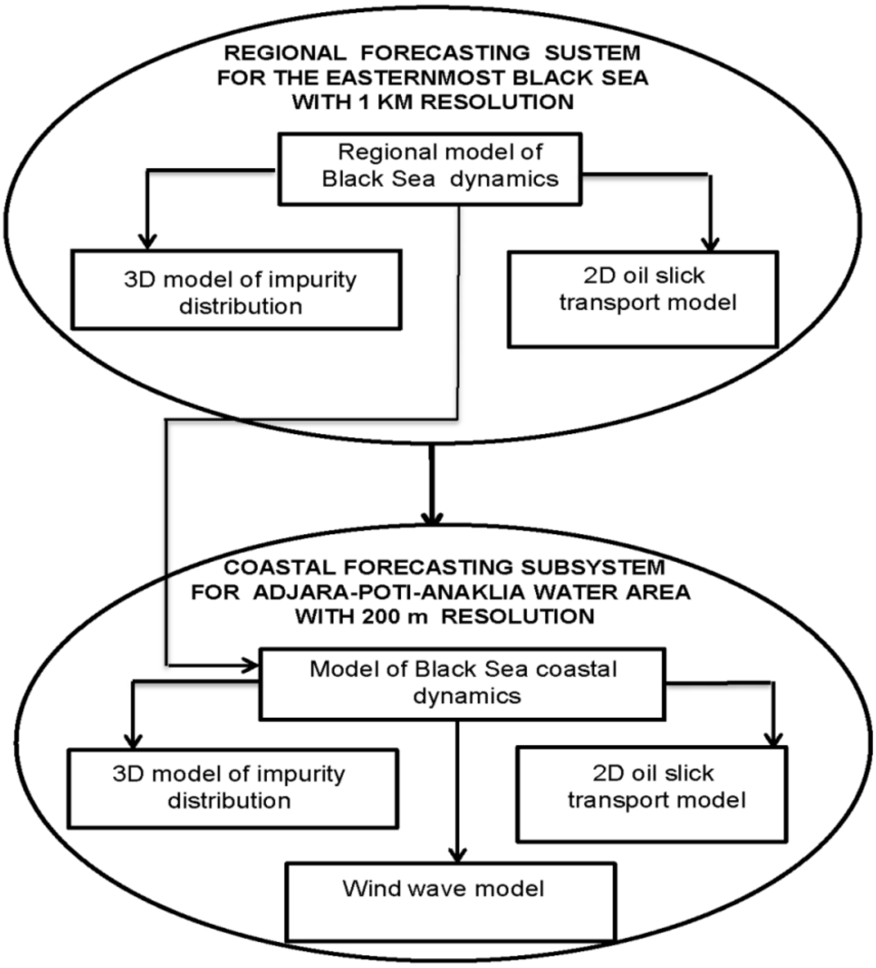

Fig. 5. The structure of the advanced version of the regional forecasting system.

The operation of the coastal forecasting subsystem will be possible together with the existing regional system using nesting modeling, which will allow us to calculate not only the forecast of dynamic fields and the spread and concentration of impurities, but also the height and direction of surface waves with a resolution of 200 m in Adjara-Poti-Anaklia nearshore zone.

the atmospheric forcing will be specified by the Meteo France regional atmospheric model **ALADIN** acting in Romanian Meteorological Organization or by the **SKIRON** forecasting system (University of Athens, http://forecast.uoa.gr/).

Conclusion

The paper presents the current state of the regional marine forecasting system for the Georgian sector of the Black Sea and adjacent water area, which will be developed by creation of a very high-resolution modeling subsystem for Batumi-Poti-Anaklia water area spatial resolution of 200 m. Modeling of hydrological processes in the Adjara-Poti-Anaklia coastal area with a very high resolution is an essential factor for high-precision reproduction of coastal processes.

Thus, a complex regional forecasting system will be created, which will combine the existing regional forecasting system with a resolution of 1 km and very high-resolution forecasting subsystem with a resolution of 200 m for the Batumi-Poti-Anaklia coastal zone. The development of this improved regional forecasting system is of great importance from the point of view of its practical use, since the operation of such a system will make it possible to provide with marine forecasts such economic sectors, for the full functioning whose operational information on the state of the Black Sea is required.

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შავი ზღვის საქართველოს წყლებში ჰიდროლოგიური ველების მოდელირებისა და პროგნოზირების სისტემა და მისი შემდგომი განვითარება

დ. დემეტრაშვილი

რეზიუმე

ნაშრომში განხილულია შავი ზღვის საქართველოს სექტორისა და მიმდებარე წყლებისთვის მაღალი გარჩევადობის საზღვაო რეგიონული მოდელირებისა და პროგნოზირების სისტემის ამჟამინდელი მდგომარეობა და შემდგომი განვითარება, რომელიც შემუშავდა ევროკავშირის საერთაშორისო სამეცნიერო-ტექნიკური პროექტების ARENA (2003-2006) და ECOOP (2007-2010) ფარგლებში. მისი შემდგომი გაფართოება პროგნოზირების სისტემაში მინარევების გადატანის მოდელების ჩართვით განხორციელდა შოთა რუსთველის ეროვნული სამეცნიერო ფონდის გრანტის ფარგლებში (2013-2015). ეს სისტემა, რომელიც დაფუძნებულია შავი ზღვის დინამიკის რეგიონულ რიცხვით მოდელსა და მინარევების 2-D და 3-D გადატანის მოდელებზე, უზრუნველყოფს ძირითადი ჰიდროლოგიური ველების და ნავთობისა და სხვა მინარევების გავრცელების მოდელირებას 1 კმ სივრცითი გარჩევადობით. რეალური შემავალი მონაცემებით უზრუნველყოფის შემთხვევაში, სისტემა შესაძლებელს ხდის ზღვის მდგომარეობის პროგნოზირებას რამოდენიმე დღის წინსწრებით. არსებული რეგიონული პროგნოზირების სისტემის შემდგომი განვითარება დაკავშირებულია ბათუმი-ფოთი-ანაკლიის სანაპირო წყლებისთვის ძალიან მაღალი გარჩევადობის მოდელირების ქვესისტემის შემუშავებასთან და ქვესისტემაში ქარისმიერი ტალღების პროგნოზირების მოდელის ჩართვასთან. ძალიან მაღალი გარჩევადობის მოდელირების ქვესისტემის მიზანია უფრო დეტალური საზღვაო პროგნოზის განხორციელება (200 მ სივრცითი გარჩევადობით) ბათუმი-ფოთი-ანაკლიის სანაპირო წყლებისთვის, რომლებიც ყველაზე დიდ ანთროპოგენურ დატვირთვას განიცდიან.

საკვანძო სიტყვები: პროგნოზის სისტემა, მეზომასშტაბური გრიგალები, მაღალი გარჩევისუნარიანი მოდელი, განტოლებათა სისტემა, სასაზღვრო პირობები.

Система моделирования и прогнозирования гидрологических полей в грузинских водах Черного моря и ее дальнейшее развитие

Д. Деметрашвили

Резюме

В данной работе рассматривается современное состояние и дальнейшее развитие системы морского регионального моделирования и прогнозирования с высоким разрешением для грузинского сектора Черного моря и прилегающих вод, разработанной в рамках международных научно-технических проектов ЕС ARENA (2003-2006), ECOOP (2007-2010). Дальнейшее ее расширение с включением в систему прогнозирования моделей переноса примесей было осуществлено в рамках гранта Национального научного фонда имени Шота Руставели (2013-2015). Данная система на основе региональной численной модели динамики Черного моря и 2-D и 3-D моделей переноса примесей обеспечивает моделирование основных гидрологических полей и распространения нефти и других примесей с пространственным разрешением 1 км. В случае предоставления реальных входных данных, система позволяет прогнозировать состояние моря на несколько суток вперед. Дальнейшее развитие существующей региональной системы прогнозирования связано с разработкой подсистемы моделирования сверхвысоко разрешения для прибрежной акватории Батуми-Поти-Анаклия и включением в подсистему модели прогноза волнового режима. Целью подсистемы моделирования со сверхвысоким разрешением является уточнение и более детальное осуществление морского прогноза для прибрежных вод Батуми-Поти-Анаклия (с пространственным разрешением 200 м), которые подвержены наибольшей антропогенной нагрузке.

Ключевые слова: система прогнозирования, мезомасштабные вихри, модель высокого разрешения, система уравнений, граничные условия.

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Methods for Assessing Flood-Prone Areas

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ABSTRACT

Assessing flood risk is essential for disaster prevention and land-use planning. This study examines techniques employed in developed countries to identify areas susceptible to flooding. The evaluation emphasizes hydraulic and hydrological modeling methods, the combination of Geographic Information Systems (GIS) with remote sensing data, and the impact of climate change on flood hazard evaluations. The integration of GIS, hydrodynamic modeling, and remote sensing enhances the precision of risk assessments and fosters sustainable management practices.

Key words: *flood hazard, GIS, hydrodynamic modeling, risk assessment.*

Introduction. Flooding ranks among the most common natural disasters, leading to significant human, economic, and environmental damage each year. The World Meteorological Organization (2023) reports that floods represent nearly 40% of all natural calamities globally. The rise in both the frequency and severity of flood occurrences is closely associated with climate change, rapid urban sprawl, and deforestation, which disrupt natural runoff and drainage systems. As a result, accurately identifying and evaluating areas susceptible to flooding has become a crucial aspect of contemporary hydrological research and disaster risk management.

In recent decades, there has been considerable advancement in modeling and mapping flood hazards. Countries with developed economies, including the United States, the United Kingdom, Germany, the Netherlands, Japan, and Australia, have adopted sophisticated hydrodynamic models, Geographic Information Systems (GIS), and remote sensing technologies to evaluate and anticipate flood risks [1]. These technologies enable researchers and policymakers to simulate various flood scenarios, assess water depths during inundation, and devise strategies for preventive infrastructure.

Conversely, many developing regions still depend on simplified empirical methods and limited hydrometric data for flood risk assessments. Integrating advanced modeling techniques into national flood management systems continues to pose a significant challenge. This study seeks to summarize and compare globally recognized methods for assessing flood-prone areas, with a focus on their relevance to the circumstances in Azerbaijan and comparable hydrographic environments. This research enhances the understanding of effective flood risk assessment methods and offers perspectives on tailoring global experiences to meet local requirements.

Methods and Data. The evaluation of areas vulnerable to flooding utilizes a combination of hydrological and hydraulic modeling, remote sensing, and Geographic Information Systems (GIS). This research involved a review and comparison of international methodologies employed in various developed nations. The analysis was bolstered by secondary data collected from scientific publications, institutional reports, and publicly available hydrological databases [2].

Hydrological Modeling. Hydrological models replicate rainfall–runoff dynamics to forecast the volume and timing of surface water flows. Among the most commonly used models, HEC-HMS (Hydrologic Modeling System) created by the U.S. Army Corps of Engineers is a key model in the United States. In Australia, the ARR (Australian Rainfall and Runoff) guidelines establish standardized approaches for calculating design floods based on regional precipitation information [3]. These models depend on meteorological inputs, characteristics of the catchment area, and soil infiltration variables.

Hydraulic Modeling. Hydraulic models illustrate the physical dynamics of water movement in rivers and floodplains. The one-dimensional (1D) and two-dimensional (2D) Saint-Venant equations serve as the mathematical basis for such models:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0, \quad \frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A} + gAh\right) = gA\left(S_0 - S_f\right)$$

where Q – discharge, A – flow area, t – time, x – distance, h – water depth, S_0 – bed slope, and S_f – friction slope.

Widely used software includes HEC-RAS (USA), MIKE FLOOD (Germany), INFOWORKS ICM (United Kingdom), and SOBEK (Netherlands). These tools allow simulation of flood propagation, inundation mapping, and evaluation of protective structures.

GIS and Remote Sensing Integration. The combination of GIS and remote sensing technologies enhances spatial accuracy in flood risk assessment. LiDAR (Light Detection and Ranging) and satellite-based Digital Elevation Models (DEM) are frequently used to derive topography and surface characteristics. By overlaying hydrological results with land-use and population density data, researchers can determine the potential exposure and vulnerability of flood-prone areas [4, 5].

Data Sources and Limitations. Hydrological and meteorological data were referenced from global databases such as NOAA, NASA, and the European Space Agency (ESA). The comparative analysis focused on the methodological frameworks rather than specific field observations. Lack of data and model parameter uncertainty remain major limitations, especially in developing regions such as the South Caucasus.

Comparative Analysis of International Approaches. Different countries have developed distinctive frameworks for evaluating and managing flood-prone regions based on their climatic, topographic, and institutional conditions. Table 1 summarizes the main approaches and tools applied in selected developed countries.

Table 1. Comparative overview of flood risk assessment methods in developed countries.

Country	Main Tools/Models	Core Features
USA	HEC-RAS, HEC-HMS, FEMA Flood Maps	Integration of hydrological and hydraulic models; standardized national flood mapping; real-time data assimilation.
United Kingdom	INFOWORKS ICM, ISIS, Flood Map for Planning	Advanced 2D modeling; focus on urban flooding and climate change impact.
Germany	MIKE FLOOD, Hydro_AS-2D	Compliance with EU Floods Directive; probabilistic hazard mapping.
Netherlands	SOBEK, Delft-FEWS	Coupled river–coastal flood modeling; integration of remote sensing and sensor networks.
Japan	2D/3D hydrodynamic models, radar data	Emphasis on short-term flood forecasting; integration of rainfall radar and real-time telemetry.
Australia	TUFLOW, XP-RAFTS, ARR Guidelines	Designed for flash floods; regionalized rainfall–runoff estimation.

A review of international practices shows that both the United States and the Netherlands operate highly advanced flood management systems, where real-time hydrological monitoring is closely linked with hydraulic modeling and public risk communication. In the United Kingdom, flood hazard assessment is strongly integrated into land-use and spatial planning through the frameworks established by the Environment Agency. In Germany, the mapping and classification of flood risks are conducted under legally binding procedures consistent with the European Floods Directive (2007/60/EC). Japan, in turn, places particular emphasis on the use of modern technologies to strengthen its early warning and forecasting capacities. Meanwhile, Australia's approach is shaped by its predominantly arid climate, focusing on methods tailored to the modeling of short-duration flash floods in smaller catchments.

Overall, these countries share several common principles:

1. The use of 2D/3D numerical models for hydraulic simulation.
2. GIS-based flood hazard mapping for planning and emergency response.
3. The inclusion of climate change scenarios and probabilistic analysis in flood forecasts.
4. Public access to flood maps and open data portals to enhance community resilience.

These practices form a methodological foundation for countries aiming to improve their flood risk assessment frameworks. The adaptability of these methods depends on data availability, computational resources, and institutional coordination.

Discussion. The comparative analysis of international methodologies demonstrates that the efficiency of flood risk assessment strongly depends on the integration of data, modeling precision, and institutional coordination. Developed countries apply a combination of hydrological, hydraulic, and geospatial tools that enable dynamic flood forecasting and high-resolution hazard mapping. These systems not only improve prediction accuracy but also give a chance to prepare and make awareness for public beforehand.

Studies have shown that two- and three-dimensional hydrodynamic models such as HEC-RAS, SOBEK, and MIKE FLOOD are key tools for providing realistic simulations of flow processes in the design of dams, reservoirs, and early warning systems. However, the reliability of these model results is directly related to the availability of detailed topographic data (e.g., LiDAR-based DEMs) and continuous hydrometric observations. The application of GIS technologies allows for a clear description of hazard zones, the degree of population exposure to risk, and the level of vulnerability of important infrastructure elements, which supports scientifically based land use decisions [6, 7, 8].

However, existing systems also have certain limitations. In many cases, the hydrological observation data required for model calibration are insufficient, or the lack of long-term observation series reduces the accuracy of the results. Also, the application of modeling parameters obtained for one basin to another creates additional uncertainties. Climate change also complicates this process, as traditional models cannot always adequately reflect changing rainfall intensity and frequency patterns.

Countries with limited hydrological and topographic data should use a hybrid approach. This means using statistical and remote-sensing methods along with physically based hydrodynamic modeling to fill in gaps in the data. Adapting international tools like HEC-RAS and MIKE FLOOD to work in certain areas, with the help of national GIS databases, could make it much easier to figure out how likely floods are to happen in those areas. Working with research institutions and platforms that let people share data would also make the overall flood management framework stronger [9, 10].

Conclusion. A comparative review of global approaches to flood-prone area assessment highlights the successful practices adopted in several advanced countries, including the United States, the United Kingdom, Germany, the Netherlands, Japan, and Australia. Findings suggest that integrating hydrological and hydraulic models with GIS and remote sensing tools greatly improves both the precision and reliability of flood hazard mapping. The use of two- and three-dimensional hydrodynamic modeling enables more realistic simulations of water movement, while the incorporation of LiDAR and satellite-derived data ensures an accurate representation of surface topography.

The comparative analysis highlights that the most successful systems are those supported by comprehensive data management, real-time monitoring, and institutional cooperation. For Azerbaijan, especially for the areas along the Kura River, implementing hybrid methods that incorporate international modeling tools (like HEC-RAS and MIKE FLOOD) along with local GIS data can improve flood risk assessment capabilities. Utilizing these approaches will aid in sustainable spatial planning, infrastructure protection, and disaster risk mitigation at the national level.

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წყალდიდობისადმი მიდრეკილი ტერიტორიების შეფასების მეთოდები

ჰ. ჰუსეინოვი, ვ. ალიევი

რეზიუმე

წყალდიდობის რისკის შეფასება გადამწყვეტი მნიშვნელობისაა კატასტროფების პრევენციისა და მიწათსარგებლობის დაგეგმარებისთვის. ეს კვლევა იკვლევს განვითარებულ ქვეყნებში წყალდიდობისადმი მიდრეკილი ტერიტორიების იდენტიფიცირებისთვის გამოყენებულ მეთოდებს. შეფასება ფოკუსირებულია ჰიდრავლიკურ და ჰიდროლოგიურ მოდელირების მეთოდებზე, გეოგრაფიული საინფორმაციო სისტემების (GIS) დისტანციური ზონდირების მონაცემებთან კომბინაციაზე და კლიმატის ცვლილების გავლენას წყალდიდობის საფრთხის შეფასებაზე. GIS-ის, ჰიდროდინამიკური მოდელირებისა და დისტანციური ზონდირების ინტეგრაცია აუმჯობესებს რისკის შეფასების სიზუსტეს და ხელს უწყობს მდგრადი მართვის მეთოდების დანერგვას.

საკვანძო სიტყვები: წყალდიდობის საშიშროება, GIS, ჰიდროდინამიკური მოდელირება, რისკის შეფასება.

Методы оценки территорий, подверженных наводнениям

Х. Гусейнов, В. Алиев

Резюме

Оценка риска наводнений имеет решающее значение для предотвращения стихийных бедствий и планирования землепользования. В данном исследовании рассматриваются методы, используемые в развитых странах для выявления территорий, подверженных наводнениям. Особое внимание в оценке уделяется методам гидравлического и гидрологического моделирования, сочетанию географических информационных систем (ГИС) с данными дистанционного зондирования и влиянию изменения климата на оценку опасности наводнений. Интеграция ГИС, гидродинамического моделирования и дистанционного зондирования повышает точность оценки риска и способствует внедрению методов устойчивого управления.

Ключевые слова: опасность наводнений, ГИС, гидродинамическое моделирование, оценка риска.

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Statistical Analysis of the Total Number of Dry Months in Eastern Georgia in 1936-2023 Using the SPI-3 Index ≤ 0 and an Assessment of the Variability of this Number until 2045

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ABSTRACT

A detailed statistical analysis of the total number of dry months (N) in Eastern Georgia in 1936-2023 using the SPI-3 index ≤ 0 (agricultural drought) and an assessment of the variability of this number until 2045 is presented. Data from 18 meteorological stations on monthly precipitation sums were used. In particular, the following results were obtained. The features of intra-annual distribution of monthly N values in Eastern Georgia in 1936-2023 (Full period), 1936-1975 (I period) and 1984-2023 (II period) were studied. Overall, in the second period compared to the first for all stations, a trend of increasing aridity was observed in 136 cases (months), decreasing in 65 cases, and remaining constant in only 15 cases. In other words, the overall trend is toward increasing aridity.
Statistical analysis of N values in spring-autumn period was conducted. In the second period of time compared to the first, mean N values in spring-autumn period for Paravani, Tsalka, Bolnisi, Sagarejo, Gurjaani, Kvareli, Tianeti, Pasanauri and Stepantsminda are significant increase (aridity tendency). Only at one station (Lagodekhi) is observed significant decrease of this difference (wetting tendency). Insignificant variability of the values of N in second period compared to first are observed at the 8 stations: Gardabani, Tbilisi, Dedoplistskaro, Telavi, Gudauri, Gori, Khashuri and Shovi.
Statistical forecasting of N values in spring-autumn period up to 2045 was carried out. At all stations, except Tbilisi, Lagodekhi and Shovi in 2026-2045 compared to 2004-2023 on average, an increase in drought is expected.

Key words: *SPI, atmospheric precipitation, drought risk, climate change, correlation and regression analysis.*

Introduction

Drought is a phenomenon of prolonged water shortage, whether atmospheric (below-average precipitation), surface water, or groundwater. Drought can last for months or years. Atmospheric (or meteorological) droughts occur when an area receives below-average precipitation over an extended period. Meteorological droughts typically precede other types of drought. Agricultural droughts affect crop yields or the ecology of a habitat. Hydrological droughts occur when water reserves in sources such as aquifers, lakes, and reservoirs fall below the threshold required to support vegetation in the region [https://www.google.com/search?client=opera&q=засуха&sourceid=opera&ie=UTF-8&oe=UTF-8].

Currently, a large number of simple and complex indices for drought research exist [1]. Among these, one of the most commonly used is the so-called Standardized Precipitation Index (SPI), which the World Meteorological Organization recommended in 2009 as a starting point for monitoring meteorological droughts [2]. Calculating this index requires only precipitation information. The SPI is based on the probability of precipitation on any time scale. The probability of observed precipitation is then converted into an index. It is used in research and operational settings in more than 70 countries. A dedicated free program is used to calculate the SPI [3].

The SPI was developed to quantify precipitation deficits over multiple time scales or moving average windows. Meteorological conditions and soil moisture (in agriculture) respond to precipitation anomalies on relatively short time scales, such as 1-6 months. River runoff, reservoirs, and groundwater respond to longer precipitation anomalies, ranging from 6 months to 24 months or more. The SPI index for

1 or 2 months can be considered for meteorological drought, the SPI for a period of 1 to 6 months for agricultural drought. The SPI for a period of 6 to 24 months or more is used for the analysis and application of hydrological droughts [2].

In recent years, a significant number of studies on SPI variations (often in combination with other indices) have been conducted in various countries worldwide to analyze the above-mentioned drought types [4-8]. In particular, the review [8] systematically evaluates research on meteorological drought trends in Iran, focusing on the Standardized Precipitation Index (SPI) and the non-parametric Mann-Kendall (MK) test. Thirteen relevant articles were analyzed, and SPI data from 1951 to 2019 were reviewed. The review indicates that drought severity in Iran has generally increased over the past decades, particularly in arid and semi-arid regions. Northern Iran and the Caspian Sea region have not experienced significant changes, whereas the southern, southwestern, southeastern, eastern, and central regions have shown pronounced drought trends. The drought pattern in Iran is heterogeneous: northern regions display a slow trend with more variable and less predictable behavior, while the eastern and southern arid regions exhibit an increasing intensity and duration of drought periods.

Similar work is being carried out in Georgia [9-16], taking into account local climate changes [17-20]. For example, in our work [15] a detailed analysis of SPI variability for three months (agriculture drought) in eastern Georgia based on observations at 18 meteorological stations from 1936 to 2023 is presented. Study area covers 7 regions of eastern Georgia, including its capital - Tbilisi. The SPI values for seven categories was determined for three time periods (1936-2023; 1936-1975, first period; 1984-2023, second period) and probability of drought recurrence for the same time periods was determined for four categories of SPI.

In particular, it was found that in 1936-2023 that 13 points (Paravani, Tsalka, Bolnisi, Tbilisi, Sagarejo, Gurjaani, Kvareli, Telavi, Tianeti, Pasanauri, Gudauri, Stepantsminda and Khashuri) show a significant negative linear trend in SPI values. No significant changes in SPI values are observed in 4 points (Gardabani, Dedoplistskaro, Gori and Shovi). Only one point shows a positive linear trend in SPI values (Lagodekhi).

The general tendency towards aridity processes for all SPI ranges (a decrease in the difference in the repetition of SPI values in the range of categories “Extremely Wet” – “Moderately Wet” and an increase in the difference in this repetition in the range of categories “Moderately Dry” – “Extremely Dry”) in the second period of time compared to the first is observed on average for eastern Georgia and for the following points: Paravani, Tsalka, Tbilisi, Sagarejo, Tianeti, Pasanauri, Gudauri, Khashuri. Analysis of number of times in 100 years for different SPI category show that for category “Extreme Dryness” - N (Extr) - in 1984-2023, compared to 1936-1975 only four points (Lagodekhi, Gudauri, Gori, Shovi) had N (Extr) values less than critical value 2.5. In the remaining points, in the second period, the N (Extr) values were equal to or exceeded 2.5. The average N (Extr) values in the first period were 2.4, in the second – 3.0 (a general tendency for extreme drought to increase above the critical value).

In our other work [16] work detailed statistical analysis of the duration of drought periods D (months) normalized per decade for four SPI-3 categories (agriculture drought; SPI ≤ -1.0, ≤ -1.5, ≤ -2.0 and ≤ -2.5) in Eastern Georgia based on observations at the same18 meteorological stations during 1936-2023 is presented. The statistical characteristics of D values in 1936-2023, 1936-1975 and 1984-2023 were compared. The variability of D values in 1984-2023 compared to 1936-1975 (ΔD) was assessed. In particular, it was found that ΔD values are different at different points. On average, for eastern Georgia, ΔD values for all SPI categories, except ≤ -2.5, are increasing (i.e., an increase in the duration of droughts is observed).

This work is a continuation of two previous studies [15,16]. A detailed statistical analysis of the total number of dry months in Eastern Georgia in 1936-2023 using the SPI-3 index ≤ 0 (agricultural drought) and an assessment of the variability of this number until 2045 is presented below.

