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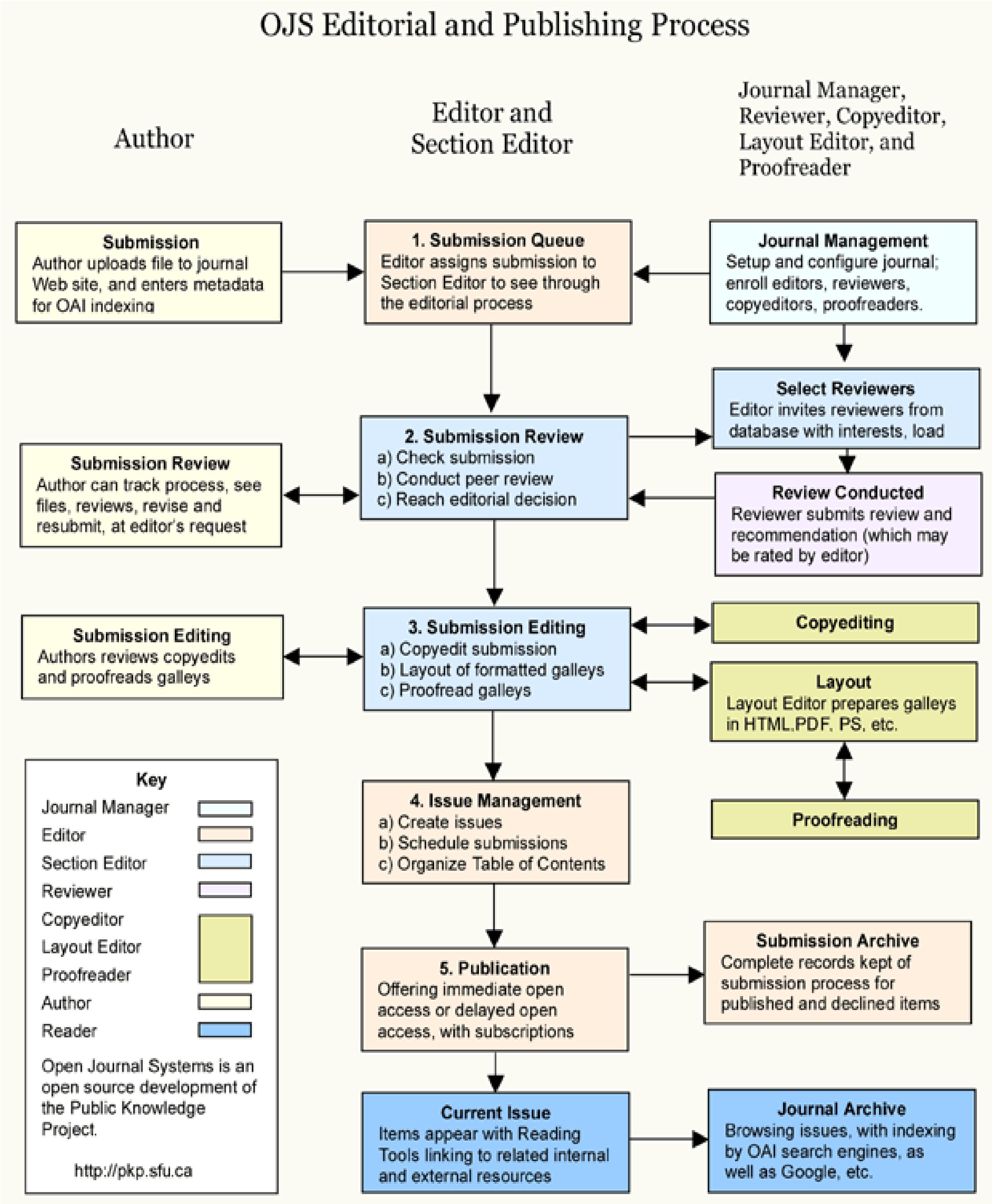

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Thermal Field in the Sedimentary Complex of the Eastern Black Sea Region and Gas Hydrates Content in the Guria Deflection

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ABSTRACT

The geological and geophysical conditions of gas hydrates formation in the Guria Trough in the Black Sea and results of studying of heat flow distribution and calculations of temperatures in the sedimentary complex of the Eastern Black Sea region are given in this work. The results are presented in the form of maps of heat flow and deep temperatures. The results of studies of gas hydrates conducted in cooperation with German scientists from the University of Bremen during the sea cruises. It is shown, that in the case of Guria Trough intensive gassing (Batumi seep) observed is associated with the content of gas hydrates in marine sediments in the region.

Key words: thermal field, sedimentary complex, Black Sea region, gas hydrates content

The Black Sea region is a small part of important and huge European-Asia Minor oil-gas bearing province. It contains the coastal shelf, eastern, northeastern and southeastern part of the Black Sea. There are certain oil and gaseous reservoirs in this area, mainly along the eastern Black Sea shelf and Guria Deflection (Guria Trough).

The zone of oil-gas formation of Guria deflection (on land) belongs to the west part of Guria sector of Ajara-Trialeti folded system. Sea prolongation of Guria foothill deflection spatially is stretched on the prolongation of the middle of rivers Supsa-Kintrishi to the south-west into Paleogene series, in the zones of shelf and the continental slope. On the whole, sea part of Guria deflection is situated in the extreme south of Georgian sector of the Black Sea.

On the basis of complex geological-geophysical, geomorphological and cosmic data, it is established that tectonic faults (observed on land) extend in the zones of shelf and the continental slope; this is well reflected in thickness distribution of separate geocomplexes of sedimentary cover and formation of wide net of submerged canyons.

These weakened zones participate with various intensity in lithogenetic processes of eastern Black Sea depression, which is well expressed in peculiarities of separate facies and sediment accumulation velocity, spatial distribution of diapirism, mud volcanism and intensive gas streaming areas at the sea ground. Sea prolongation of such weakened zones is deep faults of Supsa, Natanebi, Kobuleti, Chorokhi. Existence of these fluid-conductive mobile faults conditioned the formation of diapiric structures in Oligocene-Miocene sediments of Guria deflection. At modern stage of geological development (land-the Black Sea) weakened zones are within sedimentary cover, as well as foundation; they are characterized by high values of thermal indices. Ajara-Trialeti zone and Guria foothill deflection are characterized by anomalously high heat flows (70-80-*mvt/* m^2) and anomalously high depth temperatures, which reach up to 150-200 ^{0}C on the base of sedimentary cover.

In the article work results of studying of distribution of a heat flows and calculations of temperatures in a sedimentary complex of east part of the Black Sea water area are given.

The map of heat flows distribution (fig. 1) is made on the basis of the experimental data and also on the basis of the calculated values of flows.

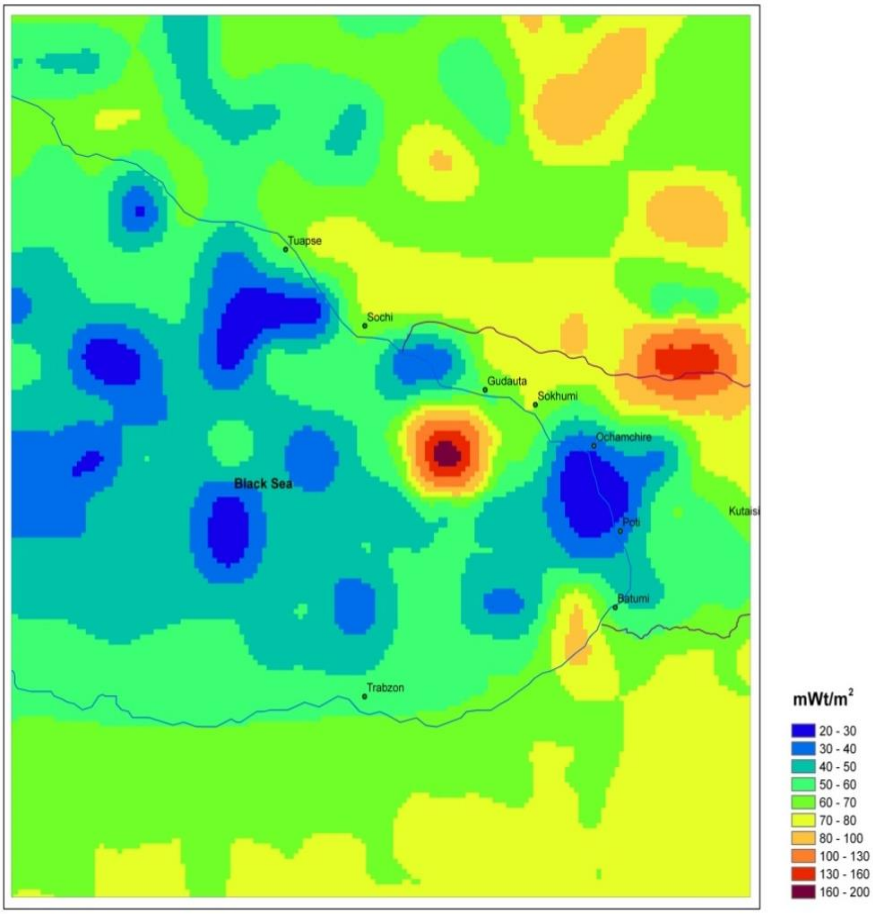

Fig.1. The map of distribution of a heat flow

Calculation of deep temperatures for Black Sea water area has been spent earlier only for points with available experimental data of flows. In the given work calculation of temperatures in a sedimentary complex of investigated region has been spent with use of the experimental and calculated values of heat flows – in points where there were no experimental data about flows its calculated values were used. Temperatures in a sedimentary complex have been received by the solving of the stationary equation of heat conductivity, and the received results are given in m of temperatures distribution on the bottom border of a sedimentary complex (fig.2).

High values of tectonically weakened zones and heat flows and temperatures, as well as intensive submersions, especially in subsequent period of Eocene, condition the formation of elision fluidodynamical system of eastern Black Sea depression and Guria deflection as well. Biochemical, lithogenetic and depth genesis hydrocarbon fluids participate at certain stages of lithogenesis.

Powerful oil-gas manifestations in land of Guria deflection are connected with Middle Eocene, Middle Miocene, Sarmatian (Supsa) and Meotian (Shromisubani) collectors.

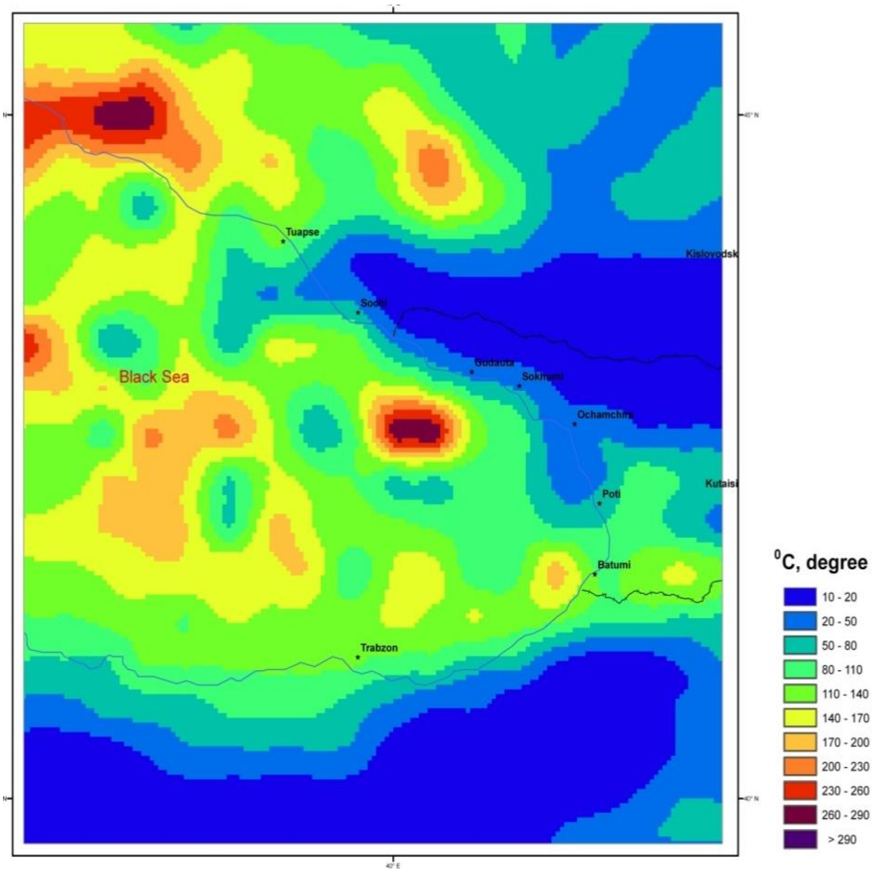

Fig. 2. The map of distribution of temperatures on the bottom border of a sedimentary complex

Hydrocarbon (oil, gas) resources can be revealed in anticlinal and diapiric structures of Cretaceous-Miocene geocomplexes. Deposits of biochemical gas can be revealed in geocomplexes of Mio-Pliocene-Quaternary, in the zone of deltaic sediments of paleorivers, in the form of lithologic-stratigraphic traps.

Highly perspective region of gas-hydrate formation is stretched in the zone of the continental slope, section of rivers Chorokhi-Supsa. Holocene-Quaternary sandy sediments are considered perspective. Gas-hydrate deposits can be revealed below sea ground till 500-800 m depth.

Activity studies of gas hydrates are concentrated in the Black sea for various reasons. It is the largest anoxic basin with much higher methane concentrations than in any other marginal sea. Sediments of 10-19 km thickness reveal a potential reservoir for methane generation and hundreds of methane emission site are known from water column investigations of Russian, Ukraine and German researchers.

In the last decade studies of gas hydrates in the Black Sea were conducted by German scientists from the University of Bremen which was coordinated by prof. Gerhard Bormann during cruises on the boards R/V Poseidon, R/V Meteor and R/V Mary S. Merian. The scientists from Georgia participated in these studies.

Shallow gas hydrates, potentially associated with free gas, are known from sediments in several areas and are of specific interest in the black Sea where a large number of active methane emission sites exist. In the territorial waters of Georgia gas flares, ascending methane gas bubbles recorded by echosounder were discovered at several sites offshore Suchumi and offshore Batumi (Guria deflection).

The area offshore Batumi (Batumi seeps area) was intensively studied by ELAC swath bathymetry, DTS side scan sonar, OFOS video sled and GC gravity corer, where gas bubbles were detected in about 800 m water depth. There in an area of about 1 km^2, occur about 25 gas bubble streams in 10 distinguishable clusters. This is the area in the Black sea with the strongest within the gas hydrate stability zone.

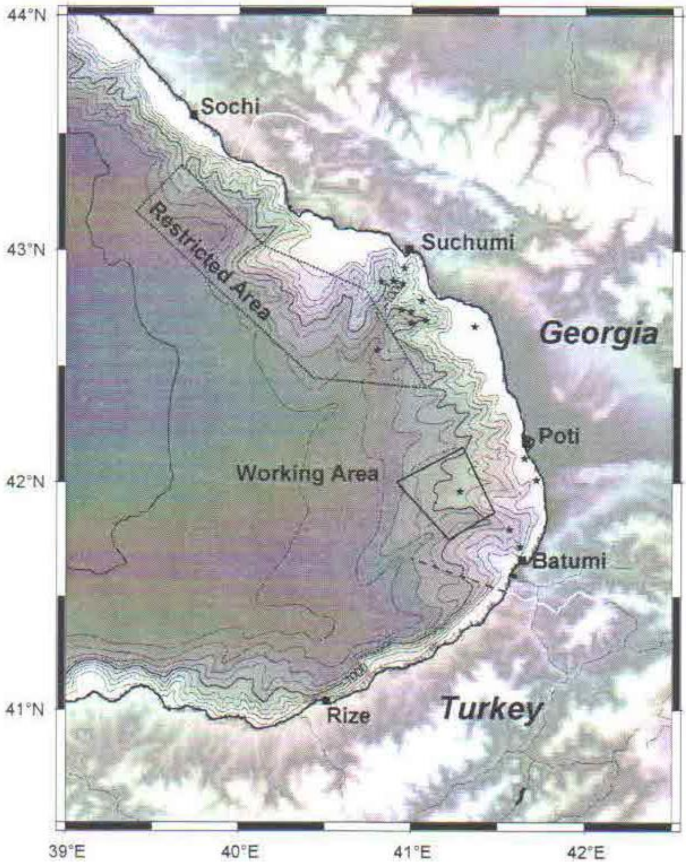

Fig. 3. The working area of Georgia, stars – the location of gas flares

Studies were concentrated on the seafloor observations and sediment sampling on Batumi Seep. It is placed on the ridge between the canyons and on a local high that rises about 10 m at 855 m water depth.

It should be noted that zones of gas emissions in the Guria deflection coincide with zones of high heat flow and high temperatures in the sedimentary complex, received by us.

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რეზიუმე

ნაშრომში განხილულია შავი ზღვის შელფზე გურიის როფში გაზური ჰიდრატების წარმოქმნის გეოლოგიურ-გეოფიზიკური წინაპირობები. აგრეთვე მოცემულია აღმოსავლეთ შავი ზღვის რეგიონში სითბური ნაკადის განაწილების სურათი და ამავე რეგიონში სედიმენტური კომპლექსის საგებზე გამოთვლილი ტემპერატურები. ნაკადებისა და ტემპერატურების განაწილება მოცემულია რუკების სახით. სტატიაშიMმოყვანილია ბრემენის უნივერსიტეტის მეცნიერებთან ერთობლივი საზღვაო ექსპედიციების დროს მიღებული გაზური ჰიდრატების კვლევების შედეგები. ნაჩვენებია, რომ გურიის როფში აღინიშნება გაზების ინტენსიური გამოყოფა (ბათუმის გაზგამოყოფა), რომელიც არის დაკავშირებული ზღვის ნალექებში გაზური ჰიდრატების არსებობასთან.

Тепловое поле осадочного комплекса восточной части региона Черного моря и содержание газовых гидратов в Гурийском прогибе

Е.А. Сакварелидзе, Г.А. Кутелия, Л.Е. Глонти

Резюме

В статье рассмотрены геолого-геофизичесеие условия формирования газовых гидратов в Гурийском прогибе на шельфе Черного моря. Предлагается картина распределения теплового потока в восточной части региона Черного моря, а также температуры, расчитанные на основании осадочного комплекса этого региона. Распределения потоков и температур дается в виде карт. В статье приведены результаты исследований газовых гидратов, полученные во время морских экспедиций, проведенных совместно с исследователями из Бременского университета. Показано, что в Гурийском прогибе имеет место интенсивное выделение газов (Батумское газовыделение), связанное с существованием в морских осадках газовых гидратов.

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Chemical Survey and Reservoir Temperature Estimations of Tbilisi Geothermal Deposit by Application of Silica-Enthalpy Mixing Method

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ABSTRACT

This study is the first attempt to use geochemical techniques to evaluate geothermal reservoir in Georgia. The geographical area of the study is named the Tbilisi geothermal reservoir and belongs to the Sartichala sub-zone of the Adjara-Trialeti folded system of the Lesser Caucasus. Thirteen thermal water samples were taken from existing thermal boreholes on the territory of Tbilisi, additionally one sample of river Legvtakhevi, to be used as cold water component for estimation of reservoir temperature. The samples revealed the majority have Na-K-HCO_3 composition compared to just few of them Na-K-Cl-SO_4 and Ca-Mg-SO_4-Cl. Water-type changes from bicarbonate to Sulfate-Chloride from the West to the East were also observed. Reservoir temperature estimations by silica-enthalpy method is 130 ºC, 163 ºC, 212 ºC.
The results of this and other current studies manifest the need for further researches and the steps and methodology thereof.

Keywords: *geochemistry, geothermal reservoir, geothermometers, silica-enthalpy mixing method*

Introduction

The objective of this study is to investigate the geochemical characteristics of the thermal waters. For hydrogeochemical evaluation, the commonly used Durov and L-L diagrams approach has been used. In order to assess the maximum reservoir temperature, the silica-enthalpy mixing method was applied.

Field survey-sampling-analytical methods

A Total of 14 samples (Fig. 1) were collected **-** 13 of them are from the thermal wells and one from the small river representative of the surface water in the central area, which may also feed thermal springs and represent one of the source the recharge area for them.

All analyses were carried out at the chemical laboratory of the Research Center of Hydrogeophysics and Geothermy, M. Nodia Institute of Geophysics, Ivane Javakhishvili Tbilisi State University.

Unstable hydrochemical parameters, including temperature, pH and electrical conductivity (EC) were measured with portable field laboratory **WTW 197i** which was calibrated in the field prior to every sampling.

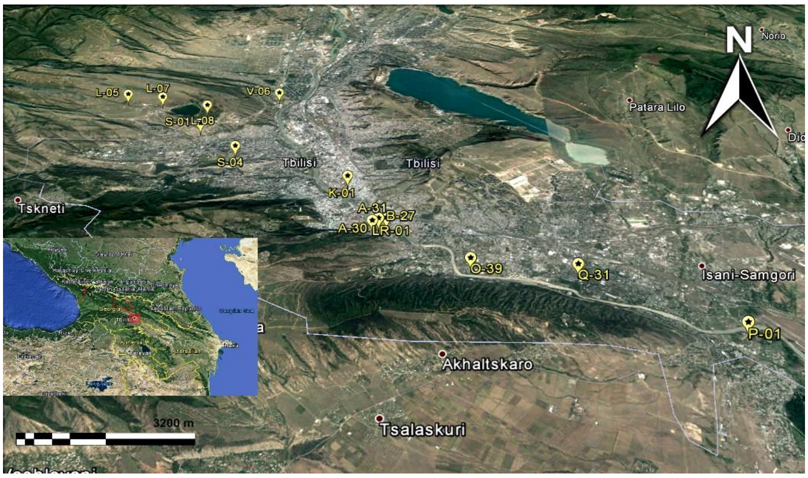

Fig. 1. Location of study area and sampling points

Physico-chemical data of the area were subjected to graphical treatment by plotting them in different diagrams using “Aquachem 5.1” software (Schlumberger water services) and graphing package “Grapher 10” (Goldensofware) in order to better understand the hydrochemical processes in the study area.

Major ions of Tbilisi thermal waters

Major ion composition and ionic ratios can act as a track-record of water-rock interaction during ascending flow. Durov (1948) diagram is based on the percentage of major ion milliequivalents. The values of cations and anions are plotted on two separate ternary diagrams and data points are projected onto square grid at the base of each triangle. The data are being presented using “Durov” diagram [1] (Figure 2), which illustrates some geochemical processes, which might affect the water genesis [2].

The Samples plotted on the Durov [1] diagram are located in the 3, 6, 9 and 5 zones [2]:

Zone (3): water is ion exchanged because HCO_3 and Na are dominants, although generation of CO_2 at depth can produce HCO_3 where Na is dominant.

Zone (6): water might be under influence of mixing. SO_4 is dominant or anion discriminant and Na dominant;

Zone (9): probably end-water type, Cl and Na dominant

Zone (5): water type exhibiting simple dissolution or mixing, no dominate anion or cation.

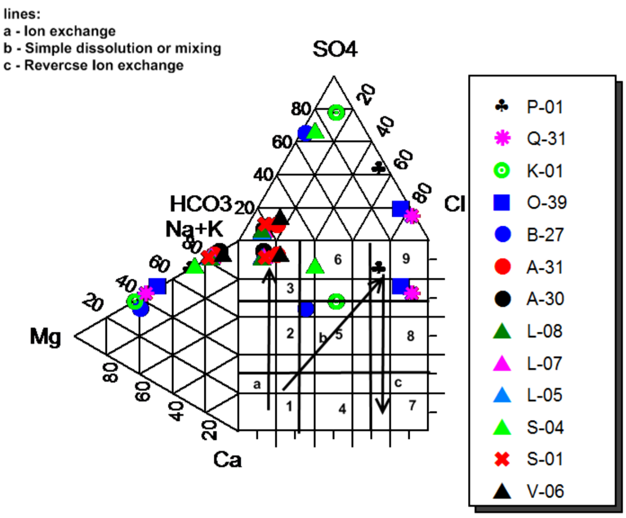

Fig. 2. Durov (1948) diagram

For major cations and anions and geochemical processes, which might affect the genesis of Tbilisi thermal waters (Lioyd and Heathcoat 1985). Data points are being projected onto square grid in 4zones illustrating the patterns of thermal waters. Zone (3): water is ion exchanged because HCO_3 and Na are dominants, although generation CO_2 at depth can produce HCO_3 where Na is dominant.Zone (6): water might be under influence of mixing. SO_4 is dominant or anion discriminant and Na dominant; Zone (9): probably end-water type, Cl and Na dominant; Zone (5): water type exhibiting simple dissolution or mixing, no dominate anion or cation.

In order to evaluate the chemical evolution of Tbilisi thermal waters in the study area, the major ion chemistry was summarized in the form of the [3] L-L diagram. L-L diagram is a useful tool to see the patterns and correlations between the major cations and anions for multiple samples. Its square plot is similar to the projection areas of the Durov plot. L-L [3] diagram displays relative ratios instead of absolute concentrations.

The diagram shown in Figure 3, according which as it was expected, we can also identify 3 different chemical types of waters:

Group I, comprising 7 samples occupies the right lower part of the plot. In this group, waters are dominated by Na+K and HCO_3 and may, therefore, be designated as "Mixed alkali-bicarbonate type".

Group II water samples (2 samples) have high concentration of Cl+ SO_4 and Na+K. This group may be named as "Alkaline-Chloride-Sulphate type".

Group III water samples have the same high concentration of Cl+SO4 but higher Ca+Mg concentration than Group II waters. This group may be called as "Ca-Mg-Cl-SO_4 type".

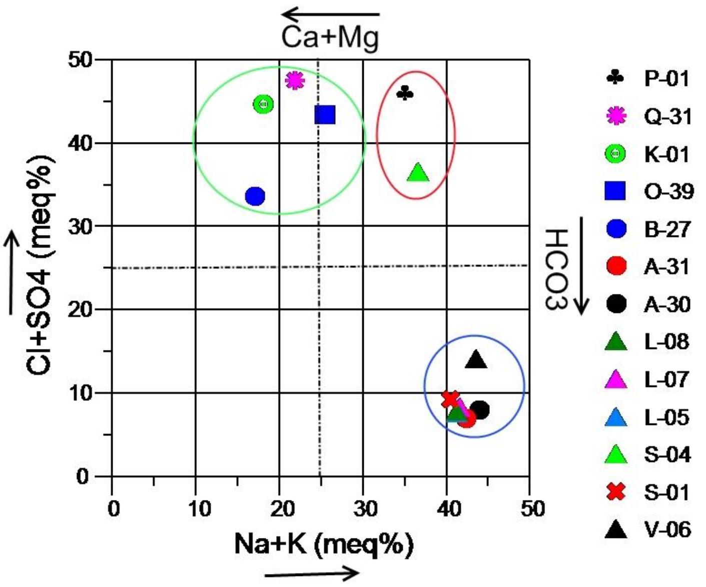

Fig. 3. Langelier and Ludwig (L-L) (1942)

Diagram summarizing the major ion chemistry of Tbilisi thermal waters. In the figure can be identified 3 different types of water: Mixed alkali-bicarbonate type, Alkaline-Chloride-sulphate type and Ca-Mg-Cl-SO_4 type. In order to estimate the temperature for the Tbilisi mixed geothermal water, the silica-enthalpy mixing model [5] was used. Despite the fact that the mentioned model is based on the assumption that the silica deposition does not occur before or after mixing and that, that quartz controls the solubility of silica in the high-temperature waters, it, in many cases, gives good results for estimations of hot water component temperature.

