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Georgian-European Center "Geodynamical Hazards of High Dams" at the Council of Europe: 20 years of activity.

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Georgian-European Center "Geodynamical Hazards of High Dams"

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Abstract

In 1987 by the resolution of the Council of Europe the EUR-OPA Major Hazards Agreement was created. EUR-OPA Major Hazards Agreement is a platform for co-operation in the field of major natural and technological disasters between Europe and the South of the Mediterranean. The Georgian-European Centre on Geodynamical Hazards of High Dams - GHHD (Tbilisi, Georgia) was founded in 1996. The paper considers the main results of GHHD activity obtainedduring 20 years after its foundation.

1. Introduction.

EUR-OPA Major Hazards Agreement is a platform for co-operation in the field of major natural and technological disasters between Europe and the South of the Mediterranean. Its field of competence covers the major natural and technological disasters - knowledge, prevention, risk management, post-crisis analysis and rehabilitation.The main objectives of the EUR-OPA Major Hazards Agreement are to reinforce and to promote co-operation between Member States in a multi-disciplinary context to ensure better prevention, protection against risks and better preparation in the event of major natural or technological disasters.

The important component of EUR-OPA is the network of 27 specialized centers. The Georgian-European Centre on Geodynamical Hazards of High Dams - GHHD (Tbilisi, Georgia) was founded in 1996 (http://www.coe.int/t/dg4/majorhazards/centres/presentation/ghhd_fr.asp).

The 271 m high Enguri arch dam, still one of the highest arch dam in operation in the world, was built in the canyon of the Enguri river (West Georgia) in the 1970s. It is located in a zone of high seismicity (MSK intensity IX) and close to the Ingirishi active fault. The high seismic and geodynamical activities together with the large number of people living downstream of the dam made the Enguri dam a potential source of a major catastrophe in Georgia. Of course, the Enguri Dam with its 1 billion cubic meters water reservoir is a potential source of large man-made catastrophe and it should be under permanent monitoring. At the same time this it is an amazing natural laboratory, where we can investigate tectonic and geotechnical strains/processes and response to the lake load-unload impact, i.e. the reaction to a controllable loading of Earth crust. This is an important scientific issue, connected with such problem as Reservoir Triggered Earthquakes.

All these factors conditioned foundation of Georgian-European Centre on Geodynamical Hazards of High Dams. The President of the Scientific Committee of GHHD is Dr. Martin Wieland (Switzerland), Director: is Academician Tamaz Chelidze, the Chairman of the Administrative Council: Prof. Vakhtang Abashidze.

Generally the hazards, such as extreme strains in the dam body, due to aging, damage or overloading can be monitored (Wieland, Mueller 2009) and in some cases even predicted by networks of special sensors (strainmeters, tiltmeters, etc).

The stability of a dam can be tested by its long-term and short-term response to the water load. The dam as a whole or its individual elements may respond to certain loading conditions through time-dependent elastic and inelastic deformations. For each action a safety limit can be determined, which must not be exceeded. Due to unusual or extreme loadings or due to accumulation of damage critical conditions may occur, which are jeopardizing the safety of dam.

The Centre is created for development of multinational, multidisciplinary approach to the problems of geodynamical hazards, generated by high dams, including:

i. development and testing of modern methods of multidisciplinary monitoring of local and regional geodynamical processes in the proximity of large dams on the basis of Enguri Dam International Test Area (EDITA).
ii. mathematical modeling of geodynamical processes at large dams,
iii. prediction of impending geodynamical events (earthquakes, tectonic deformations, landslides) and prognosis of response of large dams to these impacts
iv. monitoring of physical-chemical processes and associated variations in physical properties of foundation rocks
v. creation of databases of geodynamical observations on large dams
vi. analysis and generalization (in collaboration with other European centers) of possible natural and manmade hazards, creation of scenarios of possible damage and instructions for public education on what to do in case of alarm, during and after the disaster.
vii. active participation in international, regional and national projects related to major disasters and environmental problems.
viii. development of real time automatic telemetric monitoring and early warning systems for control of stability of large engineering objects.

By the funding of the EUR-OPA Major Hazards Agreement we realizedmore than 20 projects. The most important projects are shortly considered below:

2. *Real-time telemetric monitoring system of large dams (DAMWATCH): the case of the Enguri Dam International Test Area (EDITA).*

The M. Nodia Institute of Geophysics (MNIG) and Georgian-European Centre "Geodynamical Hazards of High Dams" operating in the frame of Open Partial Agreement on Major Disasters at the Council of Europe developed the real-time geotechnical telemetric monitoring system of large dams

(DAMWATCH). This low-cost early warning system designed by MNIG and "ALGO Ltd" (Tbilisi) consists of sensors (tiltmeters, APPLIED GEOMECHANICS Model 701-2), which are connected to terminals and central controllers and by a GSM/GPRS modem transmits the data to the diagnostic center.