Study area, material and methods

Study area – Eastern Georgia (EGeo), 18 meteorological stations: Paravani (Par), Tsalka (Ts), Bolnisi (Bol), Gardabani (Gar), Tbilisi (Tb), Sagarejo (Sag), Gurjaani (Gur), Dedoplistskaro (Ded), Lagodekhi (Lag), Kvareli (Kv), Telavi (Tel), Tianeti (Tian), Pasanauri (Pas), Gudauri (Gud), Stepantsminda (St), Gori (Gori), Khashuri (Kh) and Shovi (Sh). The altitude range of meteorological stations is from 362 (Lag) to 2194 (Gud) m a.s.l. Study area covers 7 regions of Georgia, including its capital - Tbilisi. Information on coordinates and altitudes above sea level of these meteorological stations in [15] is presented.

Data of the Georgian National Environment Agency about monthly sum of atmospheric precipitation in the period from 1936 to 2023 are used. Missing data in the observation series were reconstructed using the standard method [21], taking into account representativeness of data from meteorological stations in Georgia for monthly sum of atmospheric precipitation around of these stations [22].

SPI was determined using a special program [3] for 3 months (SPI-3, agriculture drought; below – SPI). The object of the study is the total number of dry months (N) for individual stations in Eastern Georgia with SPI-3 index values ≤ 0 (agricultural drought) both in terms of their intra-annual distribution (from January to December) and for the year as a whole, and for the agricultural season (March-November).

In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods of random events and methods of mathematical statistics for the non-accidental time-series of observations [21,23,24].

Forecasting the total number of dry months per agricultural season was performed using the AAA version of the exponential smoothing (ETS) algorithm taking into account the periodicity in the pre-forecast time series [25].

The total number of dry months (N) was determined for three time periods (1936-2023, full period; 1936-1975, first (I) period; 1984-2023, second (II) period). ΔN - difference between total number of dry months in 1984-2023 and 1936-1975.

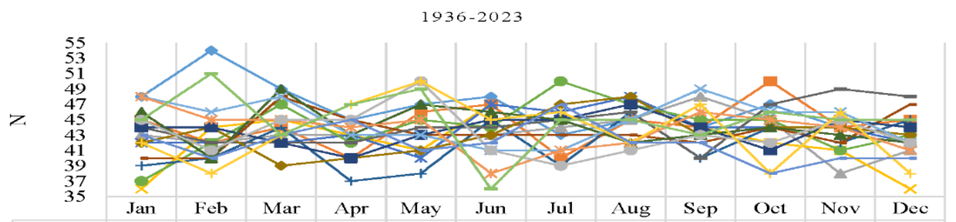
The following designations (in addition to those already indicated) will be used below: Mean – average values; Min – minimal values; Max - maximal values; Range – Max – Min; St Dev - standard deviation; C_v, - coefficient of variation, %; R – coefficient of linear correlation; R^2 – coefficient of determination; Forecast - forecast center point; 68%_Upp and 68%_Low - upper and lower levels of mean values of studied parameters; α - the level of significance; K_{DW} – Durbin-Watson statistic; a and b - coefficients of the linear regression equation a·x + b.

Comparison of mean values of N in two forty-year of time (1984-2023 and 1936-1975) was produced with the use of Student's criterion with the level of significance α not worse than 0.3.

The degree of correlation was determined in accordance with [23]: very high correlation (0.9 ≤ R ≤ 1.0); high correlation (0.7 ≤ R < 0.9); moderate correlation (0.5 ≤ R < 0.7); low correlation (0.3 ≤ R< 0.5); negligible correlation (0 ≤ R < 0.3).

Results and discussion

Results in Fig. 1-8 and Tables 1-4 are presented.

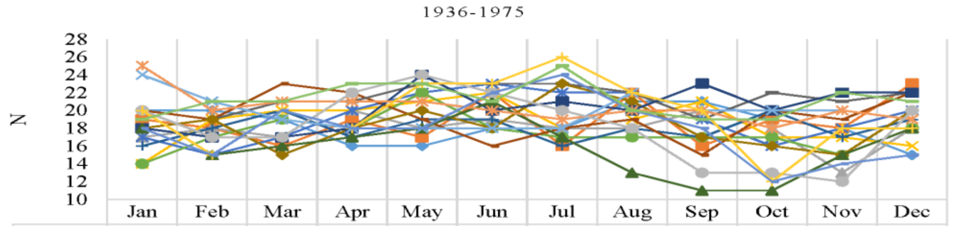


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Par	48	54	49	45	47	48	43	45	44	47	44	42
Ts	45	42	44	40	46	47	40	45	44	50	44	45
Bol	43	42	43	43	41	43	44	45	48	45	38	41
Gar	36	44	45	43	41	47	46	48	44	42	41	36
Tb	42	42	42	43	40	47	46	48	44	44	44	42
Sag	37	42	47	42	45	44	50	47	45	45	41	43
Gur	39	40	44	37	38	45	39	46	40	44	42	45
Ded	40	40	48	45	43	43	43	43	42	44	42	47
Lag	44	42	42	42	44	44	45	46	40	47	49	48
Kv	42	44	39	40	41	43	47	48	43	44	44	43
Tel	44	44	42	40	43	45	45	47	44	41	45	44
Tian	46	40	49	43	47	46	45	42	43	44	43	42
Pas	48	46	48	43	43	41	41	45	49	46	46	42
Gud	48	45	45	44	45	38	41	42	46	45	44	41
St	45	41	45	45	50	41	39	41	43	42	45	42
Gori	42	38	43	47	50	45	46	42	47	38	46	38
Kh	43	40	43	45	41	42	47	42	42	38	40	40
Sh	45	51	43	47	49	36	45	45	43	46	45	45

Fig. 1. Intra annual distribution of monthly N values in Eastern Georgia in 1936-2023.

In Fig. 1 data on intra annual distribution of total number of dry months in Eastern Georgia in 1936-2023 is presented. As follows from Fig. 1, N values changes from 36 (Gardabani, Jan, Dec; Shovi, Jun) to 54

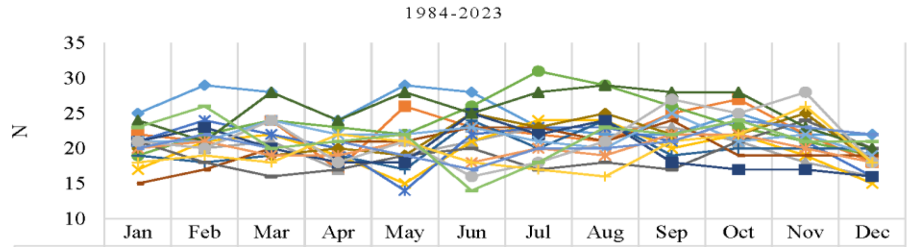
(Paravani, Feb). Mean annual values on N in 1936-2023 change from 41.6 (Gurjaani) to 46.3 (Paravani). Range between monthly values of N changes from 7 (Telavi) to 15 (Shovi).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Par	20	20	19	16	16	18	18	21	21	19	18	15
Ts	19	18	16	19	17	22	16	22	16	19	18	23
Bol	17	18	17	20	18	19	18	18	20	18	13	18
Gar	14	19	20	20	21	22	18	19	21	17	17	16
Tb	17	15	17	20	22	23	22	22	19	16	18	20
Sag	14	17	19	18	22	18	17	17	17	17	15	18
Gur	16	18	20	17	19	19	16	18	17	20	17	19
Ded	20	19	23	22	19	16	18	19	15	20	19	22
Lag	18	19	21	21	23	23	23	22	19	22	21	22
Kv	18	19	15	18	20	18	23	21	17	16	15	20
Tel	18	17	17	18	24	20	21	20	23	20	22	22
Tian	18	15	16	17	18	21	17	13	11	11	15	18
Pas	24	21	19	18	18	18	18	22	20	20	20	19
Gud	25	20	21	21	21	20	19	20	20	18	20	19
St	20	17	17	22	24	22	20	18	13	13	12	20
Gori	20	15	20	18	23	23	26	22	20	12	18	18
Kh	18	15	20	18	18	22	24	20	18	12	14	15
Sh	19	21	21	23	23	21	25	20	19	19	22	21

Fig. 2. Intra annual distribution of monthly N values in Eastern Georgia in 1936-1975.

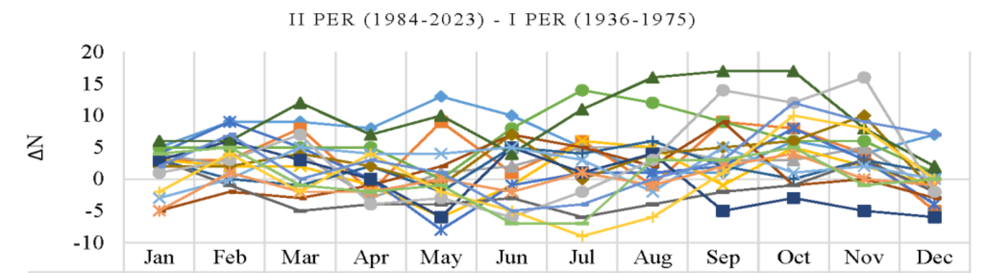
In Fig. 2 data on intra annual distribution of total number of dry months in Eastern Georgia in 1936-1975 is presented. From Fig. 2 follows, that N values changes from 11 (Tianeti, Sep, Oct) to 26 (Gori, Jul). Mean annual values on N in 1936-1975 change from 15.8 (Tianeti) to 21.2 (Lagodekhi, Shovi). Range between monthly values of N changes from 4 (Gurjaani) to 14 (Gori).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Par	25	29	28	24	29	28	23	22	22	25	22	22
Ts	22	21	24	17	26	23	22	21	25	27	22	18
Bol	21	20	21	17	19	21	23	23	23	21	18	16
Gar	17	21	22	19	15	21	24	24	20	22	19	15
Tb	21	24	22	20	14	22	23	23	21	24	21	16
Sag	19	22	24	23	22	26	31	29	26	23	21	19
Gur	19	18	19	19	17	24	20	24	19	20	20	20
Ded	15	17	20	21	21	23	23	21	24	19	19	19
Lag	21	18	16	17	19	20	17	18	17	21	24	20
Kv	20	21	19	20	19	25	23	25	22	22	25	18
Tel	21	23	20	18	18	25	22	24	18	17	17	16
Tian	24	21	28	24	28	25	28	29	28	28	23	20
Pas	21	21	24	22	22	23	21	20	25	21	22	19
Gud	20	21	19	19	21	18	20	19	22	22	20	18
St	21	20	24	18	21	16	18	21	27	25	28	18
Gori	18	19	18	22	21	18	17	16	21	22	26	18
Kh	20	22	20	21	19	17	20	20	21	24	23	22
Sh	23	26	20	21	22	14	18	23	22	24	21	21

Fig. 3. Intra annual distribution of monthly N values in Eastern Georgia in 1984-2023.

In Fig. 3 data on intra annual distribution of total number of dry months in Eastern Georgia in 1984-2023 is presented. As follows from Fig. 3, N values changes from 14 (Tbiisi, May; Shovi, Jun) to 31 (Sagarejo, Jul). Mean annual values on N in 1984-2023 change from 19.0 (Lagodekhi) to 25.5 (Tianeti). Range between monthly values of N changes from 4 (Gudauri) to 12 (Sagarejo, Shovi).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Par	5	9	9	8	13	10	5	1	1	6	4	7
Ts	3	3	8	-2	9	1	6	-1	9	8	4	-5
Bol	4	2	4	-3	1	2	5	5	3	3	5	-2
Gar	3	2	2	-1	-6	-1	6	5	-1	5	2	-1
Tb	4	9	5	0	-8	-1	1	1	2	8	3	-4
Sag	5	5	5	5	0	8	14	12	9	6	6	1
Gur	3	0	-1	2	-2	5	4	6	2	0	3	1
Ded	-5	-2	-3	-1	2	7	5	2	9	-1	0	-3
Lag	3	-1	-5	-4	-4	-3	-6	-4	-2	-1	3	-2
Kv	2	2	4	2	-1	7	0	4	5	6	10	-2
Tel	3	6	3	0	-6	5	1	4	-5	-3	-5	-6
Tian	6	6	12	7	10	4	11	16	17	17	8	2
Pas	-3	0	5	4	4	5	3	-2	5	1	2	0
Gud	-5	1	-2	-2	0	-2	1	-1	2	4	0	-1
St	1	3	7	-4	-3	-6	-2	3	14	12	16	-2
Gori	-2	4	-2	4	-2	-5	-9	-6	1	10	8	0
Kh	2	7	0	3	1	-5	-4	0	3	12	9	7
Sh	4	5	-1	-2	-1	-7	-7	3	3	5	-1	0

Fig. 4. Difference between monthly N values in 1984-2023 and 1936-1975.

In Fig. 4 data on difference between total number of dry months in Eastern Georgia in 1984-2023 and 1936-1975 is presented. As follows from Fig. 4, ΔN values changes from -9 (Gori, Jul) to 17 (Tianeti, Sep, Oct). Mean annual values on ΔN change from -2.2 (Lagodekhi) to 9.7 (Tianeti). It should be noted that the greatest trend of increasing aridity is observed in Paravani and Tianeti (for all months of the year). For the remaining stations, the trend of increasing aridity is as follows (in descending order): Sagarejo (11 months a year); Bolnisi (10); Tsalka and Kvareli (9 each); Tbilisi, Gurjaani, Pasanauri and Khashuri (8 each); Gardabani and Stepantsminda (7 each); Telavi (6); Dedoplistskaro, Gori and Shovi (5 each); Gudauri (4); Lagodekhi (2 months a year). Overall, for all stations, a trend of increasing aridity was observed in 136 cases (months), decreasing in 65 cases, and remaining constant in only 15 cases. In other words, the overall trend is toward increasing aridity.

In Table 1 information on annual and spring-autumn period data on the N values in Georgia in 1936-2023 is presented.

Table 1. Annual and spring-autumn period data on the N values in Eastern Georgia in 1936-2023.
Share = 100·(Mar-Nov)/Year, %.

Period	Loc	Year	Mar-Nov	Share, %	Loc	Year	Mar-Nov	Share, %
Full	Par	556	412	74.1	Kv	518	389	75.1
II		299	223	74.6		259	200	77.2
I		221	166	75.1		220	163	74.1
II-I		78	57	-0.5		39	37	3.1
Full	Ts	532	400	75.2	Tel	524	392	74.8

II		268	207	77.2		239	179	74.9
I		225	165	73.3		242	185	76.4
II-I		43	42	3.9		-3	-6	-1.6
Full	Bol	516	390	75.6	Tian	530	402	75.8
II		243	186	76.5		306	241	78.8
I		214	161	75.2		190	139	73.2
II-I		29	25	1.3		116	102	5.6
Full	Gar	513	397	77.4	Pas	538	402	74.7
II		239	186	77.8		261	200	76.6
I		224	175	78.1		237	173	73.0
II-I		15	11	-0.3		24	27	3.6
Full	Tb	524	398	76.0	Gud	524	390	74.4
II		251	190	75.7		239	180	75.3
I		231	179	77.5		244	180	73.8
II-I		20	11	-1.8		-5	0	1.5
Full	Sag	528	406	76.9	St	519	391	75.3
II		285	225	78.9		257	198	77.0
I		209	160	76.6		218	161	73.9
II-I		76	65	2.4		39	37	3.2
Full	Gur	499	375	75.2	Gori	522	404	77.4
II		239	182	76.2		236	181	76.7
I		216	163	75.5		235	182	77.4
II-I		23	19	0.7		1	-1	-0.8
Full	Ded	520	393	75.6	Kh	503	380	75.5
II		242	191	78.9		249	185	74.3
I		232	171	73.7		214	166	77.6
II-I		10	20	5.2		35	19	-3.3
Full	Lag	533	399	74.9	Sh	540	399	73.9
II		228	169	74.1		255	185	72.5
I		254	195	76.8		254	193	76.0
II-I		-26	-26	-2.6		1	-8	-3.4

As follows from Table 1 annual values of N in 1936-2023 change from 499 (Gurjaani) to 556 (Paravani) with mean value – 524; range – 57. Spring-autumn values of N in 1936-2023 change from 375 (Gurjaani) to 412 (Paravani) with mean value – 396; range – 37. Share spring-autumn values of N from annual change from 73.9 % (Shovi) to 77.4 % (Gori) with mean value 75.4 %; range – 3.5 %.

Annual values of N in 1936-1975 change from 190 (Tianeti) to 254 (lagodekhi) with mean value – 227; range – 64. Spring-autumn values of N in 1936-1975 change from 139 (Tianeti) to 195 (lagodekhi) with mean value – 171; range – 56. Share spring-autumn values of N from annual change from 73.0 % (Pasanauri) to 78.1 % (Gardabani) with mean value 75.4 %; range – 5.1 %.

Annual values of N in 1984-2023 change from 228 (Lagodekhi) to 306 (Tianeti) with mean value – 255; range – 78. Spring-autumn values of N in 1984-2023 change from 169 (Lagodekh) to 241 (Tianeti) with mean value – 195; range – 72. Share spring-autumn values of N from annual change from 72.5 % (Shovi) to 78.9 % (Dedoplistskaro) with mean value 76.3 %; range – 6.4 %.

Annual values of ΔN change from -26 (Lagodekhi) to 116 (Tianeti) with mean value – 29; range – 142. Spring-autumn values of ΔN change from -26 (Lagodekhi) to 102 (Tianeti) with mean value – 24; range – 128. Difference between of share spring-autumn values of ΔN from annual in 1984-2023 and 1936-1975 change from -3.4 % (Shovi) to 5.6 % (Tianeti) with mean value 0.9 %; range – 9.0 %.

Table 2. Statistical characteristics of the N values in spring-autumn period for different locations in Eastern Georgia in 1936-2023. R_{min} = 0.12, α = 0.25

Per	1936-2023								
Loc	Max	Min	Mean	St Dev	C_v, %	a	b	R	K_{DW}
Par	9	0	4.7	2.5	53.1	0.024198	3.605016	0.25	1.95
Ts	9	0	4.5	2.4	53.4	0.021028	3.609718	0.22	1.89
Bol	9	0	4.4	2.3	51.5	0.013015	3.852665	0.15	1.86
Gar	9	0	4.5	2.4	53.5	0.00085	4.47335	0.01	1.87
Tb	9	0	4.5	2.3	50.4	0.005248	4.289185	0.06	1.78
Sag	9	0	4.6	2.7	59.1	0.028953	3.325235	0.27	2.21
Gur	9	0	4.3	2.2	51.1	0.009184	3.852665	0.11	2.16
Ded	9	0	4.5	2.4	54.0	0.010417	4.002351	0.11	2.09
Lag	9	0	4.5	2.4	52.7	-0.01734	5.305643	0.19	1.72
Kv	9	0	4.4	2.4	54.0	0.017056	3.661442	0.18	1.92
Tel	9	0	4.5	2.3	51.7	0.003381	4.304075	0.04	1.85
Tian	9	0	4.6	2.6	57.6	0.054436	2.145768	0.53	2.09
Pas	9	0	4.6	2.4	53.6	0.020394	3.660658	0.21	1.90
Gud	9	0	4.4	2.5	55.7	0.006058	4.162226	0.06	1.75
St	9	0	4.4	2.5	55.3	0.02153	3.48511	0.22	1.82
Gori	9	0	4.6	2.2	48.7	-0.00113	4.641066	0.01	2.18
Kh	9	0	4.3	2.4	55.5	0.010972	3.829937	0.12	2.47
Sh	9	0	4.5	2.5	54.1	-0.00103	4.579937	0.01	2.04
EGeo	8.2	0.8	4.5	1.6	35.1	0.013837	3.88652	0.22	2.00

In Table 2 statistical characteristics of the N values in spring-autumn period for different locations in Eastern Georgia in 1936-2023 are presented. In particular, from Table 3 follows, that mean N values changes from 4.3 (Khashuri) to 4.7 (Pasanauri) with average value (EGeo) – 4.5; range – 0.4. The temporal variation of N values for individual stations and for eastern Georgia as a whole (averaged across all stations) is approximated by a linear function (the corresponding K_{DW} values indicate the absence of autocorrelation in the residuals). A significant positive trend in the average spring-autumn N values is observed for EGeo and all stations except Gardabani, Tbilisi, Telavi, Gudauri, Gori, and Shovi. For Lagodekhi, this trend is negative. For Gardabani, Gori, and Shovi, there is no trend.

Table 3. Statistical characteristics of the N values in spring-autumn period for different locations in Eastern Georgia in 1984-2023 and 1936-1975.

Per	1936-1975					1984-2023				
Loc	Max	Min	Mean	St Dev	C_v, %	Max	Min	Mean	St Dev	C_v, %
Par	9	0	4.2	2.4	58.4	9	0	5.6	2.3	40.8
Ts	9	0	4.1	2.1	51.8	9	0	5.2	2.5	49.1
Bol	9	0	4.0	2.5	62.3	9	0	4.7	2.1	44.2
Gar	9	0	4.4	2.6	59.4	9	0	4.7	2.2	48.1
Tb	9	0	4.5	2.5	55.0	9	0	4.8	2.2	46.7
Sag	9	0	4.0	2.6	65.3	9	0	5.6	2.7	47.2
Gur	9	0	4.1	2.2	54.6	9	1	4.6	2.1	45.1
Ded	9	0	4.3	2.4	56.1	8	0	4.8	2.4	50.3
Lag	9	0	4.9	2.2	44.8	9	0	4.2	2.5	60.3
Kv	9	0	4.1	2.5	61.2	9	1	5.0	2.2	44.8
Tel	9	0	4.6	2.4	51.7	9	0	4.5	2.2	49.6
Tian	8	0	3.5	2.2	64.5	9	1	6.0	2.4	39.3
Pas	9	0	4.3	2.4	56.5	9	0	5.0	2.5	50.8
Gud	9	0	4.5	2.5	55.4	9	0	4.5	2.6	57.8
St	9	0	4.0	2.4	60.5	9	1	5.0	2.6	51.7

Gori	8	0	4.6	2.2	49.0	8	0	4.5	2.3	49.8
Kh	9	0	4.2	2.4	57.6	8	0	4.6	2.4	52.2
Sh	9	0	4.8	2.6	53.7	9	1	4.6	2.3	49.4
EGeo	8.2	0.8	4.3	1.6	38.0	7.4	0.9	4.9	1.5	30.5

Statistical characteristics of the N values in spring-autumn period for different locations in Eastern Georgia in 1936-1975 and 1984-2023 in Table 3 is presented. As follows from Table 3 mean values of N in 1936-1975 changes from 3.5 (Tianeti) to 4.9 (Lagodekhi) with average value (EGeo) – 4.3; range – 1.4. In 1984-2023 mean N values changes from 4.2 (Lagodekhi) to 6.0 (Tianeti) with average value (EGeo) – 4.9; range – 1.8.

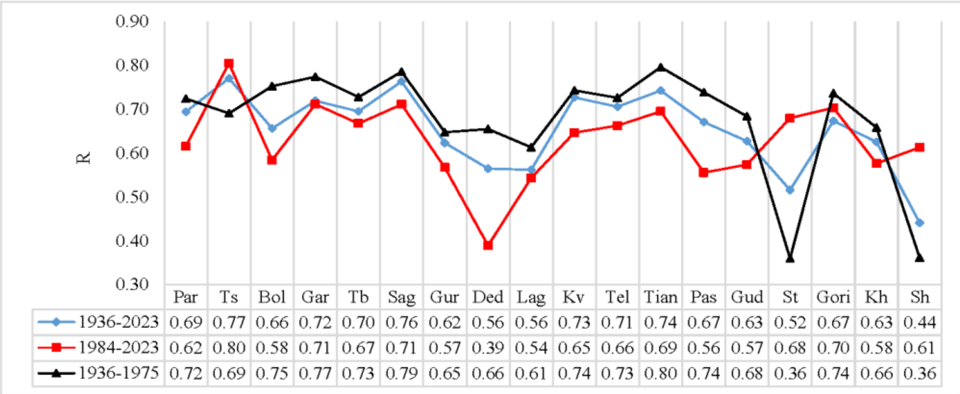


Fig. 5. Linear correlation between EGeo and another location on N values in spring-autumn period in 1936-2023, 1984-2023 and 1936-1975.

Linear correlation between EGeo and another location on N values in spring-autumn period (Fig. 5) in 1936-2023 change from 0.44 (pair: EGeo÷Shovi, low correlation) to 0.77 (pair: EGeo÷Tsalka, high correlation) with average value – 0.65 (moderate correlation), in 1936-1975 – from 0.36 (pair: EGeo÷ Shovi, low correlation) to 0.80 (pair: EGeo÷Tianeti, high correlation) with average value – 0.68 (moderate correlation) and in 1984-2023 from 0.39 (pair: EGeo÷Dedoplistskaro, low correlation) to 0.80 (pair: EGeo÷Tsalka, high correlation) with average value – 0.63 (moderate correlation).

In general, in the second period of time, compared to the first, the correlation links between the studied parameters worsened: average values were 0.63 and 0.68, respectively, and high correlation for 10 and 4 pairs, respectively (Fig. 5).

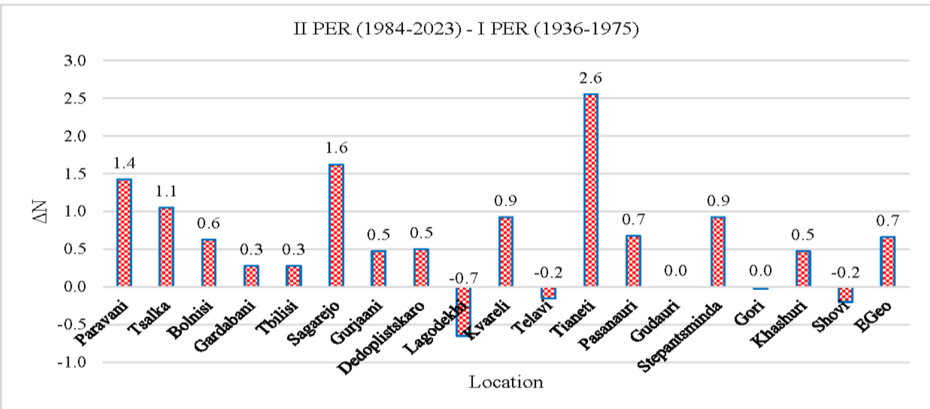


Fig. 6. Difference between mean N values in spring-autumn period in 1984-2023 and 1936-1975 in Eastern Georgia.