Silica-enthalpy mixing method

Application of chemical geothermometers is a common practice to investigate the thermal state of geothermal reservoirs [4]. Geothermal water transfers heat to the contact rock while rising to the surface and they have lower temperatures than the reservoir. In order to investigate the thermal state of Tbilisi geothermal reservoir the chemical geothermometers , as a standard tool, were applied. The data of chemical analyses of water collected from the thermal boreholes and the SiO2 concentration in waters were used for subsurface temperature calculation by using silica-enthalpy mixing model.

The sample LR-01, having the minimum SiO_2 concentration and temperature, was used as the non-thermal component of the mixed waters. In Figure 4, 3 possible a, b and c mixing lines were drawn. If we assume that maximum steam loss occurs before mixing, the three lines drawn from the cold water component of the mixed water through the mixed thermal waters till the intersection with the vertical line drawn from the boiling (100 ºC) temperature - as a steam release temperature, will give 3 points A, C, E. And the intersections of drawn horizontal lines from these points to the quartz solubility curve (B, D and F) correspond to the maximum steam loss. The values of obtained points give the original silica concentration of the thermal water component. The values are about 130 ºC, 163 ºC, 212 ºC.

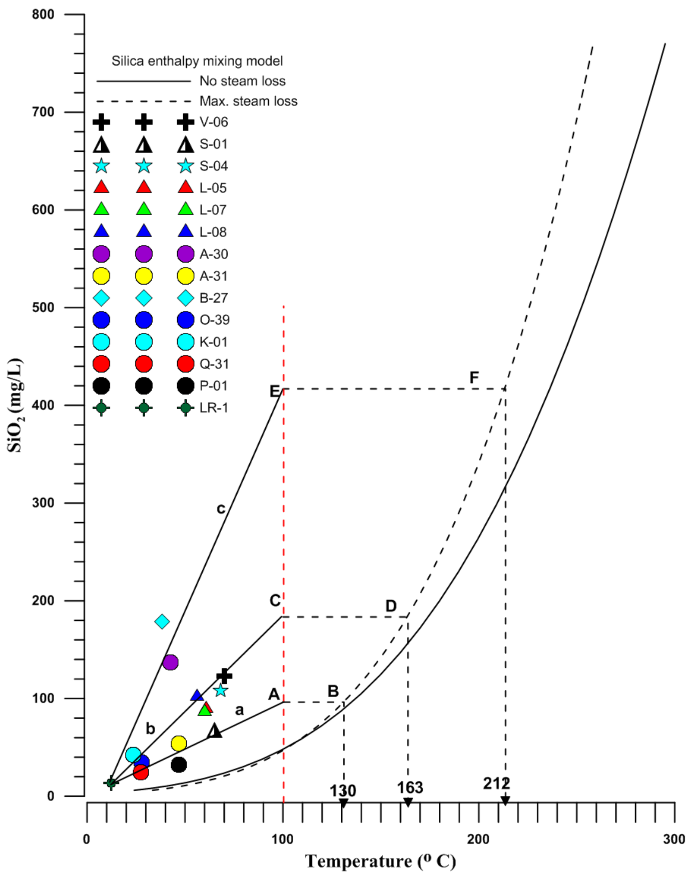

Fig. 4. Silica enthalpy mixing model (Truesdell and Fournier, 1977)

LR-1 represents the Legvtakhevi river sample, which is used for non-thermal component. Sample IDs correspond to all tables and Figures

Conclusions

Deep thermal water migrating upward mixes with shallow groundwater system and changes its chemical properties. Thermal waters have mainly Na (K)-HCO_3, Na (K)-Cl-SO_4 and Ca (Mg)-Cl-SO_4 composition. In waters of Lisi-Saburtalo area the ion exchanges because HCO_3 and Na are dominants, although generation of CO_2 at depth can produce HCO_3 where Na is dominant. As to S-04 water might be under influence of mixing. SO_4 is dominant or anion discriminant and Na dominant. Moving to the east (Ortachala. Phonichala) probably we have end-water type, with domination of Cl and Na. The reservoir temperatures according to silica-enthalpy method give the values about 130 ºC, 163 ºC, 212 ºC, that should be corrected by application of silica and cations' geothermometers.

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თბილისის გეოთერმული საბადოს ჰიდროქიმიური კვლევა და რეზერვუარის ტემპერატურის შეფასება სილიციუმ-ენთალპიის შერევის მეთოდით

ნ. კაპანაძე, გ. მელიქაძე, ი. ფორიზს, ს. ვეფხვაძე, მ. თოდაძე, ე. ჩიკვილაძე ლ. ღლონტი

რეზიუმე

აღნიშნული კვლევა გეოთერმული რეზერვუარის გეოქიმიური ტექნიკის გამოყენებით შეფასების პირველი მცდელობაა საქართველოში. საკვლევი ტერიტორია მიეკუთვნება მციერე კავკასიონის აჭარა-თრიალეთის ნაოჭა სისტემის სართიჭალის სუბ-ზონას. სინჯები ქიმიური ანალიზისთვის აღებული იქნა თბილისის ტერიტორიაზე მდებარე ცამეტი თერმული ჭაბურღილიდან. ასევე, მდინარე ლეღვთახევიდან, როგორც „ცივი“ წყლის „ კომპონენტინ თერმული რეზერვუარის ტემპერატურის შესაფასებლად. სინჯების უმეტესობის ქიმიური შემადგენლობა Na-K-HCO_3 ტიპისაა, მხოლოდ რამდენიმე Na-K-Cl-SO_4 Ca-Mg-SO_4-Cl ტიპისაა.

წყლის ტიპი დასავლეთიდან აღმოსავლეთის მიმართულებით იცვლება ბიკარბონატულიდან სულფატურ-ქლორიან ტიპამდე. სილიციუმ-ენთალპიის შერევის მეთოდით განისაზღვრული რეზერვუარის ტემპერატურები სამი სუბ-ზონისათვის შეადგენს: 130 ºC, 163 ºC, 212 ºC. აღნიშნული და წარსულში ჩატარებული კვლევები ადასტურებს მათ გაგრძელებას სხვადასხვა მეთოდოლოგიის მიხედვით

Химическое обследование и оценки пластовой температуры в геотермальном месторождении г.Тбилиси методом смешивания кремнезема-энтальпии

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Резюме

Данное исследование является первой попыткой использования геохимических методов для оценки геотермального резервуара в Грузии. Географический район исследования именуется Тбилисским геотермальным резервуаром и относится к Сартичалской подзоне Аджаро-Триалетской складчатой системы Малого Кавказа. Тринадцать проб термальной воды были взяты из существующих термальных скважин на территории г. Тбилиси, дополнительно один образец из реки Легвтахеви, который использовался в качестве компонента холодной воды для оценки температуры резервуара.

Образцы показали, что большинство из них имеют состав Na-K-HCO_3. Только несколько из них имеют состав Na-K-Cl-SO_4 и Ca-Mg-SO_4 –Cl. Также наблюдались изменения типа воды с бикарбоната на сульфатхлорид с запада на восток. Оценки температуры резервуара методом кремневой-энтальпии составляют 130°C, 163°C, 212°C. Результаты этого и других текущих исследований свидетельствуют о необходимости дальнейших исследований, а также об их этапах и методологии.

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Organization Stable Isotope Monitoring Network on the Territory of Georgia

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ABSTRACT

Application of environmental tracers was using in the assessment of water resources and their vulnerability will be elaborated. Was starting organization monitoring network for study spatial-temporal variation of stable isotope on the territory of Georgia

Keywords: *stable isotopes, monitoring network, seasonal variation*

Introduction

Climate projections for Georgia predict changes in precipitation and temperature patterns that would lead to prolonged dry periods and reduction of groundwater recharge. Precipitation has already decreased in some regions, which caused significant decrease and, in some places, even drying of the rivers and depletion of the natural springs. Significant decrease of groundwater tables resulted in the exhaustion of the soil, activation of the wind erosion and reduction of areas covered by vegetation (including pastures). Hence, there is a distinct tendency of processes actively leading to desertification.

Better understanding of the groundwater regime, interactions between surface waters and groundwaters and factors influencing groundwater quantity and quality is therefore of the utmost importance to secure the water supply for the economy and population. Improved knowledge of groundwater recharge is needed to avoid overexploitation of the resources and deterioration of current situation. Mapping of isotopic and geochemical tracers over the country would provide the essential information which is currently not available in Georgia and expand the opportunities for both research and practical recommendations related to the hydrological cycle and water management. Stable and radioactive isotopes (18O, 2H, 3H) of the water molecule provide the information which may otherwise be difficult or impossible to obtain, e.g. example on the time spent by the water in an aquifer, altitude of groundwater recharge area, contribution of river or snowmelt waters to the production wells, or identification of old waters recharged during other climatic conditions [1-5].

Material and methods

The project of Georgian Scientific foundation FR-18-10092 "Mapping environmental tracers for the assessment of water resources in Georgia under Changing Climatic Conditions" consists in the regional application of isotopic and hydrochemical methods for a better understanding of groundwater resources and links among groundwater's, surface waters and pollution sources.

The main aim of the project is Analysis of spatial and temporal distribution of isotopic and geochemical composition of natural waters in Georgia, identification of perspective water resources and their potential vulnerability. Organize new and use of existing for determining the background and character of variations isotopic and geochemical composition.

In the frame of project, during 2019, the temporal (monthly) sample collection for isotopic analyses carried out in the existing networks of Geological Hydrometeological Departments of National Environmental Agency (NEA) of Ministry of Environmental protection and Agriculture. Their network consist 8 GNIP (Global Network of Isotopes in Precipitation) and 4 GNIR (Global Network of Isotopes in Rivers) stations. Furthermore, monitoring network that includes 34 boreholes and 6 springs. Supplementary data hydrological and meteorological data from the existing networks (e.g. precipitation amount, air temperature, river discharge, results of chemical and isotopic analyses, water conductivity and pH) will be used too. Based on the existed agreement between mentioned above organization and Institute of Geophysics, carry out sampling for isotope by NEA, which will be carried out for analysis in the Institute of Geophysics. Besides, in the monitoring network included the deep aquifers monitoring network (www.hggrc.net) of Institute of Geophysics, which covered all the territory of Georgia and where carried out monthly sampling campaign for chemical and isotope analysis. The existing and newly obtained data are using for assessment temporal variation of stable isotopes and geochemical parameters (background, seasonal variation etc).

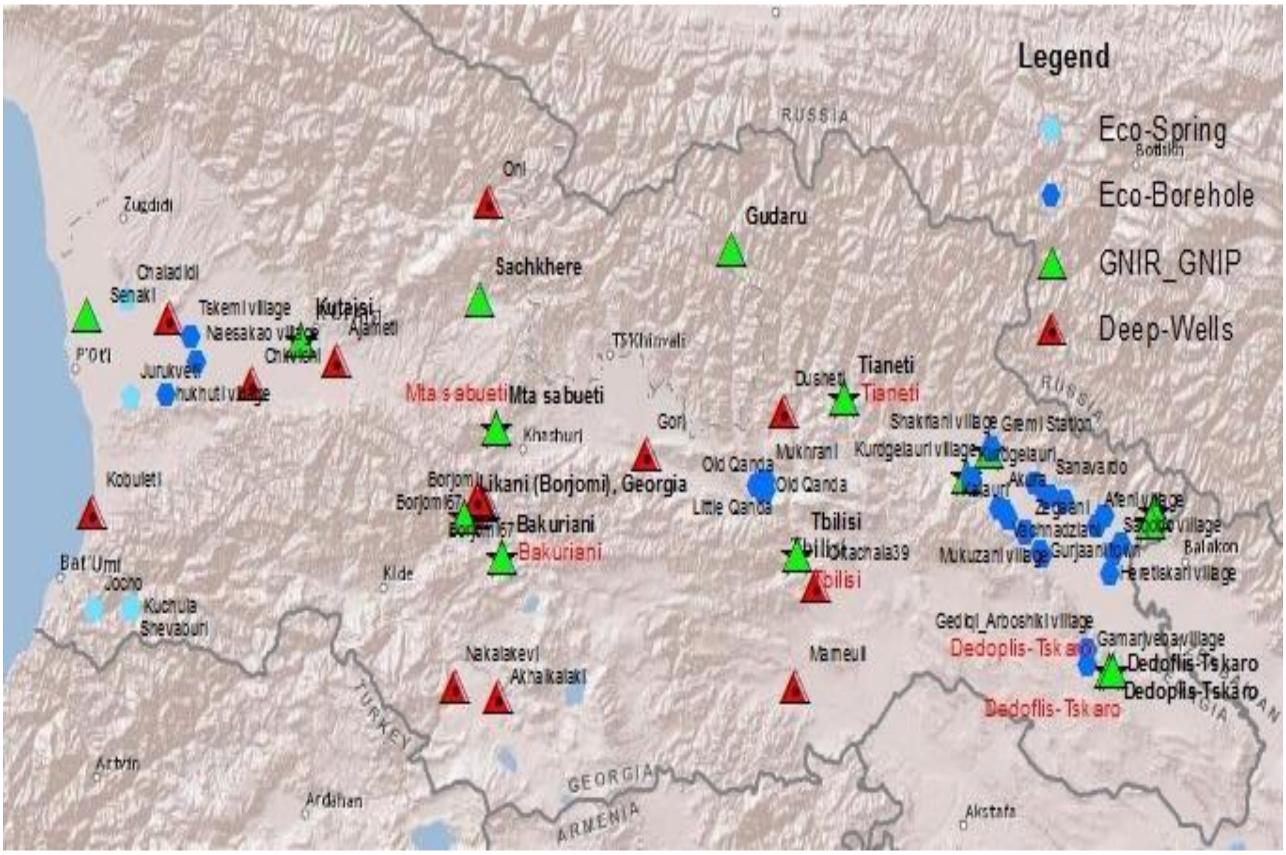

Fig 1. Location of monitoring station on the territory of Georgia

Environmental isotopic (^{18}O and ^{2}H) analysed and interpreted in the Institute of Geophysics.
In order to assessment spatial-temporal variation of stable isotope data analyzed undependably for precipitation, surface, groundwater and together.

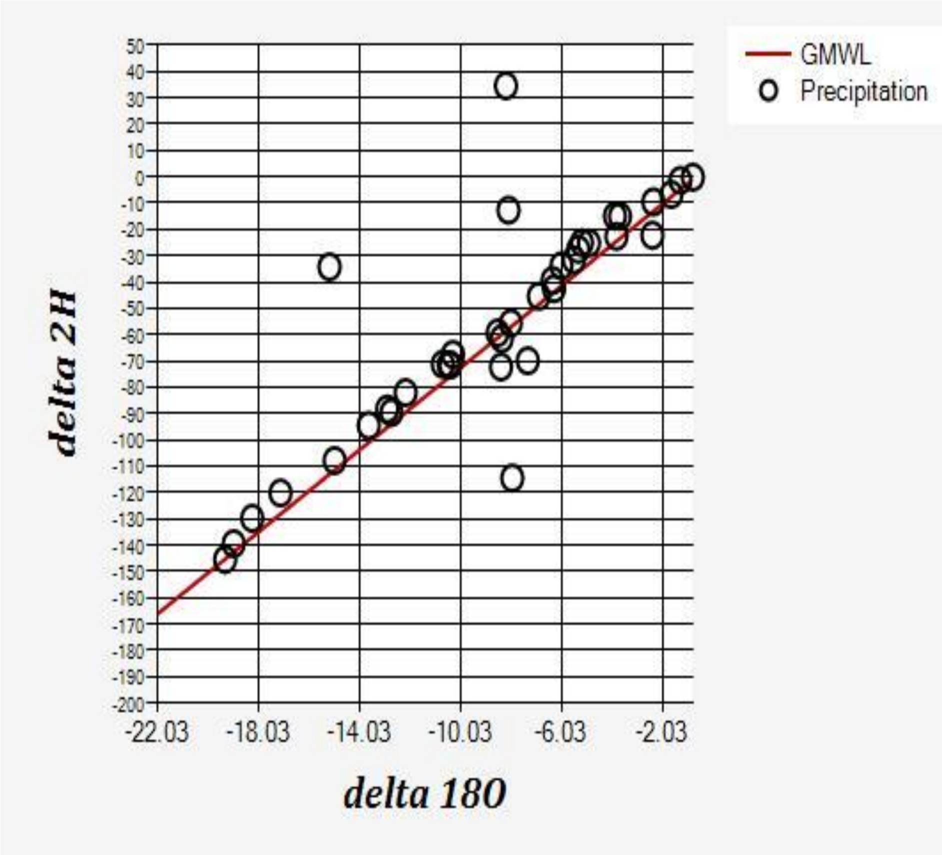

Fig. 2. Variation of isotopes in precipitation

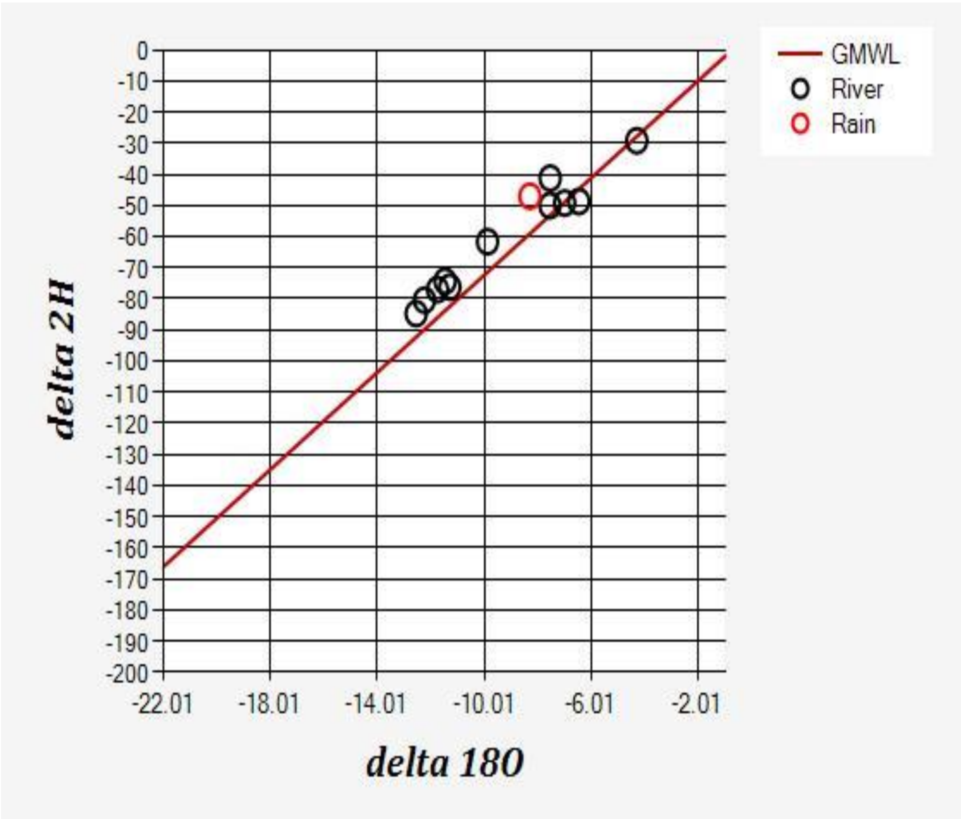

Fig. 3. Variation of isotopes in rivers and precipitation

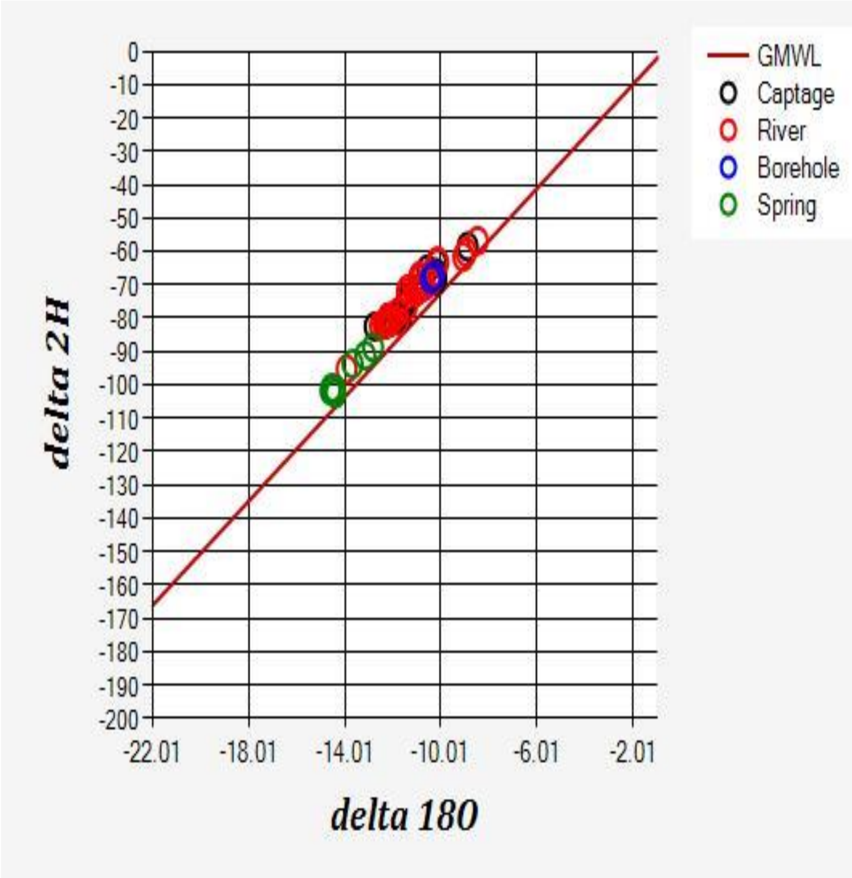

Fig. 4. Variation of isotopes in surface and groundwater

On the all figures shows the ^{18}O-^{2}H relationship. It reveals that waters in almost all samples are located along the global meteoric water line. Value of stable isotopes are mainly changing according elevation and became heavier along his pathway. Fig. 2 reveals that on the value of modern precipitation influences difference between elevation of station and seasonal variation. Its value changed between large amount -2.3 – 18.3 ‰ V-SMOW. Fig. 3 shows, that value of $\delta^{18}O$ isotopes in river is heavier -6.1 ‰ V-SMOW (compare with same period of sampling the precipitation) and variation has “narrower” diapason. Fig. 4 show value of all kind water source water (precipitation. spring, river and borehole). Because, generally all station contains fresh water, that why isotope value located nearby each other along GMWL. Pathway from precipitation to surface water (river) shorter, than to the groundwater (spring and borehole). That why spring water $\delta^{18}O$ value heavier (-14.1- -12.13 ‰ V-SMOW) tan rivers (-12.1- -10.01 ‰ V-SMOW).

Conclusions

Isotopic composition of water in the study area evolves according to a line parallel with the global meteoric water line. Studded average value of stable isotope (^{18}O-^{2}H) and its relationship. Fixed isotope value in difference water source (precipitation, surface and groundwater) and following evolution of groundwater isotopic composition in the space (pathway from recharge to the discharge area) and temporal (seasonal variation) variation.

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სტაბილური იზოტოპების მონიტორინგული ქსელის ორგანიზება საქართველოს ტერიტორიაზე

გ. მელიქაძე, მ. თოდაძე, ა. ჩანკვეტაძე, ა. გვენცაძე, რ. ჭითანავა, მ. გაფრინდაშვილი

რეზიუმე

მიწისქვეშა წყლების რესურსების შესწავლისა და მათი მოწყვლადობის შეფასებისთვის დაინერგა ეკოლოგიური ტრასერების მეთოდოლოგია. სტაბილური იზოტოპების დროით-სივრცული ცვლილებების შესწავლის მიზნით დაიწყო სამონიტორინგო ქსელის ორგანიზება საქართველოს ტერიტორიაზე.

Организация мониторинга стабильных изотопов на территорий Грузии

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Резюме

С целью оценки ресурсов подземных вод и установления их экологической уязвимости была внедрена методика экологических трассеров. С целью изучения пространственно - временной изменечивости этих трассеоров начата организация мониторинговой сети на территории Грузии.

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Using Stable Isotopes for Karstic Water Origin Assessment in Georgian Caucasus Mts.

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ABSTRACT

In order to assess karstic water origin and groundwater flow routes, mapping of the territory of West Georgia by using stable isotope application was initiated. Isotopic composition of various karstic groundwater sources in recharge and discharge areas of karst aquifers was studied on samples taken in the territory of southern slopes of the Greater Caucasus mountains.

Keywords: *karstic water, stable isotopes, mapping*

Introduction

Due to the impact of climate change, precipitation has significantly decreased in Georgia which caused significant decrease and in some places even drying of surface water flows and depletion of groundwater sources mainly in natural springs. Herewith, the water scarce western and eastern Georgia lowland can be considered as the most affected by frequent overexploitation and deterioration of local shallow groundwater resources. In the same time, the waters recharged in the karstic aquifers, outcropping on the southern slopes of the Greater Caucasus mountains, may be considered as alternative groundwater resources for the communities living in the lowland and the adjacent foothills (major cities in west Georgia such as Zugdidi, Senaki, Kutaisi and Zestafoni as well as eastern Georgian cites of Tianeti, Kvareli, Lagodekhi and their adjacent areas). Here, about half of the renewable groundwater in artesian basins and confined groundwater systems in Georgia can be considered as belonging to the above mentioned karstic water-bearing horizon.

The use of isotopes (particularly isotopes of oxygen and hydrogen present in the water molecule) was established in hydrology and hydrogeology in the past 5 decades, complements the conventional hydrological, hydrogeological, geophysical and geochemical approaches. Isotopes can quantify variables which are not otherwise measurable – for example the mean transit time (time spent by the water in the aquifer), altitude of groundwater recharge areas, contribution and mixing proportions of river water or melted snow surpluses to production wells etc… In addition, isotopes can be used to trace for the origin and pathways of recharge or contamination, thus contributing to the assessment of groundwater vulnerability and sustainability in terms of both water quantity and quality [1-6].

Material and methods

The project of Georgian Scientific foundation FR-18-18411 "Environmental tracers for assessment of karstic water resources under climate changes in Georgia" introduces the first regional application of isotopic and hydrochemical methods for a better understanding of Georgian karstic water resources. In order to assess these resources, the pathways between the recharge zones along the Caucasus and aquifers need to be addressed and risks of groundwater contamination along these pathways need to be evaluated.

On the territory of West Georgia, the hydrogeological and hydrogeochemical surveys were performed in order to define the main hydrogeological features of the region. In the frame of the aforementioned project, more than one hundred of water points of various nature (springs, wells, boreholes, rivers) were sampled during 2019. Physical parameters (pH, O_2, EC, temperature) were measured on site during sampling. Water samples were collected both for chemical (major ions) and isotope analyses.

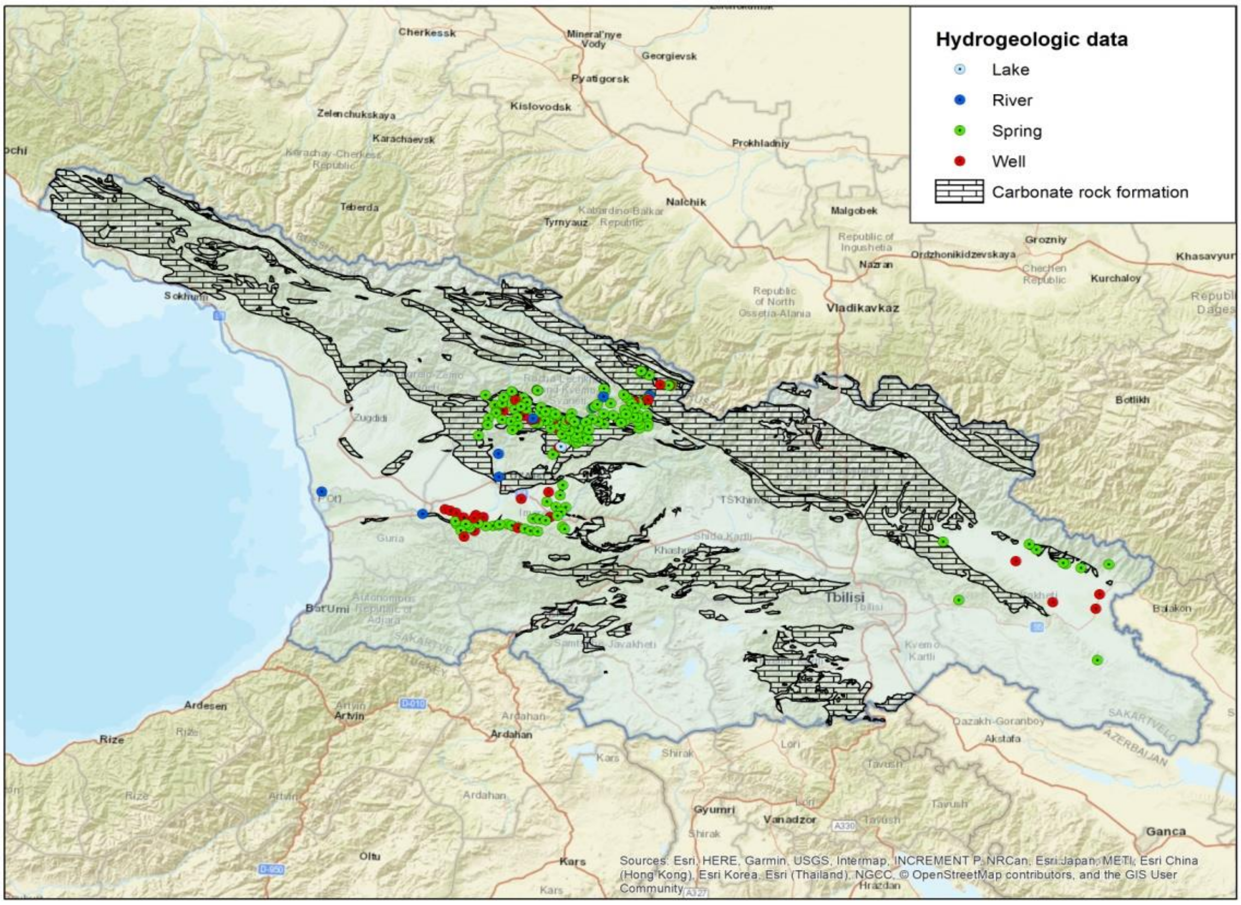

Fig. 1. Distribution of sampling point on the study area

Project activities were covering the territory of West Georgia, particularly mountain part of the southern slopes of the Great Caucasus Mountain range and part of lowland of West Georgia. Apart from karstic areas also adjacent neighbouring territories were included in the project activities. Environmental isotopes – isotopic composition of water ($\delta^{18}O$ and $\delta^{2}H$) was analysed and interpreted in laboratory of Institute of Geophysics.

Fig. 2 shows the $\delta^{18}O$/ $\delta^{2}H$ relationship in all samples taken within project activities. It reveals that waters in almost all samples are located along the global meteoric water line (GMWL).

Distribution of stable isotopes is mainly directed by water exchange between individual aquifers. Fig. 2 also reveals that modern recharge water with $\delta^{18}O$ values less than -8.5 ‰ V-SMOW is bound to the springs, boreholes, wells, and also lake and river water in the mountain areas. Boreholes tapping deep layers contain both normal and mineral groundwater with heavier $\delta^{18}O$ values between -6.5 and -8.5 ‰ V-SMOW. Thermal water samples from deep boreholes as Tskaltubo, Vani etc. reveal presence of paleo-waters with $\delta^{18}O$ values outside of GMWL, evidently affected by geochemical processes within aquifers manifested by oxygen shift.

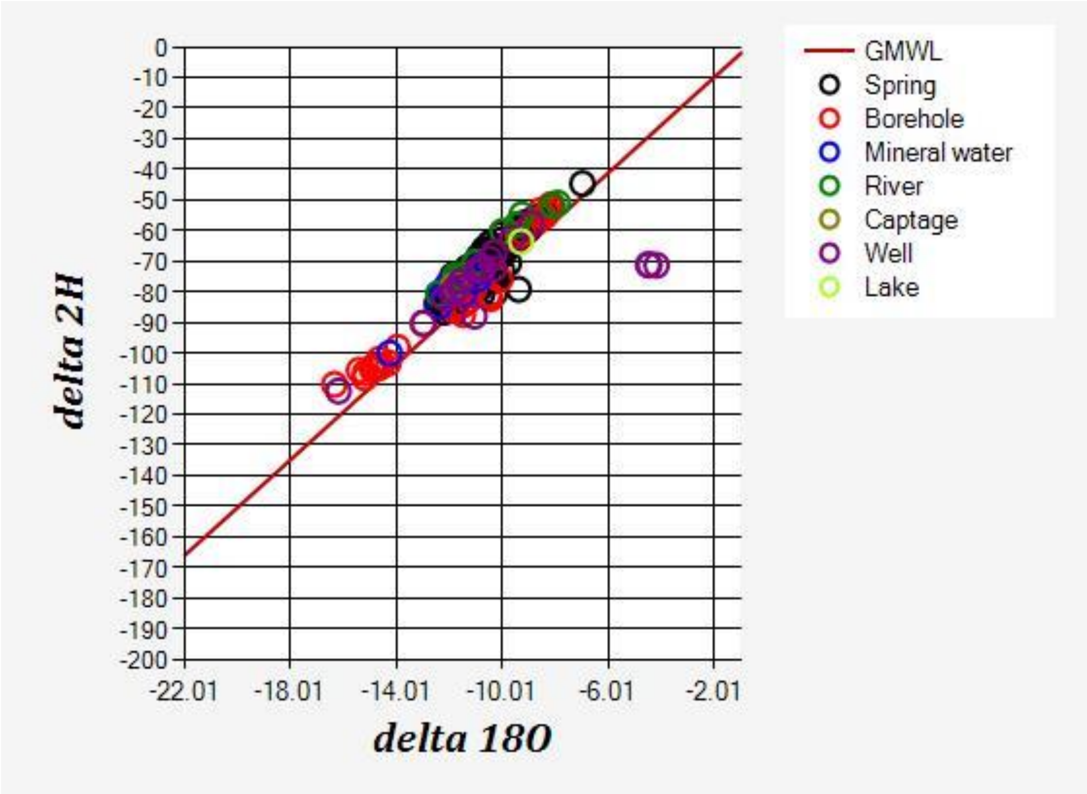

Fig. 2. Isotopic composition of samples.

In order to study groundwater flow directions, possible recharge areas and mean transit time in various seasons as well as the stability of isotope composition in various water sources, project activities will continue by sampling and monitoring of stable isotopes variation in the future.

Conclusions

Water isotopic composition in the study area evolves according to a line parallel with the global meteoric water line. According to isotopic data already available, several groups of groundwater possibly sorted by their origin are indicated. Some of these represent older waters with relative stability, majority of samples indicates the evolution of groundwater isotopic composition from the recharge area in the mountains through the river valleys to the discharge areas. Deuterium excess recorded at the majority of samples has higher values which are typical for mountain precipitation and snow, like in other mountain ranges worldwide. The conjunctive use of isotopic approaches demonstrates a high potential of this method for future studies of water resources in Georgia.

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სტაბილური იზოტოპების მეთოდოლოგიის გამოყენება კარსტული წყლების წარმოშობის დადგენის მიზნით

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ლ. ღლონტი, თ. ჭიკაძე**

რეზიუმე

კარსტული წყლების წარმოშობის და გავრცელების დადგენის მიზნით დაწყებული იქნა დასავლეთ საქართველოს ტერიტორიის აგეგმვა სტაბილური იზოტოპების მეთოდოლოგგის გამოყენებით. შესწავლილი იქნა სტაბილური იზოტოპების გავრცელება ტერიტორიაზე, მიწისქვეშა წყლების წარმოშობა, მათი კვებისა და განტვირთვის არეები.

Использование методологий стабильных изотопов для установления происхождения карстовых вод

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Резюме

Для установления происхождения и распространения карстовых вод были начаты съемочные работы с использованием методики стабильных изотопов на территории Западной Грузии. Было изучено распространение стабильных изотопов на территории, происхождение подземных вод, ареалы их питания и разгрузки.

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Peculiarities of the Development of the Black Sea Coast of Kolkheti (Georgia) in Modern Conditions

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ABSTRACT

The Kolkheti coastal zone of the Black Sea is a typical sample of joint marine and river accumulation area. At the same time, on the Black Sea coast of Georgia, the Kolkheti section is one of the most damaged in terms of technogenic impact. The cause of the crisis phenomena, developed in the Kolkheti Lowland coastal zone (Poti lithodynamic system) is only anthropogenic factor. Only the River Supsa - River Natanebi section still more or less keeps the natural dynamics and ability of independent existence. The rest of the areas that are undergoing washout or heavy accumulation, require constant monitoring and significant capital expenditure.

Keywords: coastal zone, sediments, lithodynamic system.

Introduction

Black Sea Kolkheti coastal zone is a typical example of sea and river accumulation. Kolkheti Lowland coastal zone, according to classification of, represents Poti lithodynamic system [1]. Here, at different sites, total accumulative displacement of alongshore sediment takes place from the north to the south, as well as from the south to the north direction. This is explained by various exposition of the coastal line, dominant west direction sea disturbances; also it should be noted that among the Black Sea coasts of Georgia, during the last one and a half century, Kolkheti section has undergone one of the most intensive human impact, in consequence of which many negative results are revealed.

Material and methods

Spatial-temporal comparison of events, cartographic methods and analysis. There are used background materials, published scientific articles. In some cases, by means of the material, obtained from the Internet is made visual evaluation, Also, several results of the experiments, performed in the Black Sea Kolkheti coastal zone.

Results and discussion

The coast under the study, by the direction of the alongshore stream movement towards the disturbances, feeding source and degree of autonomy, before interference of the human impact, were divided into three subsystems: 1. Riv. Enguri – Riv. Khobistskali; 2. Riv. Khobistskali – Riv. Supsa; 3. Riv. Supsa – Riv. Natanebi Fig.1, [1].

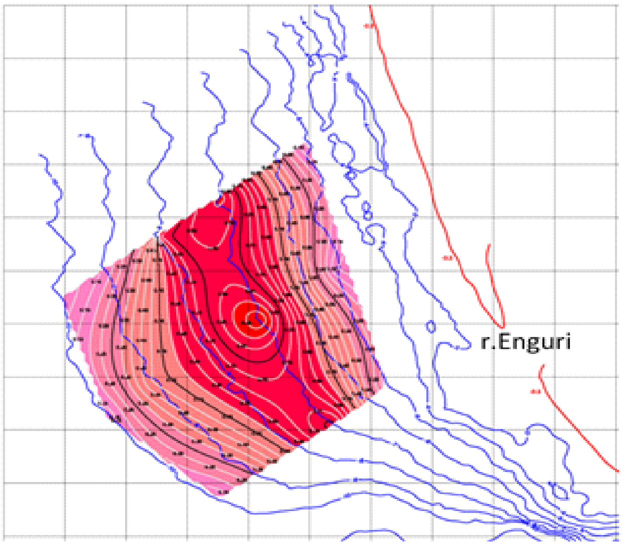
The coast, located north from the Riv. Enguri estuary, was fed by the gravel and sand alongshore stream, moving from the Riv. Mokvi via Ochamchire towards the Riv. Enguri. Abundance of the rough material conditioned creation of a spit near the estuary, by means of which cobblestone was moving to Anaklia beaches and going south to the Riv. Khobistskali together with the Riv. Enguri sand. Ochamchire port moles, built in 1934-1936, have blocked the Riv. Mokvi sediment alongshore stream and the washout of the Ochamchire coast has started. In the 60s along the town of Ochamchire were built the coast protecting constructions (walls, groins), which finally stopped southward movement of the coastal zone washout products.

Fig. 1

In the 60s of the XIX century was built Poti port. In 1939, the main mouth channel of the Rioni river at the mouth of the the sea was artificially moved 4 km northward for protecting town Poti and port against flooding. In consequence of the abovementioned, Poti lithodynamic system now is divided into four more or less autonomous subsystems: 1. Riv. Enguri – Riv. Khobistskali; 2. Riv. Khobistskali – Poti port; 3. Poti port – Riv. Supsa and 4. Riv. Supsa – Riv. Natanebi.

Breakdown of solid sediment volume of the rivers. In the Riv. Rioni average annual volume of the beachforming material decreased from 2,1 million m^3 to 1,3 million m^3. Generally, the Riv. Enguri marine estuary is quite dynamic. This was conditioned not only by significant solid runoff of the river (before construction of the hydroelectric power plant) and hydrodynamic impact of the waves, but also by important content/ratio of suspended material in the 6-7-meter layer of water near coastal zone.

Fig. 2 Q-Concentration of suspended material in 10 m sea water layer near Enguri river sea mouth



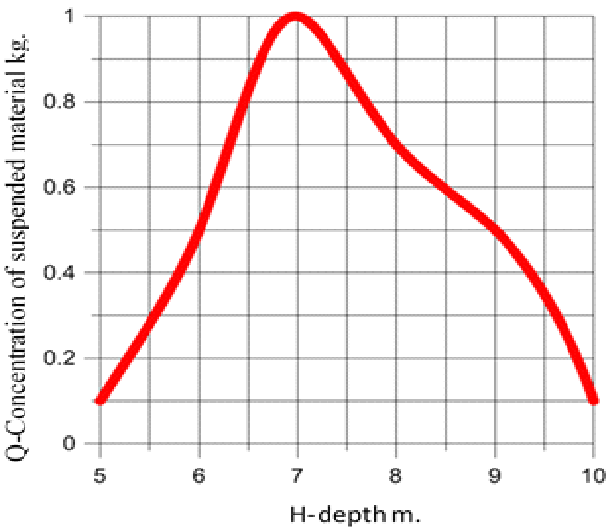


Fig. 2,3 [2]. The solid runoff of the Riv. Enguri (before construction of the HPP) was 1,5 million m^3, from them beachforming was about 0,5 million m^3. The power plant, built on the Riv. Rioni in the 70s of the XX century caused diminution of the volume of the solid sediment, brought by the river by more than 80% [3].

Riv. Enguri – Riv. Khobistskali. After construction of Riv. Mokvi port mole, Ochamchire beachprotecting groins' and walls' system, southward moving beach material stream was completely blocked. Retreat of the Riv. Enguri estuary and washout of the neighbouring lands started Fig.4. The coast retreat in Ganmukhuru (north from Enguri) and Anaklia (south from Enguri) was at least 200 m. The fishers' settlement and pinewood line were washed out.

Fig.4

In 1988-89, the Ministry of Energy deposited 200,000 m^3 of coarse cobblestone, extracted from the Enguri dewatered riverbed on the beaches, located north of Ganmukhuri. This helped to preserve the beaches [4]. The material, deposited on the beaches by this measure expired in recent years. In 2012 near the "Camp of Patriots” was built 135 m long mole, at the end of which, in the sea, was erected an abstract construction (Fig. 5).

Fig.5

During the construction process mole was surrounded with tongues and filled with ballast. As it is inadmissible to build a blind construction in the wave beat line, after finishing works the tongues should be removed or cut at the bottom level. This was not done and we do not know the reason why. We can see washout south from the mole in 2017, Fig.6.

Fig. 6

After entering inert material 2018, fig. 7

Fig.7

North from the mole accumulation of the material began, and south a coast line of 30-40 meter width was washed out. A part of a yard of a local inhabitant was washed away. To this was added the first stage of Anaklia port construction – deepening of the water area and elevation and surfacing of the shore with the extracted material. As a result, south of the under construction port was activated coast washout and on the protected area (along Churia swampland) the beach parameters significantly lessened, danger of seepage of the sea water into the swampland appear. There was such a danger earlier too, when during construction of Kulevi terminal they widened the Riv. Khobistskali estuary to 300 m, excavated access channel and turning circle. In consequence – the north located coast retreated by about 250 m. Actually this site is protected with rockfill. In 2016-17, the Ministry of Infrastructure deposited inert material on the beaches: of Ganmukhuri - 100 000 m^3 and that of Anaklia also 100 000 m^3. This measure has temporarily mitigated the danger. It is necessary to repeat this measure periodically in the future, in order to avoid the seepage of the seawater into Churia Protected Area swampland and destruction of its fauna and flora.

The future of this subsystem depends solely on artificially incorporating of the material. It would be good, if the material will be carried in by the future port administration, under the supervision of the Ministry of Infrastructure.

Riv. Khobistskali – Poti port – This section is divided into three sites: Riv. Khobistskali – Nabada, Nabada – Poti port and Poti port – Riv. Supsa. In 1939, after moving Riv. Rioni riverbed to Nabada, appeared Rioni delta, which by now has moved forward by more than 2km in the sea [5]. The length of the delta frontal part (distance between Riv. Rioni north and south confluents) is about 2.5 km. The delta parameters are constantly growing.

Riv. Khobistskali – Nabada - At this site the coast is constantly increasing, at Nabada by 10-12m and at the south limit of Kulevi terminal – by 5-6m per year. At the 400-meter section, immediately adjacent to the access channel, there are local washouts, conditioned by proximity of great depths (14m) of the access channel. Actually this section is protected by the rock fill. The dominant direction of the sediment alongshore stream is from the south to the north.

Nabada - Poti port - At this site the delta is moving forward and the port access channel is being sanded with the material, brought by the Riv. Rioni. To provide navigation, the extra material is systematically being removed from the access channel. The dominant direction of the sediment alongshore stream is from the north to the south.

Poti port – Riv. Supsa – In 1939, after moving Riv. Rioni riverbed to Nabada, as Poti city channel throughput turned out not to be sufficient, intensive washout of Poti-Supsa section started. Especially this was manifested at Poti-Maltakva section, where about 300ha coastal line was washed away. In Grigoleti the washout process continues even today. This process became particularly intensive after 2003, when in pine wood started construction of private resort buildings. The construction often took place in the wave beat line, in consequence a building got damaged and the beach washout was intensified. Nowadays, the Ministry of Infrastructure continues artificial filling of beaches with the beach material with cobblestones and the beach parameters already started to grow significantly. In Grigoleti in 2016 were entered 106 thousand m^3 cobblestones, in 2017 - 24 thousand m^3 cobblestones. The cobblestone mound on the beach retains sand. Together with this, during a sea disturbance the cobblestones are sinking and leveling underwater slope, increasing the beach stability and preventing from washout. The stability of this site depends on the city shannel pass-through function, west and north-west direction sea disturbances, which have to transport the sand, accumulated at the city channel estuary and in Maltakva, towards Grigoleti. In this case it is expectable that Maltakva beach parameters diminish. Grigoleti beaches are fed with city channel drift, which depends on the correct functioning of water dividing center. They are currently being rehabilitated. The Grigoleti section periodically requires the artificial introduction of small and medium pebbles on the beaches. The predominant alongshore sediment flow direction is from north to south.

Riv. Supsa – Riv. Natanebi – This section always managed to self restore and never had been washed out completely thanks to the rivers Natanebi and Supsa. For arranging Kobuleti by-passing way they have used alluvial material, likely hundreds of thousands of cubic meters, extracted from Riv. Natanebi and Riv. Kintrishi riverbeds, when average annual solid runoff of the both rivers does not exceed 60 000 m^3. This action will negatively impact the coasts' stability. In the early years taking away of magnetite from Ureki beaches irreparably damaged the sea coast Fig 8, [6]. In consequence, the beaches were narrowed by at least 40-50m. As a result, some of the resort buildings turned out to be in the wave beat line. Recently constructed boulevard in Ureki is in the wave beat line, which made lose the already narrow beach 6-8 meters. It is important that the population of the site under study, and particularly that of Ureki, knew that the beach is much more precious than the buildings that they construct directly on the hush and contribute to its washout.

Fig. 8

Conclusions

From our overview is seen that the reason of the crisis phenomena, developed in Kolkheti Lowland coastal zone (Poti lithodynamic system), is only the anthropogenic factor. Hence, it is clear that only Riv. Supsa – Riv. Natanebi section is still more or less keeping the natural dynamics and ability of independent existence. The other sites, undergoing washout or strong accumulation, need constant attention and research works, and also significant capital expenses. This is necessary for keeping sea coast relief, as a kind of frame of coastal ladscapes and, one of the main among them, their recreational and coast protecting functions.

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შავი ზღვის კოლხეთის სანაპიროს განვითარების თავისებურებები თანამედროვე პირობებში

ი.გელოვანი, გ.ლომინაძე, გ.ყავლაშვილი

რეზიუმე

შავი ზღვის კოლხეთის სანაპირო ზონა ერთობლივი ზღვიური და მდინარეული აკუმულაციის არეალია. ამავე დროს, შავი ზღვის საქართველოს სანაპიროზე, კოლხეთის მონაკვეთი ტექნოგენური ზემოქმედების თვალსაზრისით ერთერთი ყველაზე უფრო დაზიანებულია. კოლხეთის დაბლობის სანაპირო ზონაში (ფოთის ლითოდინამიკური სისტემა) განვითარებული კრიზისული მოვლენების მიზეზი, მხოლოდ ანთროპოგენული ფაქტორია. ბუნებრივ დინამიკას და დამოუკედებლად არსებობის უნარს მეტნაკლებად ჯერ კიდევ ინარჩუნებს მხოლოდ მდ. სუფსა- მდ. ნატანების მონაკვეთი. დანარჩენი უბნები, რომლებიც განიცდიან წარეცხვას ან ძლიერ აკუმულაციას, საჭიროებენ მუდმივ მონიტორინგს და მნიშვნელოვან კაპიტალ დანახარჯებს.

Особенности развития Колхидского побережья Черного моря в современных условиях

И.Л. Гелована, Г.Дж. Ломинадзе, Г.И. Кавлашвили

Резюме

Черноморская береговая зона Колхиды является ареалом совместной морской и речной аккумуляции. В тоже время, Колхидский участок на Черноморском побережье Грузии, в смысле техногенного воздействия, один из самых повреждённых. Причина кризисных явлений, наблюдающихся в береговой зоне Колхидской низменности (Потийская литодинамическая система), всецело антропогенный фактор. Междуречье Супса-Натанеби, в основном, еще сохраняет природную динамику и способность независимого существования. На остальных участках, где наблюдается размыв или сильная аккумуляция, требуются постоянный мониторинг и значительные капиталовложения.

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Predictive Analytics of Climate Trends

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Abstract

The accumulation of data in the weather observation will be continued steadily to infinity. To perform weather predictions, a huge amount of data needs to be processed and assimilated to create of acceptable models.
This paper presents a method of estimating a long term (more than 100 years) temperature and precipitation sets for predicting of a future trends. The method uses average solar cycle length as a uniform sampling basis for assessment of weather features. Long-term observation of climatic variables shows that in the theory of weather chaos exists a certain order. The order is expressed as a long-term increasing temperature trends and in rising of ocean levels. Here we demonstrate how the proposed approach can be highly effective in varied large-scale applications involving regional temperature trends in Caucasus region.

Key words: climate variability, precipitation, uniform sampling, solar cycle, attractor, Total Solar Irradiance, time series, sets.

Introduction

Predictive analytics encompasses a variety of statistical techniques from data mining, predictive modeling, and machine learning, and that analyze current and historical facts to make predictions about future or otherwise unknown events.

The Earth's climate has changed many times over geological history.

The last 3 million years have been characterized by cycles of glacials and interglacials within a gradually deepening ice age. Currently, the Earth is in an interglacial period, beginning about 20,000 years ago (Petit et al, 1999). Climate has changed when the planet received more or less the Sun's energy. Paleoclimatology, or the study of past climates, can help place this warming in the context of natural climate variability. The Earth warmed by roughly 0.6°C during the 20th century, the temperature changes have occurred over the past 100 to 150 years.

However, air-temperature reconstructions may underestimate pre-instrumental temperatures including warmth during Medieval and Roman times. The Roman Warm Period peaked around 150 AD at 2° C warmer than today (Scheidel et al, 2012a).

Dendrochronological evidence from wood found at the Parthenon shows variability of climate in the 5th century BC resembling the modern pattern of variation (Scheidel et al, 2012b).
It is believed, that current period of warming is occurring more rapidly than many past events.
In fact, reliable instrumental records are available only for the last 150 years. Earlier records exist for a few stations and in this paper we considered also time series with more than 250 years. We here address these issues by developing of big data processing, time series and application of attractors in data processing.
The study is based on two fundamental cores principles underlying geosciences:

1. The global climate is regulated by how much energy the Earth receives from the Sun.
2. The Doctrine of Uniformity –the assumption, that the same natural laws and processes that operate in our present-day scientific observations have always operated in the universe in the past and apply everywhere in the universe.

The Earth atmosphere is an open energy system receiving energy from the sun. The first law of thermodynamics, states that energy can neither be created nor destroyed; energy can only be transferred or changed from one form to another. Solar radiation is the major source of heat for the Earth. The sun provides light and warmth. In fact 99, 97% of energy budget of the earth arrives from the Sun (Taylor, 2005a). This energy to the atmosphere is the primary driver of the Earth's weather.

A reconstruction of total solar irradiance since 1843 to the present estimated an increase in the total solar irradiance of about 0,8 W/m². This is a huge amount of energy, taking into account the Earth's total land mass.

The goal of this study is to reveal the general underlying process which generates or allows such a variations in climate and precipitation trends in Caucasus region.

1.Method

Annual air temperature or rainfall data, in mathematical sense, represents a set of natural numbers and can be described as:

$T = \{t_0 , t_1, t_2 ,t_i , \dots\};$ (1)

-where t_0 , t_i –averaged yearly air temperature in °C.

In accordance with concept of the Earth's energy budget and notion of sets (mathematic), every member of air temperature "T" or rainfall "P" set is also a member of set solar activity presented as Total Solar Irradiance "TSI" (Nurtaev, 2019), then "T" is said to be a subset of "TSI" (Fig. 1).