As noted above (Fig. 4, Table 3), a trend toward aridity was observed in Eastern Georgia during the second period compared to the first. This is also clearly evident in Fig. 6 for ΔN mean values in spring-autumn period. As follows from Fig. 6, values of ΔN changes from -0.7 (Lagodekhi) to 2.6 (Tianeti); for EGeo ΔN = 0.7. Insignificant variability of the values of ΔN are observed at the 8 stations: Gardabani, Tbilisi, Dedoplistskaro, Telavi, Gudauri, Gori, Khashuri and Shovi. Only at one station (Lagodekhi) is observed significant decrease value of ΔN (wetting tendency). At the remaining 9 stations: Paravani, Tsalka, Bolnisi, Sagarejo, Gurjaani, Kvareli, Tianeti, Pasanauri and Stepantsminda are observed significant increase value of ΔN (aridity tendency).

Finally, in Fig. 7 and Fig. 8 examples of forecasts of N values in the spring-autumn period 2025-2045 for Stepantsminda (periodicity – 22 year) and Tianeti (without periodicity) are presented. In Table 4 data about comparison of the real (2004-2023) and forecasted (2026-2045) mean N values in spring-autumn period in Eastern Georgia is presented.

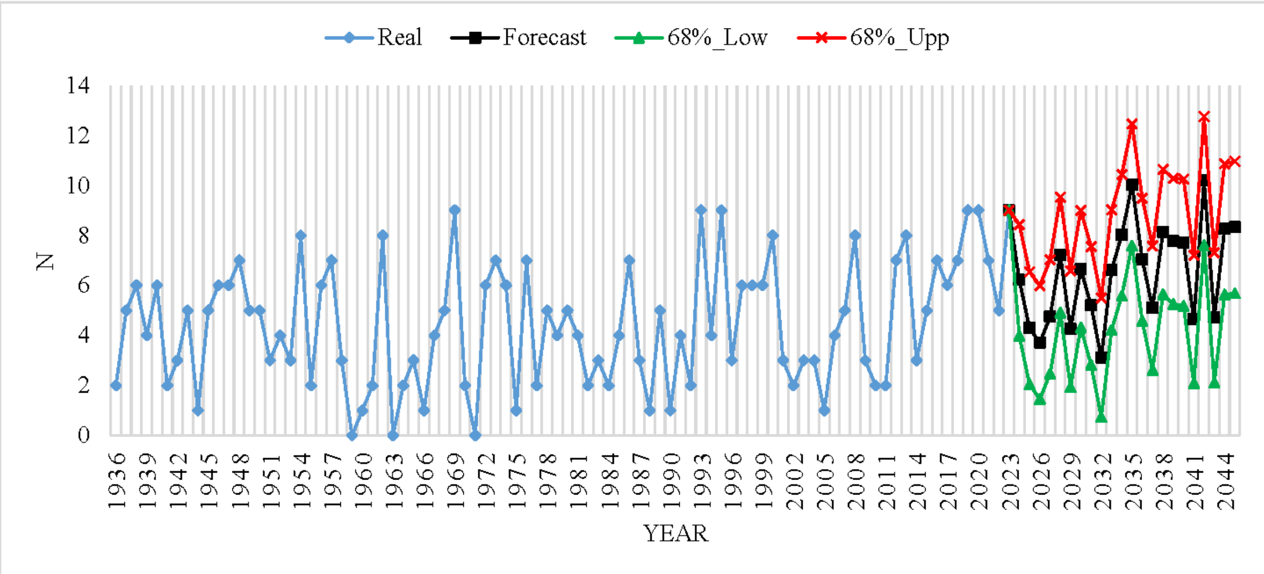


Fig. 7. Forecast of N values in the spring-autumn period 2025-2045 for Stepantsminda (periodicity – 22 year)

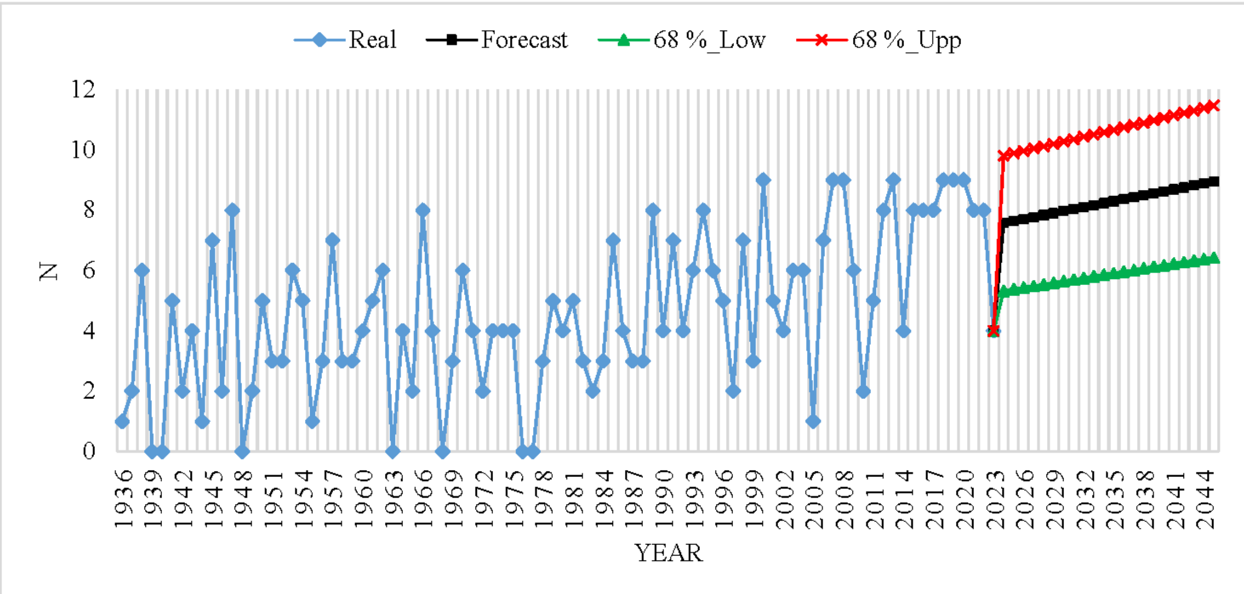


Fig. 8. Forecast of N values in the spring-autumn period 2025-2045 for Tianeti (without periodicity).

Table 4. Comparison of the real (2004-2023) and forecasted (2026-2045) mean N values in spring-autumn period in Eastern Georgia.

Period	2004-2023			2026-2045			
Location	Mean Real	68%_Low	68%_Upp	Mean Forecast	68%_Low	68%_Upp	Periodicity, Year
Paravani	4.8	4.2	5.3	6.1	2.9	9.3	no
Tsalka	5.6	4.9	6.2	6.9	4.2	9.5	no
Bolnisi	4.2	3.7	4.6	4.9	2.3	7.5	no
Gardabani	4.0	3.5	4.5	4.7	1.2	8.1	no
Tbilisi	4.3	3.7	4.8	3.5	1.0	6.5	22
Sagarejo	5.4	4.7	6.1	6.8	3.9	9.8	no
Gurjaani	4.2	3.7	4.6	4.6	2.1	7.2	29
Dedoplistskaro	5.5	4.9	6.0	8.2	5.9	10.5	no
Lagodekhi	3.1	2.7	3.5	2.8	0.2	5.5	no
Kvareli	4.8	4.2	5.3	5.8	3.0	8.5	no
Telavi	4.1	3.6	4.6	5.1	2.5	7.7	no
Tianeti	6.9	6.3	7.4	8.3	5.9	10.7	no
Pasanauri	5.0	4.4	5.6	6.7	4.0	9.4	no
Gudauri	4.8	4.1	5.4	6.3	3.4	9.1	6
Stepantsminda	5.5	4.9	6.1	6.6	4.1	9.0	22
Gori	4.1	3.6	4.6	4.5	1.9	7.1	no
Khashuri	4.8	4.2	5.4	5.7	3.3	8.1	no
Shovi	4.8	4.2	5.3	2.5	0.6	5.1	22
EGeo	4.7	4.4	5.1	5.7	3.9	7.6	no

In particular, as follows from Table 4, at all stations, except Tbilisi, Lagodekhi and Shovi in 2026-2045 compared to 2004-2023 on average, an increase in drought is expected.

Conclusion

In the future, it is planned to conduct detailed comprehensive studies of SPI for 1, 3, 6, 9 and 12 months, based on data from 39 meteorological stations in Georgia in 1936-2023.

Acknowledgments

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აღმოსავლეთ საქართველოში 1936-2023 წწ. მშრალი თვეების საერთო რაოდენობის სტატისტიკური ანალიზი SPI-3 ინდექსის ≤ 0 გამოყენებით და ამ რაოდენობის ცვალებადობის შეფასება 2045 წლამდე

ა. ამირანაშვილი, თ. დავითაშვილი, ო. ხარშილაძე,
ი. სამხარაძე, დ. ამილახვარი

რეზიუმე

სტატიაში წარმოდგენილია აღმოსავლეთ საქართველოში მშრალი თვეების (N) საერთო რაოდენობის დეტალური სტატისტიკური ანალიზი 1936-2023 წწ. SPI-3 ≤ 0 ინდექსის (სოფლის მეურნეობის გვალვა) გამოყენებით და მისი ცვალებადობის შეფასება 2045 წლამდე. გამოყენებული იქნა 18 მეტეოროლოგიური სადგურიდან მიღებული ყოველთვიური ნალექების რაოდენობის მონაცემები. კერძოდ, მიღებული იქნა შემდეგი შედეგები.
შესწავლილი იქნა აღმოსავლეთ საქართველოში ყოველთვიური N მნიშვნელობების შიდა წლიური განაწილების თავისებურებები 1936-2023 წწ. (სრული პერიოდი), 1936-1975 წწ. (I პერიოდი) და 1984-2023 წწ. (II პერიოდი). ზოგადად, მეორე პერიოდში, პირველთან შედარებით, ყველა სადგურისთვის დაფიქსირდა არიდობის ზრდის ტენდენცია 136 შემთხვევაში (თვეები), შემცირებისკენ 65 შემთხვევაში და მუდმივი მნიშვნელობის შენარჩუნებისკენ მხოლოდ 15 შემთხვევაში. სხვა სიტყვებით რომ ვთქვათ, საერთო ტენდენცია არიდობის ზრდისკენაა.
ჩატარდა გაზაფხული-შემოდგომის პერიოდში N მნიშვნელობების სტატისტიკური ანალიზი. მეორე პერიოდში, პირველთან შედარებით, გაზაფხული-შემოდგომის პერიოდში ფარავნის, წალკის, ბოლნისის, საგარეჯოს, გურჯაანის, ყვარლის, თიანეთის, ფასანაურის და სტეფანწმინდის საშუალო N მნიშვნელობები მნიშვნელოვნად იზრდება (არიდულობის ტენდენცია). მხოლოდ ერთ სადგურზე (ლაგოდეხი) შეინიშნება ამ სხვაობის მნიშვნელოვანი შემცირება (ნესტის ტენდენცია). პირველთან შედარებით მეორე პერიოდში N მნიშვნელობების უმნიშვნელო ცვალებადობა შეინიშნება რვა სადგურზე: გარდაბანი, თბილისი, დედოფლისწყარო, თელავი, გუდაური, გორი, ხაშური და შოვი.
ჩატარდა გაზაფხული-შემოდგომის პერიოდის N მნიშვნელობების სტატისტიკური პროგნოზირება 2045 წლამდე. ყველა სადგურზე, გარდა თბილისის, ლაგოდეხის და შოვისა, მოსალოდნელია გვალვის ზრდა 2026-2045 წწ. 2004-2023 წწ. საშუალო მაჩვენებელთან შედარებით.

საკვანძო სიტყვები: გვალვის ინდექსი (SPI), ნალექი, გვალვის რისკი, კლიმატის ცვლილება, კორელაციული და რეგრესიული ანალიზი.

Статистический анализ общего количества засушливых месяцев в Восточной Грузии в период 1936-2023 гг. с использованием индекса SPI-3 ≤ 0 и оценка изменчивости этого количества до 2045 года

А. Амиранашвили, Т. Давиташвили, О. Харшиладзе, И. Самхарадзе, Д. Амилахвари

Резюме

Представлен подробный статистический анализ общего числа засушливых месяцев (N) в Восточной Грузии в 1936-2023 гг. с использованием индекса SPI-3 ≤ 0 (сельскохозяйственная засуха) и оценка изменчивости этого числа до 2045 года. Использованы данные с 18 метеорологических станций о ежемесячных суммах осадков. В частности, были получены следующие результаты.

Изучены особенности внутригодового распределения ежемесячных значений N в Восточной Грузии в 1936-2023 гг. (полный период), 1936-1975 гг. (I период) и 1984-2023 гг. (II период). В целом, во втором периоде по сравнению с первым для всех станций наблюдалась тенденция к увеличению засушливости в 136 случаях (месяцах), к уменьшению в 65 случаях и к сохранению постоянного значения только в 15 случаях. Другими словами, общая тенденция направлена к увеличению засушливости.

Проведен статистический анализ значений N в весенне-осенний период. Во второй период по сравнению с первым средние значения N в весенне-осенний период для Паравани, Цалки, Болниси, Сагареджо, Гурджаани, Кварели, Тианети, Пасанаури и Степанцминды значимо увеличиваются (тенденция к засушливости). Только на одной станции (Лагодехи) наблюдается значимое уменьшение этой разницы (тенденция к увлажнению). Незначимая изменчивость значений N во втором периоде по сравнению с первым наблюдается на 8 станциях: Гардабани, Тбилиси, Дедоплистскаро, Телави, Гудаури, Гори, Хашури и Шови.

Было проведено статистическое прогнозирование значений N в весенне-осенний период до 2045 года. На всех станциях, за исключением Тбилиси, Лагодехи и Шови, в 2026-2045 гг. по сравнению со средними показателями 2004-2023 гг. ожидается увеличение засухи.

Ключевые слова: индекс засухи (SPI), атмосферные осадки, риск засухи, изменение климата, корреляционный и регрессионный анализ.

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Determination the Water Quality Classification of the River Kvirila

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ABSTRACT

In Georgia, the Chiatura municipality of the Imereti region is one of the most vulnerable points in terms of environmental pollution. The main problem of the municipality is the intensification of mining activities (manganese production). Manganese mining in Chiatura causes great damage to the Kvirila river. Determining the cleanliness of the river is necessary because the mined ore is washed with the water of the Kvirila river, after which the wastewater flows into the Kvirila river without treatment and pollutes it.
The following parameters were determined in the water samples taken: physicochemical and hydrochemical parameters, namely: pH, electrical conductivity, biogenic substances - NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, *basic ions, mineralization, heavy metals: Cu, Zn, Pb, Cd, Ni, Co and the total form of manganese. River Kvirila water samples was taken background and below the pollution source.*
The following conclusions were drawn as a result of the study:
1. According to the pollution index, the water of the Kvirila river downstream of the Andro LLC fell into the "highly polluting" category, and downstream of the Jruchula LLC - into the "dirty" category, on the basis of which they were assigned the 5th and 4th classes of water quality, respectively.
2. The Kvirila river at its background point fell into the "clean" category and was assigned the first class of water quality.

Keywords: *pollution, manganese, Kvirila river, hydrochemical parameters, water quality*

Introduction

Chiatura Municipality is located in the northern part of Upper Imereti, in the rever Kvirila Velley. The main problem of the municipality is the intensification of mining activities (manganese production). Ore mining is associated with many contradictory issues. On the one hand, it is a source of income and new job creation, on the other hand, in terms of environmental pollution, it causes significant damage to the environment and the local population [1-3]. The negative impact of the mining industry is especially noticeable when developing deposits in an open-pit manner.

Currently, the company "Georgian Manganese" carries out works the extraction of manganese concentrate by the mining method, but licenses have also been issued to small private companies. There are about 20 deposits in the municipality, of which 9 are of the mining and 11 are of the open-carries type. https://socialjustice.org.ge.

Manganese mining in Chiatura has caused significant damage to the hydrographic network there, in particular the Rgani Gorge and the Kvirila river. In Chiatura Municipality, the Kvirila river flows into a ravine, so it is not used in the irrigation system, as the location of the villages and the river complicates this process. At the same time, the Kvirila river is used for hydromelioration in the villages of Zestaponi, Terjola, and Baghdati, which causes pollution of agricultural lands.

In Chiatura, ore processing plants are located on the river bank and use the water of the Kvirila river to wash ore, as a result of which the river becomes significantly polluted and turns black. The industrial wastewater generated during the ore washing process contains a large amount of suspended particles, heavy metals, and manganese compounds and flows into the Kvirila river without treatment.

Research area and methods

The work uses the physicochemical and hydrochemical indicators of the waters of the Kvirila river in the areas adjacent to the manganese processing plants of Chiatura Municipality.

To solve the set tasks, samples of the Kvirila river water were taken from the background and downstream of the pollution source 4 times over a period of 2 years.

The following physicochemical and hydrochemical parameters were determined in the water samples taken: pH, electrical conductivity, biogenic substances - NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, basic ions, mineralization, heavy metals: Cu, Zn, Pb, Cd, Ni, Co and the total form of manganese [4].

The analyses were carried out using modern methods and equipment that meet and comply with European standards, namely:

1. Ion Chromatograph-IC-1000; ISO100304-1:2007
2. Spectrophotometric method - SPECORD 205; ISO 7150-1: 2010;
3. Plasma-emission spectrometer - ICP-OES; Epa method 200.8;
4. Field portable equipment - Hanna Combo pH/EC/TDS/PPM Tester HI98129;
5. pH-meter - Milwaukee-Mi 150.

According to the recommendations of the Water Framework Directives of the European Union countries (2000/60/EC), for the classification of surface waters, a water pollution index (S) was calculated, for the calculation of which at least 6 or 7 hydrochemical indicators are required. In our case, the average multi-year data of 9 hydrochemical and physicochemical indicators were used in the calculations.

The pollution index was calculated according to Equation 1 [5]:

$$S = \sum_{i=1}^{N} \frac{Ci/MAC}{N} \qquad (1),$$

Where,

Ci - is the concentration of the hydrochemical indicator;
MAC - the maximum permissible concentration of the hydrochemical component;
N - is the number of indicators used in the calculations.

Results

The Chiatura municipality was selected for the study, where the Kvirila river is under anthropogenic load. The work uses the multi-year database of the National Environment Agency, which fully meets the requirements proposed by the Framework Directive, as well as the results of research conducted within the framework of the Shota Rustaveli National Science Foundation grant FR-23-6375.

Among the biogenic compounds, inorganic nitrogen compounds are noteworthy, which can be formed in water by the decomposition of nitrogen-containing organic compounds, and can also enter surface waters through atmospheric precipitation, leaching of fertilizers from the soil, and industrial and agricultural-domestic wastewater. Research on the distribution of nitrogen-containing substances in river waters and water quality assessment are important in ensuring a safe environment for human health.

Table 1 discusses 12 ingredients, of which only two (ammonium and manganese ions) exceed the maximum permissible concentration. Fig. 1 shows a graphical representation of manganese values.

As can be seen from the data, at the Kvirila-Chiatura upper point, all data are within the normal range, while at the Kvirila-Chiatura lower and Kvirila-Zestafoni lower points, the content of ammonium ions exceeds the MPC. The manganese content is also high at the Kvirila-Chiatura lower, Kvirila-Zestafoni upper and lower points. As can be seen from Fig. 1, the ammonium content slightly exceeds the MPC, namely, 1.1 and 1.3 times the MPC. The manganese content is 2.7; 2.5 and 2.5 times the corresponding MPC.

Table 1. Average multi-year data of the Kvirila river
Statistical data of the National Environmental Agency (2020-2024)

N	Ingredient	Kvirila-Chiatura Upper	Kvirila-Chiatura Lower	Kvirila-Zestafoni Upper	Kvirila-Zestafoni Lower	MPC*
1	pH	7.58	7.67	7.69	7.72	6.5-8.5
2	Ammonium, mgN/l	0.331	0.439	0.360	0.486	0.39
3	Nitrites, mgN/l	0.126	0.111	0.110	0.106	3.3
4	Nitrates, mgN/l	0.467	0.699	0.611	0.571	45
5	Phosphates, mg/l	0.049	0.076	0.057	0.061	3.5
6	Calcium, mg/l	31.00	40.84	37.43	36.44	
7	Magnesium, mg/l	7.34	8.31	8.20	8.01	
8	Mineralization, mg/l	199.20	257.18	240.71	236.72	
9	Manganese, mg/l	0.0892	0.2725	0.2445	0.2484	0.1
10	Copper, mg/l	0.0048	0.0062	0.0066	0.0051	1.0
11	Zinc, mg/l	0.0157	0.0234	0.0216	0.0254	1.0
12	Lead, mg/l	0.0025	0.0030	0.0031	0.0033	0.03

***** - **MPC** - maximum permissible concentrations according
to Technical Regulations for Surface Water (Decree №425
of the Georgian government as of 31th december of 2013, Tbilisi) [6]

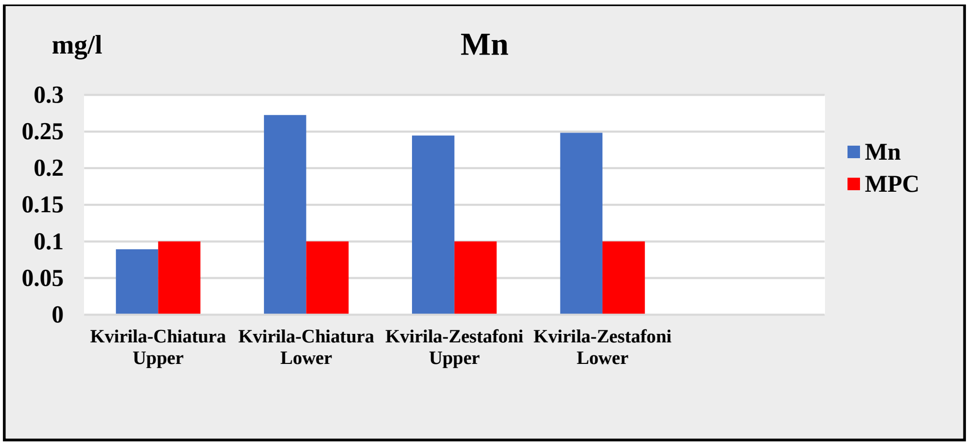

Fig. 1. Average multi-year manganese content in the Kvirila river, 2020-2024.

According to our data, out of the 12 ingredients identified, two ingredients stand out with a content exceeding the MPC - ammonium and the total content of manganese. However, it should be noted that the content of some elements is close to or exceeds the MPC, but their high content is no longer visible in the average content. As can be seen from Fig. 2, the content of ammonium ions below Kvirila-LLC “Andro” is 1.2 times higher than the MPC. And the content of manganese is 92.5 times and 37.9 times higher than the MPC, respectively, which is clearly seen in Fig. 1 and 2. The remaining ingredients are within the norm.

Tables 1 and 2 provide a list of hydrochemical and physicochemical indicators, from which we selected 9 components that more or less characterize the water quality of the Kvirila river and which will be used in the relevant calculations.

Table 2. Average two-year data for the Kvirila river
Results obtained within the framework of the grant (2024-2025) [7]

N	Ingredients	Kvirila-below "Andro" Ltd	Kvirila-below "Jruchula" Ltd	Kvirila-background	MPC*
1	pH	8.0	8.1	7.9	6.5-8.5
2	Ammonium, mgN/l	0.479	0.361	0.301	0.39
3	Nitrites, mgN/l	0.341	0.021	0.045	3.3
4	Nitrates, mgN/l	1.597	0.808	0.945	45
5	Phosphates, mg/l	0.194	0.132	0.096	3.5
6	Calcium, mg/l	84.19	43.89	30.89	
7	Magnesium, mg/l	28.11	12.27	10.40	
8	Mineralization, mg/l	928.07	322.68	234.58	
9	Manganese, mg/l	9.2536	3.7933	0.1083	0.1
10	Copper, mg/l	0.0257	0.0190	0.0038	1.0
11	Zinc, mg/l	0.0254	0.0277	0.0031	1.0
12	Lead, mg/l	0.0053	0.0024	0.0012	0.03

* - MPC - maximum permissible concentrations according
to Technical Regulations for Surface Water (Decree №425
of the Georgian government as of 31th december of 2013, Tbilisi) [6]

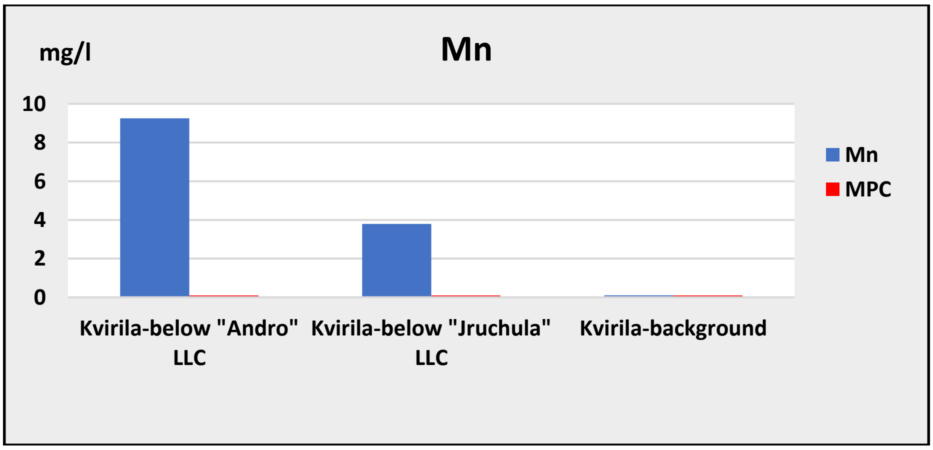

Fig. 2. Average two-year manganese content from the bacground of the Kvirila river and downstream of "Andro" LLC and "Jruchula" LLC, 2024-2025

Based on the results obtained, the classifications of the considered river (i.e. the pollution degree class) were assessed according to the values given in Table 3, which are proposed by the European Directive.