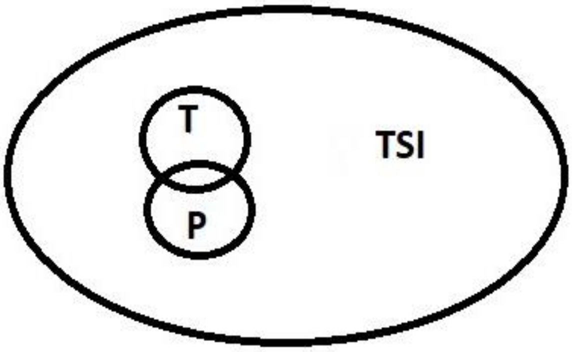


Fig. 1. Air temperature (T) and precipitation (P) are subsets of solar activity, $T \subset TSI$, $P \subset TSI$.

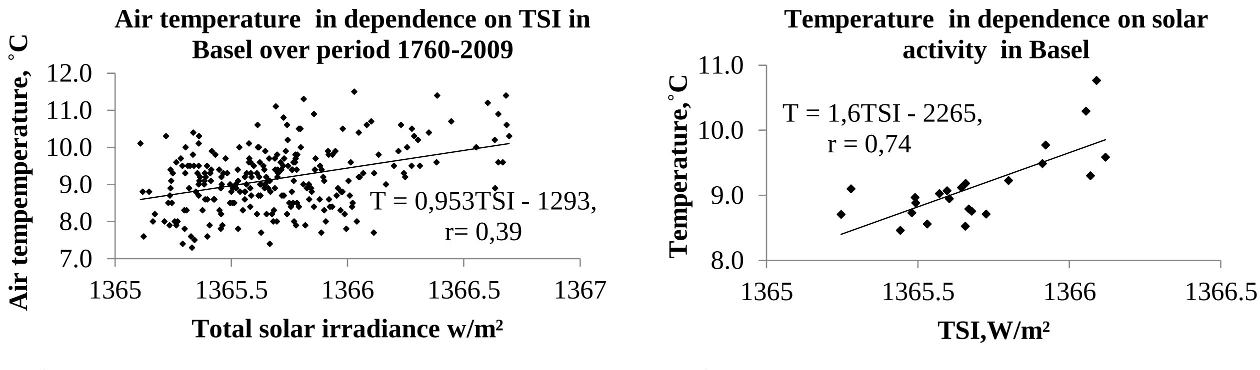
$TSI = \{tsi_0, tsi_1 ,tsi_2, tsi_3 , tsi_i , \dots\};$ (2)

-where tsi_1, tsi_2 ,… tsi_i - measured Total Solar Irradiance in W/m².

Each value of tsi_i predetermines the corresponding value of air temperature t_i. The conversion of meteorological time series into numerical sets allows working with them as with mathematical objects.

For discovery of relationship a set of data points plotted on an x and y axis to represent two sets of variables is created. An independent variable "tsi" is plotted along the horizontal axis. The measured air temperature or dependent variable t is plotted along the vertical axis.

We tested a relationship between temperature and solar activity "tsi" over the period 1760-2009 on an example of the Basel weather station, a longest time series of observations (HISTALP data, 2013). The generally positive relationship between the two variables can be easily discernible from the cloud formed by 250 points (Fig.2a).



a) b)

Fig.2.Yearly averaged air temperature in Basel in dependence from Total Solar Irradiance (a) and averaged in solar cycles (b).

In accordance with concept of the Earth's energy balance and sets theory (Figure 1) –every change of sun output- "tsi", leads to change of subset air temperature "t". This means, that every change in average annual solar energy leads to a change in average air temperature

To enhance the trend in the graph, we used an global attractor (Nurtaev, 2019), expressed in the length of the solar cycle.

Observation period for meteorological objects was divided on 11 years solar cycles time intervals for air temperature and solar activity. It was calculated for every such interval averaged Total Solar Irradiance and air temperature Nurtaev (2015):

$$TSI = \frac{1}{n}\sum_{i=0}^{n} \text{tsi}_i; \qquad (3)$$

$$T° = \frac{1}{n}\sum_{i=0}^{n} \text{t}_i; \qquad (4)$$

where TSI– averaged Total Solar Irradiance for one solar cycle with length n = 11 years; T° – averaged air temperature for one solar cycle °C, i - solar cycles 1 to current 24.

This averaging allows avoiding a cyclic variability of Total Solar Irradiance as well air temperature and leads to uniform sampling both parameters in the same time interval. Solar minima and maxima are the two extremes of the Sun's 11-year activity cycle. Averaging over 11 years as a rule gives a smoothing effect and reveals a climate trend at centennial timescales, which are more than two centuries in our test case study in Basel weather station Fig.2 (b).

2. Climate trends in Caucasus region.

The climate change in Caucasus region and its effects on the environment, ecology, and economy in the 20th century close connected with global climate trends. Over the period 1855–1996 was observed a long-term increase trend of global surface temperature. During this period also was observed an increase in solar activity in the Northern Hemisphere. The average global temperature on Earth has increased by about 0.8° Celsius. The averaged TSI analysis reveals that input of solar energy in Earth atmosphere also increased on 0, 8 W/m² (Fig. 3).

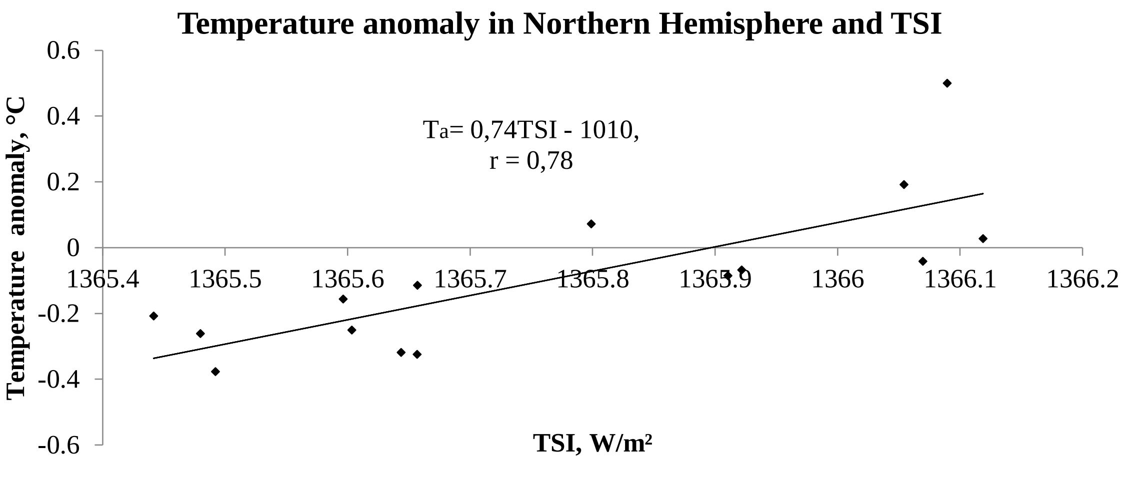


Fig.3. Dependence of air temperature anomaly in Northern Hemisphere from solar activity over the period 1843-2008.

The temperature trends in capitals of Caucasus region were presented in our previous study (Nurtaev, 2016).

Temperature in Yerevan has following trend:

T= 1.18TSI- 1597, r = 0.87 (5)

Temperature in Tbilisi has following trend:

T= 0.73TSI - 980.2, r = 0.83 (6)

This study is based on the World Bank Data for Caucasian countries and Turkey, Climate Change Knowledge Portal, World Bank Group, 2019).

Yearly averaged air temperature data in the Armenia country are presented in Fig. 4.

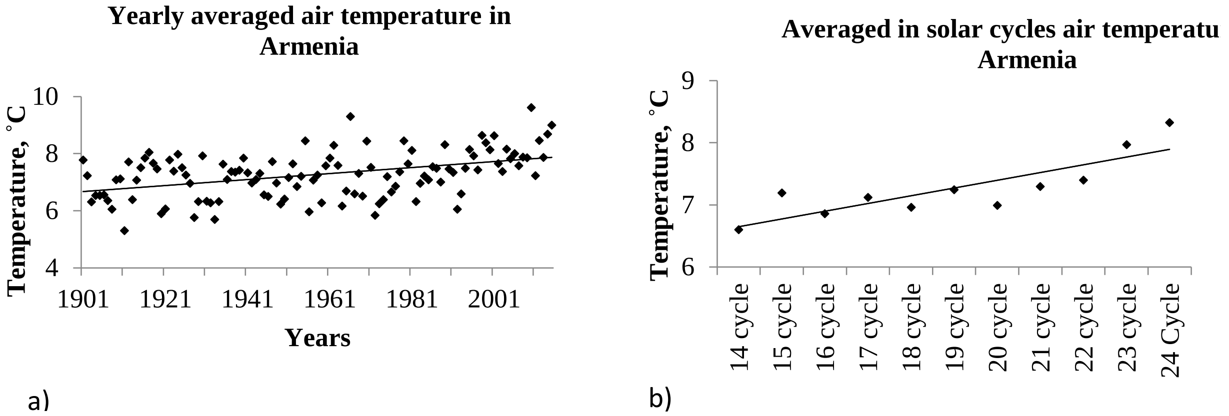


Fig.4.Long term air temperature data sets in Armenia country (a) and averaged in solar cycles (b).

The graph in Fig.4a presents the point cloud or noisy data with weak trend. In the graph in Fig.4b we divided this dimension of the scatter plot into uneven intervals of averaged solar cycle's lengths. Simple visual inspection reveals already a strong trend- 0, 84.

Among the factors that increase the temperature, the main driving force is solar activity. Average annual solar radiation arriving at the top of the Earth's atmosphere is roughly 1365 W/m².

So we compared two variables TSI and air temperature observed in Armenia divided in non-equal segments (length of solar cycles).

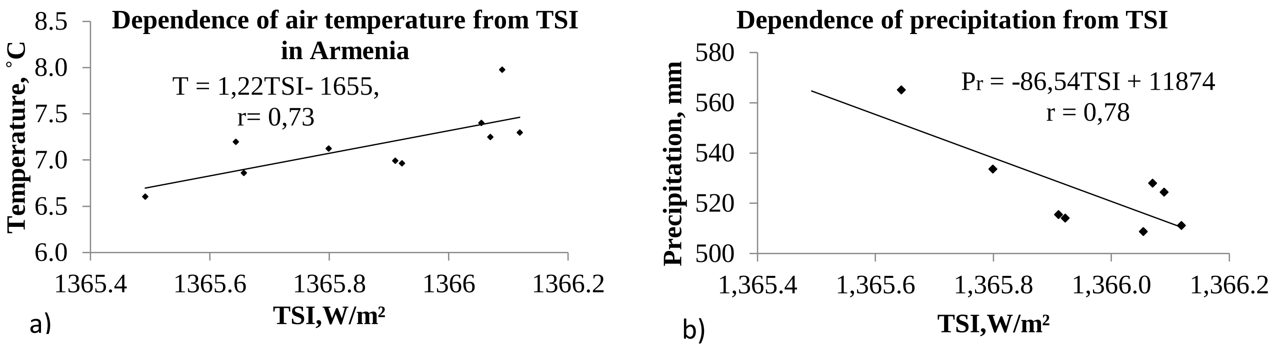


Fig. 5. Dependence of air temperature (a) and precipitation (b) from TSI in Armenia over the period 1902-2008.

T he same analyses of datasets were applied for other countries of the Caucasus region and near located Turkey, Fig. 6,7,8.

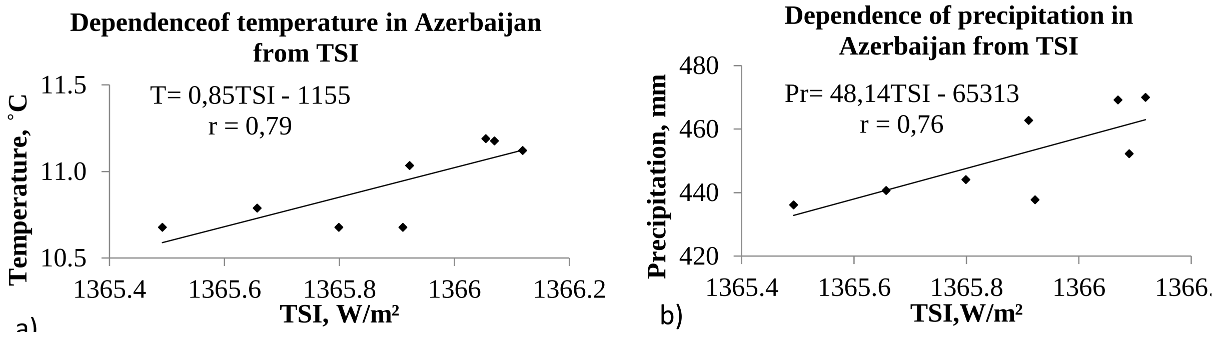


Fig. 6. Dependence of air temperature (a) and precipitation (b) from TSI in Azerbaijan over the period 1902-2008.

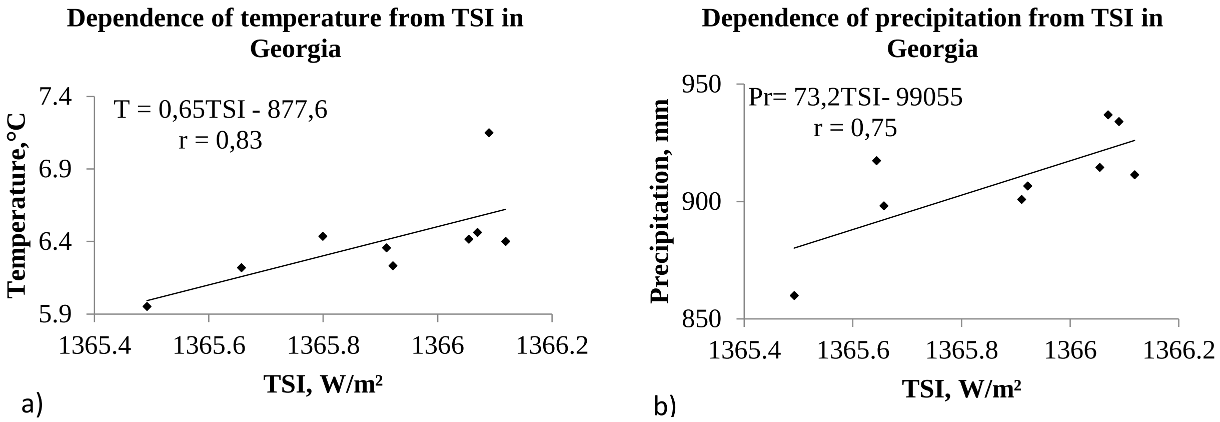


Fig. 7. Dependence of air temperature (a) and precipitation (b) from TSI in Georgia over the period 1902-2008.

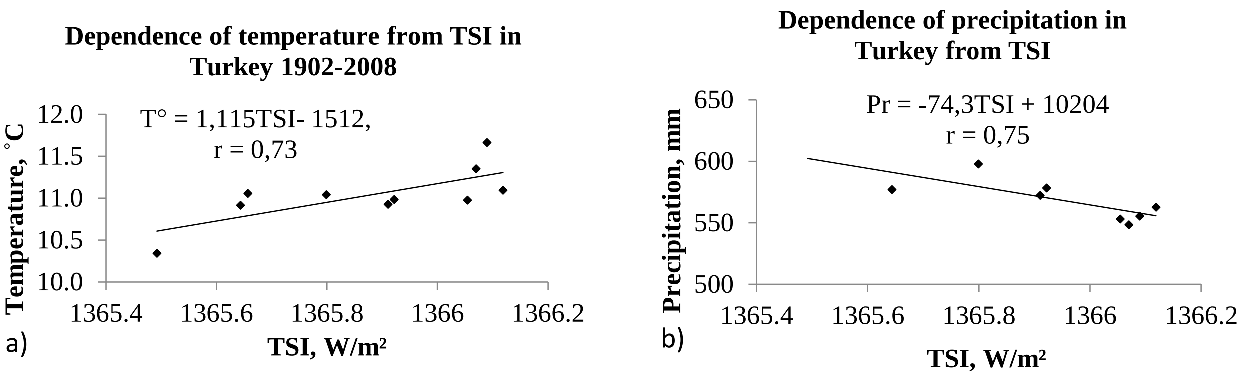


Fig. 8. Dependence of air temperature (a) and precipitation (b) from TSI in Turkey over the period 1902-2008.

3. Discussion

Despite a long term observation of weather variable, a significant part of the observed data is rarely used.

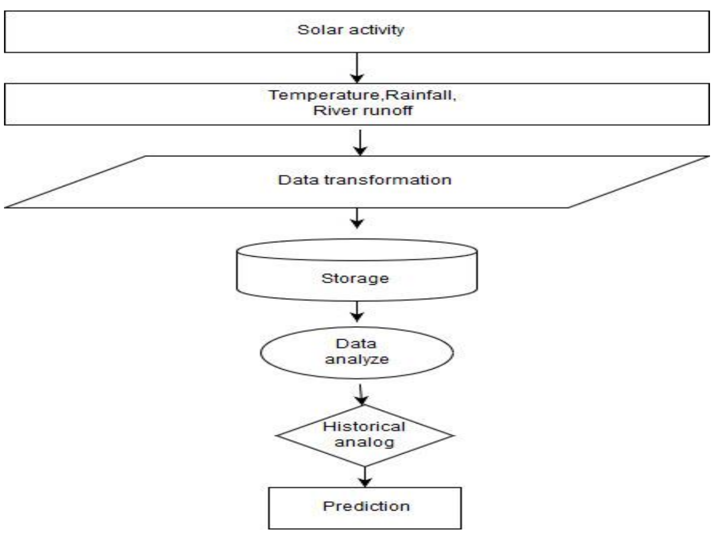


Fig. 9. Scheme of predictive analytics for climate trend forecasting.

The World Meteorological Organization defines a climate normal period as a period of at least 30 years. The current climatological standard normal period (1981–2010) at the time of writing (WMO, 2017) be used for these datasets to allow comparison among different data forms on a consistent basis. Climate normals are used implicitly or explicitly, as a prediction of the conditions most likely to be experienced in a given location

Here, we find that use of global attractor as solar cycle averaging for climate variables may be a productive way to predict future climate trends for the Caucasus countries.

Importantly, direct effects of study, to perform a meteorological data as mathematical numerals and work with these as an object of mathematics. (Mathematical object is an abstract object arising in mathematics).

Figure 9 presents a hierarchical scheme of predictive analytics for climate trends application.

Here we demonstrate how the same approach can be highly effective for one station as well as in large-scale applications on country level, where climate conditions vary over a wide range from mountains to valleys and coastal zones.

It is clear of course, that relationship for one station is higher than for country. For example-Yerevan station- r =0,83 (5) and for all Armenia country, r=0,73 (Fig.5)

4.Conclusion

Proposed method of averaging of weather variables in solar cycles allows us reveal with high probability the averaged temperature in the next averaged solar cycle. Bringing all weather parameters together in solar intervals alleviates to assess relationships between all pair of variables and see the trend for next 11 years.

NASA's forecast for the next solar cycle (25) reveals it will be the weakest of the last 200 years, TSI = 1365.5 W/m² (National Geophysical Data Center (NGDC) forecasting, 2009). Temperature in all studied countries of Caucasus region will be decreased on 0, 5-0,6 °C in the next averaged solar cycle.

Solar cycle 25 is the upcoming and 25th solar cycle since 1755, when extensive recording of solar sunspot activity began. It is expected to begin in late 2019 and continue through 2030.

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კლიმატური ტენდენციების პროგნოზული ანალიტიკა

ბ. ნურტაევი

რეზიუმე

ამინდზე დაკვირვებების მონაცემების დაგროვება მოხდება უსასრულოდ. ამინდის პროგნოზის შესასრულებლად საჭიროა დიდი რაოდენობის მონაცემების დამუშავება და ათვისება მისაღები მოდელების შესაქმნელად.

მოცემულ სტატიაში წარმოდგენილია ტემპერატურისა და ნალექების ნაკრებების გრძელვადიანი (100 წელზე მეტი) შეფასების მეთოდი მომავალი ტენდენციების პროგნოზირებისათვის. მეთოდი იყენებს მზის ციკლების საშუალო ხანგრძლივობას როგორც ამონაკრების ერთიან საფუძველს ამინდის მახასიათებლების შეფასებისათვის. კლიმატურ ცვლადებზე მრავალწლიანი დაკვირვებები გვიჩვენებს, რომ ამინდის ქაოსის თეორიაში არსებობს გარკვეული წესრიგი. ეს წესრიგი ვლინდება ტემპერატურული ტრენდების მრავალწლიან ზრდაში და ოკეანის დონის მომატებაში. აქ ჩვენ დემონსტრაციას ვაკეთებთ, როგორ შეიძლება შემოთავაზებული მიდგომა იყოს ძალზე ეფექტური სხვადასხვა დიდმასშტაბიანი გამოყენების დროს, რომლებიც მოიცავენ კავკასიის რეგიონში ტემპერატურულ ტრენდს

Прогнозная аналитика климатических тенденций

Б. Нуртаев

Резюме

Накопление данных в наблюдениях за погодой будет продолжаться до бесконечности. Для выполнения прогнозов погоды необходимо обработать и усвоить огромное количество данных для создания приемлемых моделей.

В данной статье представлен метод оценки долгосрочных (более 100 лет) наборов температуры и осадков для прогнозирования будущих тенденций. Метод использует среднюю продолжительность солнечного цикла в качестве единой основы выборки для оценки характеристик погоды. Многолетние наблюдения за климатическими переменными показывают, что в теории погодного хаоса существует определенный порядок. Порядок выражается в долгосрочном повышении температурных трендов и повышении уровня океана. Здесь мы демонстрируем, как предлагаемый подход может быть очень эффективным в различных крупномасштабных применениях, включающих региональные тренды температуры в Кавказском регионе.

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Some Characteristics of Hail Process in Georgia and Azerbaijan on May 28, 2019

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ABSTRACT

The detailed information about such characteristics of hail process in Georgia and Azerbaijan on 28 May, 2019 as: the maximum diameter of hail stones in the cloud and on the earth's surface, trajectory and velocity of the migration of convective cells with the maximum size of hail stones, the rate of growth in the maximum size of hail stones in cloud, etc. is presented.

In particular, the connections of the speed of migration of convective cells and maximum size of hail stones with the height of area relief are established. The comparison of the data about the rate of growth in the hail stones in the actual conditions with previously obtained analogous data under laboratory conditions for the uncharged cloud medium, they showed the satisfactory agreement between them.

Key Words: Radar monitoring, dangerous meteorological processes, hail, precipitation.

Introduction

Among the enumeration of natural catastrophes in Georgia, hail processes occupy one of the leading positions [1-3]. Hail will regularly do serious material damage to agriculture, buildings, infrastructure, truck transport, etc. [1-8]. Therefore, taking into account the importance of problem, to studies of hail processes in Georgia was always paid special attention, including in recent years [1-9]. What is more, taking into account the significant economic damage, brought by hail damages, in Georgia in the beginning of the fifties of past century began works on the fight with the hail [2, 10]. These works continued until 1989 and were renewed using newest technologies in Kakheti region of Georgia in 2015 [10-14]. The anti-hail service is equipped with a modern meteorological radar "METEOR 735 CDP 10 - Doppler Weather Radar" [15-17], which in the future, in addition to anti-hail activities, is planned to be used for operational monitoring of different dangerous hydro-meteorological processes in eastern Georgia and adjacent territories [13, 14].

Thus, in recent years in a number of works were represented the preliminary results of radar studies of hail processes [18-21], rainfall [22-25] and dust formation migration [26, 27] in Eastern Georgia and its neighboring countries (Azerbaijan, Armenia). In particular, in the work [21] preliminary data about the hail process in Tbilisi and Kakheti on May 28, 2019 from 16 hour 34 min to 17 hour 04 min was presented. More detailed data on this process, which, besides Georgia, has spread to the territory of Azerbaijan, is presented below.

Material and methods, study regions

The Anti-hail service is equipped with contemporary C-band, dual polarized Doppler meteorological radar “METEOR 735 CDP 10 - Doppler Weather Radar”, which is installed in the village Chotori (1090 m height from sea level) of the Signagi municipality of the Kakheti region of Georgia [12-14]. The products of radar are sufficiently varied [15-17]. For the anti-hail works the optimal radius of action of radar is 100-120 km, (distance, which practically covers the territory of Kakheti and some parts of the territories of Armenia and Azerbaijan). In this work two radar products are presented, MAX (dBZ) and HAILSZ (Size) [16, 17]. The expected size of hailstones falling out to the earth's surface was calculated according to the Zimenkov-Ivanov model of hail melting in the atmosphere [28-31] by taking into account the radar data about their diameter in the clouds and freezing level in atmosphere [32-34].

Study regions: Georgia – areas of Tbilisi and Rustavi, Kakheti (municipalities of Sagarejo and Kvareli); Azerbaijan – areas east of Agstafa and Tovuz. Date and time of the study: May 28, 2019 from 15 hour 23 min to 20 hour 37 min (below - 15:23, etc.). Discreteness of radar measurements - every three minutes.

Accordingly, every three minutes, the following characteristics of hail clouds were determined: the maximum hailstones diameter D_o (mm), coordinates of the convective cells with the maximum size of hailstones, air temperature at the level of this cells T (°C), height of the relief under this cells H (km), horizontal speed of migration of the cells with the maximum diameter of hailstones V (m/sec), maximum hail diameter at the ground level D (mm), speed of growth of maximum hailstones diameter in hail clouds $\check{D}_o$ (mm/min).

The vertical distribution of air temperature, wind speed and direction in the atmosphere over the studied region using data of the worldwide network of the aerological observations [http://ready.arl.noaa.gov/READYcmet.php] was determined.

The following designations of statistical information are used below:

Min – minimal values; Max - maximal values; St Dev - standard deviation; C_V = 100·St Dev/ Mean – coefficient of variation, %; R^2 – coefficient of determination.

In Fig. 1 and 2 data about vertical distribution of wind direction and wind speed about the investigated territory are presented.

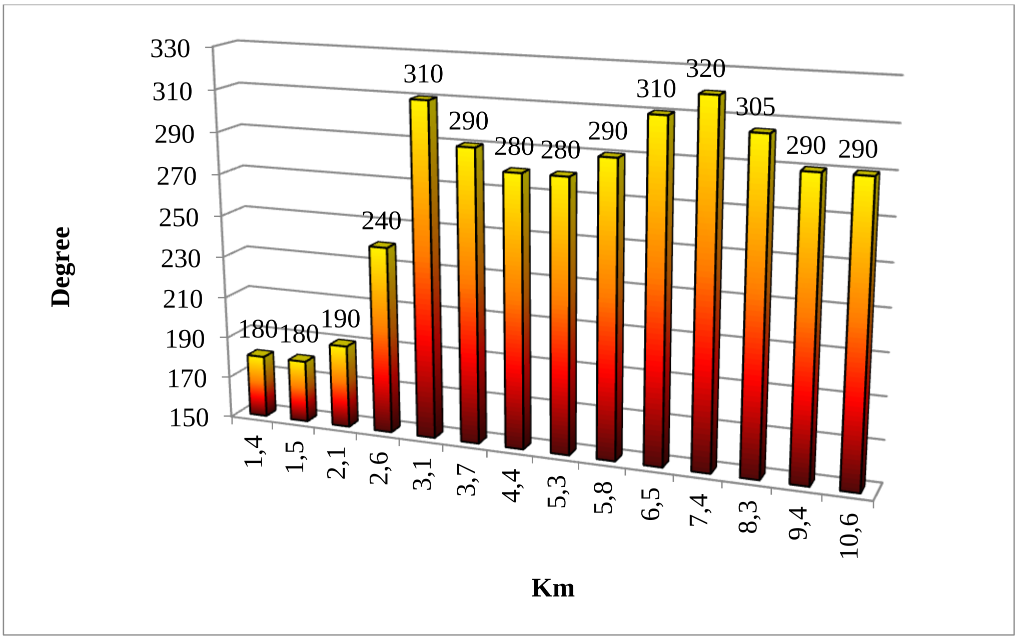

Fig.1. Vertical distribution of wind direction about the investigated territory

As follows from these figures in the layer of the atmosphere from 1.4 to 10.6 km wind direction changed from 180 to 320 degrees, and wind speed - from 1 to 17 m/sec. Speed of the main flow - 7 m/sec, direction - 280 degrees.