Table 3. Assessment of water quality classification using pollution indices

Surface water	Pollution index	Water quality class
Clean	0.2 - 1.0	1
Slightly polluted	1.0 - 2.0	2
Polluted	2.0 - 4.0	3
Dirty	4.0 - 6.0	4
Heavily polluted	>6.0	5

By inserting the values from Tables 1 and 2 into Equation (1), the river pollution index at the mentioned points was obtained (Table 4 and 5), on the basis of which they were assigned the corresponding water quality class.

Table 4. Water quality classifications assigned to the Kvirila River according to pollution indices

River		Pollution Index	Water Quality Class
1	Kvirila-Chiatura Upper	0.3	1
2	Kvirila-Chiatura Lower	0.6	1
3	Kvirila-Zestafoni Upper	0.5	1
4	Kvirila-Zestafoni Lower	0.6	1

Table 5. Water quality classifications assigned to the Kvirila river according to pollution indices at the bakground and downstream of "Andro" LLC and "Jruchula" LLC

River		Pollution Index	Water Quality Class
1	Kvirila-below "Andro" LLC	10.6	5
2	Kvirila-below "Jruchula" LLC	4.5	4
3	Kvirila-background	0.3	1

According to the data, the Kvirila river was classified as “clean” according to the pollution index and was assigned the first class of water quality at its background point, while below “Andro” LLC and “Jruchula” LLC, pollution indices were assigned 10.6 and 4.5, respectively, and at the background point - 0.3. At the mentioned points, the Kvirila river was classified as “highly polluting” below “Andro” LLC, and as “dirty” below “Jruchula” LLC. On the basis of which they were assigned the corresponding water quality classes of 5th and 4th.

Conclusion

1. The paper presents the data obtained within the framework of the multi-year (2020-2024) and grant (2024, 2025) study of the Kvirila river by the National Environmental Agency. Physico-chemical and hydrochemical indicators were determined in the analyzed water samples;
2. The river pollution index and river water quality were determined (taking into account the Water Framework Directive-2000/60/EC);
3. It was determined that the Kvirila river was assigned the 1st water quality class in terms of the pollution index and was classified as “clean” (according to the data of the National Environmental Agency), which is due to the fact that the observation points were taken below from the pollution sources and the river self-cleans and, accordingly, low concentrations were recorded;
4. The Kvirila river downstream of Andro LLC was classified as “highly polluting”, and downstream of Jruchula LLC as “dirty”. On this basis, they were assigned the corresponding water quality classes 5 and 4, which is due to the fact that we took samples ~ 50 m from the pollution points, which is why the river cannot self-clean and high concentrations were recorded. Kvirila, at its bacground, fell into the “clean” category according to the pollution index and was awarded the first class of water quality.

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მდინარე ყვირილას წყლის ხარისხის კლასიფიკაციის განსაზღვრა

ლ. შავლიაშვილი, გ. კუჭავა, ე. შუბლაძე, გ. გავარდაშვილი,
ზ. რიკაძე, მ. ტაბატაძე

რეზიუმე

საქართველოში, იმერეთის რეგიონის ჭიათურის მუნიციპალიტეტი ერთერთი მოწყვლადი წერტილია გარემოს დაბინძურების თვალსაზრისით. მუნიციპალიტეტის მთავარ პრობლემას წარმოადგენს სამთო-მოპოვებითი საქმიანობის (მარგანეცის წარმოება) ინტენსიფიკაცია. ჭიათურაში მანგანუმის მოპოვების შედეგად დიდი ზიანი ადგება მდინარე ყვირილას. მდინარის სისუფთავის დადგენა აუცილებელია, რადგან მდ. ყვირილას წყლით აწარმოებენ მოპოვებული მადნის გარეცხვას, რის შემდეგაც ჩამდინარე წყლები გაწმენდის გარეშე ჩაედინება მდ. ყვირილაში და ხდება მისი დაბინძურება.

აღებულ წყლის სინჯებში განისაზღვრა: ფიზიკურ-ქიმიური და ჰიდროქიმიური პარამეტრები, კერძოდ: pH, ელექტროგამტარობა, ბიოგენური ნივთიერებები - NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, ძირითადი იონები, მინერალიზაცია, მძიმე ლითონები: Cu, Zn, Pb, Cd, Ni, Co და მანგანუმის საერთო ფორმა. მდ. ყვირილას წყლის სინჯები აღებული იყო ფონური და დაბინძურების წყაროს ქვემოთ.

კვლევის შედეგად მიღებულია დასკვნები:

1. მდ.ყვირილას წყალი შპს „ანდრო"-ს ქვემოთ დაბინძურების ინდექსის მიხედვით მოხვდა „ძლიერ დაბინძრებულ", ხოლო შპს „ჯრუჭულას" ქვემოთ - „ბინძურ" კატეგორიაში, რის საფუძველზეც მათ მიენიჭათ შესაბამისად წყლის ხრისხის მე-5 და მე-4 კლასი.
2. მდ. ყვირილა ფონურ წერტილში მოხვდა ,,სუფთა" კატეგორიაში და მიენიჭა წყლის ხარისხის პირველი კლასი.

საკვანძო სიტყვები: დაბინძურება, მარგანუმი, მდ. ყვირილა, ჰიდროქიმიური პარამეტრები, წყლის ხარისხი

Классификации качества воды реки Квирила

Л. Шавлиашвили, Г. Кучава, Е. Шубладзе, Г. Гавардашвили, З. Рикадзе, М. Табатадзе

Резюме

В Грузии муниципалитет Чиатура Имеретской области является одним из наиболее уязвимых мест с точки зрения загрязнения окружающей среды. Главная проблема муниципалитета — интенсификация горнодобывающей деятельности (производство марганца). Добыча марганца в Чиатуре наносит большой ущерб реке Квирила. Определение чистоты реки необходимо, поскольку добытая руда промывается водой реки Квирила, после чего сточные воды без очистки попадают в реку и загрязняют ее.
В отобранных пробах воды были определены следующие физико-химические и гидрохимические параметры, а именно: pH, электропроводность, биогенные вещества - NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, основные ионы, минерализация, тяжелые металлы: Cu, Zn, Pb, Cd, Ni, Co и общая форма марганца. Пробы воды реки Квирила были отобраны ниже фонового уровня и источника загрязнения.
Исследование показало:
1. По индексу загрязнения вода реки Квирила ниже ООО «Андро» попала в категорию «сильно загрязнённая», а ниже ООО «Джрухула» - в категорию «загрязненная», на основании чего им были присвоены 5-й и 4-й классы качества воды соответственно.
2. Река Квирила в фоновой точке была классифицирована как «чистая» и получила первый класс качества воды.

Ключевые слова: загрязнение, марганец, река Квирила, гидрохимические параметры, качество воды.

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Problems of Regional Water-Bodies' Pollution

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ABSTRACT

Paradoxically, while water is a vital substance on Earth, it remains one of the least studied compounds in nature. Its complexity poses challenges for scientists, making it difficult to understand fully. Although the chemical composition of water is stable, its effects on organisms vary depending on environmental conditions.

Going forward, we face significant threats related to water that will require considerable attention. One alarming concern, recognized globally, is the potential emergence of a widespread issue in our water supply systems and recreational reservoirs. Labeled by some as the "plague of the 21st century," this problem is linked to the evolving nature of certain microorganisms—some of the oldest life forms on Earth—but now becoming harmful due to chemical pollution. Research from the Gamaleya Scientific Research Institute indicates that these microorganisms can develop new, dangerous strains that show effects over time, functioning like a "slow-acting mine." They produce substances with carcinogenic, mutagenic, and immunosuppressive properties, notably seen with "blue-green" algae or cyanobacteria.

This article highlights the critical issue of harmful algal blooms (HABs), particularly in the Tbilisi reservoir, predicting eutrophication in the Zhinvali reservoir due to human activities. Such insights can be applied globally, emphasizing the urgent need for action to protect our water resources and public health.

The article addresses the issue of harmful algal blooms (HABs), focusing on the production and occurrence of cyan-bacteria in different water bodies, including the Tbilisi reservoir. It predicts that eutrophication will occur in the Zhinvali reservoir as a result of human activities. This approach can be applied broadly for forecasting similar phenomena in water bodies around the world.

***Keywords**: phytoplankton, eutrophycation, biogenic elements, treatment, water body.*

Introduction

Anthropogenic eutrophication of water bodies refers to the increase in biogenic substances in aquatic environments due to human economic activities. This process often leads to excessive growth of phytoplankton. As this excess biomass decomposes, it can release harmful substances such as hydrogen sulfide, which can be toxic. Consequently, this may cause the death of aquatic life (zoocenoses) in the water and render it unsafe for drinking. Additionally, many species of planktonic algae can release toxins during their life processes.

Due to human activity, the natural evolution of water bodies is being accelerated, alongside the intense economic development of these bodies and their surrounding catchments. This phenomenon is primarily caused by the introduction of biogenic elements, such as nitrogen and phosphorus, into water bodies. These elements often come from wastewater discharged by industrial facilities, urban areas, and agricultural land through runoff. The excessive presence of biogenic elements results in rapid phytoplankton growth, which deteriorates water quality and disrupts its gas dynamic[1-3].

The increase in biogenic elements in the upper layers of water leads to a rise in phytoplankton populations in this area. As a result, water transparency often decreases, and sunlight penetration becomes shallower, which can cause underwater plants to die due to insufficient light. Eventually, dead organisms sink to the bottom of the reservoir, where they undergo decomposition. This anaerobic decomposition occurs in the oxygen-depleted sediment and produces harmful substances such as phenols and hydrogen sulfide. Consequently, the eutrophication process can severely impact most species of flora and fauna in the reservoir, significantly degrading the water's sanitary and hygienic properties. This degradation makes the water unsuitable for swimming and drinking, as well as for the living conditions of aquatic organisms, leading to a decline in biota's living conditions, due to which biota die.

Materials and methods

This article briefly examines pollution cases in major regional water bodies, based on research conducted by a group of authors. It also analyzes the characteristics and findings presented in various scientific papers and manuscripts.

Results and their discussion

Water pollution originates from various sources. Primarily, it comes from municipal and industrial runoff in cities. In recent years, these sources have been competing with agricultural runoff from irrigation. For instance, in the 1980s, approximately 160 cubic kilometers of runoff entered water bodies from the countries of the former Soviet Union. Out of this, 7 cubic kilometers was untreated, and 9 cubic kilometers was incompletely purified.

Additionally, water bodies are increasingly affected by pollution from acid rain, which is caused by industrial emissions into the atmosphere. Changes—whether natural or artificial—in the hydrological regimes of rivers and lakes also contribute to the deterioration of water quality.

Industrial runoff, particularly from chemical industries, contains a high concentration of phenols. These compounds not only alter the smell of water but also disrupt the balance of biological processes in the ecosystems. Recently, the presence of synthetic substances in this runoff has significantly reduced the water's ability to naturally purify itself biochemically [4-5].

Every year, more than 500 million tons of nitrogen oxides, 200 million tons of carbon oxides, up to 150 million tons of sulfur dioxide, 200-250 million tons of dust, and 120 million tons of ash enter the atmosphere from industrial emissions. Air masses carry these particles over long and short distances, which, along the way, hit the water surface. Gaseous emissions, being diluted with water particles in the atmosphere, return to the Earth, including water bodies, many hundreds of kilometers from their place of origin, in the form of acid rain [6-8].

A significant source of water pollution is the wastewater generated by settlements. This communal runoff includes fecal matter, which contains helminthes eggs that pose risks to human health, as well as disease-causing microbes and viruses. Additionally, it carries many hazardous compounds from various sources, including the food industry, motor transport, food services, and medical or pharmaceutical organizations.

Household runoff alone contributes to 42% of the total volume of mineral substances and 58% of organic substances. Moreover, sediment able and activated substances, along with suspensions, account for 20% of the runoff, while colloids make up 10% and diluted substances constitute 50% [9-11].

It is noteworthy that more than half of the detergents used by housewives contain such a substance dangerous to water bodies as sodium tri-polyphosphate (NTF). It's content in washing powder ranges from 15-40%. When washing, it softens water and improves the washing quality of the powder; it skillfully passes through all, even the most technologically advanced purification systems. When this detergent enters a water body, it plays the role of the most active fertilizer [10-12]. Due to its action, the number of algae in reservoirs increases not by days, but by hours. One gram of NTF stimulates the release of 5-10 kilograms of algae. Unfortunately, we do not have accurate data on the use of such detergents in Georgia. It is only known that in 1987, 1.5 million tons were used throughout the Soviet Union. Despite the cold and murky water, large and small rivers of Russia, including the Riv.Volga, "thrived" from such phosphate-containing powder. The poison of one box of powder slowly but surely affects the environment. If in 1965 there were 50 grams of microorganisms in one cubic meter of water in the Black Sea, today their number is 20 times higher. Scientists attribute this to the influence of NTF. Phosphates also stimulate the growth and development of plankton. The presence of various substances in water bodies decreases their usefulness as sources for recreation or drinking water. Unlike municipal runoff, much of the runoff from populated areas, which can cover between 100 to 1000 square kilometers, often goes untreated. As a result, it can contain high levels of oil and organic materials, which ultimately reach reservoirs during the spring snowmelt and prolonged periods of heavy rain [13-16].

Agricultural activity is one of the major sources of pollution. The primary pollutants found in surface runoff include soil particles, organic matter, humus, various types of pesticides and fertilizers, and harmful microorganisms. These contaminants ultimately make their way into rivers and reservoirs. Research shows that even from slightly sloping areas, 20% of nitrogen fertilizers, 2-5% of phosphorus, and 10-70% of potassium can be washed away. The amount of toxic chemicals released can range from 1% to 20%. It's alarming to note that 1 billion tons of animal's waste are produced by livestock complexes and private farms, which is comparable to the biogenic pollution caused by a human population of around 300 million[17].

We will no longer focus on the negative impact of other anthropogenic factors on water quality (mineral extraction, water transport development, recreational industry, timber processing, etc.).

Global warming, along with pollution, has led to excessive eutrophication of water bodies. For example, global warming has led to water blooms in European lakes. Swiss scientists have found that the growing explosions of blue-green algae (cyanobacteria), which cause water blooms in European lakes, are associated with the effects of global warming. The researchers studied data on the temperature regime of Lake Zurich and the reproduction of the cyanobacterium Lanktothrix rubescens in it and found that over the past 40 years, the temperature of the surface layer of water in the lake has increased by an average of 0.6 to 1.2 degrees. As a result, the waters of Lake Zurich began to mix less, causing favorable conditions for more intensive reproduction of blue-green algae [18].

Phytoplankton serves as an important ecological and biological indicator for evaluating the sanitary, hygienic, and pollution conditions of reservoirs, as well as addressing large-scale water usage issues. Polluted river waters promote the growth of phytoplankton, which can lead to algal blooms in reservoirs. This phenomenon occurs because the water becomes enriched with easily digestible organic substances that accelerate the growth of bacterioplankton. As a result, oxygen consumption in the water increases, leading to hypoxic conditions and potentially causing anaerobiosis.

In summary, studying phytoplankton enables an assessment of reservoirs regarding their suitability for various purposes, their current sanitary, hydrobiological, and ecological status, as well as their future conditions.

Pollution and eutrophication are closely interconnected in their effects on water systems, often causing one another. This interaction leads to an overload of the ecosystem, disrupts sustainability, reduces beneficial biological production, and deteriorates water quality. The decay of organisms associated with eutrophication, often referred to as "bloom," leads to further biological pollution of water bodies. Scientific research has shown that "bloom" occurs in all types of water bodies [19-20].

Eutrophication can be observed in reservoirs and lakes that experience stable hydrological and hydrodynamic characteristics. For instance, in the United States, algal blooms in Lake Erie, which is over 12,000 years old, began to emerge only in the second half of the 20th century. The significant development and spread of algae have been noted in various lakes, including those in mountainous regions of Switzerland, Sweden, and Yakutia, all of which are situated in northern latitudes [21].

It is widely recognized that negative effects in reservoirs begin when algae biomass reaches concentrations between 500 to 5000 g/m³. An excessive algal bloom indicates the accumulation of organic matter in the water, which poses a risk of secondary pollution and eutrophication. Furthermore, it is important to note that algae can accumulate significant amounts of heavy metals, including mercury, iron, copper, zinc, molybdenum, lead, aluminum, boron, manganese, and cadmium. When these plants die, the heavy metals are released into the water in their free form.

The Caspian Sea is the largest enclosed body of water on our planet. Its salty waters border five countries, including Kazakhstan and Russia, and it is rich in natural resources such as oil. What makes the Caspian Sea unique is its diverse marine life, home to over 120 species, including sturgeon, urchins, wrasses, and many other animals. The maximum depth of the Caspian Sea reaches 1,025 meters, and it stretches approximately 1,200 kilometers from north to south, earning it the nickname "sea."

However, the ecological state of the Caspian Sea is deteriorating and approaching a catastrophe. Various industrial waste water is flowing into the sea, leading to the inevitable decline of fish, crustaceans, Caspian seals, and other marine inhabitants. Oil slicks are increasingly appearing on the water's surface. Samples taken from the seabed indicate contamination with hazardous substances, including lead, mercury, cadmium, arsenic, zinc, nickel, and vanadium. The levels of these pollutants exceed the established safety limits for such bodies of water by several times. [22]

Mingachaur Reservoir, also known as the Mingachevir Sea, is a large reservoir on the Kura River in northwestern Azerbaijan. It supplies water to the Upper Karabakh and Upper Shirvan channels, and is used for electricity generation, irrigation water supply, and fishing. The Mingachevir Reservoir is the largest in the Caucasus, having a length of 70 km, a width of 18 km, a maximum depth of 75 m, an average depth of 26 m, a maximum volume of 15.73 km3, a shoreline length of 247 km, and an overall area of 605 km2 . The reservoir's water level is maintained by the dam of the Mingachevir Hydro Power Plant, built near Mount Bozdağ from 1945 to 1953. It is the largest hydroelectric power station in Azerbaijan, with an installed electric capacity of 401.6 megawatts. Its dam has a length of 1,550 m, a width of 16 m, and a height of 80 m.

In the current period, the eutrophic layer in the reservoir has been deepened. Thus, it is known that during the formation of the eutrophication process in the Mingechaur reservoir, along with the intensive development of phytoplankton, the area of their assimilation the eutrophic layer in the reservoir has deepened in recent times. Research indicates that the eutrophication process in the Mingechaur reservoir has led to significant phytoplankton growth, which has subsequently expanded and deepened their assimilation area. Over the past 50 years, the continuation of eutrophication in the Mingechaur reservoir has been increasingly noticeable, especially during the summer months.

It is noteworthy that the primary phytoplankton product in the Mingechaur reservoir has increased 11 times over the past 53 years. Interestingly that the dynamics of the phytoplankton initial primary product of reproduction by seasons of the year has been preserved, since in previous years the productivity on the entire area of the reservoir sharply decreased on the right bank. This is due to increased erosion along the coast. Depending on the seasons of the year, the formation of the primary product - the harvest - continues intensively in spring, summer, and autumn, except for the winter period.

In modern times, there have been significant changes in the physico-chemical properties of the waters of the Mingechaur reservoir. For the same reason, the intensity in the process of forming the biological productivity of the Mingechaur reservoir differs. The Mingechaur reservoir is a typical eutrophic reservoir of trophic type. It should be noted that in the last 25-30 years reservoirs have been created in the course of the three main rivers –Kur, Araz, Gabyrra, flowing into the Mingechaur reservoir, and unlike previous years, biogenic solid sediments are not discharged directly into the basin. However, the average annual amount of primary organic matter synthesized by phytoplankton in the Mingechaur reservoir is higher than the indicators defined in the eutrophic type and anthropogenic eutrophication continues without weakening [22].

Sevan' lake. By the mid-1990s, the water level of Lake Sevan had dropped by about 19 meters, eutrophication (excessive accumulation of plant nutrients) began, and the concentration of phosphorus, nitrogen, and other plant nutrients increased. To restore the balance and prevent a catastrophe, the almost 50-kilometer Arpa-Sevan tunnel was built. In the 1980s, the water level stabilized at about 1,897 meters. As of July 2021, the lake is located at an altitude of 1,900.75 m above sea level and contains a volume of water of 38 cubic kilometers [23-25].

It was determined that the cause of anthropogenic eutrophication of the lake is the combined action of two leading factors: restructuring of processes within the reservoir, disruption of the natural dynamic balance in the "water and sediment" system, and excessive inflow of biogenic substances from the catchment area. Currently, the water level of the lake is gradually increasing (by 6 m by 2030), however, this increase, like the previous decrease, is accompanied by water pollution as a result of intensive development of the banks, pollution of the coastal strip, point and diffuse pollution, and the deterioration of water quality indicators of the reservoirs - Martuni, Vardenis - leads to periodic "blooming" of the lake, changes in biodiversity, and other negative consequences. The main cause of Sevan eutrophication in 2018 was an increase in the number of algae in the reservoir, which was first observed in 1964 . According to the Ministry of Environmental Protection, the bloom was caused by wastewater entering the lake, including household and agricultural waste. Out of 400 business facilities in the coastal areas of the lake, only 14 treat wastewater. Pollutants are salts of heavy metals and the heavy metals themselves. The problem of pollution of the lake with heavy metals is more complex. Excessive levels of heavy metal ions have been periodically detected in the lake, such as: V- 5-6 times, Cr- 2 times, Se- 2-3 times, Cu- in some areas 2-3 times, Mg- 1.2-1.4 times [31-33]

Several environmental factors have significantly contributed to the decline in the ecological condition of the lake. These include a reduction in water levels, rising temperatures, an increase in cyanobacteria, a decrease in lake fauna, and the discharge of wastewater from cottages, hotels, restaurants, and residential buildings along the shore. In many villages and settlements, homes are either not connected to the sewage network or the networks are poorly maintained.

The unrestricted flow of fecal and domestic wastewater into the rivers that feed into the lake raises serious concerns about water quality. This is particularly evident in the varying water quality observed in both large and small rivers at their confluences, especially near populated areas. The findings indicate that water is clean at its source; however, there is a significant increase in E. coli levels and other pathogenic microorganisms near the settlements.

Fig. 1. The polluted water surface of Lake Sevan.

A sharp increase in eutrophication levels has been observed in the Aparan and Azati reservoirs. The flow of the rivers Kasakhi and Gegharot is regulated in the Aparan reservoir, which has a basin area of 7.6 km². The Azati reservoir, with a basin area of 3.2 km², regulates the flow of the Azati River. The average water levels in these reservoirs are 1835 m and 2620 m, respectively.

Both reservoirs are filled during the flood period. During this time, water losses due to filtration greatly exceed the design values, resulting in a significant layer of alluvial material being deposited in the central part of the reservoirs. Eutrophication is primarily linked to the use of nitrogen and phosphorus fertilizers, phosphorus-containing pesticides, livestock waste, and water from irrigation reservoirs. Additionally, the water quality is compromised by untreated domestic and industrial wastewater from nearby cities and villages before the river flow is regulated.

Positive trends are currently being observed in the Lake Sevan biosphere. Measures continue to be taken to prevent poaching, and activities aimed at boosting the fish population are ongoing. In 2022, the number of crayfish amounted to 100 tons. The overall increase in the fish population was also influenced by the artificial reproduction of fries; in May 2023, 130 thousand "Ishkhani" fries - Sevan trout (weight 10 g) were released in the Karchakhpur district.

Black Sea.Due to its limited connection with the ocean, the Black Sea is very sensitive to anthropogenic impacts. As a result of human activity, the Black Sea has become one of the most degraded regional seas on the planet in recent decades. According to a report prepared by the Black Sea Commission, the Black Sea ecosystem was severely damaged in the 1970s-1980s, when large amounts of biogenic substances were introduced into the sea by rivers, leading to eutrophication of the sea. These processes were especially pronounced and intensively expressed on the northwestern coast of the sea, although eutrophication is also observed on the eastern coastal waters of Georgia.

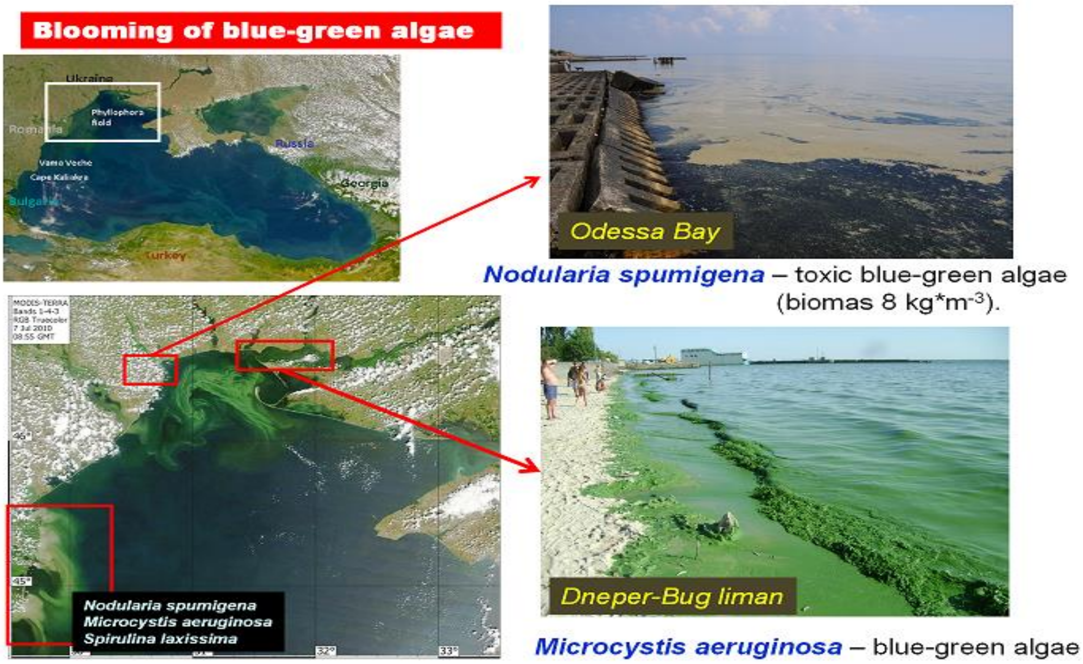

Fig. 2. The polluted water surfaces of the northwestern coasts of the Black Sea

The issue concerns the waters of the Ambassador Islands complex under construction, where three rivers Bartskhana, Kubistskali and Korolistskali, bring various types of pollutants that have caused the rapid generation, growth, and reproduction of cyan-bacteria [26].

It is noteworthy that phytoplankton in the ecosystem of the Black Sea, Georgia's coast, is quite diverse and is represented by six main groups of algae: Limestone ***(Bacillariophyta)*** 73%, dinoflagellates ***(Dinophyta)***-57%, green ***(Chlorophyta)***-2-3%, Golden ***(Chromophyta)***-6%, blew-green ***(Cyanophyta)***-16% and Yellow-green ***(Xanthophyta)***-%5, algae, among which the group of diatoms ***(Bacillariophyta)*** stands out for its species and quantitative superiority.

It is important to note that in certain study areas, such as the River Chorokhi, Batumi, and Supsa, local or point eutrophication occurs during the warmer months of the year. The aquatic waters of the River Supsa are particularly noteworthy, as they display a significant presence of blue-green algae (which contain especially toxic metabolites) and yellow-green algae. Additionally, one of the phagotrophic species of dinoflagellates**,** ***Noctiluca scintillans***—commonly known as "sea glow"—dominates the estuaries of the Chorokhi and Supsa rivers, serving as an indicator of local eutrophication.

The total number of phytoplankton in the Georgian Black Sea coastline usually experiences seasonal fluctuations and in spring and summer, precisely during the recreational period, it reaches an average of 1400 to 2300 million units/m^3, which negatively affects the health of vacationers, and in autumn and winter it varies from 1000 to 200 million units/m^3. According to the Black Sea Strategic Action Plans, in addition to eutrophication, the causes of environmental degradation in the Black Sea are chemical pollution of water (including as a result of oil spills), excessive fishing of marine fauna and the invasion of alien species into the sea [27].

Based on the analysis of the information obtained as a result of monitoring, it can be said that the main causes of water pollution in the Black Sea region of Georgia are water-using enterprises (especially communal ones), where a complete technological regime for wastewater treatment has not been implemented or water treatment facilities are operating inefficiently. Besides, it is also worth noting that 20 European countries discharge their wastes into the Black Sea, including through the Danube, Prut, and Dnieper rivers, with the main load falling on its relatively shallow northwestern part, where 65% of all living organisms are conceived, and the main spawning grounds are located.

The Tbilisi reservoir ecology. The reservoir is located in the northeastern part of Tbilisi. It has an elongated shape from northwest to southeast. The length of the coastline is 23.9 km, the surface area is 11.8 km2, the total volume of water is 308 and the usable volume is 155 million cubic meters, respectively; the average depth is 26.6 m, the maximum - 45 m; the maximum water level is 548 m, and the minimum - 333 m. The natural inflow of the reservoir is insignificant. The reservoir is supplied with water both from the Zhinvali reservoir, with a gravitational flow of Q = 12.5 m^3/s, of which 12.0 m^3/s is considered the city's water supply, and 0.5 m^3/s for irrigation of agricultural lands in Samgori, and from the Sioni reservoir, through the Zemo Samgori main canal, with a water flow of 6 m^3/s, of which an average of 2/3 is used for irrigation. The remaining volume of water accumulated in the reservoir is used for drinking water .

It is worth noting that, according to hydro-chemical characteristics, the surface waters of the Aragvi, Zhinvali, and Tbilisi reservoir basins are suitable for drinking water supply. Nevertheless, it is advisable to allocate such local areas that are potentially dangerous to any extreme events (damage to sewage systems of settlements and industrial facilities, failure of treatment plants, etc.), and in the future, due to increased anthropogenic load, in terms of chemical pollution. In such areas, it is desirable to carry out preventive water protection measures, which in these cases will create a reliable guarantee of protecting the quality of drinking water.

The study of samples taken from the reservoir showed that the main algae in the Tbilisi reservoir are: 1. Blue-greens – ***Cyan-bacteria***; 2. Greens - ***Cylorophyceae;*** 3. Diatoms - ***Diatomeae***; 4. Desmidiales - ***Desmidiales***; 5. Pyrophyta - ***Peridineae;*** 6. Volvox - ***Volvocales***; 7. ***Euglenineae***. They cover the water surface and float along the coastline with a width of 15-85 m. Observations conducted in the spring showed that mainly diatom algae (***Melosira, Asterionella, Fragilaria and Naviculaceae***) developed and spread, the number of cells per liter ranged from 40 to 165 thousand units [28].

During the observation, other species of algae were detected, including toxic algae represented by Anabeana. In spring, their number was 1000-3500 units/l, and in summer the concentration was approximately doubled, depending on the distance from the water inflow point and the wind direction.

The results of hydrochemical studies showed that the mineralization of the waters of the Aragvi, Zhinvali and Tbilisi reservoirs is below average, the content of biogenic elements is small, and the dichromatic oxidation is low, which indicates that chemical pollution is insignificant. The concentrations of trace elements are also low. The values of these indicators do not exceed the maximum permissible concentrations (MPC) provided for by water supply standards. In most cases, the studied waters belong to ecologically very clean - Class I waters, and only in terms of the content of phenols and oil products do they belong to Class II and III - clean and insignificantly polluted waters.

From a sanitary bacteriological point of view, the studied waters often fail to meet the requirements imposed on the water supply source. For a number of areas, there is a significant excess of coli-index concentrations over the maximum permissible norm (10,000 units/l). In the upper reaches of the Aragvi River, above the Zhinvali Reservoir, bacteriological pollution is seasonal, sharply increasing during the summer-autumn low-water period after rains, and is mainly caused by the washout of fecal pollution from pastures and livestock farms. The bacteriological pollution of the Zhinvali Reservoir is due to a sharp increase in this type of pollution in rivers; however, due to the dilution and self-cleaning processes taking place in the reservoir, the coli-index concentration values are two orders of magnitude lower than the values in the river [29].

Determination of changes in concentrations of biogenic ingredients (nitrogen, phosphorus) in Zhinvali reservoir

The equation that takes into account the changes in concentrations of various chemical elements in a reservoir has the following form [5,11]:

$$C_j = C_{0j}\, exp\left[-\left(\frac{Q_{flout}}{W} + K_j\right)t\right] + \frac{C_{trib.j}\cdot Q_{trib}}{Q_{flout} + KW}\left\{1 - exp\left[-\left(\frac{Q_{flout}}{W} + K_j\right)t\right]\right\} \quad (1)$$

(1) Here - is the initial concentration of the j-th element in the reservoir, the volume of which is W; kj - non-conservative (destruction) coefficient; $C_{trib.j}$- concentration of the j-th ingredient in the effluent Q_{trib}; C_j - concentration of the element that flows out of the reservoir $Q_{flout.}$

We calculate for the following data: $C_P = 0,01$mg/l; nitrogen $C_N = 1,75$ - mg/l; the flow of the Aragvi tributary Q_{trib} =23.2 m^3/s; Pshavi's Aragvi Q_{trib} =20.6 m^3/s;. The flow for the HPP is Q_{flout} =9.0 m^3/s. According to the formula (1), we obtain $C_P = 0,009$ mg/l for phosphorus concentration, and $C_N = 1,52$ mg/l for nitrogen concentration [5,11].

Predicting the level of Zhinvali reservoir' eutrophication. In case to determine the eutrophication of the Zhinvali reservoir, it is first necessary to determine the amount of primary products formed as a result of photosynthetic reactions in the reservoir, i.e., to determine the average annual concentrations of chlorophyll [chlor.a]. In the case when the ratio of nitrogen and phosphorus in the study waters is N : P >12, we will use the Dillon and Riegler relationship.

$$Log_{10}\,[clor.\mathbf{a}]=1,45log_{10}\,([P]\cdot 1000)1,14 \qquad (2)$$

And in the case when the ratio of nitrogen and phosphorus is N : P <4, the following relationship

$$Log_{10}\,[clor.\mathbf{a}]=1,4\,log_{10}\,([N]\cdot 1000)-1,9 \qquad (3)$$

In these relationships, the concentrations of nitrogen and phosphorus are expressed in mg/l, and the concentration of chlorophyll in mkg/l. which can be used to determine the amount of primary products formed as a result of photosynthetic reactions in the reservoir, i.e.,to determine the chlorophyll-a average concentrations, one of the most important indicators of eutrophication. After determining the concentrations of biogenic substances nitrogen and phosphorus in the reservoir, since these data are essential for assessing the biomass in the reservoir, it is already possible to predict the level of the reservoir' eutrophication.

Using this method, the concentration of was determined in the Zhinvali reservoir, which is 2.31 mg / m^3.

$Cl._{"a"} = 0,28P^{0,96}$, (4)

As for the Tbilisi Reservoir, there is a growing trend in bacteriological and biological pollution: the coli-index value in some cases reached 50,000 units/l. It should be noted that the determining factors of the pollution of the Tbilisi Reservoir are: water and solid sediment entering from the Zhinvali and Samgori canals, which causes siltation of the Tbilisi Reservoir, as a result of which the depths of the reservoir decrease and favorable conditions are created for the spread of phyto- and zooplankton, which is already noted; use of the reservoir for recreational purposes - swimming, tourism, fishing, etc., which results in pollution of the surrounding areas and its washing into the reservoir as a result of rains; as well as the use of the areas surrounding the reservoir as pastures and watering places for livestock belonging to the population[31].

Of course, there are direct ways to determine phytoplankton biomass directly in the laboratory, but these measurements are quite difficult, time-consuming, and not very accurate.

It is also worth noting that various economic facilities are located on the territory of the recreational zone of the Tbilisi Reservoir. Despite the fact that they are sewered, as established by a survey of the population, in a number of cases, when accidents occur in the sewage systems, polluted waters enter the Tbilisi Reservoir. According to the hydrochemical characteristics, the surface waters of the Aragvi, Zhinali and Tbilisi Reservoir basins are suitable for drinking water supply. Nevertheless, it is advisable to allocate such local areas that, in the event of any extreme event (damage to the sewage systems of settlements and industrial facilities, malfunction of treatment plants, etc.) and in the future, will be considered potentially dangerous areas in terms of chemical pollution caused by an increase in anthropogenic load. In such areas, it is desirable to carry out preventive water protection measures, which in these cases will create a reliable guarantee of protecting the quality of drinking water. Unfortunately, the Sanitary Supervision Service does not function at all in Georgia today. Even before its abolition, sanitary doctors had limited rights and could not influence such issues; they could only identify sources of pollution and could not impose administrative fines.

Conclusion*:*

Water is one of the natural resources that has been directly linked to human life from the very first moments, has an incessant connection with it, and uses it quite frequently and extensively throughout its existence.

Based on comprehensive research, it is essential to develop new approaches to water treatment before and after water abstraction. This includes creating specialized methods and recommendations for implementation in the water supply system. We need to establish complex barriers and technologies for water treatment that will significantly reduce the burden on reservoirs and water treatment plants from various pollutants. Additionally, this approach could allow for the use of safer disinfectants instead of chlorine, which poses risks to human health.

Therefore, the main problem related to the quality of river and reservoir waters is the presence of chlorinated organic compounds, pesticides, and detergent residues in them, which, after disinfection of water with chlorine, form dioxins, the analysis of which is very difficult and possible only with special expensive equipment. It is known that water is chlorinated to destroy harmful microorganisms and preserve the organoleptic properties of drinking water. As a result, the first organochlorine compounds are formed in the water, and then, under the influence of soluble oxygen, they form very toxic dioxins, which contribute to the development of cancerous tumors. Organochlorine compounds containing fluorine, chlorine, and bromine cause nephritis (kidney disease), hepatitis (liver disease), increase the number of stillbirths and toxicosis during pregnancy, congenital anomalies, mutagenic defects, weakening of immunity, and disruption of reproductive function in both men and women. It is precisely due to the subsequent formation of dioxins that mutagenic, carcinogenic, teratogenic (ugly) properties are manifested in water at concentrations of 5-10 -12 mg/l.

We strongly believe that in order to protect water resources, it is necessary to prohibit the discharge of untreated runoff into reservoirs, prohibit any activities that negatively affect water quality in water protection zones, and take various administrative measures; strengthen the self-cleaning processes of reservoirs, improve and maintain the conditions for the formation of surface and groundwater; pay special attention to the introduction of methods and technologies for improving the ecological and hygienic state of water in the direction of cleaning runoff from agricultural fields; find and attract adequate methods for cleaning and disinfecting drinking water; replace worn-out branches of the network and implement planned flushing measures; impose strict control and punitive sanctions for excessive water consumption; Tightening control over the irrational placement of industrial and various agricultural, as well as recreational facilities near water supply facilities by local government bodies, sanitary-epidemiological and water supply services .This is a current, unsolved, life-and-death problem for the whole world, to which the government of our country, healthcare and non-governmental organizations should pay special attention [31-34].

We do not allow the health of our future generation to be encroached upon by the above-mentioned horrors. A priori, it must be said that preventing the causes of an accident is cheaper than eliminating its consequences, especially an epidemic.

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რეგიონული წყლის ობიექტების დაბინძურების პრობლემები

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რეზიუმე

პარადოქსულია, მაგრამ მიუხედავად იმისა, რომ წყალი დედამიწაზე სასიცოცხლოდ მნიშვნელოვან ნივთიერებას წარმოადგენს, ის ბუნებაში ერთ-ერთ ყველაზე ნაკლებად შესწავლილ ნაერთად რჩება. მისი სირთულე მეცნიერებისთვის გამოწვევებს ქმნის, რაც მის სრულად გაგებას ართულებს. მიუხედავად იმისა, რომ წყლის ქიმიური შემადგენლობა სტაბილურია, მისი გავლენა ორგანიზმებზე გარემო პირობების მიხედვით იცვლება.
მომავალში წყალთან დაკავშირებული მნიშვნელოვანი საფრთხეების წინაშე ვდგავართ, რაც მნიშვნელოვან ყურადღებას მოითხოვს. ერთ-ერთი საგანგაშო შეშფოთება, რომელიც გლობალურად არის აღიარებული, არის ფართოდ გავრცელებული პრობლემის პოტენციური გაჩენა ჩვენს წყალმომარაგების სისტემებსა და რეკრეაციულ წყალსაცავებში. ზოგიერთის მიერ „21-ე საუკუნის ჭირად“ მოხსენიებული ეს პრობლემა დაკავშირებულია გარკვეული მიკროორგანიზმების - დედამიწაზე არსებული უძველესი სიცოცხლის ფორმების - ევოლუციურ ბუნებასთან, რომლებიც ამჟამად ქიმიური დაბინძურების გამო მავნე ხდება.
გამალეას სამეცნიერო-კვლევითი ინსტიტუტის კვლევა მიუთითებს, რომ ამ მიკროორგანიზმებს შეუძლიათ განავითარონ ახალი, საშიში შტამები, რომლებიც დროთა განმავლობაში ავლენენ ეფექტებს და ფუნქციონირებენ როგორც „ნელი მოქმედების მაღარო“. ისინი წარმოქმნიან ნივთიერებებს კანცეროგენული, მუტაგენური და იმუნოსუპრესიული თვისებებით, რაც განსაკუთრებით შეინიშნება „ლურჯ-მწვანე“ წყალმცენარეებში ან ციანობაქტერიებში.
ეს სტატია ხაზს უსვამს მავნე წყალმცენარეების აყვავების (HABs) კრიტიკულ საკითხს, განსაკუთრებით თბილისის წყალსაცავში, და პროგნოზირებს ჟინვალის წყალსაცავში ადამიანის საქმიანობით გამოწვეულ ევტროფიკაციას. ასეთი მოსაზრებების გამოყენება შესაძლებელია გლობალურადაც, რაც ხაზს უსვამს ჩვენი წყლის რესურსებისა და საზოგადოებრივი ჯანმრთელობის დასაცავად მოქმედების სასწრაფო აუცილებლობას.

საკვანძო სიტყვები: ფიტოპლანქტონი, ევტროფიკაცია, ბიოგენური ელემენტები, გასუფთავება, წყალსატევები.

Проблемы загрязнения региональных водоемов

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Резюме

Парадоксально, но, несмотря на то, что вода является жизненно важным веществом на Земле, она остается одним из наименее изученных соединений в природе. Ее сложность создает проблемы для ученых, затрудняя полное понимание ее состава. Хотя химический состав воды стабилен, ее воздействие на организмы варьируется в зависимости от условий окружающей среды.
В будущем мы столкнемся со значительными угрозами, связанными с водой, которые потребуют значительного внимания. Одна из тревожных проблем, признанных во всем мире, — это потенциальное возникновение широко распространенной проблемы в наших системах водоснабжения и водохранилищах для отдыха. Эта проблема, которую некоторые называют «чумой XXI века», связана

с эволюционирующей природой определенных микроорганизмов — одних из древнейших форм жизни на Земле, — которые теперь становятся опасными из-за химического загрязнения.
Исследования Научно-исследовательского института имени Гамалеи показывают, что эти микроорганизмы могут развивать новые, опасные штаммы, которые проявляют свои эффекты с течением времени, функционируя как «медленно действующая мина». Они производят вещества с канцерогенными, мутагенными и иммунодепрессивными свойствами, что особенно заметно у «сине-зеленых» водорослей или цианобактерий.
В данной статье освещается критическая проблема вредных цветений водорослей (ВЦВ), в частности, в Тбилисском водохранилище, и прогнозируется эвтрофикация в Жинвальском водохранилище вследствие деятельности человека. Полученные данные могут быть применены в глобальном масштабе, подчеркивая острую необходимость принятия мер по защите наших водных ресурсов и здоровья населения.
В статье рассматривается проблема вредных цветений водорослей (ВЦВ), уделяя особое внимание образованию и распространению цианобактерий в различных водоемах, включая Тбилисское водохранилище. Прогнозируется, что в Жинвальском водохранилище происходит эвтрофикация в результате деятельности человека. Этот подход может быть широко применен для прогнозирования подобных явлений в водоемах по всему миру.

Ключевые слова: Фитопланктон, эвтрофикация, биогенные элементы, очистка, водоем.

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Comparative Radioecological Assessment of Soil Contamination in Mining Areas of Chiatura, Kazreti, and Zestaponi, Georgia

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ABSTRACT

Abandoned mining areas, especially those areas where heavy metals and radioactive elements were previously mined, represent one of the most important ecological problems. Chiatura, as the main center of manganese mining in Georgia, turned out to be a region where heavy metals and radioactive substances caused significant contamination of soil and water resources. The aim of the study is to analyze, assess and study the radioecological risks of soil contamination from abandoned mines in Chiatura. The study discusses the concentration of heavy metals in the soil, including manganese, lead, cadmium and others, as well as the impact of their potential radioactive contaminants on ecosystems. Modern ecological monitoring methods were used, including measuring the content of radioactive elements, analyzing soil samples and testing water. The results showed that the concentration of heavy metals in the territory of the abandoned mines of Chiatura exceeds safety standards, which directly affects both the ecological state of the soil and the flora and fauna. The article emphasizes the need to study radioecological risks and effectively respond to them. The study also includes an analysis of the subsidence of the soils of Kazreti, Zestaponi and Chiatura. These results indicate an increased risk of radioactive and non-radioactive substances, which requires the implementation of appropriate ecological remediation measures.

Key words*: radioactive elements, radionuclides, soil, radioecological, Georgia*

Introduction

The mining industry plays a critical role in soil contamination with lead, zinc, manganese, iron, and copper ions. Mining activities, product processing, waste management, and atmospheric deposition are major sources of contamination. These pollutants have a wide range of impacts on soil, water, plants, wildlife, and human health [1-5].

Chiatura — one of the most important industrial centers of Georgia — has been a major site for the extraction and processing of manganese for decades. As a result of intensive mining and quarrying activities, numerous open-pit and underground mines have been created in the region, many of which are currently abandoned and in a neglected state. Abandoning mines without proper ecological rehabilitation creates environmental and, in particular, radioecological hazards.Although manganese itself is not a radioactive element, its deposits often contain natural radionuclides such as uranium, thorium, and potassium-40 [6-8]. The spread of these compounds in the environment can have a significant impact on soil, water resources, and living organisms.Special attention needs to be paid to studying the content of radionuclides in soil, as it is both an indicator of environmental pollution and a source of risk transmission for humans and ecosystems.The aim of this study is to assess the radioecological state of the soil in the areas near the abandoned mines of Chiatura and analyze the potential risks associated with it. [9-12].

Our study includes a comparative analysis of pollution in the mining and industrial areas of three large regions: Chiatura, Kazreti, and Zestaponi. Kazreti, Chiatura and Zestaponi are three important technogenically loaded regions of Georgia, which are polluted by various types of industrial activities. Kazreti is characterized by intensive open-pit mining of copper-polymetallic ores; Chiatura - by long-term underground mining of manganese; and Zestaponi - by metallurgical production of ferro-alloys (ferromanganese). These differences significantly determine the nature and intensity of soil pollution.

Fig. 1. Long-term underground mining of manganese

Fig. 2. Long-term underground mining of manganese

Kazreti and Zestaponi represent two important industrial-technogenic zones of Georgia, however, the nature, intensity, and chemical profile of soil contamination are different, which is determined by the type of production and technological processes. Differences in pollution sources. [14,15].

Fig. 3. Fig. 4.

Kazret: open-pit mining (copper-polymetallic ores)

Kazret:

• Main sources: open-pit mining (copper-polymetallic ores);
• Tailings;
• Ore enrichment processes.

Zestafoni

• Main source: Metallurgical production of ferroalloys (ferromanganese);
• Atmospheric emissions;
• Technogenic dust deposition. Kazreti

Elevated concentrations of Cu, Zn, Pb, Cd and As are recorded in the soils of the Kazreti mining district, especially in the vicinity of quarries, waste heaps and ore enrichment facilities. The dominant contaminant is copper, the content of which often significantly exceeds background values. The presence of cadmium and arsenic indicates a high level of technogenic impact and increases the ecological risk [16,17].

Fig. 5. Metallurgical production of ferroalloys (ferromanganese) in Zestafoni

Chiatura
The contamination of Chiatura soils is mainly associated with high concentrations of manganese (Mn), which is due to the long-term extraction of manganese ores. Additionally, increased contents of lead (Pb), zinc (Zn) and iron (Fe) are noted [16,17]. The contamination is spatially heterogeneous and is especially high in the areas adjacent to mines, waste heaps and transport routes.

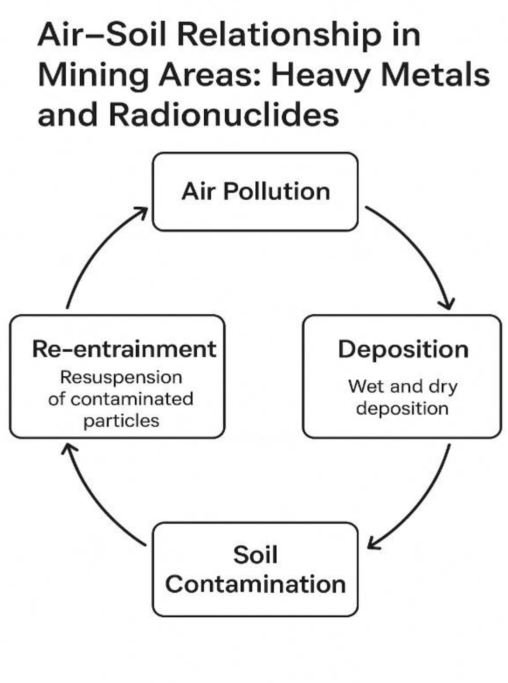

Fig. 6. Air-Soil Relationship in Mining Areas:Heavy Metals and Radionuclides

Zestafoni

The dominant element in Zestafoni soils is manganese (Mn), accompanied by Pb, Zn, Cr, and Ni. Unlike Kazreti and Chiatura, pollution here is mainly caused by the deposition of atmospheric dust generated by metallurgical production, due to which heavy metals are relatively evenly distributed over a wide area. Soil Chemical and Physical Changes

Kazret soils are often characterized by increased acidity, decreased organic matter content, and structural degradation, which is associated with acid mining drainage.

In Chiatura soils, structural damage is relatively moderate, although the accumulation of heavy metals occurs mainly in the upper horizons.

In Zestafoni soils, a tendency to alkalization is observed in some areas, which is due to industrial emissions, while the physical structure is relatively better preserved.

Overall, Kazreti is characterized by the highest level of pollution in terms of heavy metal concentration and toxicity (especially Cu and Cd). Chiatura is a region mainly polluted by manganese, with additional impacts of Pb and Zn. Zestafoni is under relatively less concentrated, but constant and widespread technogenic impact.

Research methodology

The study aims to assess the radioecological state of the soil in the area surrounding the abandoned mines in Chiatura. For this purpose, a scientific procedure was carried out in several stages:
1. Fieldwork and sampling

• Soil samples were taken in the immediate vicinity of the abandoned mines and, for comparison, in control areas located away from them.
• Samples were taken from different depths: surface layer (0–10 cm), middle layer (10–30 cm) and deep layer (30–50 cm).
• At least three parallel samples were taken at each site to ensure representativeness.
Laboratory Analysis
• Soil samples were dried, ground, and calcined according to standard procedures.
• Gamma-spectrometry with a high-precision detector was used to determine the concentration of radioactive elements (including ^238U, ^232Th, ^40K).
• In parallel, soil pH, moisture, organic matter content, and granular composition were determined — to enable an in-depth analysis of the conditions for the spread of contamination.
• The obtained radioactive data were compared with international norms (e.g., UNSCEAR or IAEA limits).

Results and discussion

Analysis of the data obtained as a result of the study showed that in the areas surrounding the abandoned mines of Chiatura, an increased concentration of natural radionuclides was found in the soil, especially in the form of ^238U (uranium), ^232Th (thorium) and ^40K (potassium-40). Their average activity levels in some samples significantly exceeded the background characteristic of Georgia and international safety threshold levels.

Radionuclide distribution

• ^238U concentrations near abandoned mines ranged from 35–60 Bq/kg, in some cases twice the regional background.

• ^232Th was found in the range of 40–70 Bq/kg, especially in areas where the soil is saturated with past industrial wastewater.

• ^40K levels remained largely within normal limits, although locally elevated levels (>500 Bq/kg) were noted.

Spatial and depth variations

• The intensity of contamination was mostly concentrated within a radius of ≤500 meters from the shafts and in the surface layer (0–10 cm).