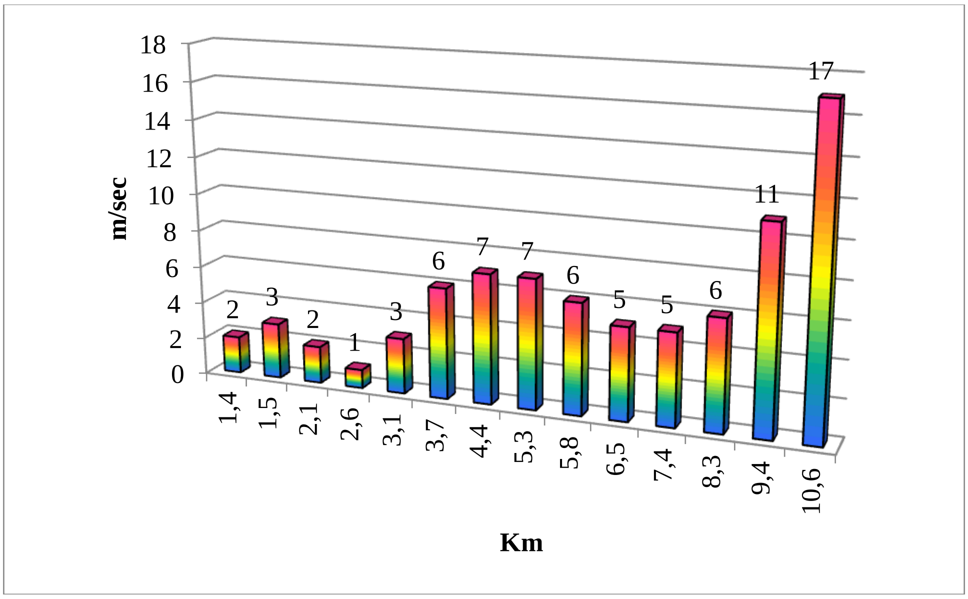

Fig.2. Vertical distribution of wind speed about the investigated territory

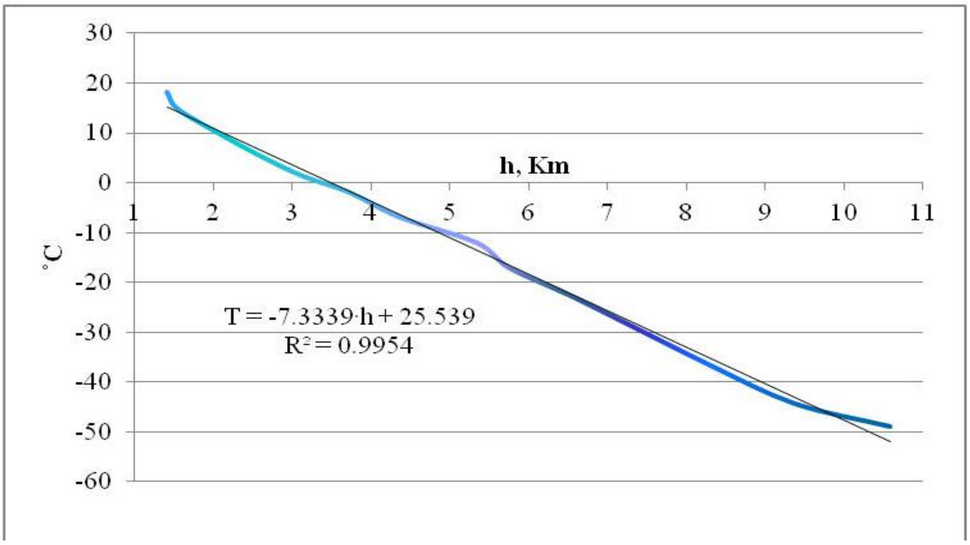

Fig. 3.Vertical distribution of air temperature about the investigated territory

Data about vertical distribution of air temperature about the investigated territory in Fig.3 is presented. The air temperature changed from 18.1 °C at the height of 1.4 km to -49 °C at the height of 10.6 km with the gradient of -7.33 degree/km. Height of zero isotherm was 3.38 km

On 28 May 2019 above the investigated territory northwestern synoptic process with the wave perturbations was observed.

Examples of radar picture of the movement of hail process above the investigated territory on May 28, 2019 in different times on Fig.4 are present. On this day, for a number of reasons, there were no active impacts on the hail processes in Kakheti.

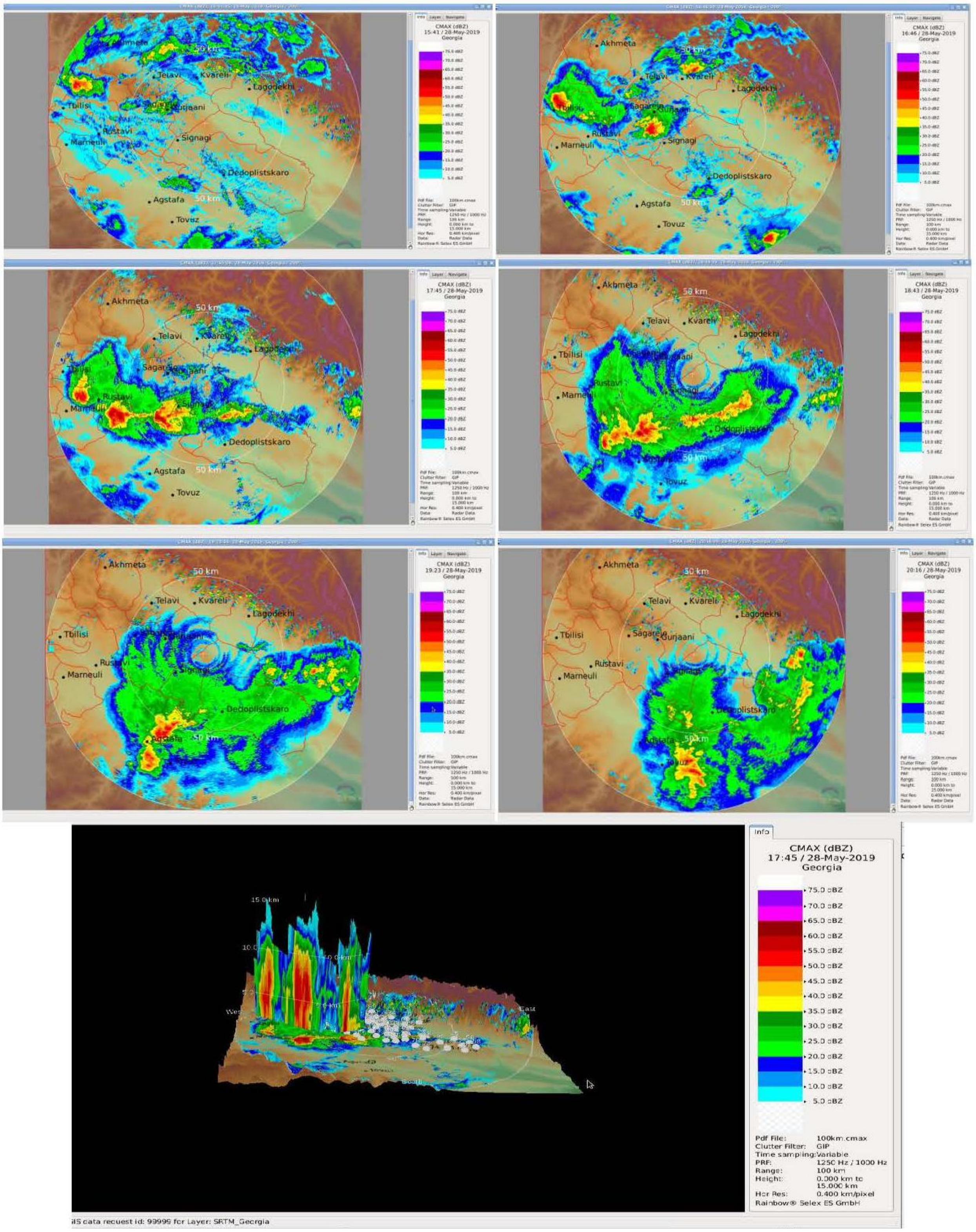

Fig.4. Radar picture of the movement of hail process above the investigated territory on 15:41, 16:46, 17:45, 18:43, 19:23 and 20:16. Below - 3D the picture of hail process on 17:45

Results

The results in Fig. 5-15 and Table 1,2 are represented.

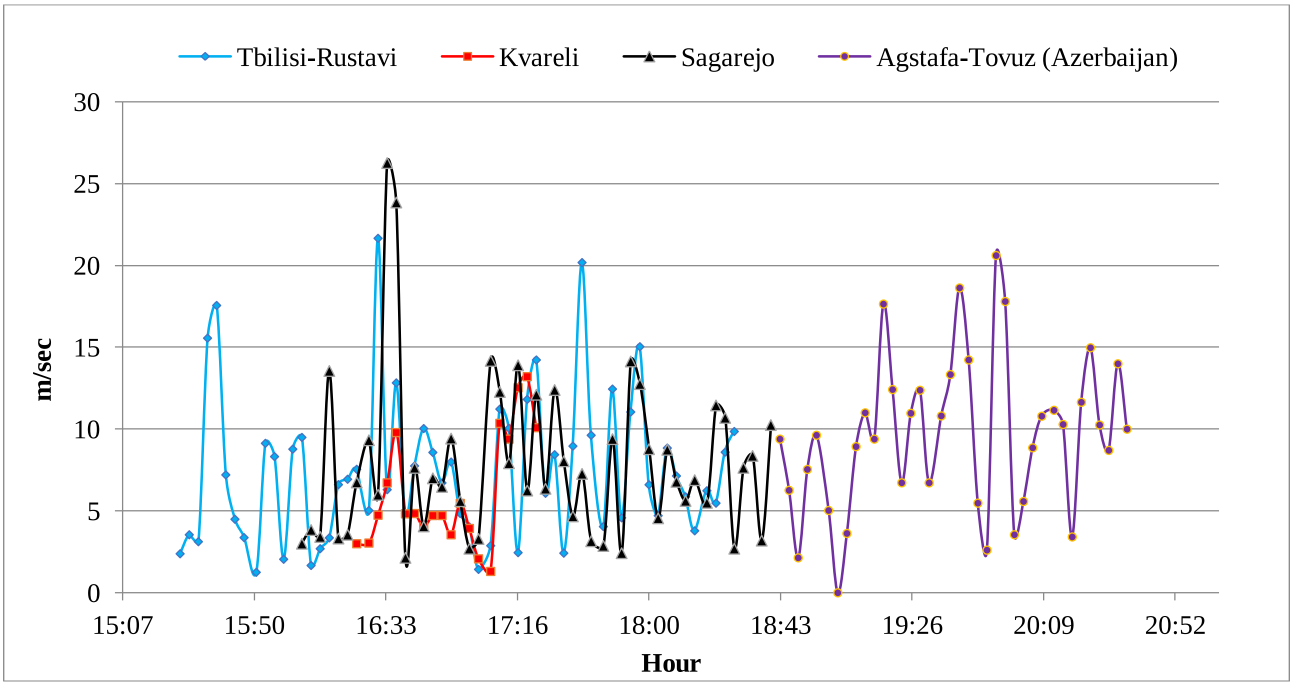

Fig.5. Changeability in the time of the speed of migration of convective cells with the maximum diameter of hailstones

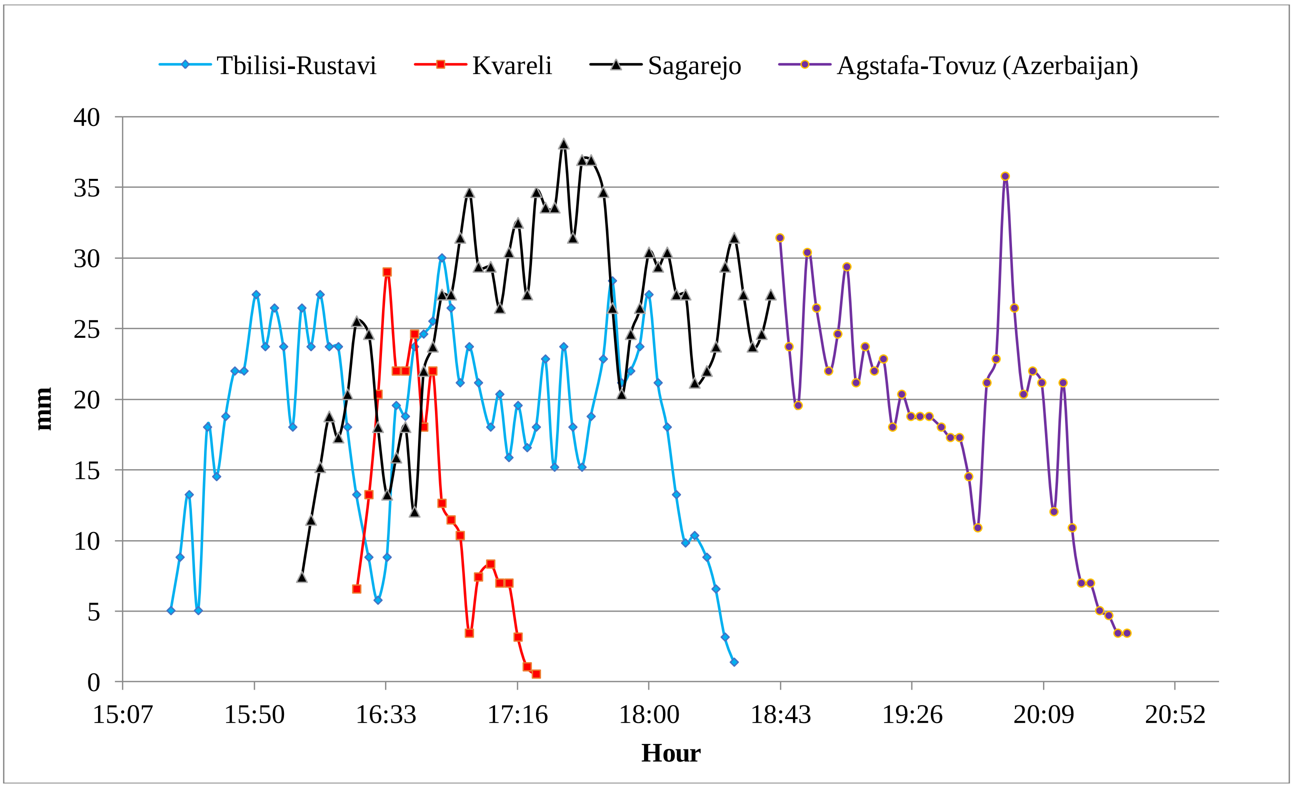

Fig.6. Changeability in the time of the maximum diameter of hailstones in the clouds from 15:23 to 20:37

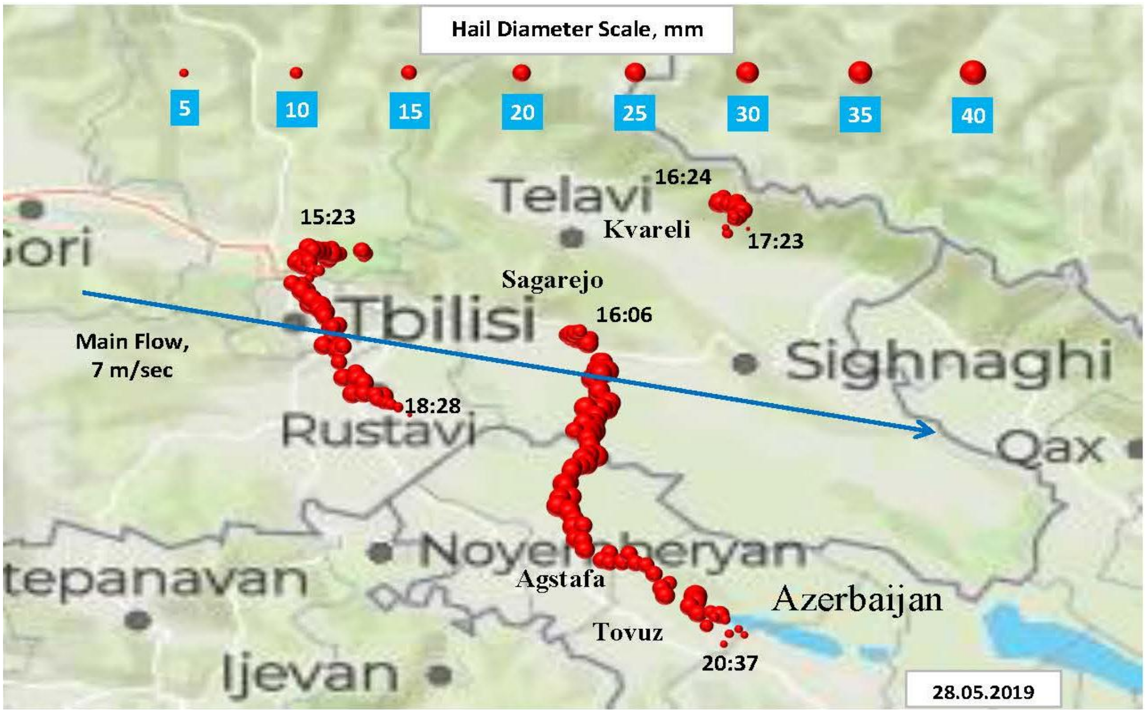

Fig.7. Convective cells with the maximum diameter of hailstones trajectory about the investigated territory from 15:23 to 20:37

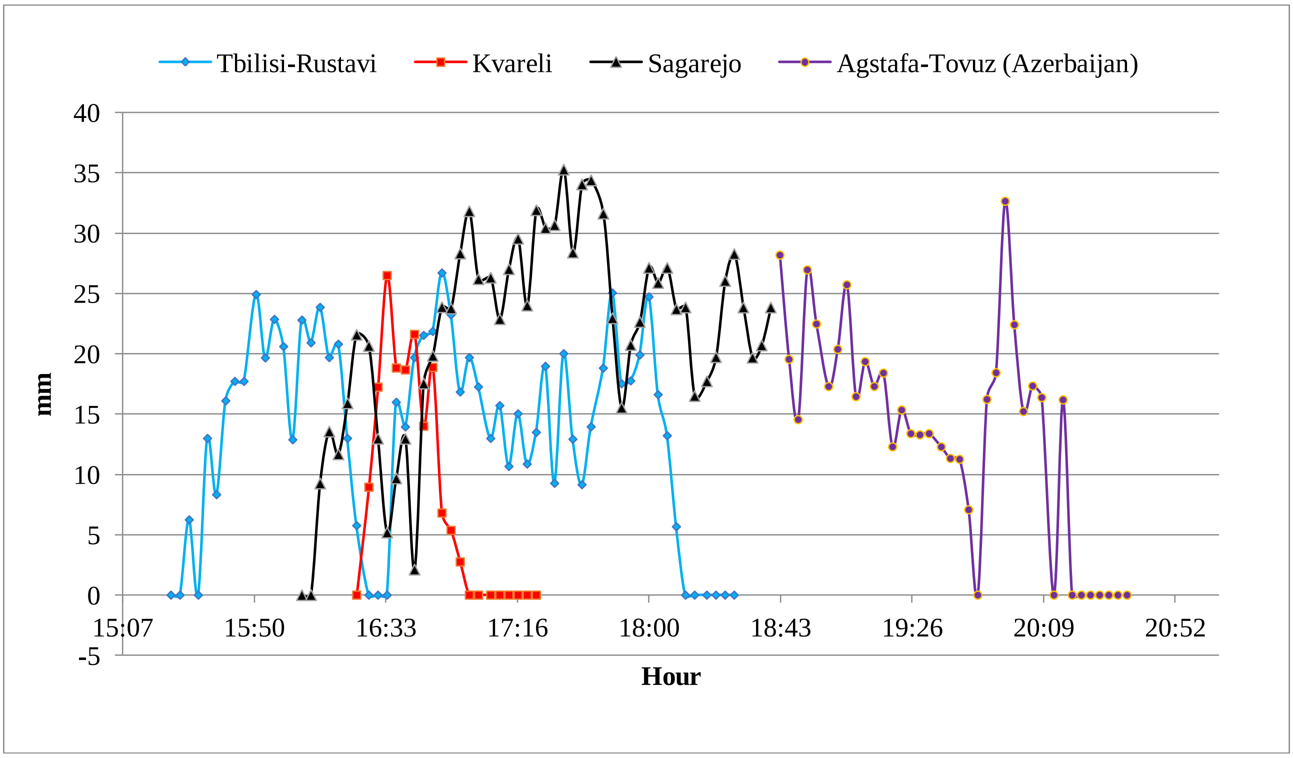

Fig.8. Changeability in time of the maximum diameter of hailstones falling on the earth surface from 15:23 to 20:37

Table 1

Statistical characteristics of hail process in Georgia and Azerbaijan on May 28, 2019

Parameter	Beginning - End of Process, Hour	Duration of Process, Minute	H, relief, km	T, °C	Do, mm	D, mm	V m/sec
Location	**Tbilisi - Rustavi**						
Min	15:23	0	0.345	-32.2	1.4	0	1.3
Max	18:28	185	1.720	-1.4	30.0	26.7	21.7
Mean			0.651	-15.5	18.4	13.5	7.5
St Dev			0.291	9.4	7.0	8.3	4.5
Cv, %			44.7	60.3	38.1	61.0	60.0
Location	**Kvareli Municipality**						
Min	16:24	0	0.543	-24.1	0.5	0	1.3
Max	17:23	59	1.476	-2.1	29.0	26.5	13.2
Mean			1.057	-9.9	12.5	8.0	6.1
St Dev			0.249	6.7	8.5	9.2	3.5
Cv, %			23.5	68.0	67.9	115.4	57.3
Location	**Sagarejo Municipality**						
Min	16:06	0	0.307	-35.1	7.4	0	2.1
Max	18:40	154	0.676	-0.7	38.1	35.3	26.3
Mean			0.437	-10.8	25.7	21.6	7.9
St Dev			0.102	8.1	7.1	8.6	5.0
Cv, %			23.2	75.4	27.5	40.0	62.9
Location	**Agstafa - Tovuz regions**						
Min	18:43	0	0.142	-25.6	3.4	0	0
Max	20:37	114	0.377	-0.7	35.8	32.6	20.6
Mean			0.226	-5.0	18.8	13.4	9.6
St Dev			0.056	5.7	7.9	9.0	4.8
Cv, %			24.8	113.7	42.1	67.1	49.5

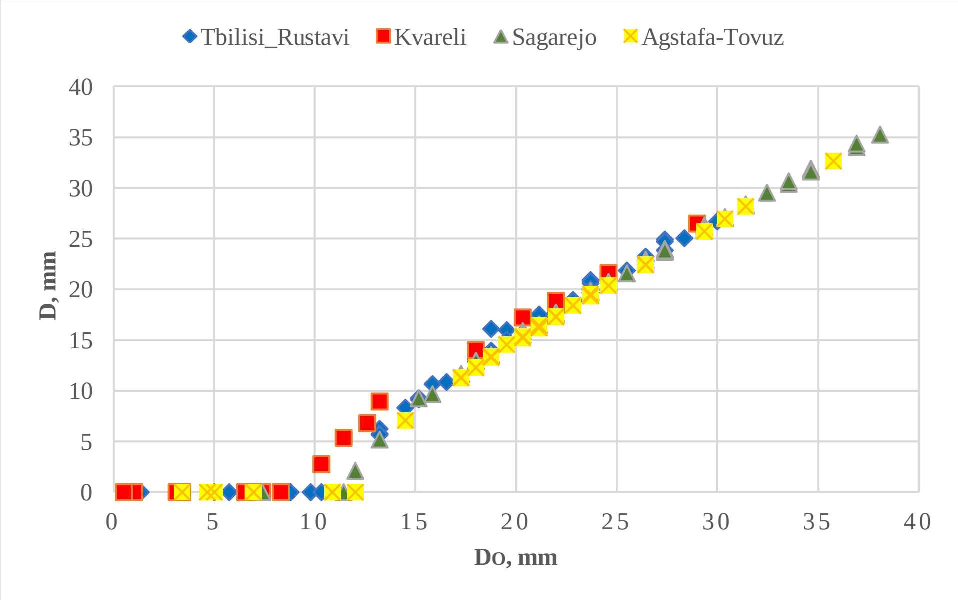

Fig.9. The ratio between values of Do and D in the study region from 15:23 to 20:37

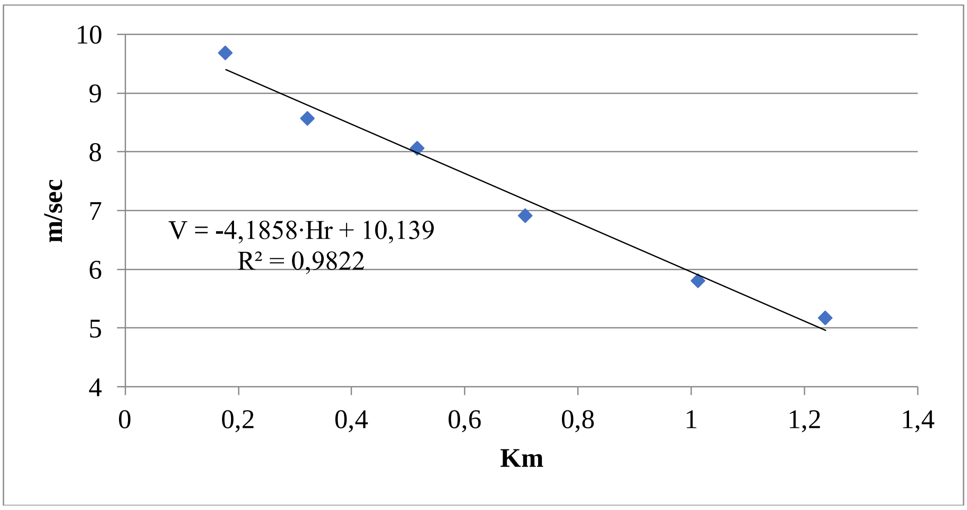

Fig.10. Dependence of the mean speed of migration of convective cells with the maximum diameter of hailstones on the height of locality

In Fig. 5-8 and Table 1 presents data on the various characteristics of the hail process on May 28, 2019.

The results of the analysis of these data are given below.