• The radionuclide content tended to decrease in the lower layers, indicating that the contamination is superficial and likely spread through atmospheric transport and surface waters. The obtained data were compared with the radiological normative limits of the IAEA, UNSCEAR and the Ministry of Internal Affairs of Georgia. It turned out that although some indicators are within the norm, local excesses should be given attention as areas of long-term radioecological risk. The results of the study showed that in the areas surrounding the abandoned mines of Chiatura, elevated concentrations of natural radionuclides were found in the soil, especially in the form of ^238U, ^232Th, and ^40K.

The concentration of ^238U near the mines ranged from 35–60 Bq/kg, which in some cases is 2 times higher than the regional background.

^232Th was recorded in the range of 40–70 Bq/kg, especially in contaminated areas.

^40K values are generally within the normal range, although local exceedances are noted.

The analysis of the present data of the service has shown that similar surface contamination is observed in comparison with other former mining sites, for example, as in the study on environmental risks of abandoned mines in Donbass and Lermontov (Mashusa & Makgae, 2017). Below I provide you with the ecological impact of the Chiatura mines on the environment and a list of heavy metals that are recorded in the soil according to scientific studies. The text is written in accordance with the academic style so that you can directly use it in your work.

Ecological damage to the environment in the Chiatura mining region

The impact on the environment as a result of many years of exploitation of the Chiatura manganese deposits is complex and multifaceted. The scientific literature identifies several main ecological problems:

1. Soil degradation and pollution

Mining and extraction activities lead to:

• Disruption of soil structure;

• Reduction of the humus layer;

• Increased chemical pollution.
Dust and waste generated during mining and ore processing accumulate in the soil, leading to the accumulation of heavy metals.
2. Heavy metal pollution
According to scientific studies, the following heavy metals are most often detected in the soil of the Chiatura region:
• Manganese (Mn) – the main polluting element, often significantly exceeding the natural background;
• Iron (Fe) – high concentrations are associated with the mineral composition of the ore;
• Lead (Pb) – a toxic element of technogenic origin;
• Cadmium (Cd) – in small quantities, but with high ecotoxicity;
• Zinc (Zn) – often accompanies manganese ores;
• Copper (Cu) – recorded in areas affected by waste and dust;
• Nickel (Ni) – exceeds background values in some areas;
• Chromium (Cr) – associated with geological structure and technogenic impact.
Studies have highlighted that heavy metal accumulation is particularly high in areas surrounding mines, waste dumps, and transportation routes.

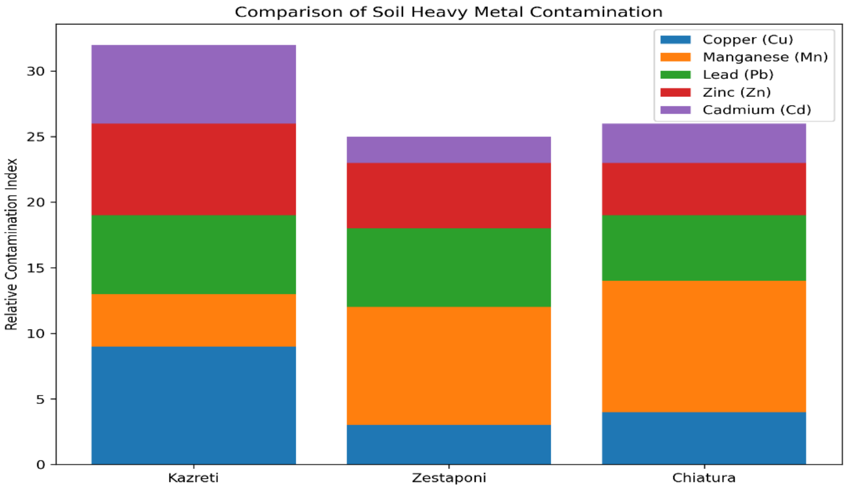

Fig. 7. Comparison of Soil Heavy Metal Contaminatyon

3. Impact on aquatic ecosystems
Heavy metals accumulated in the soil as a result of precipitation and erosion processes enter:
• Surface waters;
• Groundwater.
This leads to an increase in water mineralization and disruption of the biochemical balance.
4. Biological damage
According to scientific articles:
• Heavy metals are transferred to vegetation;
• Bioaccumulation occurs in agricultural crops;
• Ecotoxicological impact on ecosystems increases.
5. Secondary air pollution
Dust enriched with metals in the soil is re-entered into the atmosphere by the action of the wind, which:
• Increases the concentration of PM particles;
• Creates constant circulating pollution.
Kazreti has the highest and increasing activity of Cs-137, although the maximum value (15.1 Bq/kg) still does not exceed the permissible limit. Sr-90 levels exceed other locations and reach a maximum in 2023 – 10.2 Bq/kg, which indicates a higher radioecological load, most likely due to mineral extraction and processing processes.
Comparative profile of heavy metals in soil
Region Dominant heavy metals

Kazreti Cu, Zn, Pb, Cd, As, Fe
Zestafoni Mn, Pb, Zn, Cr, Ni, Fe
Kazreti
• High concentrations of copper (Cu) and zinc (Zn);
• Cadmium (Cd) and arsenic (As) are often detected;
• Heavy metals often significantly exceed the background in the immediate vicinity of the quarry and waste.
Zestaponi
• Manganese (Mn) is dominant;
• Increased chromium (Cr) and nickel (Ni) content is noted;
• Pollution is relatively evenly distributed throughout the city and surrounding area.

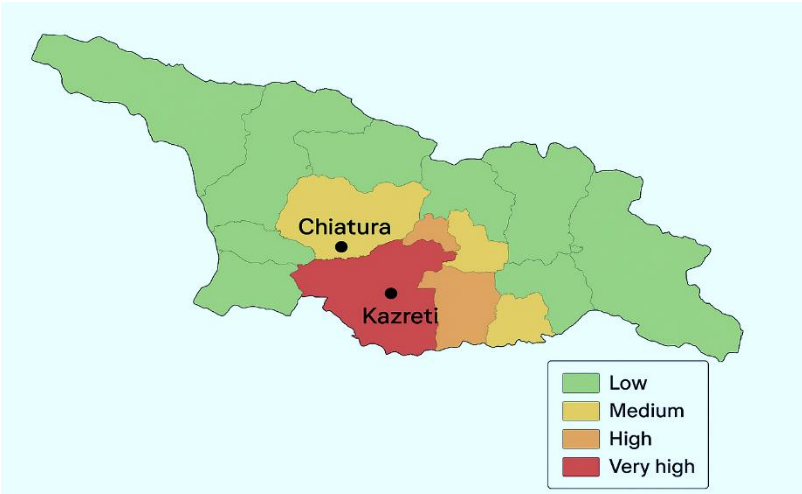

Fig. 8. Schematic map of Georgia showing the relative levels of soil contamination in mining and industrial regions:

Schematic map of Georgia showing the relative levels of soil contamination in mining and industrial regions: Chiatura (manganese mining), Zestaponi (ferroalloy production) and Kazreti (RMG – mining and quarrying activities). The color scale represents the estimated levels of contamination (low–very high) and is based on literature and environmental sources, rather than on-site geochemical measurements.

Conclusion

The comparative analysis of soil pollution in Kazreti, Chiaturi and Zestaponi conducted within the framework of the presented study revealed that the level, structure and ecological risks of heavy metal pollution in the mentioned regions differ significantly depending on the type and intensity of technogenic activity. The long-term impact of mining and metallurgical processes is one of the main factors of soil quality degradation in these regions.

The results of the study indicate that soil pollution in the Kazreti mining region is characterized by high intensity and sharply localized nature. Increased concentrations of copper, zinc and cadmium, especially in the vicinity of quarries, waste heaps and enrichment plants, create a high ecotoxic risk for both the biological functioning of the soil and the quality of surface and groundwater. The high mobility of heavy metals and acidic environmental conditions increase their potential for migration and bioaccumulation, posing a threat to agricultural lands and the health of the local population.

Soil contamination in the Chiatura region is mainly associated with long-term underground mining of manganese and historical mining activities. High concentrations of manganese, often exceeding background values, are the main characteristic of soil contamination in this region. In addition, the increased content of lead and zinc indicates the complex impact of technogenic processes. The spatial heterogeneity of pollution, especially in the vicinity of abandoned mines and waste heaps, emphasizes the need for rehabilitation and constant monitoring.

Soil contamination in Zestaponi is characterized by a different mechanism and is mainly caused by atmospheric emissions from the production of ferroalloys. Chronic deposition of manganese, chromium and nickel leads to uniform accumulation of heavy metals in the upper soil horizons over a wide area. Although the maximum concentrations of individual metals are in some cases relatively low compared to the data for Kazreti, the constant and long-term nature of the pollution in Zestaponi creates a long-term ecological risk, especially in terms of bioaccumulation and air-soil pollution circulation processes.

According to the general assessment, soil pollution in all three regions significantly affects the stability of ecosystems, soil physicochemical properties and biological activity. The results obtained confirm that a single, universal environmental approach is not effective and it is necessary to develop management strategies tailored to the region. For Kazreti, local reclamation and improved waste management are priorities; for Chiaturi — safe conservation of abandoned mines, introduction of geodynamic and ecological monitoring systems; and for Zestaponi — control of atmospheric emissions and long-term monitoring of soil quality.

In conclusion, it can be said that heavy metal pollution of soils in the mining and industrial regions of Georgia is one of the most important environmental challenges. Its effective management requires an interdisciplinary approach that combines geochemical studies, ecological risk assessment and practical rehabilitation measures. This study creates a scientific basis for further, more detailed monitoring and development of sustainable environmental policies.

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ნიადაგის დაბინძურების შედარებითი რადიოეკოლოგიური შეფასება ჭიათურის, კაზრეთისა და ზესტაფონის სამთო რაიონებში, საქართველო

ს. მათიაშვილი, ზ. ჩანქსელიანი

რეზიუმე

მიტოვებული სამთომოპოვებითი ზონები, განსაკუთრებით ის ტერიტორიები, სადაც ადრე მძიმე მეტალები და რადიოაქტიური ელემენტები მოიპოვებოდა, ერთ-ერთ უმნიშვნელოვანეს ეკოლოგიურ პრობლემას წარმოადგენს. ჭიათურა, როგორც მანგანუმის მოპოვების მთავარი ცენტრი საქართველოში, აღმოჩნდა რეგიონი, სადაც მძიმე მეტალებმა და რადიოაქტიურმა ნივთიერებებმა ნიადაგისა და წყლის რესურსების მნიშვნელოვანი დაბინძურება გამოიწვია. კვლევის მიზანია ჭიათურაში მიტოვებული მაღაროებიდან ნიადაგის დაბინძურების რადიოეკოლოგიური რისკების ანალიზი, შეფასება და შესწავლა. კვლევაში განხილულია ნიადაგში მძიმე მეტალების, მათ შორის მანგანუმის, ტყვიის, კადმიუმის და სხვათა კონცენტრაცია, ასევე მათი პოტენციური რადიოაქტიური დამაბინძურებლების გავლენა ეკოსისტემებზე. გამოყენებული იქნა თანამედროვე ეკოლოგიური მონიტორინგის მეთოდები, მათ შორის რადიოაქტიური ელემენტების შემცველობის გაზომვა, ნიადაგის ნიმუშების ანალიზი და წყლის ტესტირება. შედეგებმა აჩვენა, რომ ჭიათურის მიტოვებული მაღაროების ტერიტორიაზე მძიმე მეტალების კონცენტრაცია აღემატება უსაფრთხოების სტანდარტებს, რაც პირდაპირ გავლენას ახდენს როგორც ნიადაგის ეკოლოგიურ მდგომარეობაზე, ასევე ფლორასა და ფაუნაზე. სტატიაში ხაზგასმულია რადიოეკოლოგიური რისკების შესწავლისა და მათზე ეფექტური რეაგირების აუცილებლობა. კვლევა ასევე მოიცავს კაზრეთის, ზესტაფონისა და ჭიათურის ნიადაგების დაწოლის ანალიზს. ეს შედეგები მიუთითებს რადიოაქტიური და არარადიოაქტიური ნივთიერებების გაზრდილ რისკზე, რაც მოითხოვს შესაბამისი ეკოლოგიური რემედიაციის ღონისძიებების განხორციელებას.

საკვანძო სიტყვები: რადიოაქტიური ელემენტები, რადიონუკლიდები, ნიადაგი, რადიოეკოლოგიური, საქართველო

Сравнительная радиоэкологическая оценка загрязнения почв в горнодобывающих районах Чиатура, Казрети и Зестапони, Грузия

С. Матиашвили, З. Чанкселиани

Резюме

Заброшенные горнодобывающие районы, особенно те, где ранее добывались тяжелые металлы и радиоактивные элементы, представляют собой одну из важнейших экологических проблем. Чиатура, как главный центр добычи марганца в Грузии, оказалась регионом, где тяжелые металлы и радиоактивные вещества вызвали значительное загрязнение почв и водных ресурсов. Цель исследования – проанализировать, оценить и изучить радиоэкологические риски загрязнения почв заброшенными шахтами в Чиатуре. В исследовании рассматривается концентрация тяжелых металлов, включая марганец, свинец, кадмий и другие, в почве, а также воздействие их потенциальных радиоактивных загрязнителей на экосистемы. Использовались современные методы экологического мониторинга, включая измерение содержания радиоактивных элементов, анализ образцов почвы и анализ воды. Результаты показали, что концентрация тяжелых металлов в районе заброшенных шахт Чиатуры превышает нормы безопасности, что напрямую влияет как на экологическое состояние почвы, так и на флору и фауну. В статье подчеркивается необходимость изучения радиоэкологических рисков и эффективного реагирования на них. Исследование также включает анализ осадочных пород почв Казрети, Зестапони и Чиатуры. Полученные результаты указывают на повышенный риск радиоактивных и нерадиоактивных веществ, что требует внедрения соответствующих мер по экологической реабилитации.

Ключевые слова: радиоактивные элементы, радионуклиды, почва, радиоэкология, Грузия

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Synchronization Effects in the Interaction of Complex Nonlinear Systems

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ABSTRACT

This study investigates the fundamental mechanisms of synchronization in nonlinear dynamical systems under external influences, bridging theoretical analysis with real-world geophysical applications. We first focus on the van der Pol nonlinear oscillator to explore forced synchronization, employing numerical modeling to analyze how external periodic forces modify the system's phase and frequency dynamics. A key finding reveals that the introduction of random noise can, counter-intuitively, contribute to the regulation of complex or chaotic regimes, leading to enhanced stability. Extending this analysis to the Sun-Earth connection, we utilize the wavelet coherence method to quantitatively assess the time-frequency coherence between solar parameters (such as the f10.7 index and the IMF B_z component) and terrestrial responses. This analysis successfully detects significant synchronization effects, confirming that the coherent interaction between these systems is directly responsible for triggering geomagnetic storms. Overall, this work provides a comprehensive framework for understanding synchronization phenomena, from controlled nonlinear systems to large-scale astrophysical interactions.

Key words: *Synchronization, Van der Pol Oscillator, Wavelet Coherence, Stochastic Resonance, Geomagnetic Storms.*

Introduction

Synchronization is a universal organizing principle describing the process by which two or more interacting dynamical systems operate in a time-coordinated manner. Using numerical modeling, we proceed to analyze how applied external periodic forces and the introduction of random noise collectively influence the oscillator's characteristic phase and frequency behavior. Crucially, we seek to determine the precise conditions under which noise often seen as a disruptive element can surprisingly contribute to the regulation of chaotic regimes, thereby inducing stability through stochastic resonance [1-2]. Using numerical modeling, we analyze how external periodic forces and the introduction of random noise change the oscillator's phase and frequency behavior. A key area of focus is determining the conditions under which noise can surprisingly contribute to the regulation of chaotic regimes, thereby inducing stability through stochastic resonance.

Beyond laboratory models, synchronization is fundamental to solar-terrestrial coupling the complex interaction chain through which solar energy influences the Earth's Geospace environment. To evaluate this coupling, we employ wavelet coherence, which provides a time-frequency assessment of the interaction between solar drivers and terrestrial signals. By analyzing specific parameters such as the IMF (B_z) component and the solar flux index F10.7, this study identifies synchronization windows that trigger geomagnetic storms on Earth, offering a unified framework that links nonlinear oscillator dynamics with large-scale space-weather phenomena and clarifies how coherent external forcing shapes system-wide responses.

Materials and methods

This article briefly considers Causes of geomagnetic storms on Earth in 1960-2025, 27 days apart. Based on the available study, some characteristics of these cases are analyzed. The averaged data is taken from several stations on Earth.

The study is processed using proven methods of mathematical statistics, validated statistical and probability-based methods commonly used in magnetospheric physics and solar–terrestrial research.

Results

The van der Pol oscillator is a prototypical nonlinear self-sustained system characterized by a non-linear damping regime in the absence of external forcing.

$$\frac{d^2x}{dt^2} - (\varepsilon - x^2)\frac{dx}{dt} + \omega^2 x = 0 \qquad (1)$$

To analyze the system's dynamics, the Fast Fourier Transform (FFT) is employed, which decomposes complex signals into simpler frequency components. The first case examined is the unforced oscillator. As shown in Figure 1, with no external influence, the oscillator oscillates at its natural frequency, which is clearly represented by the fundamental peak corresponding to the selected frequency data.

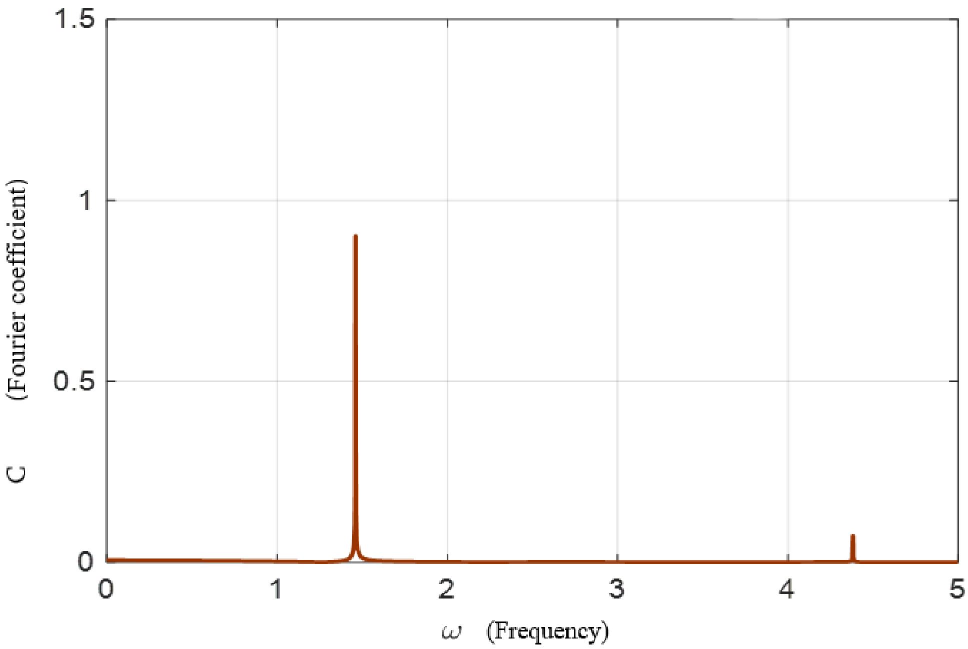

Fig.1. Oscillator without external force. ε =1;ω= 1.5;

When the oscillator is subjected to an external force, the governing equation takes the form:

$$\frac{d^2x}{dt^2} - (\varepsilon - x^2)\frac{dx}{dt} + \omega^2 x = A\sin(\Omega t) \qquad (2)$$

In this case, the external force is a harmonic excitation. The application of this force yields two possible outcomes: synchronous and asynchronous regimes.

Asynchronous Regime (Figure 2): Figure 2 shows the frequency spectrum when the amplitude of the external force is relatively small, insufficient to force the system into synchronization with its frequency. The result is an asynchronous regime, clearly indicated by the distinct, separate frequency peaks of the external force and the oscillator's natural frequency. They do not coincide.

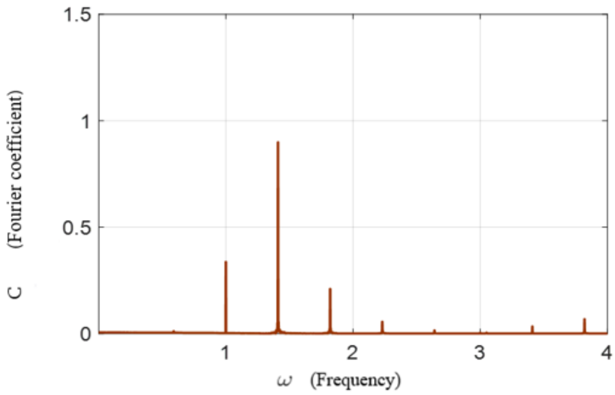

Fig.2. Asynchronous mode
$\varepsilon = 1;\ A = 1;\ \omega = 1.5;\ \Omega = 1;$

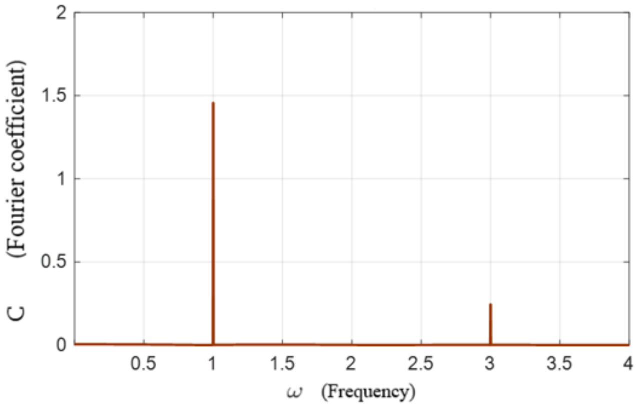

Fig.3. Synchronization without force.
$\varepsilon = 1; A = 4; \omega = 1.5; \Omega = 1;$

Synchronous Regime (Figure 3): To demonstrate synchronization between the external force and the oscillator, the amplitude of the external force was increased while keeping the frequency parameter constant. The increased amplitude successfully induced synchronization, which is evident in the spectrum by the presence of a single fundamental frequency component (Figure 3), which now matches the frequency of the external force.

We next observe the van der Pol oscillator when the system is subjected to a random, unpredictable force, or noise. The equation is modified to include a noise term:

$$\frac{d^2x}{dt^2} - (\varepsilon - x^2)\frac{dx}{dt} + \omega^2 x = A\sin(\Omega t) + \sqrt{2b}B(t) \tag{3}$$

As shown previously, a small amplitude external force alone did not establish synchronization between the oscillator's natural frequency and the forcing frequency. However, the addition of white noise to the system, even with the small amplitude external force, successfully established the synchronization effect (Figure 4). This illustrates a key principle related to Stochastic Resonance, where noise aids coherence.

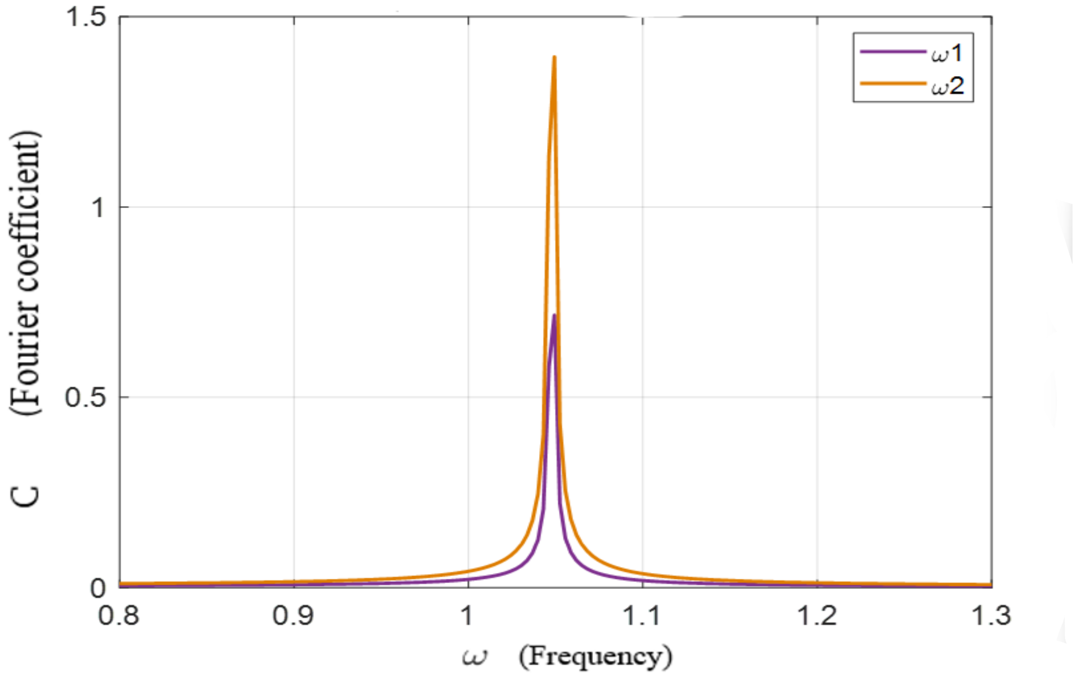

Fig.4. Synchronization of Van der Pol oscillators under the influence of white noise. ε=0,5; b=0.2;
Ω=1.5; ω=1; B=2.5;

Now let's look at the synchronization effect using the example of Adler's equation [3-4]. If the parameters included in the Van der Pol equation satisfy the given conditions: $\omega \approx \Omega$, $\varepsilon > 0, A \ll 1$, We look for the solution in the following form: $x(t) = R(t)cos(\omega t + \varphi(t))$, where A and φ are slowly varying functions of time, and A_0 and ω_0 are the amplitude and frequency of the self-oscillation *without* the external force. By substituting this solution and performing averaging (or other asymptotic methods), we obtain an equation for the phase (φ), which is called Adler's equation:

$$\dot{\varphi} = -\Delta + \frac{\beta}{R_{b\vartheta}} sin(\varphi(t)) \tag{4}$$

Synchronization can be classified as having either a continuous (constant) or intermittent (variable) character. We examined the phase synchronization behavior in the case of a single external force.

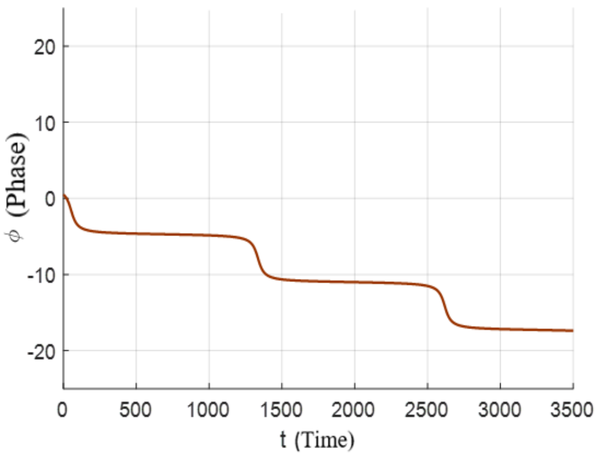

Fig.5.a. Phase synchronization for the Adler equation. Phase transitions. $\varepsilon = 0.1$; Δ=0.032; β =0.02;

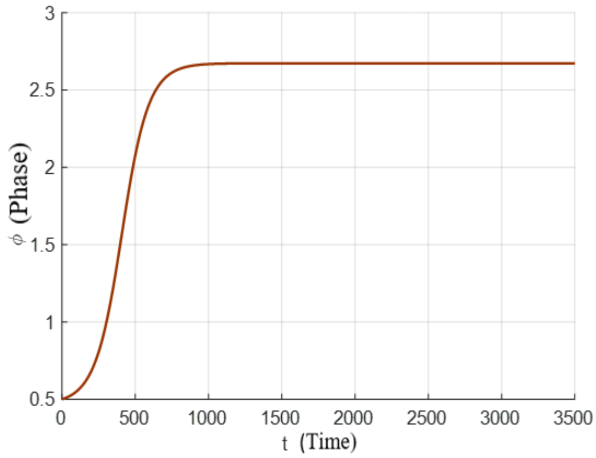

Fig. 5.b. Phase synchronization for the Adler equation. $\varepsilon = 0.1$; Δ=0.005; $\beta = 0.007$;

Intermittent Phase Synchronization (Figure 5a): Over a specific time interval, the phase remains constant, followed by a phase slip (a jump). The system then re-establishes a synchronization regime at a different phase value, and this cycle repeats (Figure 5a).

Continuous Phase Synchronization (Figure 5b): We can also observe a case where phase synchronization adopts a constant character. With the given parameters, synchronization did not occur over an initial time interval, but then took on a continuous (constant) character (Figure 5b).

In order to clarify how solar variability imprints itself on Earth's magnetosphere, we investigated long-term Sun–terrestrial coupling using multi-decadal records of the Dst geomagnetic index, the solar flux index F10.7, and the sunspot number R. The purpose of this analysis was to determine whether coherent structures, synchronization regimes, or phase-locking patterns could explain the emergence and statistical distribution of geomagnetic disturbances, including storm-time events. Our results show that synchronization between solar drivers and the geomagnetic response appears at several characteristic scales.

Wavelet coherence reveals a broad, persistent synchronization band near the 11-year solar cycle, accompanied by intermittent coherence patches around the 27-day rotational period, indicating that both long-term and recurrent solar features leave detectable signatures in Dst variability. These findings are supported by the F10.7-Dst scatter distribution, which shows weak but systematic coupling during quiet and moderate conditions, and by the R-Dst density plot, where most values cluster between 20 and 60 nT, reflecting the background state of the magnetosphere. Only a small fraction of points extend below $Dst <$ 100 nT, corresponding to intense geomagnetic storms.

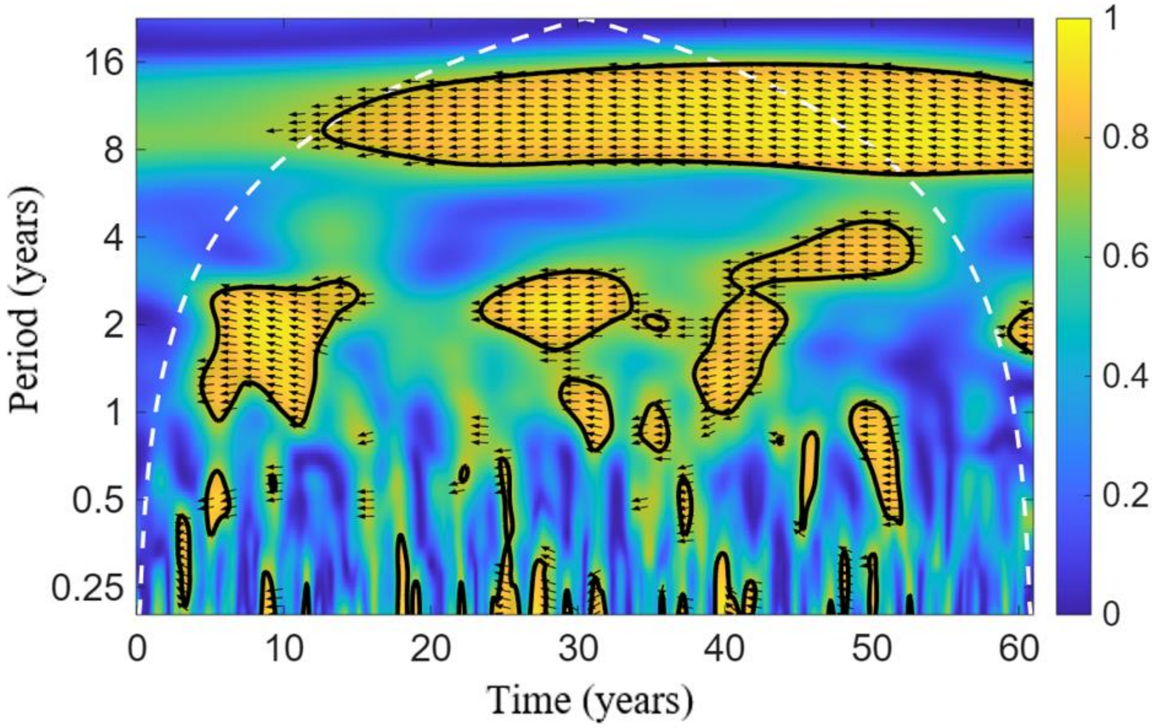

Fig.6. Coherence of the interplanetary magnetic field and the Earth's magnetic field

This figure.6 presents the wavelet coherence between the interplanetary magnetic field (IMF) and the Earth's magnetic field. The coherence map displays scale-dependent correlations, where high-coherence regions highlight intervals of strong coupling between IMF fluctuations and geomagnetic responses. The cone of influence and significance contours outline the statistically reliable coherence zones.

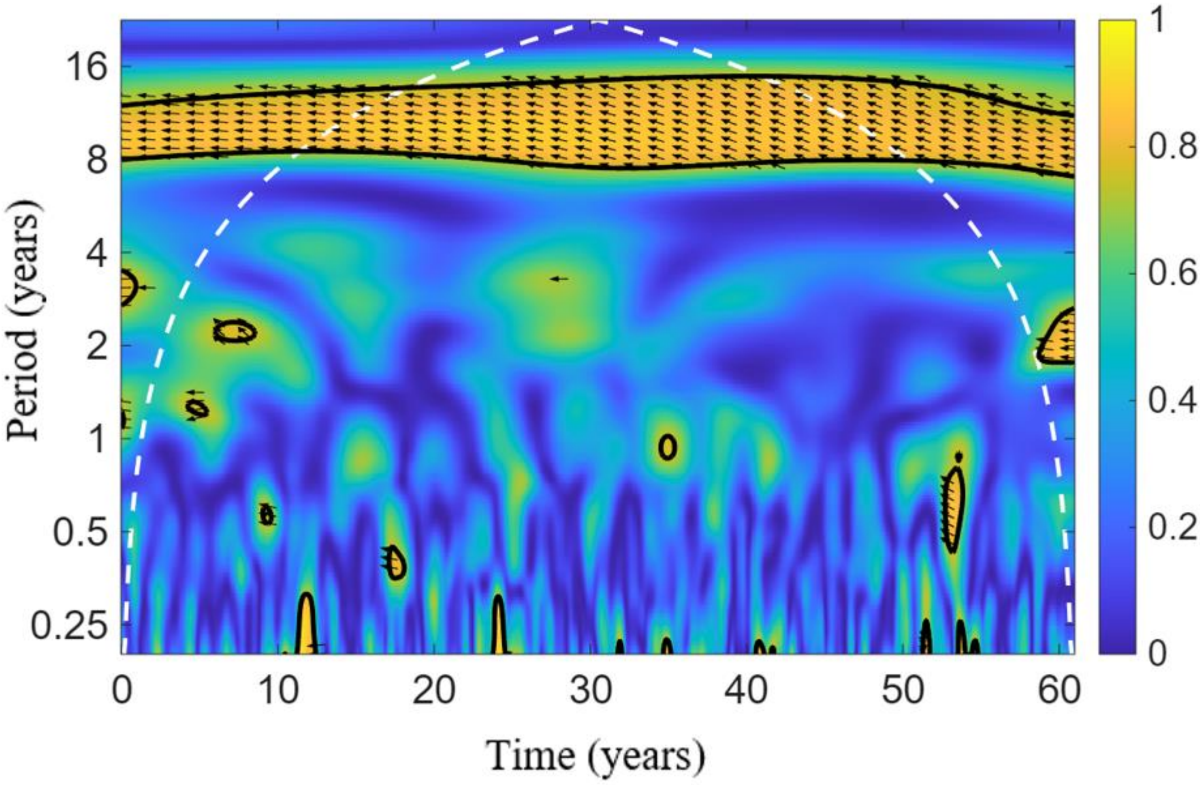

Fig.7. Coherent analysis of sunspot activity and geomagnetic field variations

This figure.7 shows the wavelet coherence between the sunspot number time series and geomagnetic field variations. The diagram reveals localized periods of elevated coherence across multiple time scales, indicating intervals where solar activity and geomagnetic disturbances exhibit synchronized behavior. Significant coherence patches are delineated by contour boundaries.

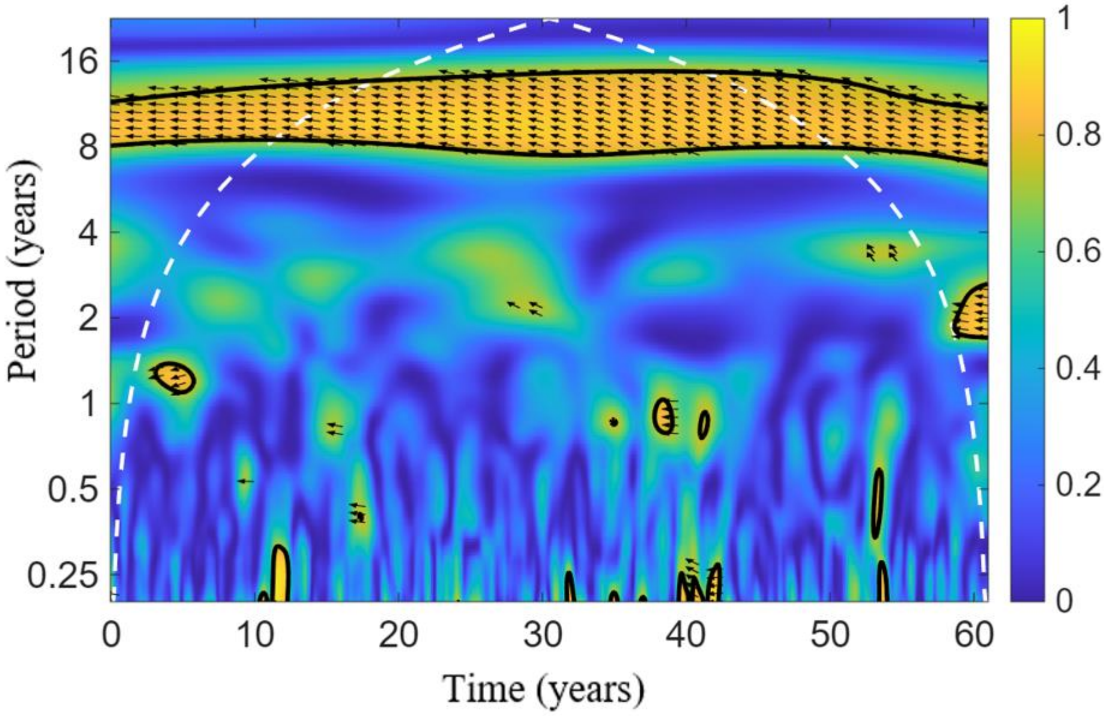

Fig.8. Radio emission from the Sun between 10.7 cm and Dst.

This figure.8 illustrates the coherence between the 10.7-cm solar radio flux and the geomagnetic Dst index. The coherence plot highlights frequency bands where radio emission variability corresponds to geomagnetic storm intensity. High-coherence areas, emphasized by significance contours, indicate time–scale intervals characterized by strong coupling.

Taken together, these results demonstrate that geomagnetic storms emerge precisely when the magnetosphere transitions into a state of maximal synchronization with the intensified interplanetary magnetic field. The persistence and phase uniformity within the high-coherence regions are the necessary and sufficient conditions for efficiently driving the ring current. This finding suggests that forecasting severe space weather should incorporate not only the amplitude of the solar wind parameters but also the degree of sustained phase coherence between the driver and the terrestrial response system.

Conclusion

We initially explored the concept and importance of synchronization through theoretical models. Specifically, we demonstrated frequency synchronization in the van der Pol model and phase synchronization in the Adler equation using numerical experiments. Applying this understanding to real-world data, we used Wavelet Coherence to show a time- and frequency-dependent relationship between solar activity indices (including sunspot numbers and the 10.7 cm radio flux) and the Earth's magnetic field (proxied by the Dst index and IMF B_z components). The highest period of coherence consistently corresponds to the phases of solar maxima, confirming that strong solar activity significantly affects the Earth's magnetosphere. These results confirm that changes in the solar cycle fundamentally determine geomagnetic oscillations and demonstrate a close dynamical coupling between the solar magnetic field and that of the Earth.

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სინქრონიზაციის ეფექტები რთული არაწრფივი სისტემების ურთიერთქმედებისას

მ. მარტიაშვილი, ო. ხარშილაძე, დ. ზილფიმიანი

რეზიუმე

ეს კვლევა იკვლევს სინქრონიზაციის ფუნდამენტურ მექანიზმებს არაწრფივ დინამიურ სისტემებში გარე გავლენის ქვეშ, აკავშირებს თეორიულ ანალიზს რეალურ გეოფიზიკურ აპლიკაციებთან. ჩვენ თავდაპირველად ვამახვილებთ ყურადღებას ვან დერ პოლის არაწრფივ ოსცილატორზე, რათა შევისწავლოთ იძულებითი სინქრონიზაცია, რიცხვითი მოდელირების გამოყენებით გავაანალიზოთ, თუ როგორ ცვლიან გარე პერიოდული ძალები სისტემის ფაზურ და სიხშირულ დინამიკას. მთავარი აღმოჩენა ავლენს, რომ შემთხვევითი ხმაურის შემოღებას, ინტუიციის საწინააღმდეგოდ, შეუძლია წვლილი შეიტანოს რთული ან ქაოტური რეჟიმების რეგულირებაში, რაც იწვევს სტაბილურობის გაზრდას.

ამ ანალიზის მზე-დედამიწის კავშირზე გაფართოებით, ჩვენ ვიყენებთ ტალღური კოჰერენტობის მეთოდს, რათა რაოდენობრივად შევაფასოთ დრო-სიხშირის კოჰერენტობა მზის პარამეტრებს (როგორიცაა $f10.7$ ინდექსი და $IMF\ B_z$ კომპონენტი) და ხმელეთის რეაქციებს შორის. ეს ანალიზი წარმატებით აფიქსირებს მნიშვნელოვან სინქრონიზაციის ეფექტებს, რაც ადასტურებს, რომ ამ სისტემებს შორის კოჰერენტული ურთიერთქმედება პირდაპირ პასუხისმგებელია გეომაგნიტური შტორმების გამოწვევაზე. საერთო ჯამში, ეს ნაშრომი უზრუნველყოფს ყოვლისმომცველ ჩარჩოს სინქრონიზაციის ფენომენების გასაგებად, კონტროლირებადი არაწრფივი სისტემებიდან დაწყებული მასშტაბური ასტროფიზიკური ურთიერთქმედებებით დამთავრებული.

საკვანძო სიტყვები: სინქრონიზაცია, ვან დერ პოლის ოსცილატორი, ვეივლეტ კოჰერენტობა, სტოქასტური რეზონანსი, გეომაგნიტური შტორმები.

Эффекты синхронизации во взаимодействии сложных нелинейных систем

М. Мартиашвили, О. Харшиладзе, Д. Зилпимиани

Резюме

Исследование посвящено фундаментальным механизмам синхронизации в нелинейных динамических системах под внешними воздействиями, объединяя теоретический анализ с практическими геофизическими приложениями. Сначала внимание уделяется нелинейному осциллятору ван дер Поля для изучения вынужденной синхронизации; с помощью численного моделирования анализируется, как внешние периодические воздействия изменяют фазовую и частотную динамику системы. Ключевой результат показывает, что введение случайного шума может, вопреки ожиданиям, способствовать регулированию сложных или хаотических режимов, повышая устойчивость системы.

Расширяя анализ на связь Солнце-Земля, мы применяем метод вейвлет-когерентности для количественной оценки временно-частотной когерентности между солнечными параметрами (такими как индекс F10.7 и составляющая IMF B_z) и земными откликами. Этот анализ успешно выявляет значимые эффекты синхронизации, подтверждая, что согласованное взаимодействие между этими системами напрямую отвечает за запуск геомагнитных бурь. В целом работа формирует комплексную основу для понимания явлений синхронизации от управляемых нелинейных систем до крупномасштабных астрофизических взаимодействий.

Ключевые слова: Синхронизация, осциллятор Ван дер Поля, вейвлет-когерентность, стохастический резонанс, геомагнитные бури.

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Control of Inversions of the Earth's Magnetic Field with Rikitake's Model

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ABSTRACT

Paleomagnetic data demonstrates that the Earth's dipole magnetic field which shields the planet from solar wind, has undergone numerous irregular polarity reversals, with an average rate of approximately 5 per Myr. While many theories exist regarding the cause of these reversals, the most popular linking them to Milankovitch cycles, direct numerical investigation of the core's dynamo is constrained by the extreme parameter values of the Earth's outer core. Consequently, simplified models are essential. One such model is the two-disk Rikitake's dynamo, which is characterized by inherent chaotic inversions, unlike the earlier Bullard's model. Statistical analyses show that the Rikitake's model, much like real paleomagnetic data, exhibits a strong deviation from Poisson statistics. In this study, we modified the Rikitake's system by introducing an external current i_0 corresponding to an external magnetic field. This modification incorporates the hypothesis that the geodynamo is influenced by the weak interstellar magnetic fields found in the Local Interstellar Cloud. Our results show that when the modified Rikitake's model is driven by an external current whose sign changes are synchronized with real paleomagnetic data, the model successfully reproduces the timing of the geomagnetic reversals, supporting the hypothesis of external control of the geodynamo.

Key words: *Earth's magnetic field, Geodynamo, Reversals, Rikitake's Model*

Introduction

The geomagnetic field is essential in protecting Earth from the harmful solar wind and cosmic radiation. It primarily has a dipole structure, with its magnetic moment generally aligned with the planet's rotation axis [1]. Paleomagnetic data confirms that the axial dipole component of the Earth's magnetic field has reversed its polarity many times [2], with these flips occurring in an irregular fashion, shortest interval between reversals are observed to be ~ 1000 years, while longest ones being million years and more. Averaged over the last few million years, the mean reversal rate is approximately 5 per Myr [3]. The reversal process itself shows a notable asymmetry: the field's decay is slower than its return to the opposite polarity. Data also indicates a possibility of a correlation between the field intensity and the time interval between successive reversals [4,5].

The magnetohydrodynamic (MHD) dynamo hypothesis, while still containing unresolved aspects, is the generally accepted theory for the generation of the Earth's magnetic field. The Earth's core consists of a solid inner core and a liquid outer core. The outer core is an electrically conducting fluid, and the convective motion of this liquid metal, creating circular electric currents, drives the dynamo action. The resulting field is predominantly a dipole, with its axis closely aligned with the Earth's axis of rotation. However, to initiate this field generation process, an initial magnetic field is required. Potential sources for this initial field include the gyromagnetic effect, where a rotating body spontaneously develops magnetization along its rotation axis or, alternatively, the influence of the external solar or interstellar magnetic fields.

The random nature of the reversals is attributed to the fact that, given the parameters of the Earth's core, the geodynamo operates close to an instability regime. In this state, a minor external perturbation can cause a transition from a stable to a chaotic regime (leading to reversals). In the same way, a small, deterministic external influence can also lead to the suppression of the chaotic regime, forcing a transition back to a stable mode, a key method in the control of chaotic systems.

Numerical simulations of the geodynamo face significant difficulty because they cannot accurately match the extreme fluid parameters of the Earth's outer core, such as a magnetic Prandtl number $\sim 10^{-5}$ [1]. Consequently, simplified models are often used to explore the mechanisms of field reversals.

Statistical analysis of the paleomagnetic data provides key insights into the geodynamo's behavior. Sorriso-Valvo et al. [6] showed that the sequence of polarity reversals strongly deviates from simple Poisson statistics. This deviation is attributed to temporal clustering, suggesting the presence of long-range correlations and memory effects in the underlying process. Consolini and De Michelis [7] offered evidence that these reversals may be a stochastic resonance phenomenon, identifying connections between reversal residence times and the Earth's orbital eccentricity variation (~ 0.1 Myr). There is also more evidence given from data linking geomagnetic reversals to other Milankovitch cycles [8]. There are experiments like "DRESDYN" aiming to investigate precession as a source of dynamo action [9].

Runcorn demonstrated that an internal vortex magnetic field is generated within the Earth's core during its rotation. Furthermore, he showed that the MHD equations theoretically permit the inversion of the core's magnetic moment, providing the first mathematical proof of magnetic field reversal [10]. The first physical realization of this problem, however, was provided by Rikitake. The two-disk Rikitake model is a well-known system used to investigate reversals because it inherently produces chaotic reversals. Statistical work [6] has demonstrated that the Rikitake model's reversal sequence also shows strong evidence of clustering, mirroring the non-Poissonian behavior of real data. Our work presents results showing that the Rikitake's model can reproduce real reversal data patterns when an external driver is applied to the system during these reversals.

Rikitake two disc model

Bullard [11] established a single-disk model in 1955, which was based on Faraday's effect, where a moving conductive disk created a magnetic field. Although it was possible to record changes in the magnetic field in Bullard's model, magnetic reversals were not observed in this model. Tsuneji Rikitake [12], however, developed Bullard's idea in 1957 and hypothesized that each convective cell in the liquid core could be represented by a solid conductive disk. His model is a two-disk system where the disks rotate within the magnetic field created by the current flowing in the other disk . It is characterized by inherent chaotic polarity inversions, mimicking real paleomagnetic data.

By considering Faraday's Law and Kirchhoff's Voltage Law, we obtain a system of differential equations:

$$L_1 \frac{dI_1}{dt} = -R_1 I_1 + \Omega_1 M I_2 \tag{1}$$

$$L_2 \frac{dI_2}{dt} = -R_2 I_2 + \Omega_2 N I_1 \tag{2}$$

$$C_1 \frac{d\Omega_1}{dt} = G_1 - M I_1 I_2 \tag{3}$$

$$C_2 \frac{d\Omega_2}{dt} = G_2 - N I_1 I_2 \tag{4}$$

Where I_1 and I_2 denote the current passing through the first and second conductors, and ω_1 and ω_2 are the angular velocities of the disks. L represents the inductance. R is the resistance, and M is the mutual inductance. C_1 and C_2 are the moments of inertia of the disks, and G_1 and G_2 are the torques acting on them. For simplicity:

$$L_1 = L_2 \equiv L, \quad R_1 = R_2 \equiv R, \quad M = N, \quad C_1 = C_2 \equiv C, \quad G_1 = G_2 \equiv G$$

To simplify the numerical calculations and reduce the number of parameters, we transition to dimensionless variables:

$$I_1 = \sqrt{\frac{G}{M}} i_1, \quad I_2 = \sqrt{\frac{G}{M}} i_2, \quad \Omega_1 = \sqrt{\frac{GL}{CM}} \omega_1, \quad \Omega_1 = \sqrt{\frac{GL}{CM}} \omega_1, \quad t = \sqrt{\frac{CL}{GM}} \tau$$

Thus, equations (1), (2), (3), and (4), using dimensionless variables, are written in the form of the following system of differential equations:

$$\begin{cases} \frac{di_1}{d\tau} = -\mu i_1 + \omega_1 i_2 \\ \frac{di_2}{d\tau} = -\mu i_2 + \omega_2 i_1 \\ \frac{d\omega_1}{d\tau} = 1 - i_1 i_2 \\ \frac{d\omega_2}{d\tau} = 1 - i_1 i_2 \end{cases} \quad (5)$$

Where $\mu = R\sqrt{\frac{C}{LMG}}$

According to Cook and Roberts [13] (1990), the Rikitake's system is characterized by two distinct time scales $\tau_m = \frac{CR}{GM}$ ("mechanical time scale") and $\tau_e = \frac{L}{R}$ ("electromagnetic diffusion time"), The dimensionless time is denoted by τ.

The electromagnetic diffusion time, τ_e, can be interpreted as the decay time of the magnetic field in the core. It is given by the formula - $\tau_e = \frac{L^2}{\nu_m}$ [14], where L is the characteristic scale of the outer core ~ $2000\ km$ and magnetic diffusivity $\nu_m \approx 2\ m^2/s$ [1], based on these typical τ_e can be estimated as ~ 10^4 years.

Cook and Roberts [13] treat the mechanical time scale, τ_m, as a time required for the slow Alfven waves crossing the core, and they give formula $\mu = \sqrt{\frac{\tau_m}{\tau_e}} \sim 10^{-3} - 10$ for earth.

For our research we take values of $\tau_m = 10^4, \mu = 1$ and therefore the dimensionless time unit is equivalent to $\tau = \sqrt{\tau_e \tau_m} = 10^4$ years.

Result of (5) for a certain set of parameters are shown in Fig. 1.