Changeability in the time of the speed of migration of convective cells with the maximum diameter of hailstones (Fig 5, Table 1).

Tbilisi – Rustavi: Values of V changes from 1.3 to 21.7 m/sec (mean value – 7.5 m/sec);

Kvareli Municipality: Values of V changes from 1.3 to 13.2 m/sec (mean value – 6.1 m/sec);

Sagarejo Municipality: Values of V changes from 2.1 to 26.3 m/sec (mean value – 7.9 m/sec);

Agstafa - Tovuz regions: Values of V changes from 0 to 20.6 m/sec (mean value – 9.6 m/sec).

It should be noted that speed of migration of convective cells with the maximum diameter of hailstones above the three investigation locations (excluding Kvareli Municipality) in some moments of time is higher, that max wind speed (Fig.2).

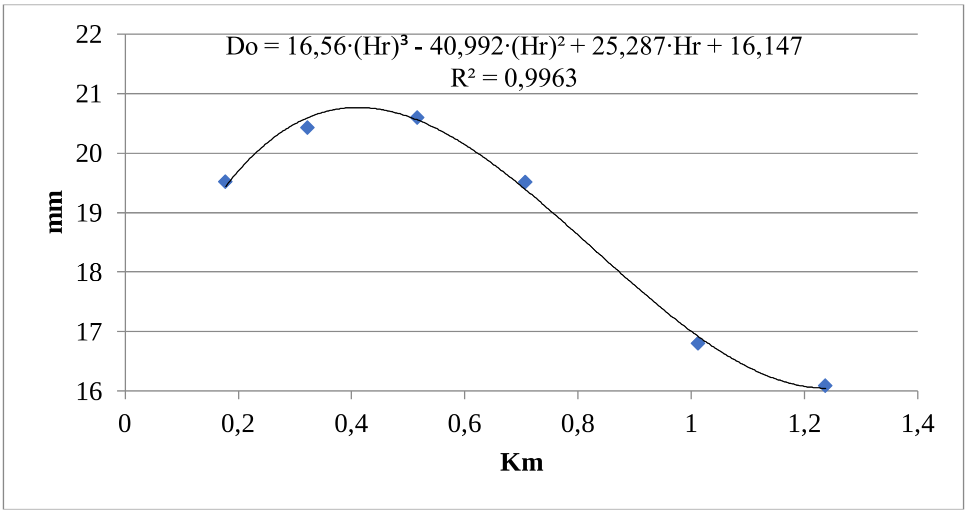

Fig.11. Dependence of the mean values of Do in hail clouds on the height of locality

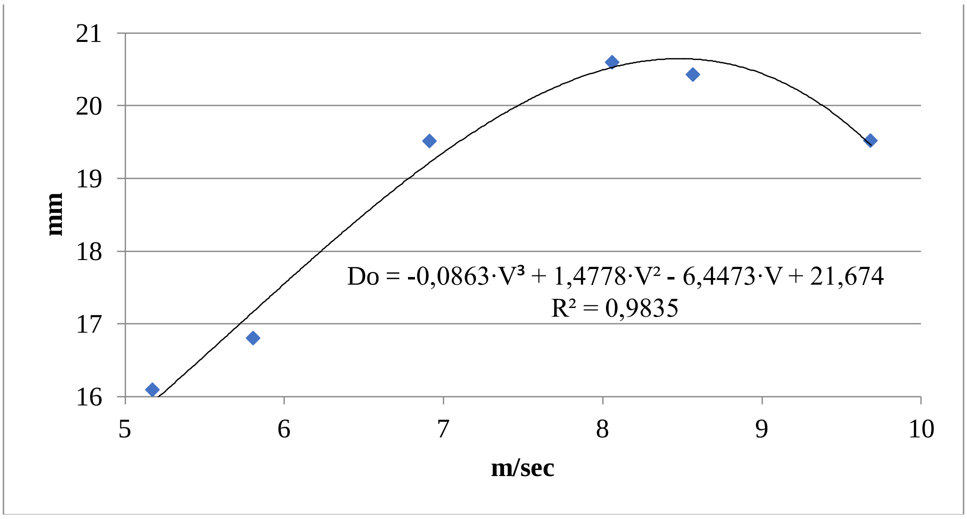

Fig.12. Dependence of the mean values of Do in hail clouds from the mean speed of their migration

Changeability in the time of the maximum diameter of hailstones in the clouds (Fig 6-7, Table 1).

Tbilisi – Rustavi: Values of Do changes from 1.4 to 30.0 mm (mean diameter – 18.4 mm);

Kvareli Municipality: Values of Do changes from 0.5 to 29.0 mm (mean diameter – 12.5 mm);

Sagarejo Municipality: Values of Do changes from 7.4 to 38.1 mm (mean diameter – 25.7 mm);

Agstafa - Tovuz regions: Values of Do changes from 3.4 to 35.8 mm (mean diameter – 18.8 mm).

Changeability in time of the maximum diameter of hailstones falling on the earth surface (Fig 8, Table 1).

Tbilisi – Rustavi: Values of Do changes from 0 to 26.7 mm (mean diameter – 13.5 mm);

Kvareli Municipality: Values of Do changes from 0 to 26.5mm (mean diameter – 8.0 mm);

Sagarejo Municipality: Values of Do changes from 0 to 35.3 mm (mean diameter – 21.6 mm);

Agstafa - Tovuz regions: Values of Do changes from 0 to 20.6 mm (mean diameter – 9.6 mm).

The ratio between values of Do and D in the all study regions on Fig. 9 is presented.

As follows from Fig. 10 the mean speed of migration of convective cells with the maximum diameter of hailstones linearly decreases with increasing of relief altitude.

Dependence of the mean values of Do in hail clouds on the height of locality has the form of a third power polynomial (Fig. 11).

Dependence of the mean values of Do in hail clouds from the mean speed of their migration has the form of a third power polynomial also (Fig. 12).

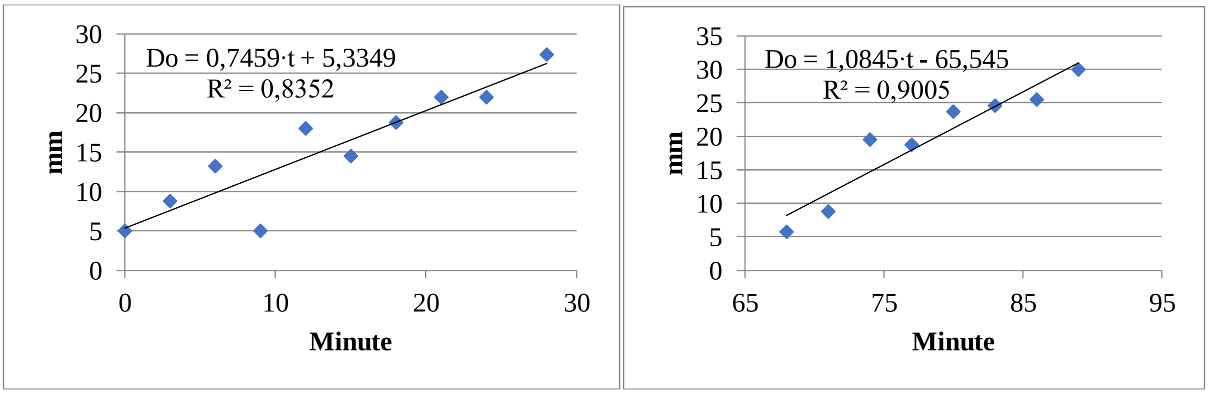

Fig.13a. Increase of value of Do in hail cloud from 15:23 to 15:51 (to the left) and from 16:31 to 16:52 (to the right), Tbilisi-Rustavi

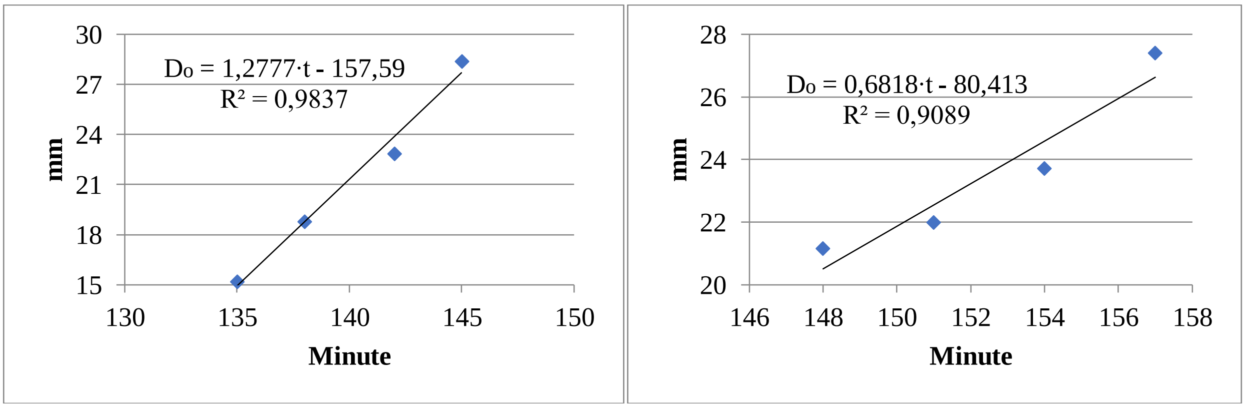

Fig.13b. Increase of value of Do in hail cloud from 17:38 to 17:48 (to the left) and from 17:51 to 18:00 (to the right), Tbilisi-Rustavi

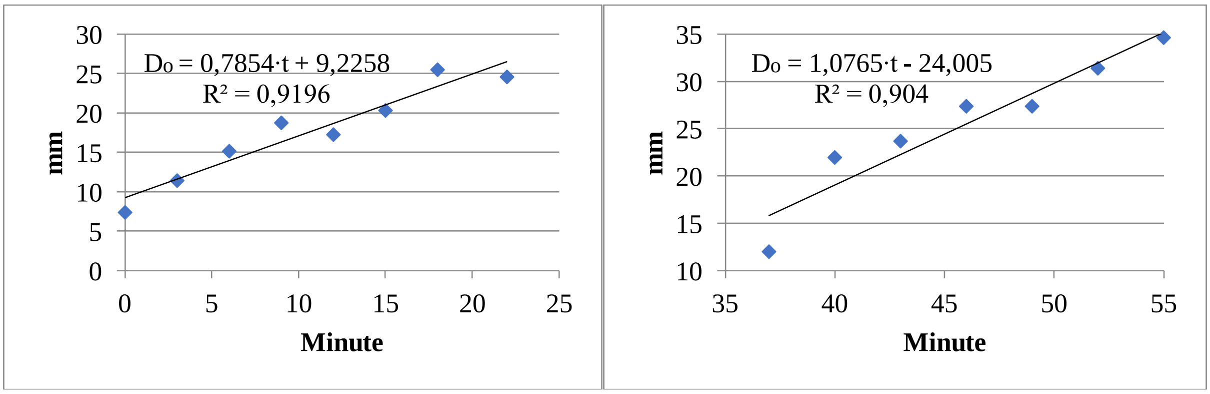

Fig.14a. Increase of value of Do in hail cloud from 16:06 to 16:28 (to the left) and from 16:43 to 17:01 (to the right), Sagarejo Municipality

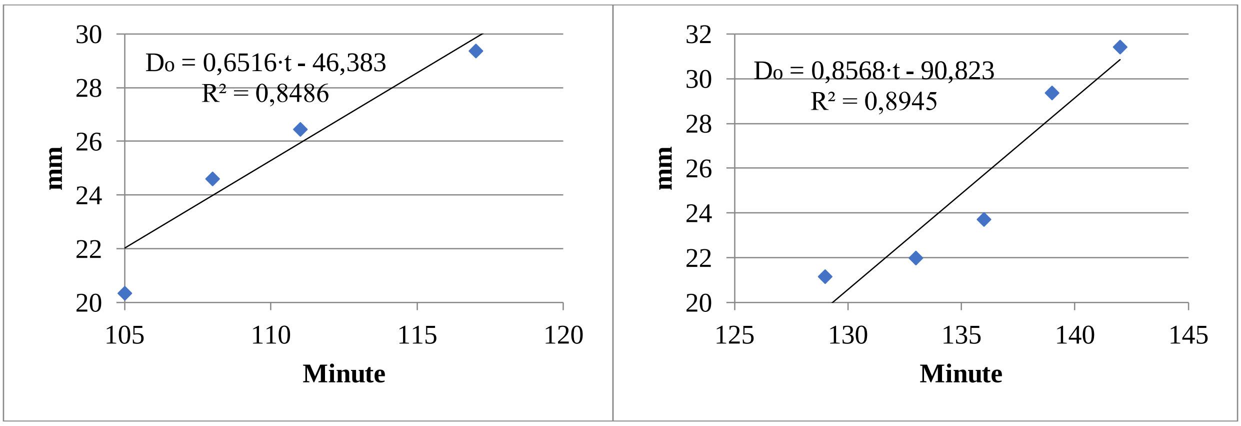

Fig.14b. Increase of value of Do in hail cloud from 17:51 to 18:06 (to the left) and from 18:15 to 14:28 (to the right), Sagarejo Municipality

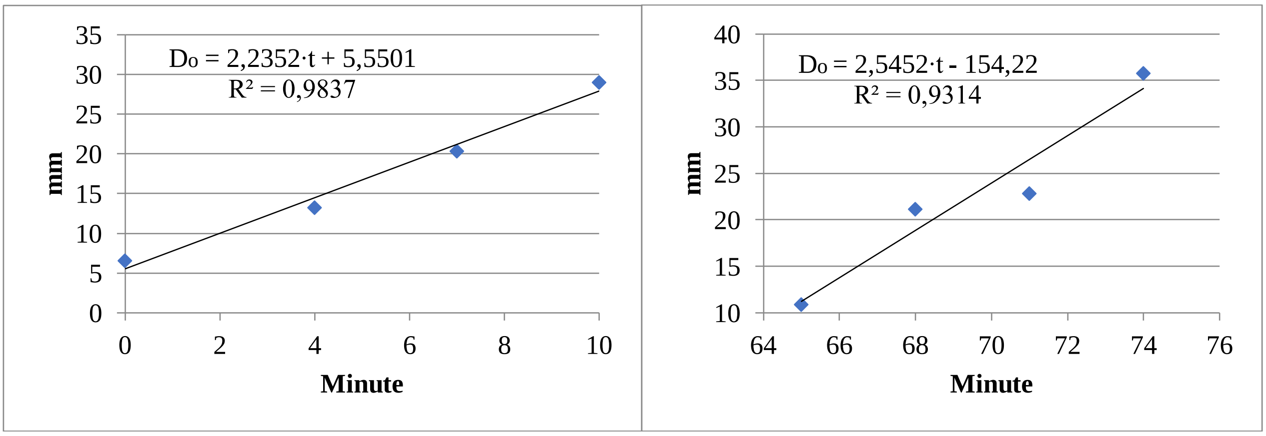

Fig.15. Increase of value of Do in hail cloud from 16:24 to 16:34 (to the left, Kvareli Municipality) and from 19:48 to 19:57 (to the right, Agstafa-Tovuz)

Table 2

Speed of growth of Do in hail clouds on May 28, 2019

Location	Tbilisi-Rustavi	Sagarejo	Kvareli	Agstafa - Tovuz
Hour	15:23 - 15:51	16:06 - 16:28	16:24 - 16:34	19:48 - 19:57
Speed of growth of Do, mm/min	0.75	0.79	2.24	2.55
T, °C	-29.3÷-7.3 (-14.2)	-19.0÷-8.7 (-16.7)	-24.1÷-12.4 (-16.2)	-4.3÷-0.7 (-2.9)
Hour	16:31 - 16:52	16:43 - 17:01		
Speed of growth of Do, mm/min	1.08	1.08		
T, °C	-32.2÷-5.1 (-22.6)	-22.7÷-4.3 (-12.0)		
Hour	17:38 - 17:48	17:51 - 18:06		
Speed of growth of Do, mm/min	1.28	0.65		
T, °C	-25.6÷-22.7 (-24.5)	-35.1÷-0.7 (-11.5)		
Hour	17:51 - 18:00	18:15 - 18:28		
Speed of growth of Do, mm/min	0.68	0.86		
T, °C	-22.7÷-5.8 (-10.9)	-18.3÷-3.6 (-8.0)		

In Fig. 13-15 and Table 2 data about speed of growth of Do in hail clouds are presented. Above the four investigation locations speed of growth of Do is following:

Tbilisi – Rustavi: 0.68÷1.28 mm/min (4 cases, cloud medium temperature range: -32.2÷-5.8 °C); **Sagarejo Municipality:** 0.65÷1.08 mm/min (4 cases, cloud medium temperature range: -35.1÷-0.7 °C); **Kvareli Municipality:** 2.24 mm/min (1 case, cloud medium temperature range: -24.1÷-12.4 °C); **Agstafa - Tovuz regions:** 2.55 mm/min (1 case, cloud medium temperature range: -4.3÷-0.7 °C). Average growth rate of Do for all 10 cases: 1.20 ± 0.57 mm/min (confidence interval - 99%).

Table 3

Statistical characteristics of the parameters of uncharged cloud medium and mean rate of growth of the diameter of hailstones for the conditions for a dry and wet increase in the hail (data of laboratory experiments [35])

Regime	**Dry growth**			**Wet growth**		
Parameter	**Cloud water content, g/m^3**	**T, °C**	**Speed of growth of Do, mm/min**	**Cloud water content, g/m^3**	**T, °C**	**Speed of growth of Do, mm/min**
Mean	2.6	-14.0	0.74	3.4	-5.4	0.82
Min	1.2	-19.3	0.35	0.9	-9.7	0.13
Max	4.3	-6.8	1.14	4.8	-1.2	1.4
St Dev	0.77	3.77	0.24	1.18	2.64	0.36
Count	35			17		

In Table 3 for comparison data of laboratory experiments [35] about rate of growth of the diameter of hailstones for the conditions for a dry and wet increase in the hail in uncharged cloud medium are presented. As follows from this Table, speed of growth of Do change from 0.35÷1.14 mm/min (dry growth, mean value - 0.74 mm/min) to 0.13÷1.4 mm/min (wet growth, mean value - 0.82 mm/min).

As follows from Tables 2 and 3, the agreement between field and laboratory data on the growth rate of Do is generally satisfactory (coincidence - 80%, excluding hail processes over Kvareli Municipality and Agstafa - Tovuz regions).

Conclusions

In the near future, a similar analysis is planned for hail processes in Kakheti during the days of the works of anti-hail service in order to assess the physical effectiveness of these works. In addition to this, the analysis of the temporary changeability of the parameters of hail processes with the use of methods of mathematical statistics for investigating the non stationary time series of observations (autocorrelation, periodicity, etc.) will be carried out.

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სეტყვის პროცესის ზოგიერთი მახასიათებლები საქართველოში და აზერბაიჯანში 2019 წლის 28 მაისს

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ხ. თავიდაშვილი, მ. მიტინი

რეზიუმე

განხილულია სეტყვის პროცესი საქართველოს და აზერბაიჯანის ტერიტორიაზე 2019 წლის 28 მაისს. სეტყვის მარცვლის მაქსიმალური დიამეტრი ღრუბელში და დედამიწის ზედაპირზე, სეტყვის მარცვლის მაქსიმალური ზომით კონვექტიური უჯრედის გადაადგილების ტრაექტორია და სიჩქარე, სეტყვის მარცვლის ზრდის სიჩქარე ღრუბელში და სხვ. დადგენილია კავშირი კონვექტიური უჯრედის გადააადგილებასა და აგრეთვე, სეტყვის მარცვლის ზრდის სიჩქარეს, ზღვის დონიდან რელიეფის სიმაღლესთან. სეტყვის მარცლის ზრდის სიჩქარის შედარებამ რეალურ პირობებში და ადრე მიღებულ ანალოგიურ მონაცემებთან, ლაბორატორიულ, დაუმუხტავი ხელოვნური ღრუბლის პირობებში აჩვენა დამაკმაყოფილებელი თანხვედრა.

Некоторые характеристики градового процесса в Грузии и Азербайджане 28 мая 2019 г.

А.Г. Амиранашвили, Т.Г. Блиадзе, Н.К. Джамришвили, Э.Н. Кекенадзе, Х.З. Тавидашвили, М.Н. Митин

Резюме

Приводится подробная информация о таких характеристиках градового процесса в Грузии и Азербайджане 28 мая 2019 года, как: максимальный диаметр градин в облаке и у поверхности земли, траектории и скорости миграции ячеек с максимальным размером градин, скорость роста максимального размера градин в облаке и др. В частности, установлены связи скорости миграции конвективных ячеек и максимального размера градин с высотой рельефа местности. Сравнение данных о скорости роста градин в реальных условиях с ранее полученными аналогичными данными в лабораторных условиях для незаряженной облачной среды, показали удовлетворительное согласие между ними.

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Statistical Characteristics of Aerosol Pollution of Atmosphere in Three Points of Tbilisi in 2017-2018

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ABSTRACT

The statistical characteristics of the weight concentrations of aerosols (particulate matter PM2.5 and PM10) in three points of Tbilisi city (A. Kazbegi av., A. Tsereteli av. and Varketili) in 2017-2018 are represented. The data of National Environmental Agency of Georgia about the hourly values of PM2.5 and PM10 are used. In particular, it is obtained that the greatest average annual values of PM2.5 on the A. Tsereteli av. were observed (24.9 μg/m³, the range of the change: 0-440 μg/m³), smallest - on A. Kazbegi av. (16.6 μg/m³, the range of the change: 0-494 μg/m³). The greatest average annual values PM10 also on. A. Tsereteli av. were observed (57.2 μg/m³, the range of the change: 0-553 μg/m³), smallest - in Varketili (37.4 μg/m³, the range of the change: 0-319 μg/m³).
It is obtained, that the value of the linear correlation coefficient between the hourly values PM2.5 and PM10 on all points sufficiently high and changes from 0.77 to 0.89. The value of the correlation coefficient between the hourly values of PM2.5 between the points changes from 0.64 to 0.73, and PM10 - from 0.49 to 0.60.
The correspondence of values of PM2.5 and PM10 at the indicated points of Tbilisi city to the standards of WHO is examined.

Key Words: atmospheric aerosols, particulate matter, PM2.5, PM10

Introduction

At the M. Nodia Institute of Geophysics for many decades has been conducting research on atmospheric aerosols (including radioactive ones) and their properties [1,2]. In particular, some theoretical studies of the structure of atmospheric aerosols, their optical properties, distribution in the atmosphere, etc. are presented in [3–9]. The results of experimental laboratory studies of the processes of washing out aerosols, their ice-forming properties, etc. are presented in [10, 11]. Particular attention is paid to full-scale studies of mineral and secondary aerosols (stationary monitoring of solid particles and secondary aerosols in the surface atmosphere [10, 12-17], aircraft research of mineral aerosols in the lower troposphere [1,2,18-20], mobile monitoring of aerosols in Tbilisi [15], data analysis of stationary ground-based remote and satellite monitoring of the aerosol optical depth of the atmosphere [15,21-29], radar monitoring of large dust formations in the atmosphere [30,31]).

In recent years, in Georgia, the Environmental Agency, in accordance with international standards, began monitoring particulate matter with a diameter of ≤2.5 μm (PM2.5) and ≤10 μm (PM10). This paper presents the results of a statistical analysis of hourly data of PM2.5 and PM10 values at three points in the city of Tbilisi in 2017 and 2018.

Study area, material and methods

Study area – three locations of Tbilisi. In Table 1 coordinates and locations of air pollution measurements points in Tbilisi are presented.

Table 1

Coordinates of air pollution measurements points in Tbilisi

No	Location	Location, Abbreviation	Latitude, N°	Longitude, E°	H, m
1	Varketili	VRKT	41.699947	44.871611	518
2	A. Kazbegi av.	KZBG	41.724767	44.752956	467
3	A. Tsereteli av.	TSRT	41.742539	44.779069	423

The hourly data of Georgian National Environmental Agency about the dust concentration (atmospheric particulate matter - PM2.5 and PM10) in three points of Tbilisi city are used [http://air.gov.ge/reports_page]. Period of observation: January 1, 2017- December 31, 2018

The data analysis with the use of standard statistical methods was conducted [32]. The following designations will be used below: Mean – average values; Min – minimal values; Max - maximal values; Range = Max-Min; St Dev – standard deviation; σ_m - standard error ; Cv = 100·St Dev/Mean, coefficient of variation (%); Count - the number of measurements; R – coefficient of linear correlation; 99% Low and 99% Upp – 99% confidence interval of lower and upper calculated level accordingly. The difference between the mean values of PM with the use of Student's criterion was determined (level of significance α is not worse than 0.1).

In the correspondence with the standards of the World Health Organization maximum permissible concentration (MPC) composes: annual mean for PM2.5 - 10 μg/m³ and for PM10 - 20 μg/m³ [33].

Table 2 verbal description of the level of aerosol pollution of the atmosphere (so-called PM Index) depicts [Air quality index - http://air.gov.ge/en/pages/11/11].

Table 2

PM Index

Pollutants	Good	Fair	Moderate	Poor	Very Poor
PM2.5 **Particle less than 2.5 μm, μg/m³**	0-10	10-20	20-25	25-50	50-800
PM10 **Particle less than 10 μm, μg/m³**	0-20	20-35	35-50	50-100	100-1200

Results and discussion

Results in Tables 3-5 and Fig. 1-2 are presented.

Data analysis of PM2.5 values (Table 3, Fig. 1)

As it follows from Table 3, mean annual values of PM2.5 in each year of observations at all three stations differ from each other (α≤0.1). In 2018 in comparison with 2017 mean annual value of PM2.5 in Varketili they did not change, whereas in two remaining points the level of the air pollution somewhat decreased. The smallest mean annual values of PM2.5 are observed on A. Kazbegi av. (17.3 and 16.6 to μg/m³ respectively into 2017 and 2018), and greatest - on A. Tsereteli av. (24.9 and 22.8 μg/m³ respectively into 2017 and 2018).

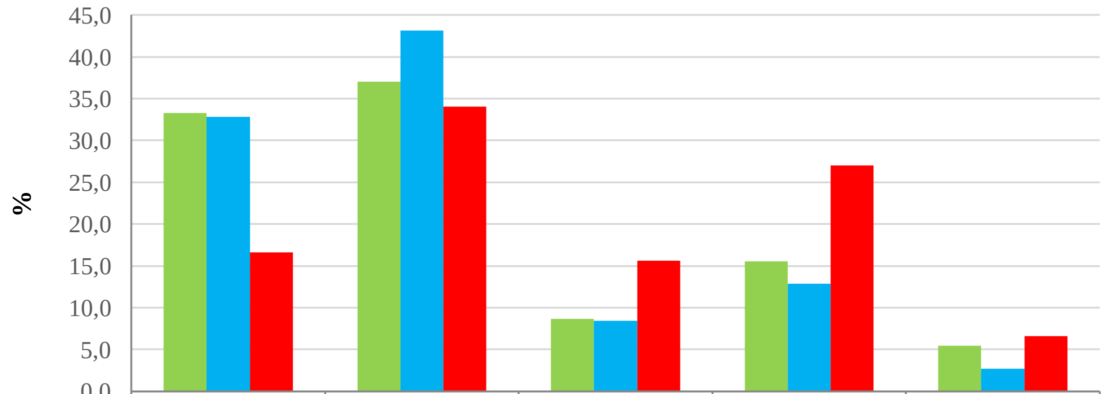
Range of a change in the hourly values of PM2.5 in two years of observation - from 0 to 494 to μg/m³. Changeability in the time of hourly values of PM2.5 is sufficiently high (Cv changes from 68.5 to 91.3 % in 2017 and from 72.3 to 80.7 % in 2018).