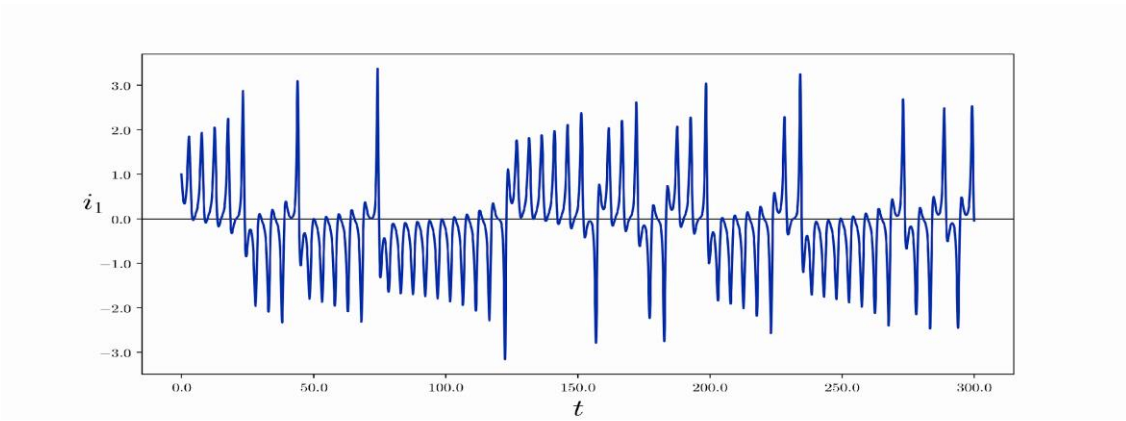

Fig. 1. Result of Rikitake's system for parameters - $\mu = 1,\ i_1 = 1,\ i_2 = -1,\ \omega_1 = 0,\ \omega_2 = 1$

New System

Now we want to study the behavior of the system when some external factor an external magnetic field acts on it. The effect of the external factor is expressed by the induced current i_0. The modified system will take the following form:

$$\begin{cases} \dfrac{di_1}{d\tau} = -\mu i_1 + \omega_1(i_2 + i_0) \\ \dfrac{di_2}{d\tau} = -\mu i_2 + \omega_2(i_1 + i_0) \\ \dfrac{d\omega_1}{d\tau} = 1 - i_1(i_2 + i_0) \\ \dfrac{d\omega_2}{d\tau} = 1 - (i_1 + i_0)\, i_2 \end{cases} \tag{6}$$

Here i_0 is determined by the external magnetic field. The Earth and the Solar System are constantly moving through the galaxy, where many types of magnetic fields are encountered. It is possible that the external magnetic field acting on our system is the interstellar magnetic field found within the Local Interstellar Cloud. In order to estimate characteristic values for the induced current, i_0, and the system currents, i_1 and i_2, we must use Ohm's Law. Ohm's Law states that current density, j, is proportional to the product of conductivity, σ, velocity, v, and magnetic field, B, i.e., $j \propto \sigma v B$, Since the current i is proportional to the current density, j, a reasonable estimate requires using the characteristic values for conductivity, velocity, and magnetic field strength for both the Earth's outer core and the interstellar medium. For the Earth's inner core these parameters are:

$\sigma_1 \sim 10^{14} - 10^{16}\ [s^{-1}]$ [15], $v_1 \sim 10^{-2}\ cm/s$ [16] , $B_1 \sim 2.5 \cdot 10\ Gauss$ [17]

In the interstellar medium conductivity is given by the formula [18] :

$$\sigma \sim 6.5 \times 10^6 T^{3/2} s^{-1} \tag{7}$$

And the temperature, $T \sim 10^3 - 10^4 K$ [19], therefore for the interstellar medium:

$\sigma_1 \sim 6.5 \cdot 10^{10} - 6.5 \cdot 10^{12}\ [s^{-1}]$, $v_1 \sim 2.5 \cdot 10^6\ cm/s$ [20] , $B_1 \sim 10^{-5}\ Gauss$ [2]

We found that $\frac{j_1}{j_0} \sim 1 - 10^2$, and currents, i_0 and i_1, may differ by one or two orders of magnitude

Results

We conducted numerical calculations on the modified system for individual i_0 - s. For a constant i_0, we found that after a certain amount of time, the currents stabilize at a constant value. If the magnitude of the external current is smaller, it takes a longer time to stabilize at the constant value. If the i_0 signal represents a rectangular wave, the numerical calculations show that inversions in the system occur in correspondence with the rectangular wave (Fig.2, b). We obtain a similar result when adding a sinusoidal signal as well (Fig. 2, a).

Besides well-known functions, we chose to incorporate a signal corresponding to the geomagnetic field reversals themselves to investigate the system's response. Panel (b) in Fig 3. displays the polarity reversals for the last 3.5 Myr, while Panel (a) presents the results from the modified Rikitake's system. In this modified model, the external current i_0 is represented by a rectangular signal that switches polarity in accordance with the real geomagnetic reversal data [2]. The signal is defined with a constant amplitude of ± 1 and includes additive weak white noise, simulating a realistic external perturbation. The results clearly demonstrate that the modified model changes sign at approximately the same moments in time as the actual paleomagnetic observations.

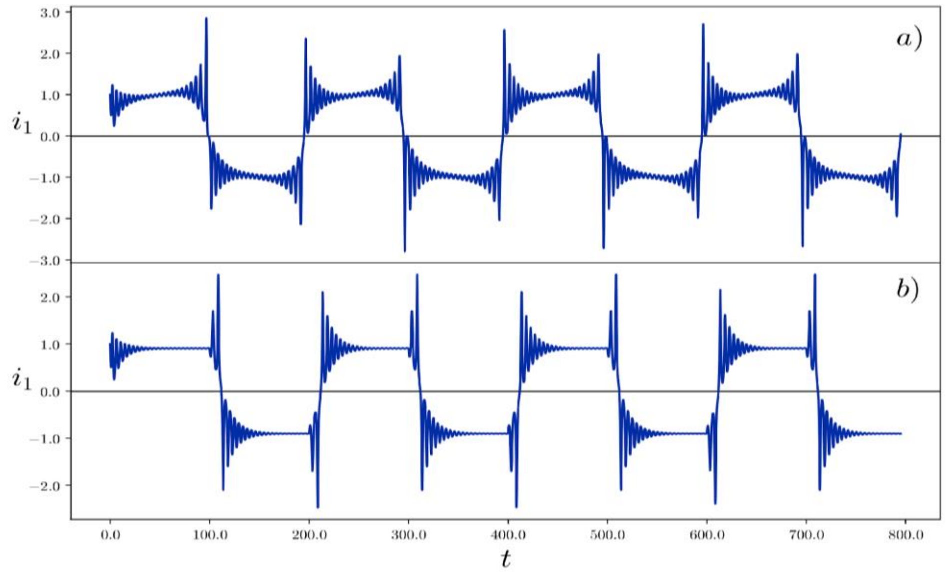

Fig. 2 Response of the modified Rikitake's system with parameters $\mu = 1$, $i_1 = 1$, $i_2 = -1$, $\omega_1 = 0$, $\omega_2 = 1$. Panel (a) presents the system's behavior when the external current i_0 is a sinusoidal signal, and Panel (b) displays the results obtained using a rectangular signal for i_0.

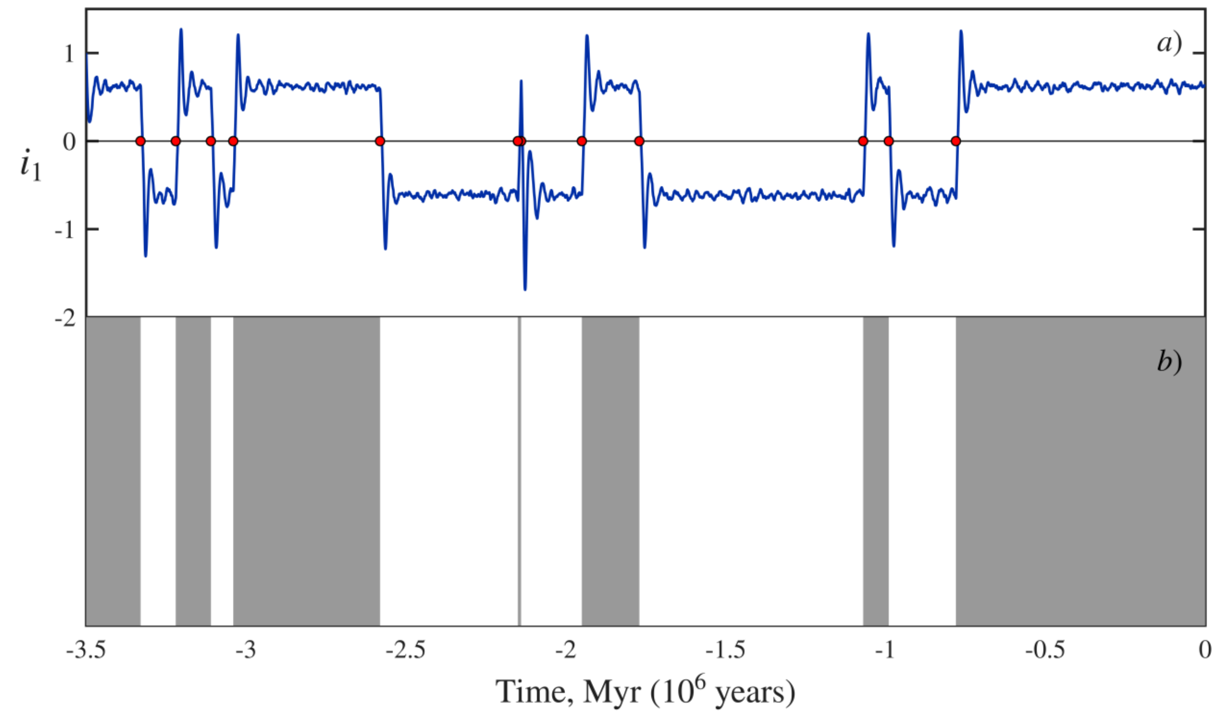

Fig. 3 Simulation results of the modified Rikitake's dynamo and comparison with paleomagnetic data. The system is driven by a external current (rectangular signal) whose polarity is dictated by the real reversal record, potentially mimicking the effect of the interstellar magnetic field. Panel (a) shows the output of the modified Rikitake's system. Panel (b) displays the paleomagnetic reversal data, where the gray areas indicate the current (normal) polarity of the Earth's magnetic field, and the white areas showcase reversed polarity.

Conclusions

In this article, we investigated the Rikitake's two-disk dynamo model, which is frequently utilized to describe the Earth's magnetic field dynamics. Unlike the classical version of the model, we explored a modified Rikitake's system by introducing an external parameter: an external current i_0.

Following the estimation of the characteristic order of this external parameter, we subjected the system to various forms of i_0 and observed its subsequent behavior. The application of a constant external current drove the system's internal currents toward a stable, constant value. Conversely, the introduction of a sinusoidal or rectangular wave induced polarity inversions within the system that synchronized with the changes in the external current.

Beyond using standard mathematical functions, we introduced an external current that directly correspons to the time series of known geomagnetic field reversals [2]. The result demonstrated that the system's polarity inversions occurred in agreement with the paleomagnetic data. This suggests that if the interstellar magnetic field in space changes according to a specific rule, it can significantly influence the geodynamo's behavior and potentially control the timing of magnetic field reversals.

Overall, we conclude that by modifying the Rikitake's model and incorporating an external factor, it is possible to control and synchronize the inversions within the system. This hypothesis that the geodynamo may be controlled by the Local Interstellar Cloud's magnetic fields opens up an interesting question for future research, that needs further theoretical analysis and numerical investigation.

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დედამიწის მაგნიტური ველის ინვერსიების კონტროლი რიკიტაკის მოდელის გამოყენებით

ო. ხარშილაძე, ლ. წულუკიძე, ლ. კეზუა, დ. ზილფიმიანი

რეზიუმე

პალეომაგნიტური მონაცემები აჩვენებს, რომ დედამიწის დიპოლურ მაგნიტურ ველს, რომელიც იცავს პლანეტას მზის ქარისგან, წარსულში მრავალი არარეგულარული პოლარობის ინვერსია (შებრუნება) ჰქონდა, საშუალო სიხშირით დაახლოებით 5 ინვერსია მილიონ წელიწადში (Myr). მიუხედავად იმისა, რომ არსებობს მრავალი თეორია ამ ინვერსიების გამომწვევ მიზეზებთან დაკავშირებით, რომელთაგან ყველაზე პოპულარული მათ გარე ზემოქმედებას, მაგალითად, მილანკოვიჩის ციკლებს, უკავშირებს, დედამიწის გარე ბირთვის ექსტრემალური პარამეტრები ზღუდავს დინამოს პირდაპირ რიცხვით კვლევას. შესაბამისად, გამარტივებული მოდელები აუცილებელია. ერთ-ერთი ასეთი მოდელია ორდისკიანი რიკიტაკის დინამო, რომელიც, ადრინდელი ბულარდის მოდელისგან განსხვავებით, ხასიათდება შინაგანი ქაოსური ინვერსიებით. სტატისტიკური ანალიზი აჩვენებს, რომ რიკიტაკის მოდელი, ისევე როგორც რეალური პალეომაგნიტური მონაცემები, მნიშვნელოვნად გადახრილია პუასონის სტატისტიკიდან. ამ კვლევაში ჩვენ შევცვალეთ რიკიტაკის სისტემა გარე დენის (i_0) შემოტანით, რომელიც გარე მაგნიტურ ველს შეესაბამება. ეს მოდიფიკაცია ეფუძნება ჰიპოთეზას, რომ გეოდინამოზე გავლენას ახდენს ადგილობრივ ვარსკვლავთშორის ღრუბელში (Local Interstellar Cloud) არსებული სუსტი ვარსკვლავთშორისი მაგნიტური ველები. ჩვენი შედეგები აჩვენებს, რომ როდესაც მოდიფიცირებული რიკიტაკის მოდელი იმართება გარე დენით, რომლის ნიშნის ცვლილებაც სინქრონიზებულია რეალურ პალეომაგნიტურ მონაცემებთან, მოდელი წარმატებით იმეორებს გეომაგნიტური ინვერსიების დროს, რაც მხარს უჭერს გეოდინამოს გარე მოდულაციის ჰიპოთეზას.

საკვანძო სიტყვები: დედამიწის მაგნიტური ველი, გეოდინამო, რევერსალები, რიკიტაკეს მოდელი

Контроль инверсий магнитного поля Земли с помощью модели Рикитаки

О. Харшиладзе, Л. Цулукидзе, Л. Кезуа, Д. Зилпимиани

Резюме

Палеомагнитные данные демонстрируют, что дипольное магнитное поле Земли, которое защищает планету от солнечного ветра, претерпело многочисленные нерегулярные инверсии полярности со средней частотой около 5 инверсий на миллион лет. Хотя существует множество теорий относительно причин этих инверсий, самая популярная из которых связывает их с внешним воздействием, например, с циклами Миланковича, прямое численное исследование динамо-процесса в ядре ограничено экстремальными значениями параметров внешнего ядра Земли. Следовательно, упрощенные модели имеют важное значение. Одной из таких моделей является двухдисковое динамо Рикитаки , которое, в отличие от более ранней модели Булларда, характеризуется внутренними хаотическими инверсиями. Статистический анализ показывает, что модель Рикитаки, как и реальные палеомагнитные данные, демонстрирует сильное отклонение от статистики Пуассона. В данном исследовании мы модифицировали систему Рикитаки, введя внешний ток i_0, соответствующий внешнему магнитному полю. Эта модификация включает гипотезу о том, что на геодинамо влияют слабые межзвездные магнитные поля, обнаруженные в Локальном межзвездном облаке. Наши результаты показывают, что когда модифицированная модель Рикитаки управляется внешним током, смена знака которого синхронизирована с реальными палеомагнитными данными, модель успешно воспроизводит время геомагнитных инверсий, что подтверждает гипотезу о внешнем модулировании геодинамо.

Ключевые слова: Магнитное поле Земли, геодинамо, инверсии магнитного поля, модель Рикитаки

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Chronicle

1st International Scientific Conference “Modern problems in Geophysics”

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ABSTRACT

Information about the 1stIinternational Scientific Conference “Modern problems in Geophysics”, which was held on November 6-8, 2025 at Ivane Javakhishvili Tbilisi State University is presented.

Key words: *Earth and its envelopes, geophysical processes, complex geophysical monitoring, natural disasters, earth ecology, mitigation, promoting sustainable development.*

Introduction

On November 6-8, 2025, the 1st International Scientific Conference “Modern Problems of Geophysics” organized by the M. Nodia Institute of Geophysics was held at Ivane Javakhishvili Tbilisi State University. Scientists of the relevant fields from Georgia, Armenia, Azerbaijan, Italy, Germany, Slovenia, the Chechen Republic, Belarus, and others participated in the conference. Scientists presented the results of new researches. Scientific problems arising from the conference topic were discussed.

The aim of the conference was to present the results of research in the field of complex geophysical monitoring in Georgia and other countries (history, modern problems, assistance to sustainable development of countries) at the plenary session (oral\poster\video). As well as presentation of reports selected by the scientific committee and their discussion at plenary, sectional sessions and in the form of poster reports.

The target group was Georgian and foreign scientific, educational, governmental and non-governmental organizations, which have direct contact with the theme of the conference (universities, research institutes, educational organizations, structures of emergency situations, etc.).

The conference participants were given certificates. A book (**1st International Scientific Conference “Modern problems in Geophysics”. Proceedings, ISBN 978-9941-36-434-1, ISSN 3088-4349, Tbilisi, Georgia, November 6-8, 2025. Publish House of Iv. Javakhishvili Tbilisi State University, Tbilisi, 2025**) of conference materials (papers) was published in printed and electronic form.

The collection of conference materials and all of its separate articles is available on the website of the National Scientific Library: **http://openlibrary.ge/handle/123456789/10715**

Goal of the Conference

- Discovering the potential scientists in the field of complex geophysical monitoring;
- Establishing and strengthening connections of scientists;
- Defining the prospects for the development of scientific research;
- Identify opportunities for improving the scientific-educational field of secondary and higher education institutions in relation to the issues of the conference;
- Strengthening international scientific cooperation on conference topics;
- To acquaint the world scientific community, governmental structures, other interested organizations

and individuals with the current state of the problems related to the fields of complex geophysical monitoring.

Conference Organizers

The conference was organized by:
• Ivane Javakhishvil Tbilisi State University, Mikheil Nodia Institute of Geophysics;
• Georgian Technical University, Institute of Hydrometeorology;
• Georgian Geophysical Association.

Scientific Committee and Editorial Board

Tamaz Chelidze: Academician, Chairman of the Scientific Committee, Editor-in-Chief; **Nodar Varamashvili, Jemal Kiria:** Co-Chairmans of the Scientific Committee - TSU, M. Nodia Institute of Geophysics, Georgia; **Nana Bolashvili**: Co-Chairman of the Scientific Committee – TSU, Vakhushti Bagrationi Institute of Geography, Georgia; **Mikheil Pipia:** Co-Chairman of the Scientific Committee – GTU, Institute of Hydrometeorology, Georgia; **Avtandil Amiranashvili** (Deputy Editor-in-Chief); **Aliev Vugar** - CEO & Founder, International Event Organizer Company AMIR Technical Services Azerbaijan, Azerbaijan; **Davitashvili Magda** - I. Gogebashvili Telavi State University, Telavi, Georgia**; Fórizs István-** Institute for Geological and Geochemical Research, Hungary; **Ghlonti Nugzar, Melikadze George** - TSU, M. Nodia Institute of Geophysics, Georgia; **Japaridze Nino** - Tbilisi State Medical University, Georgia; **Kartvelishvili Liana** - National Environmental Agency, Georgia; **Khazaradze Ketevan** - Georgian State Teaching University of Physical Education and Sport, Georgia; **Nazaretyan Sergey-** Regional Survey for Seismic Protection, Ministry of Internal Affairs of the Republic of Armenia, Armenia; **Rustioni Laura, Pappaccogli Gianluca** - University of Salento, Italy; **Tatishvili Marika, Meladze Maia-** GTU, Institute of Hydrometeorology, Georgia; **Varazanashvili Otar** - TSU, M. Nodia Institute of Geophysics, Georgia; **Vaupotič Janja–** Jožef Stefan Institute, Slovenia.

Organizing Committee

Ekaterine Mepharidze, Chairman of Organizing Committee; **Manana Nikolaishvili:** Deputy Chairman of Organizing Committee; **Irma Glonti, Aleksandre Sborshchikovi, Thea Gventsadze, Sophiko Matiashvili, Dimitri Amilakhvari, Dimitri Tepnadze, Levan Laliashvili** – TSU , M. Nodia Institute of Geophysics, Georgia; **Nino Taniashvili -** Georgian Geophysical Association, Georgia; **Nazibrola Beglarashvili, -** GTU, Institute of Hydrometeorology, Georgia; **Inga Janelidze –** Georgian Technical University, Georgia.

Conference Themes – All problems of the complex geophysical monitoring in Georgia and other countries.

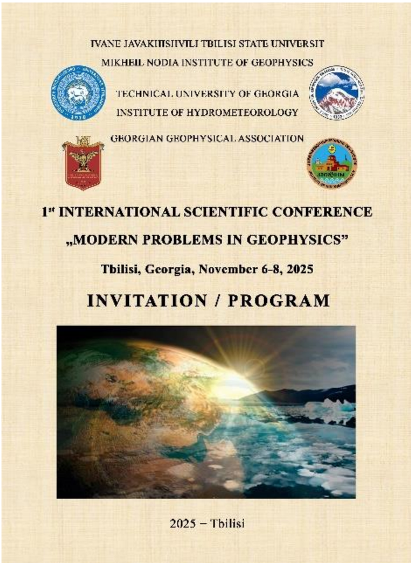
Expected Results

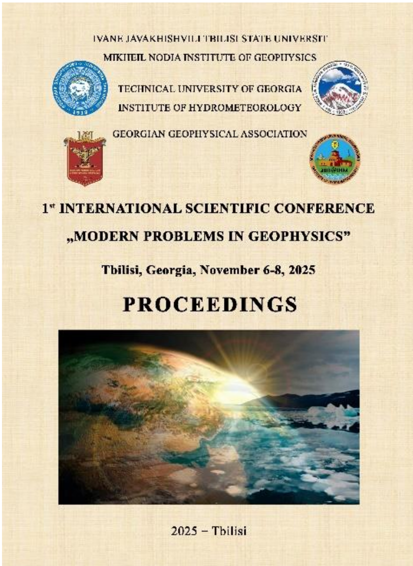
- Promoting historical and modern achievements in the field of complex geophysical monitoring;
- To acquaint the world community with the current state of the problems related to the complex geophysical monitoring;
- Enhance international cooperation for the scientific and practical application of modern achievements related to the conference topics;
- Assess the social and economic risks associated with the conference topics and identify opportunities for joint action to prevent these risks;
- Assess opportunities to expand the use of complex geophysical monitoring to support sustainable development of countries;
- Identify opportunities to improve the scientific-educational base of secondary and higher education institutions in the field of complex geophysical monitoring.
- The conference was opened by the deputy rector of Ivane Javakhishvili Tbilisi State University Nino Gvenetadze, chairman of the scientific committee academician Tamaz Chelidze, co-chairman of the scientific committee, deputy director of Mikheil Nodia Institute of Geophysics,

TSU, Nugzar Ghlonti and co-chairman of the scientific committee, director of Institute of Hydrometeorology, GTU, Mikheil Pipia. Speakers made a general overview about the modern problems of the complex geophysical monitoring in Georgia and wished the conference participants fruitful work.

- A total of 73 oral and posters presentations at the conference (see References) were considered and published.
- The proceedings of this conference as a whole, as well as its individual works, are published and posted on the portal of the M. Nodia Institute of Geophysics, which are included in the international electronic library data base DSpace, indexed in Google Scholar and Publish or Perish.
- According to the results of the conference, a decision was made, in which the achievements and gaps in the directions of the complex geophysical monitoring in Georgia and other countries are discussed. Future meetings have been planned.

Photos from Conference









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პირველი საერთაშორისო კონფერენცია „გეოფიზიკის აქტუალური პრობლემები"

ე. მეფარიძე, მ. ნიკალაიშვილი

რეზიუმე

წარმოდგენილია ინფორმაცია პირველ საერთაშორისო სამეცნიერო კონფერენციაზე „გეოფიზიკის აქტუალური პრობლემები", რომელიც ჩატარდა 2025 წლის 6-8 ნოემბერს ივანე ჯავახიშვილის სახელობის თბილისის სახელმწიფო უნივერსიტეტში.

საკვანძო სიტყვები: დედამიწა და მისი გარსები, გეოფიზიკური პროცესები, კომპლექსური გეოფიზიკური მონიტორინგი, ბუნებრივი კატასტროფები, დედამიწის ეკოლოგია, შედეგების შერბილება, მდგრადი განვითარების ხელშეწყობა.

1-я Международная научная конференция "Актуальные проблемы геофизики"

Е. Мепаридзе, М. Николаишвили

Резюме

Представлена информация о 1-й Международной Научной Конференции "Актуальные проблемы геофизики", которая была проведена 6-8 ноября 2025 года в Тбилисском государственном университете им. Иване Джавахишвили.

Ключевые слова: Земля и ее оболочки, геофизические процессы, комплексный геофизический мониторинг, стихийные бедствия, экология Земли, смягчение последствий, содействие устойчивому развитию.

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Congratulations to Vugar Aliyev on His 70th Birthday!

Dear Vugar!

M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University warmly congratulates you on your 70th birthday.

Your work as the founder and CEO of AMİR Technical Services Company, co-author of scientific discovery in the field of semiconductor physics and technology, laureate of various prizes and awards, author and co-author of numerous patents, monographs and scientific articles, main organizer and sponsor of the next 7th Eurasian Conference "RISK-2025", indexed in Scopus, as well as the editor-in-chief of the newly created international journal "International Journal of Sustainability and Risk Control", an exemplary colleague, friend and family man, is well known to your family, friends and a wide circle of the scientific community.

We wish you happiness, health, long life, and success for the benefit of the development of science and the expansion and strengthening of scientific ties between scientists from different countries.

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მყარი დედამიწის, ატმოსფეროს, ოკეანისა და კოსმოსური პლაზმის ფიზიკა

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