The value of the coefficient of linear correlation between the observation points into 2017 and 2018 covers the range 0.64÷0.73 (or, in the correspondence with the Chaddock scale correlation - "noticeable"). For all three points of measurement both into 2017 and in 2018 the average annual values of PM2.5 are above maximum permissible concentration for the indicated type of aerosols in the correspondence with the standards of WHO [33].

Table 3

Statistical characteristics of hourly values of PM2.5 at three points of Tbilisi in 2017 and 2018 (μg/m³)

Parameter	**PM2.5**					
Year	**2017**			**2018**		
Location	**VRKT**	**KZBG**	**TSRT**	**VRKT**	**KZBG**	**TSRT**
Mean	18.9	17.3	24.9	18.8	16.6	22.8
Min	0	0	0	0	0	0
Max	214	494	247	166	283	440
Range	214	494	247	166	283	440
St Dev	17.2	14.5	17.0	14.9	13.4	16.5
σm	0.20	0.16	0.20	0.16	0.15	0.18
Cv (%)	91.3	83.7	68.5	78.9	80.7	72.3
Count	7749	7751	7513	8483	8400	8434
99% Low	18.4	16.8	24.3	18.4	16.2	22.3
99% Upp	19.4	17.7	25.4	19.2	17.0	23.3
	Correlation Matrix			**Correlation Matrix**		
VRKT	1	0.64	0.73	1	0.64	0.71
KZBG	0.64	1	0.64	0.64	1	0.72
TSRT	0.73	0.64	1	0.71	0.72	1



	Good	Fair	Moderate	Poor	Very Poor
VRKT	33,3	37,1	8,6	15,6	5,4
KZBG	32,9	43,2	8,4	12,9	2,7
TSRT	16,6	34,1	15,6	27,0	6,6

Fig.1. Repetition of PM2.5 Index in three point of Tbilisi in 2017-2018 (%)

Fig. 1 presents the data about the repetition of hourly values of PM2.5 in two years of measurements for three points of Tbilisi into the correspondence with the scale of PM Index (Table 2). As follows from this Fig. the repetition of values of PM2.5 in the range "Poor÷ Very Poor" is following: in Varketili - 21 %, on A. Kazbegi av. - 15.6 %, on A. Tsereteli av. - 33.6 %.

Data analysis of PM10 values (Table 4, Fig. 2)

The statistical characteristics of hourly values of PM10 for three points of Tbilisi in Table 4 are presented. As it follows from this Table, mean annual values of PM10 in each year of observations at all three stations differ from each other ($\alpha \le 0.1$). In 2018 in comparison with 2017 mean annual values of PM10 in Varketili and on A. Kazbegi av. somewhat grew, whereas on A. Tzereteli av. - they decreased. The smallest mean annual values of PM10 are observed in Varketili (37.4 and 38.1 μg/m^3 respectively into 2017 and 2018), and greatest - on A. Tsereteli av. (57.2 and 51.2 μg/m^3 respectively into 2017 and 2018).

Table 4

Statistical characteristics of hourly values of PM10 at three points of Tbilisi in 2017and 2018 (μg/m³)

Parameter	**PM10**					
Year	**2017**			**2018**		
Location	**VRKT**	**KZBG**	**TSRT**	**VRKT**	**KZBG**	**TSRT**
Mean	37.4	39.8	57.2	38.1	42.1	51.2
Min	0	0	0	0	0	0
Max	258	835	540	319	792	553
Range	258	835	540	319	792	553
St Dev	29.7	28.4	36.7	27.5	35.9	33.7
σ_m	0.34	0.32	0.42	0.30	0.39	0.37
Cv (%)	79.4	71.4	64.2	72.2	85.2	65.7
Count	7749	7751	7513	8483	8399	8434
99% Low	36.5	38.9	56.1	37.3	41.1	50.3
99% Upp	38.2	40.6	58.3	38.8	43.1	52.2
	Correlation Matrix			**Correlation Matrix**		
VRKT	1	0.54	0.58	1	0.49	0.60
KZBG	0.54	1	0.60	0.49	1	0.51
TSRT	0.58	0.60	1	0.60	0.51	1

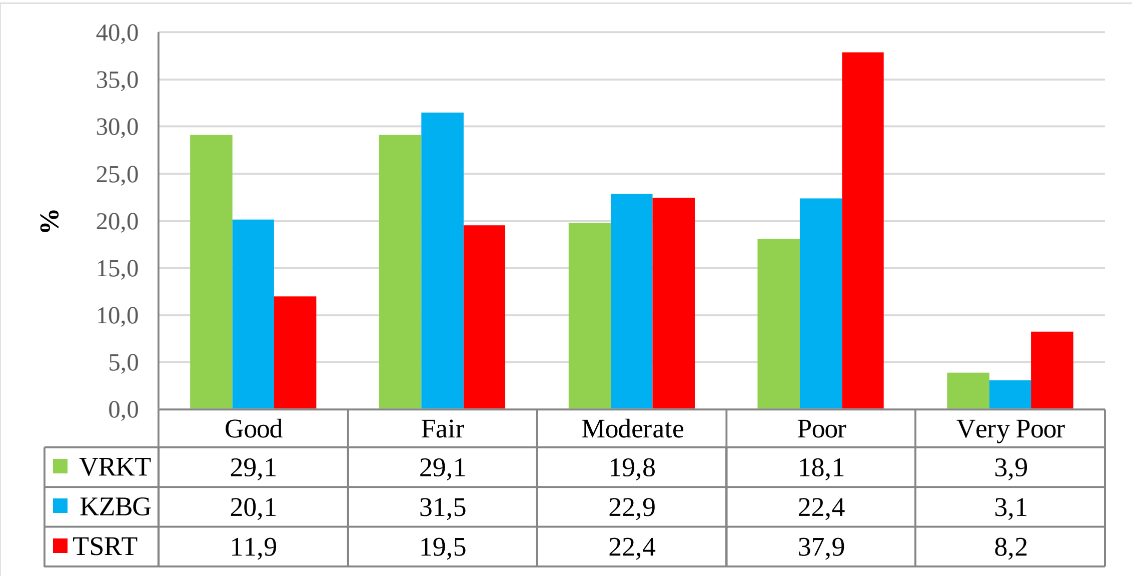


Fig.2. Repetition of PM10 Index in three point of Tbilisi in 2017-2018 (%)

Range of a change in the hourдн values of PM10 in two years of observations - from 0 to 835 μg/m^3. Changeability in the time of hourly values of PM10 (as PM2.5), also the sufficiently is high (Cv changes from 64.2 to 79.4 % in 2017 and from 65.7 to 72.2 % in 2018).

The value of the coefficient of linear correlation between the observation points into 2017 and 2018 covers the range 0.49÷0.60 (or, as in the case with PM2.5 – "noticeable" correlation).

For all three points of measurement both into 2017 and in 2018 the mean annual values of PM10 (as PM2.5) are above maximum permissible concentration for the indicated type of aerosols in the correspondence with the standards of WHO [33].

Fig. 2 presents the data about the repetition of hourly values of PM10 in two years of measurements for three points of Tbilisi into the correspondence with the scale of PM Index (Table 2). As follows from this Table the repetition of values of PM10 in the range "Poor ÷ Very Poor" are following: in Varketili - 22 %, on A. Kazbegi av. - 25.5 %, on A. Tsereteli av. - 46.1 %.

The comparison of the data about the repetition of hourly values of PM2.5 and PM10 shows that the level of the air pollution by both types of aerosols in the range "Poor ÷ Very Poor" in Varketili is approximately identical (21 and 22 % respectively), whereas on A. Kazbegi av. and A. Tsereteli av. the level of air pollution by particles with the diameter ≤2.5 μm, it is lower than by coarse dispersed aerosols (respectively: 15.6 and 25.5 % on A. Kazbegi av. and 33.6 and 46.1 % on A. Tsereteli av..

Table 5

Linear correlation between PM2.5 and PM10 at three points of Tbilisi in 2017 and 2018

Year	**2017**			**2018**		
Location	**VRKT**	**KZBG**	**TSRT**	**VRKT**	**KZBG**	**TSRT**
R	0.89	0.77	0.79	0.87	0.79	0.85

Finally, Table 5 presents the data about coefficients of linear correlation between the hourly values of PM2.5 and PM10 for each point of measurement. As it follows from this Table, values of R in 2017-2018 cover the range 0.77÷0.89 (or, in the correspondence with the Chaddock scale correlation – "strong").

Conclusion

As is known, air pollution in Tbilisi leads to a considerable increase in the mortality of the population of this city [15]. Last studies showed that Georgia (after Serbia) is found in the second place in Europe according to the indices of mortality because of air pollution [https://www.cei.int/ansa/76693]. Therefore, over the long term is planned the more detailed study of the aerosol pollution of the atmosphere, in particular, conducting the statistical analysis of monthly, daily, day and night variations in the values of PM2.5 and PM10 for Tbilisi and other cities of Georgia.

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2017-2018 წლებში ატმოსფეროს აეროზოლური დაბინძურების სტატისტიკური მახასიათებლები თბილისის სამ პუნქტში

დ. კირკიტაძე

რეზიუმე

წარმოდგენილია აეროზოლების წონითი კონცენტრაციების სტატისტიკური მახასიათებლები (PM2.5 და PM10) ქალაქ თბილისის სამ პუნქტში (ა.ყაზბეგის პრ., ა.წერეთელის პრ. და ვარკეთილი) 2017-2018 წლებში. გამოყენებულია გარემოს დაცვის ნაციონალური სააგენტოს მონაცემები PM2.5 და PM10 -ის საათობრივი მნიშვნელობების შესახებ. კერძოდ მიღებულია რომ PM2.5-ის მაქსიმალური საშუალოწლიური მნიშვნელობები დაიკვირვებოდა პუნქტში

ა.წერეთელის პროსპექტზე (24.9 მკგ/მ³, ცვლილების დიაპაზონი: 0-440 მკგ/მ³), მინიმალური - ა.ყაზბეგის პროსპექტზე (16.6 მკგ/მ³, ცვლილების დიაპაზონი: 0-494 მკგ/მ³). PM10 -ის მაქსიმალური საშუალოწლიური მნიშვნელობები დაიკვირვებოდა აგრეთვე პუნქტში ა.წერეთელის პროსპექტზე (57.2 მკგ/მ³, ცვლილების დიაპაზონი: 0-553 მკგ/მ³), მინიმალური- ვარკეთილში (37.4 მკგ/მ³, ცვლილების დიაპაზონი: 0-319 მკგ/მ³). მიღებულია, რომ წრფივი კორელაციის კოეფიციენტის მნიშვნელობა PM2.5 და PM10-ის საათობრივ სიდიდეებს შორის ყველა პუნქტზე საკმაოდ მაღალია და იცვლება 0.77-სა და 0.89-ს შორის. წრფივი კორელაციის კოეფიციენტის მნიშვნელობა პუნქტებს შორის PM2.5 საათობრივი სიდიდეებისა იცვლება 0.64-დან 0.73-მდე, PM10-ისა -0.49დან -0.60 მდე.
განხილულია PM2.5 და PM10-ის მნიშვნელობების შესაბამისობა მჯო-ს ნორმებთან თბილისის სამ პუნქტში ჰაერის აღნიშნული დამაბინძურებლებისთვის.

Статистические характеристики аэрозольного загрязнения атмосферы в трех пунктах Тбилиси в 2017-2018 гг.

Д.Д. Киркитадзе

Резюме

Представлены статистические характеристики весовых концентраций аэрозолей (PM2.5 и PM10) в трех пунктах города Тбилиси (пр. А. Казбеги, пр. А. Церетели и Варкетили) в 2017-2018 гг. Использованы данные национального агентства по окружающей среде о часовых значениях PM2.5 и PM10. В частности, получено, что наибольшие среднегодовые значения PM2.5 наблюдались в пункте на пр. А. Церетели (24.9 мкг/м^3, диапазон изменения: 0-440 мкг/м^3), наименьшие – на пр. А. Казбеги (16.6 мкг/м^3, диапазон изменения: 0-494 мкг/м^3). Наибольшие среднегодовые значения PM10 наблюдались также на пр. А. Церетели (57.2 мкг/м^3, диапазон изменения: 0-553 мкг/м^3), наименьшие – в Варкетили (37.4 мкг/м^3, диапазон изменения: 0-319 мкг/м^3). Получено, что величина линейного коэффициента корреляции между часовыми значениями PM2.5 и PM10 на всех пунктах достаточно высокая и меняется от 0.77 до 0.89. Величина коэффициента корреляции между часовыми значениями PM2.5 между пунктами меняется от 0.64 до 0.73, а PM10 – от 0.49 до 0.60.
Рассмотрено соответствие значений PM2.5 и PM10 в трех пунктах города Тбилиси нормам ВМО.

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Statistical Characteristics of Surface Ozone Concentration in Three Points of Tbilisi in 2017-2018

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ABSTRACT

The statistical characteristics of surface ozone concentration (SOC) in three points of Tbilisi city (A. Kazbegi av., A. Tsereteli av. and Varketili) in 2017-2018 are represented. The data of *National Environmental Agency of Georgia about the eight hour values of SOC are used.*

In particular, it is obtained that the greatest average annual values of SOC in Varketili were observed (53.9 μg/m³, the range of the change: 1-134 μg/m³), smallest – at the A. Tsereteli av. (21.6 μg/m³, the range of the change: 0-102 μg/m³). The value of the correlation coefficient between the eight hour values SOC between the points sufficiently high and changes from 0.74 to 0.91.

The correspondence of values of SOC at the indicated points of Tbilisi city to the standards of WHO is examined.

Key Words: surface ozone concentration, ecology

Introduction

It is known, that atmospheric ozone is one of the most important species defining the quality of life [1,2]. Therefore, special attention in many countries of world, including in Georgia, is paid to studies of surface ozone concentration (SOC) [3-13].

The ozone concentration in the atmospheric surface layer, varies widely depending on photochemical processes, horizontal advection, intrusions of stratospheric air, vertical mixing, dry and humid deposition, etc.

In recent years, the Environment Agency has been monitoring surface ozone concentrations in Georgia in accordance with international standards. This paper presents the results of a statistical analysis of eight-hour data of SOC values at three points in of Tbilisi in 2017 and 2018.

Study area, material and methods

Study area – three locations of Tbilisi. In Table 1 coordinates and locations of air pollution measurements points in Tbilisi are presented.

Table 1

Coordinates of air pollution measurements points in Tbilisi

No	Location	Location, Abbreviation	Latitude, N°	Longitude, E°	H, m
1	**Varketili**	**VRKT**	41.699947	44.871611	518
2	**A. Kazbegi av.**	**KZBG**	41.724767	44.752956	467
3	**A. Tsereteli av.**	**TSRT**	41.742539	44.779069	423

The eight hourly data of Georgian National Environmental Agency about the Surface Ozone Concentration (SOC) in three points of Tbilisi city are used [http://air.gov.ge/reports_page]. Period of observation: January 1, 2017- December 31, 2018

The data analysis with the use of standard statistical methods was conducted [14]. The following designations will be used below: Mean – average values; Min – minimal values; Max - maximal values; Range = Max-Min; St Dev – standard deviation; σ_m - standard error ; Cv = 100·St Dev/Mean, coefficient of variation (%); Count - the number of measurements; R – coefficient of linear correlation; 99% Low and 99% Upp – 99% confidence interval of lower and upper calculated level accordingly. The difference between the mean values of SOC with the use of Student's criterion was determined (level of significance α is not worse than 0.001).

In the correspondence with the standards of the World Health Organization maximum permissible concentration (MPC) composes eight hourly mean for SOC - 100 μg/m³ [15].

Table 2 verbal description of the level of aerosol pollution of the atmosphere (so-called O_3 Index) depicts [Air quality index - http://air.gov.ge/en/pages/11/11].

Table 2

O_3 Index

Pollutants	Good	Fair	Moderate	Poor	Very Poor
O_3 - Ozone, μg/m³	0-80	80-120	120-180	180-240	240-600

Results and discussion

Results in Table 3 and Fig. 1 are presented.

The statistical characteristics of eight-hour values of SOC for three point of Tbilisi in Table 3 are presented. As it follows from this Table, mean annual values of SOC in each year of observations at all three stations differ from each other (α≤0.001). In 2018 in comparison with 2017 mean annual values of SOC on all points of measurement decreased.

The smallest mean annual values of SOC are observed on A. Tsereteli av. (27.9 and 21.6 μg/m³ respectively into 2017 and 2018), and greatest - in Varketili (53.9 and 46.3 μg/m³ respectively into 2017 and 2018).

Range of a change in the eight-hour values of SOC in two years of observation - from 0 to 133.5 μg/m³. Changeability in the time of values of SOC is sufficiently high (Cv changes from 49.9 to 70.7 % in 2017 and from 59.0 to 80.4 % in 2018).

The values of the coefficient of linear correlation between the observation points into 2017 and 2018 cover the range 0.74÷0.91 (or, in the correspondence with the Chaddock scale correlation – "strong").

Fig. 2 presents the data about the repetition of eight-hour values of SOC in two years of measurements for three points of Tbilisi into the correspondence with the scale of O_3 index (Table 2). As follows from this Fig. the repetition of values of SOC in the range "Poor ÷ Very Poor" for all points it is equal to zero. Repetition of values of SOC ≥ 100 μg/m³ is the following: in Varketili - 1.63 %, on A. Kazbegi av. - 0.19 %, on A. Tsereteli av. – 0.01 %. I.e., for all three points of measurement both into 2017 and in 2018 the values of SOC above maximum permissible concentration in the correspondence with the standards of WHO [15] practically are absent.

Table 3

Statistical characteristics of the 8-hour mean values of SOC at three points of Tbilisi in 2017 and 2018 (μg/m³)

Parameter	SOC					
Year	**2017**			**2018**		
Location	**VRKT**	**KZBG**	**TSRT**	**VRKT**	**KZBG**	**TSRT**
Mean	53.9	41.6	27.9	43.6	35.0	21.6
Min	2.1	0.6	0.0	1.1	0.0	0.0
Max	133.5	116.0	94.8	125.0	113.8	101.9
Range	131.4	115.4	94.8	123.9	113.8	101.9
St Dev	26.7	26.1	19.7	25.7	23.6	17.3
σm	0.30	0.29	0.22	0.28	0.25	0.19
Cv (%)	49.6	62.6	70.7	59.0	67.6	80.4
Count	7918	7844	7777	8579	8608	8522
99% Low	53.1	40.9	27.3	42.9	34.3	21.1
99% Upp	54.7	42.4	28.5	44.3	35.6	22.0
	Correlation Matrix			Correlation Matrix		
VRKT	1	0.88	0.84	1	0.91	0.74
KZBG	0.88	1	0.85	0.91	1	0.76
TSRT	0.84	0.85	1	0.74	0.76	1
≥100 μg/m³						
%	2.34	0.31	0.00	1.00	0.10	0.02

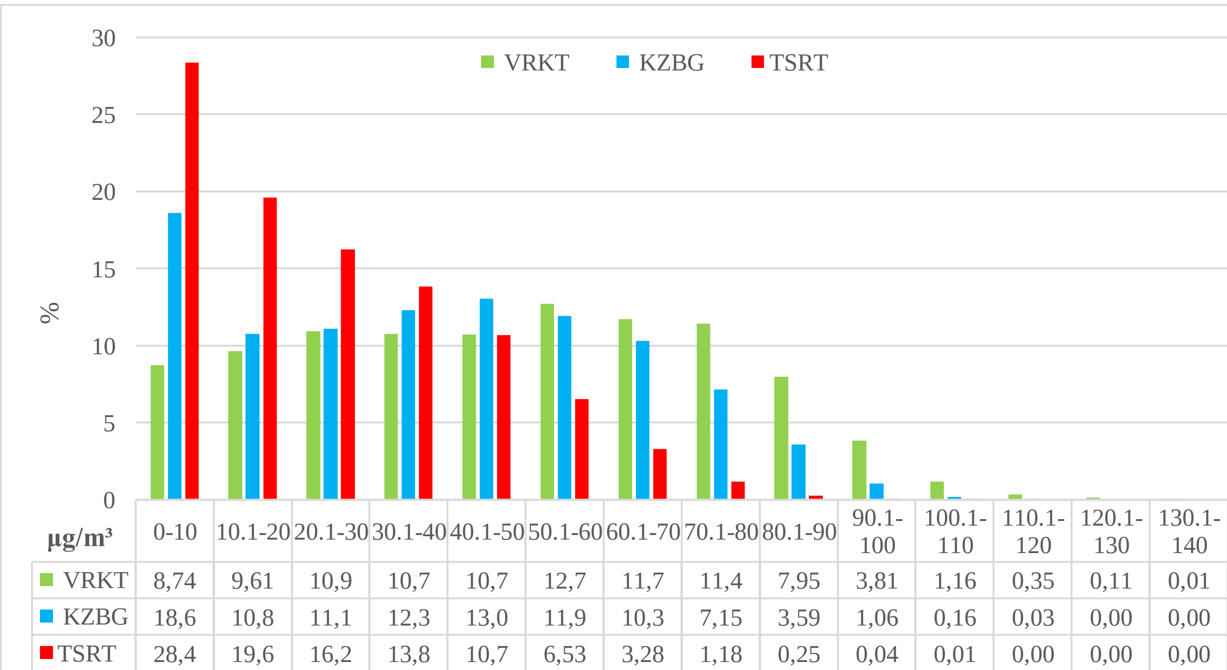

Fig. 1. Repetition of SOC in three point of Tbilisi in 2017-2018

However, this by no means does not testify about the purity of air in Tbilisi. The low concentrations of ozone are caused by the high level of the aerosol pollution of the atmosphere [16], by the expenditure of ozone for photochemical transformation of gas components of the atmosphere [2], etc. Therefore, ozone, together with other aerosol and gas components, creates an extremely unfavorable ecological situation in Tbilisi, contributing to an increase in mortality due to air pollution [2], in terms of which Georgia (after Serbia) is in second place in Europe [https://www.cei.int/ansa/76693].

Conclusion

Over the long term is planned the more detailed study of variations of surface ozone concentration in Tbilisi and other cities of Georgia.

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2017-2018 წლებში მიწისპირა ოზონის კონცენტრაციის სტატისტიკური მახასიათებლები თბილისის სამ პუნქში

ე. კეკენაძე

რეზიუმე

წარმოდგენილია მიწისპირა ოზონის კონცენტრაციის (მოკ) სტატისტიკური მახასიათებლები ქალაქ თბილისის სამ პუნქტში (ა.ყაზბეგის პრ., ა.წერეთელის პრ. და ვარკეთილი) 2017-2018 წლებში. გამოყენებულია გარემოს ეროვნული სააგენტოს მონაცემები მოკ-ის რვა საათიანი საშუალო მნიშვნელობების შესახებ. კერძოდ მიღებულია რომ მოკ-ის მაქსიმალური საშუალოწლიური მნიშვნელობები დაიკვირვებოდა ვარკეთილში (53.9 მკგ/მ³, ცვლილების დიაპაზონი: 1-134 მკგ/მ³), მინიმალური - ა. წერეთელის პროსპექტზე (21.6 მკგ/მ³, ცვლილების დიაპაზონი: 0-102 მკგ/მ³). წრფივი კორელაციის კოეფიციენტის მნიშვნელობები მოკ-ის სიდიდეებს შორის სხვადახვა პუნქტებზე საკმაოდ მაღალია და იცვლება 0.74 -დან 0.91-მდე.
განხილულია მოკ-ის მნიშვნელობების შესაბამისობა მჯო-ს ნორმებთან.

Статистические характеристики концентрации приземного озона в трех пунктах Тбилиси в 2017-2018 гг.

Э.Н. Кекенадзе

Резюме

Представлены статистические характеристики концентрации приземного озона (КПО) в трех пунктах города Тбилиси (пр. А. Казбеги, пр. А. Церетели и Варкетили) в 2017-2018 гг. Использованы данные национального агентства по окружающей среде о восьмичасовых значениях КПО. В частности, получено, что наибольшие среднегодовые значения КПО наблюдались в Варкетили (53.9 мкг/м^3, диапазон изменения: 1-134 мкг/м^3), наименьшие – на пр. А. Церетели (21.6 мкг/м^3, диапазон изменения: 0-102 мкг/м^3). Величина коэффициента корреляции между значениями КПО между пунктами достаточно высокая и меняется от 0.74 до 0.91.
Рассмотрено соответствие значений КПО в указанных пунктах города Тбилиси нормам ВОЗ.

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Statistical Characteristics of the Monthly Mean Values of Tourism Climate Index in Mestia (Georgia) in 1961-2010

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ABSTRACT

The statistical characteristics of the monthly mean values of the Tourism Climate Index (TCI) and its components for Mestia in the period from 1961 through 2010 are represented. In particular, the changeability of the indicated bioclimatic parameters into 1986÷2010 in comparison with 1961÷1985 is studied.

Key Words: Bioclimate, Tourism Climate Index.

Introduction

Health resort - tourist industry is one of the most important sectors of the world economy. This sector in many respects depends on geographical position, topography, landscape, vegetation, fauna, ecological situation, weather, climate and so forth weather and climate - this two factors, in many respects of the determining bioclimatic resources localities/terrains, which should be visited for the treatment, leisure or tourism. Therefore, to a study of these resources, which can be useful for organization or development of the health resort- tourist of branch, in many countries, including in Georgia, is paid special attention [1-9].

There are more than 200 biometeorological and bioclimatic indices, which determine the influence of meteorological and climatic factors on the health of people (Air Equivalent-Effective Temperature – EET, Air Effective Temperature - ET, Wet-Bulb-Globe Temperature - WBGT, Wind Chill – WCI, Cooling Power – CP, Subjective temperature index –STI, Perceived temperature - PMV, Physiologically Equivalent Temperature - PET, Standard Effective Temperature - SET, Physiological Subjective Temperature and Subjective Temperature - MENEX, Universal Thermal Climate Index – UTCI, etc.) [11-14, http://www.igipz.pan.pl/Bioklima-zgik.html]. With the use of different indices in the last century a study of bioclimate in many countries of world [13-22], including Georgia [6, 7, 10, 23-27] is carried out.

Several indices have been developed to assess the suitability of climate for tourism activities [2, 17, 28, 29]. The most widely known and applied index is the tourism climate index proposed by Mieczkowski [28]. This index is combination of seven factors and parameters. Mieczkowski's "Tourism Climate Index" (TCI) was designed to use climate data, being widely available for tourist destinations worldwide. Data about TCI are using for the information of "Average Tourist" and can be useful for the planning developments of mass tourism.

In some work the criticism of TCI is noted. Thus, in the paper [30] the Holiday Climate Index (HCI) was developed and discuss the design of the HCI and how the limitations of the TCI were overcome. It then presents an inter-comparison of the results from HCI:Urban and TCI for geographically diverse urban destinations across Europe. The results illustrate how the HCI:Urban rates the climate of many cities higher than the TCI, particularly in shoulder seasons and the winter months, which is more consistent with observed visitation patterns. The authors note, that the results empirically demonstrate that use of the TCI should be discontinued.

However, in our opinion, until is revealed united bioclimatic index for the tourism, use of TCI, in spite of its deficiencies, it is nevertheless useful (at least, is a possibility of the comparison of the level of bioclimatic comfort for the "Average Tourist" in the different countries).

TCI (frequently together with other bioclimatic indices) sufficiently long ago is used in many countries of the world [2, 3, 29, 31- 47], including the South and Nord Caucasus regions [10, 41, 48-56].

The number of works is dedicated to the study of the influence of climate change to the TCI changeability [10, 22, 29, 35, 37, 41, 52, 56, etc.].

In Georgia the changeability of TCI in the period from 1961 through 2010 was studied for four points of Adjarian Autonomous Republic [10, 52] and four points of Kakheti region [56]. For the indicated localities the monthly average values of TCI with the use data of Georgian National Environmental Agency [57] are calculated.

In particular in 1986-2010 in comparison with 1961-1985 the average number of days per annum with the categories of TCI "Marginal" and higher, with those causing for the "Average Tourist" favorable bioclimatic situation, in the separate points of Adjarian Autonomous Republic it changed as follows: Batumi - insignificant decrease - 293 and 286 days, respectively; Kobuleti - invariability (on 278 days for both periods of time); Khulo - significant decrease (281 and 264 days, respectively); Goderzi - significant increase (178 and 200 days, respectively) [10, 52]. In Kakheti these changes are the following: Telavi - practically invariability (357 and 359 days, respectively); Dedoplistskaro - insignificant decrease (348 and 341 days, respectively); Kvareli - practically invariability (341 and 345 days, respectively); Sagarejo - small increase (346 and 353 days, respectively) [56].

In this work the changeability of TCI and its components for Mestia from 1961 to 2010 is studied.

Study Area, material and methods

Study area – Mestia. Mestia (population - 2700 people) is a small town and the capital of the Svaneti Region and has been named a World Heritage by UNESCO.

Mestia is situated 425 km (distance by car) from Georgia’s capital city, Tbilisi, and located at 1500 meters above sea level.Mestia is a paradise for mountain lovers and home to the country’s highest mountain Shara (5201 metres above sea level).

This young mountain resort of Georgia with well-developed tourism facilities gives huge opportunities for free riding, backcountry skiing, glade skiing, and cross country skiing. Mestia and the surrounding villages with their medieval towers are unique and very beautiful. There are two ski resorts in this area, Hatsvali, and Tetlundi. These resorts are covered by stunning pine forests and are perfect for enjoying glade skiing. Hatsvali is for beginners and intermediate skiers with short and well-groomed slopes that are easy to ride. Tetnuldi ski area is for skiers of any level with slopes ranging from easy to extremely hard. It is surrounded by tall mountains and the Alpine zone with great snow conditions.

Tourists interested in religious history will find plenty of examples of wall paintings, frescoes and icons from the Middle Ages in the churches around Mestia. Within Mestia, the Church of Saint George contains well-preserved crosses and icons from the XII century. Additionally, Pusdi Church still contains fragments of XIII century wall paintings [https://www.houseoftours.com/travel-tips/amazing-ski-resorts-perfect-skiing-in-georgia; https://www.georgia.travel/destinations/mestia].

Coordinates and heights of the meteorological stations in Mestia: Latitude – 43.05° N, Longitude – 42.75 E°, Height - 1441 m, a.s.l., straight distance from Tbilisi – 225 km (Fig. 1).

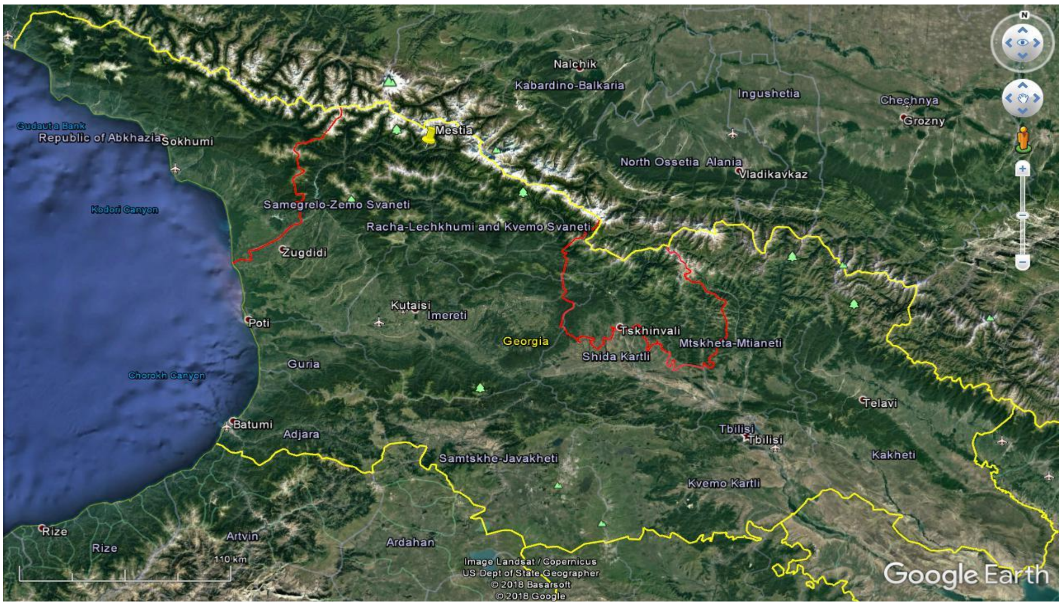


Fig.1. Locations of meteorological stations in Mestia

In the work the Tourism Climate Index (TCI) developed by Mieczkowski [28] is used. TCI is a combination of seven parameters, three of which are independent and two in a bioclimatic combination:

$$TCI = 8 \cdot Cld + 2 \cdot Cla + 4 \cdot R + 4 \cdot S + 2 \cdot W$$

Where Cld is a daytime comfort index, consisting of the mean maximum air temperature Ta, max (°C) and the mean minimum relative humidity RH (%), Cla is the daily comfort index, consisting of the mean air temperature (°C) and the mean relative humidity (%), R is the precipitation (mm), S is the daily sunshine duration (h), and W is the mean wind speed (m/s).

In contrast to other climate indices, every contributing parameter is assessed. Because of a weighting factor (a value for TCI of 100), every factor can reach 5 points. TCI values >= 80 are excellent, while values between 60 and 79 are regarded as good to very good. Lower values (40 – 59) are acceptable, but values < 40 indicate bad or difficult conditions for understandable to all tourism.

Table 1 presents information about the categories of TCI depending on its values. In the right column of table are given frequently used below the shortened versions of these categories.

Table 1

Categories of TCI

TCI	**Category**	**Categ.**	**TCI**	**Category**	**Categ.**
90 ÷ 100	Ideal	Ideal	40 ÷ 49	Marginal	Marg.
80 ÷ 89	Excellent	Excell.	30 ÷ 39	Unfavorable	Unf.
70 ÷ 79	Very Good	V_Good	20 ÷ 29	Very Unfavorable	V_Unf.
60 ÷ 69	Good	Good	10 ÷ 19	Extremely Unfavorable	Extr. Unf.
50 ÷ 59	Acceptable	Accept.	- 30 ÷ 9	Impossible	Imp.

For the indicated localitie the monthly average values of TCI in the period from 1961 through 2010 with the use data of Georgian National Environmental Agency are calculated.

For the data analysis the standard statistical methods of the studies were used [58]. The following designations will be used below: Mean – average values; Min – minimal values; Max - maximal values; Range = Max-Min; St Dev – standard deviation; σm - standard error; Cv = 100·St Dev/Mean, coefficient of variation (%); Skew - coefficient of skewness; Kurt - coefficient of kurtosis; R^2 – coefficient of determination; 99% Low and 99% Upp – 99% confidence interval of lower and upper calculated level accordingly. The difference between the mean values of TCI into 1986-2010 and 1961-1985 with the use of Student's criterion was determined (level of significance not worse than 0.15).

Results and discussion

Results in the Table 2-5 and Fig. 2-6 are presented.

Table 2-4 and in Fig. 2,3 presents the generalized statistical data about the values of TCI for Mestia. The results of the analysis of these data are given below.

Mean monthly values of TCI varied from 30.5 (Dec, Unf.) to 76.1 (Jul, V_Good). Range of a change of the values of TCI in 1961÷2010 - from 13.0 (Jan, Extr. Unf.) to 88.0 (Aug, Excell.).

99% Low and Upp level of confidence interval of mean values of TCI change from 28.1 (Dec, V_Unf.) to 78.0 (Jul, V_Good).

The largest variations in TCI values are observed in October and December (Cv = 23.1%), the smallest - in July (Cv = 7.0%).

The distribution of TCI values in individual months is close to normal (corresponding values of the Skew and Kurt coefficients).

The intra-annual distribution of mean monthly values of TCI in Mestia is unimodal with the plateau from June through September and take the form of eight power polynomial.

For comparison, we note that this distribution for the previously studied points of Kakheti is the following: Telavi - bimodal with the extrema in May-June and September; Dedoplistskaro - bimodal with the extrema during June and September; Kvareli - bimodal with the extrema during May and September; Sagarejo - unimodal with the plateau from June through September [56]. But all four distributions, as in Tbilisi, Baku and Yerevan [51], take the form of ninth power polynomial.

Table 2

Statistical characteristics of TCI in Mestia

Param.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						TCI						
Mean	32.1	36.6	43.2	50.3	66.7	74.5	76.1	75.7	74.7	56.2	41.1	30.5
Min	13.0	23.0	25.0	35.0	47.0	61.0	65.0	62.0	56.0	38.0	22.0	21.0
Max	52.0	50.0	55.0	72.0	84.0	86.0	87.0	88.0	85.0	87.0	64.0	49.0
Range	39.0	27.0	30.0	37.0	37.0	25.0	22.0	26.0	29.0	49.0	42.0	28.0
Median	33.0	35.5	43.5	50.0	67.0	75.5	77.0	76.5	75.0	53.5	42.5	32.0
Mode	35.0	35.0	41.0	37.0	77.0	81.0	77.0	72.0	77.0	46.0	43.0	32.0
St Dev	7.37	6.20	6.83	9.09	9.31	6.15	5.34	6.14	6.37	13.01	8.97	6.50
σm	1.05	0.89	0.98	1.30	1.33	0.88	0.76	0.88	0.91	1.86	1.28	0.93
Cv (%)	23.0	16.9	15.8	18.1	14.0	8.3	7.0	8.1	8.5	23.1	21.8	21.3
Skew	-0.1	0.2	-0.6	0.3	-0.1	-0.4	-0.3	-0.2	-0.7	0.7	0.1	0.3
Kurt	0.7	-0.5	0.3	-0.5	-0.5	-0.5	-0.7	-0.3	0.6	-0.5	-0.3	-0.2
99% Low	29.4	34.4	40.7	47.0	63.3	72.3	74.1	73.4	72.3	51.4	37.8	28.1
99% Upp	34.8	38.9	45.7	53.6	70.1	76.7	78.0	77.9	77.0	61.0	44.4	32.9

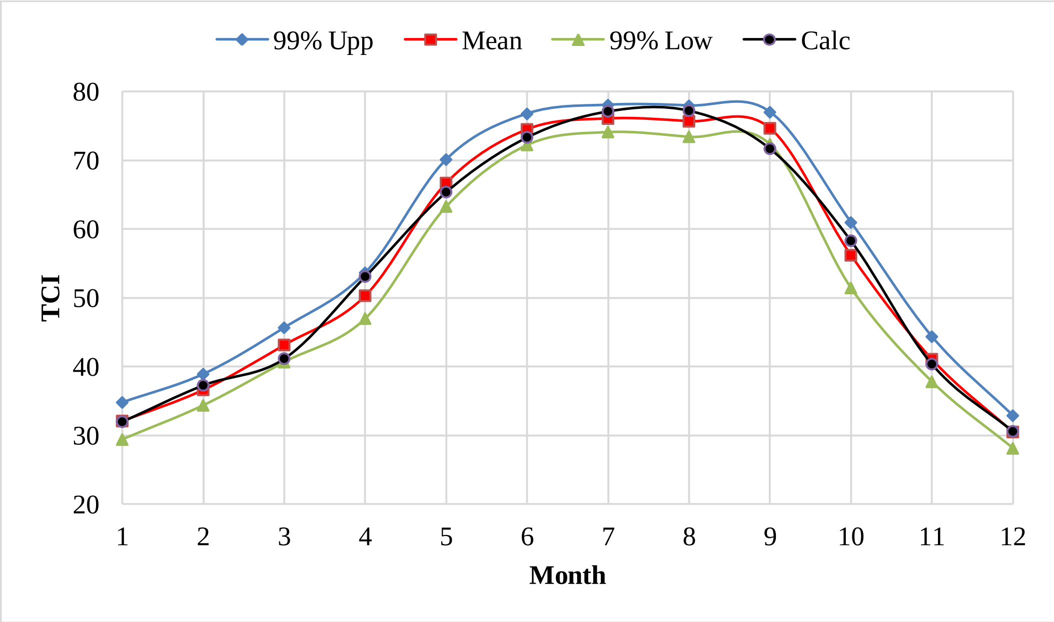


Fig.2. Mean real and calculated values of TCI and their 99% confidence interval in Mestia

Table 3

Coefficients of the equation of the regression of the intra-annual motion of mean monthly values of TCI for Mestia

Equation of regression	$TCI = a \cdot X^8 + b \cdot X^7 + c \cdot X^6 + d \cdot X^5 + e \cdot X^4 + f \cdot X^3 + g \cdot X^2 + h \cdot X + i$, (X-Month)		
Coefficients	Value	Coefficients	Value
a	-0.00011	f	66.03142
b	0.006476	g	-160.213
c	-0.15528	h	196.2885
d	2.003176	i	-56.9114
e	-15.0458	R^2	0.99085

Table 4

Statistical characteristics of TCI category in Mestia in 1961-2010

Parameter	**TCI category**					
Month	Jan	Feb	Mar	Apr	May	Jun
Mean	Unf.	Unf.	Marg.	Accept.	Good	V_Good
Min	Extr. Unf.	V_Unf.	V_Unf.	Unf.	Marg.	Good
Max	Accept.	Accept.	Accept.	V_Good	84	86
Month	Jul	Aug	Sep	Oct	Nov	Dec
Mean	V_Good	V_Good	V_Good	Accept.	Marg.	Unf.
Min	Good	Good	Accept.	Unf.	V_Unf.	V_Unf.
Max	Excell.	Excell.	Excell.	Excell.	Good	Marg.

Fig.3. Category of TCI in Mestia and their 99% confidence intervals in different months of year (Photo from [https://georgia.travel/en_US/svaneti/mestia])

Table 5

Monthly variations of TCI and TCI components in Mestia in 1961-2010

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Param.						**TCI**						
Mean 1961-2010	32.1	36.6	43.2	50.3	66.7	74.5	76.1	75.7	74.7	56.2	41.1	30.5
I - Mean 1986-2010	31.0	34.8	42.7	50.8	66.9	73.8	75.8	75.5	74.4	55.9	40.6	29.6
II - Mean 1961-1985	33.2	38.4	43.6	49.8	66.5	75.2	76.4	75.9	74.9	56.5	41.6	31.4
Differ. I-II, α ≤ 0.15	No	-3.6	No	No	No	No	No	No	No	No	No	No
Param.						**Cld**						
Mean 1961-2010	1.3	1.5	2.0	2.7	4.1	4.9	4.9	4.9	4.8	3.1	2.0	1.4
I - Mean 1986-2010	1.2	1.5	2.0	2.8	4.1	4.9	4.9	4.8	4.8	3.2	2.0	1.4
II - Mean 1961-1985	1.3	1.5	2.0	2.5	4.1	4.9	5.0	5.0	4.9	3.1	2.0	1.4
Differ. I-II, α ≤ 0.15	-0.14	No	No	0.3	No	No	No	-0.2	No	No	No	No
Param.						**Cla**						
Mean 1961-2010	0.4	0.8	1.3	1.8	2.3	2.7	3.4	3.3	2.5	2.0	1.4	0.7
I - Mean 1986-2010	0.4	0.7	1.3	1.8	2.3	2.7	3.6	3.6	2.5	2.0	1.4	0.8
II - Mean 1961-1985	0.3	0.8	1.3	1.8	2.4	2.6	3.3	3.0	2.5	2.0	1.4	0.6
Differ. I-II, α ≤ 0.15	No	No	No	No	-0.1	0.14	0.28	0.54	No	0.08	No	No
Param.						**R**						
Mean 1961-2010	3.1	3.2	2.8	2.3	2.3	2.0	2.3	2.3	2.5	2.2	2.6	2.5
I - Mean 1986-2010	2.9	2.8	2.5	2.1	2.1	2.0	2.4	2.5	2.5	2.0	2.4	2.2
II - Mean 1961-1985	3.3	3.7	3.0	2.4	2.4	2.0	2.2	2.0	2.4	2.4	2.7	2.7
Differ. I-II, α ≤ 0.15	No	-0.88	-0.52	No	No	No	No	No	No	No	No	No
Param.						**S**						
Mean 1961-2010	1.4	1.6	2.2	2.1	2.7	3.2	3.7	3.7	2.9	2.4	1.6	1.1
I - Mean 1986-2010	1.4	1.6	2.3	1.9	2.8	3.0	3.7	3.7	2.9	2.3	1.7	1.1
II - Mean 1961-1985	1.3	1.6	2.0	2.2	2.7	3.4	3.7	3.7	2.9	2.4	1.5	1.1
Differ. I-II, α ≤ 0.15	No	No	0.3	-0.24	No	-0.3	No	No	No	No	0.18	No
Param.						**W**						
Mean 1961-2010	1.6	1.8	2.5	3.9	4.7	4.5	2.9	3.0	4.7	4.4	2.7	1.7
I - Mean 1986-2010	1.5	1.8	2.5	4.1	4.9	4.4	2.6	2.5	4.6	4.4	2.7	1.7
II - Mean 1961-1985	1.6	1.8	2.5	3.7	4.5	4.6	3.2	3.5	4.8	4.4	2.8	1.7
Differ. I-II, α ≤ 0.15	No	No	No	0.4	0.44	No	-0.6	-1.02	No	No	No	No

Table 5 presents information about the values of TCI and TCI components in Mestia in 1961-2010 and their changeability in 1986-2010 in comparison with 1961-1985 In particular, the range of mean for two periods observations of the values of TCI and components of TCI and their changeability in the second period of time in comparison with the first are following:

TCI: 29.6÷ 76.4 (December and July respectively). Changeability is observed only during February (decrease in the limits of one and the same category);

Cld: 1.2÷5.0 (January, July and August respectively). Changeability is observed during January (decrease), April (increase) and August (decrease);

Cla: 0.3÷3.6 (January and July, August respectively); Changeability is observed during May (decrease), from June to August and October (increase);

R: 2.0÷3.7 (June, August October and February, respectively). Changeability is observed during February and March (decrease);

S: 1.1÷3.7 (December and July, August respectively). Changeability is observed during March (increase), April, June (decrease) and November (increase);

W: 1.5÷4.9 (January and May respectively). Changeability is observed in April, May (increase) and July, August (decrease).

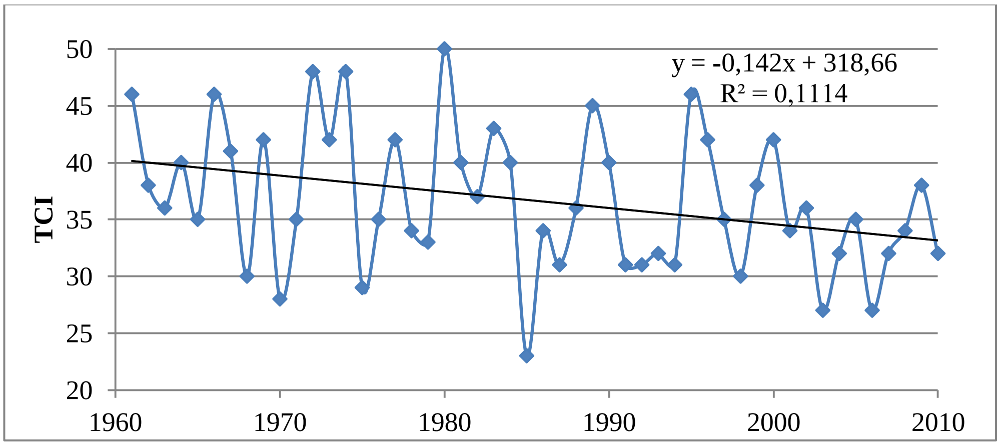
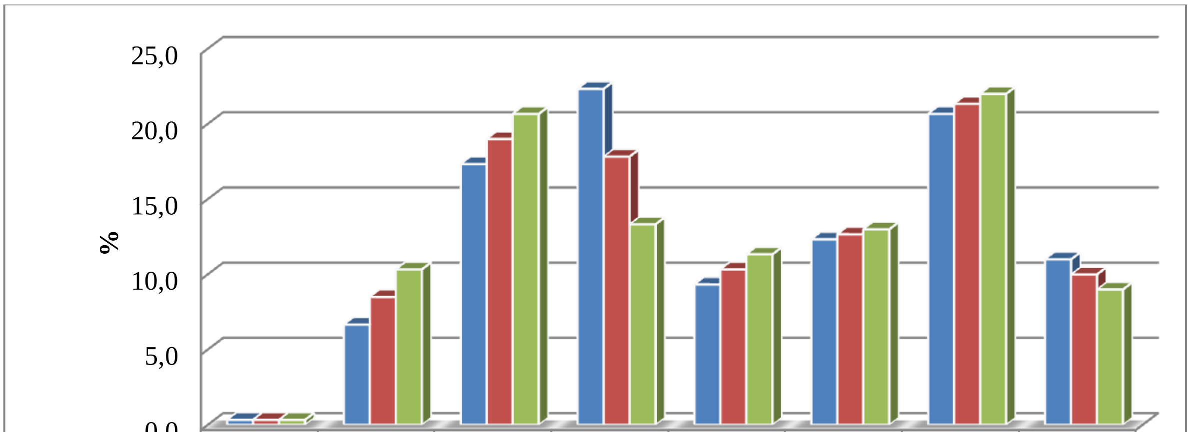


Fig.4. Trend of TCI in Mestia in 1961-2010 (Feb)

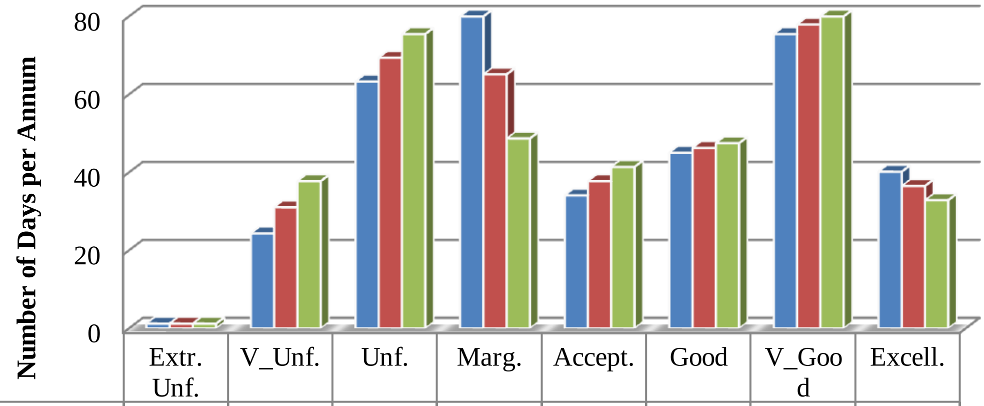
The graph of linear trend of TCI in the period from 1961 through 2010 for February in Fig. 4 is depicted.



	Extr. Unf.	V_Unf.	Unf.	Marg.	Accept.	Good	V_Good	Excell.
1961-1985	0,3	6,7	17,3	22,3	9,3	12,3	20,7	11,0
1961-2010	0,3	8,5	19,0	17,8	10,3	12,7	21,3	10,0
1986-2010	0,3	10,3	20,7	13,3	11,3	13,0	22,0	9,0

Fig.5. Repetition of category of monthly values of TCI in Mestia in three period of time

Fig.5 presents data about repetition of category of monthly values of TCI in Mestia in three period of time. As follows from this Fig. in different period of time repetition with TCI category “Magr.- Excell.” is following: 1961÷1985 – 75.7 %, 1961÷2010 – 72.2 %, 1986÷2010 – 68.7 %



	Extr. Unf.	V_Unf.	Unf.	Marg.	Accept.	Good	V_Good	Excell.
1961-1985	1	24	63	82	34	45	75	40
1961-2010	1	31	69	65	38	46	78	37
1986-2010	1	38	75	49	41	47	80	33

Fig.6. Number of days per annum with different category of TCI in Mestia in three period of time

Finally, Fig.6 presents data about number of days per annum with different category of TCI in Mestia in three period of time. As follows from Fig. 6 in different period of time number of days per annum with TCI category “Magr.- Excell.” is following: 1961÷1985 – 276 , 1961÷2010 – 264 , 1986÷2010 – 251.

Thus, in 1986-2010 in comparison with 1961-1985 the average number of days per annum with the categories of TCI "Marginal" and higher, with those causing for the "Average Tourist" favorable bioclimatic situation, decreased by 13 days.

Conclusion

Climate has a strong influence on the tourism and recreation sector and in some regions represents the natural resource on which the tourism industry is predicated. In this work the determination of the climatic potential of tourism for Mestia (Georgia) into the correspondence with that frequently utilized in other countries of the “Tourism Climate Index” (TCI) is carried out.

In the future we plan a more detailed study of the climatic resources of this and others regions of Georgia for the tourism (mapping the territory on TCI, long-term prognostication of TCI, determination of other contemporary climatic and bioclimatic indices for tourism – HCI etc.).

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მესტიაში (საქართველო) ტურიზმის კლიმატური ინდექსის საშუალო თვიური მნიშვნელობის სტატტისტიკუროი მახასიათებლები 1961-2010 წწ.

ა.ამირანაშვილი, ლ.ქართველიშვილი

რეზიუმე

ნაშრომში წარმოდგენილია ტურიზმის კლიმატური ინდექსის (TCI) საშუალო თვიური საშუალო წლიური მნიშვნელობები მესტიაში 1961÷2010 წ.წ. პერიოდის მიხედვით. კერძოდ, შესწავლილია აღნიშნული ბიოკლიმატური პარამეტრების ცვლილება 1986÷2010 წლებში 1961÷1985 წლებთან შედარებით.

Статистические характеристики среднемесячных значений климатического индекса туризма в Местия (Грузия) в 1961-2010 гг.

А.Г. Амиранашвили, Л. Г. Картвелишвили

Резюме

Представлены статистические характеристики среднемесячных значений климатического индекса туризма (TCI) и его составляющих для Местия (Грузия) в период с 1961 по 2010 гг. В частности, изучена изменчивость указанных биоклиматических параметров в 1986÷2010 гг. по сравнению с 1961÷1985 гг.

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