Fig. 1. Google view of Enguri Dam International Test Area (EDITA) territory. The arrow shows position of major Ingirishi fault.

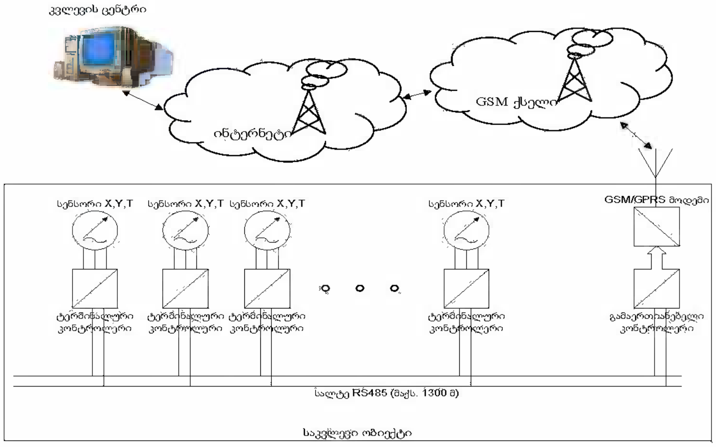


Fig.2. The cost-effective early warning system designed by MNIG and "ALGO Ltd" (Tbilisi) consists ofsensors (tiltmeters, APPLIED GEOMECHANICS Model 701-2), which are connected to terminals and central controllers and by a GSM/GPRS modem transmits the data to the diagnostic center.

The simplest approach to dam safety problem is to compare response of real strain/tilt data with design values, which as a rule use Hook's rheology (static, linear elasticity approach). If measured characteristics, e.g. strains are close to or larger than theoretically predicted limit deformations, some preventive measures will be realized. Of course, predictions of the model have to be compared with monitoring data (Table 1).

Table 1. Comparison of observed plumbline horizontal displacements (Bronshtein, 2008) and corresponding tiltmeters data (horizontal displacements in mm and tilts in seconds, with Root Mean Square) at maximal water level in the lake (510 m) for three sections of Enguri HPP (Abashidze et al. 2008) with theoretical (critical) admissible values of plumblines calculated by (Emukhvari, Bronshtein, 1991).

Level	Section 12			Section 18			Section 26		
	Observed plumbline data	Observed tiltmeter data	Critical Admissible values	Observed plumbline data	Observed tiltmeter data	Critical Admissible values	Observed plumbline data	Observed tiltmeter data	Critical Admissible values
360 m	20 mm	11 mm (38±5.1)"	89 (122)"	35 mm			15 mm	14 mm (46±5.6)"	88 mm
402 m	40 mm	32 mm (63±4.5)"	59 (112)"	60 mm	55 mm (70±3.9)"'	55 mm	30 mm	37 mm (74±4.1)'	58 mm
475 m	60 mm	48 mm (56±8.7)"	31 (182)"	65 mm			55 mm	42 mm (55±5.5)"	26 mm

The Table 1 presents observed data: plumbline horizontal displacements (Bronshtein, 2008) and corresponding tiltmeters data (horizontal displacements in mm and tilts in seconds, with Root Mean Square) at maximal water level in the lake (510 m) for three sections of Enguri HPP (Abashidze et al. 2008) and theoretical (critical) admissible values of plumblines calculated by (Emukhvari, Bronshtein, 1991). The generally accepted approach is to compare the observed stress (strain) to calculated stresses, which correspond to some fraction of yield strength or of the ultimate strength of the material, which the construction is made of.

Analysis of the Table leads to following conclusions: i. at the level 360 m all displacements are less than critical values; ii. at the level 402 m only in the central 18-th section the displacements are close to critical ones; iii. at the highest level (475 m) displacement of the side sections are larger than critical, i.e. at this level the state should be considered as diagnosis MAS or "faulty". According to Emukhvari and Bronshtein (1991) in this case it is necessary to carry out repeated diagnostics of construction on the basis of re-examination of monitoring data and correction of theoretical predictions of response of the dam to loads. The displacement observation data obtained by two different methods are in satisfactory agreement. Besides, the dam performs normally and there are no visual signs of significant damage.

This means that the theoretical model needs some corrections, possibly taking into account complexity of construction structure (lifts, joints, inhomogeneity etc).

Indeed, the real engineering structures manifest deviations from this simple model, which can be used for diagnostics. From above it follows that a promising technique could be analysis of deviations from static elasticity model, namely, analysis of nonlinearity of stress-strain relation such as hysteretic behavior during load-unload cycle. Figure 3 (left) shows how two components of tilts of dam body, along (X) and normal (Y) to the dam crest at Enguri Dam respond to the seasonal recharge-discharge cycle of the reservoir; on the right the hysteresis in seismic velocities of foundation section for the same cycle is shown.

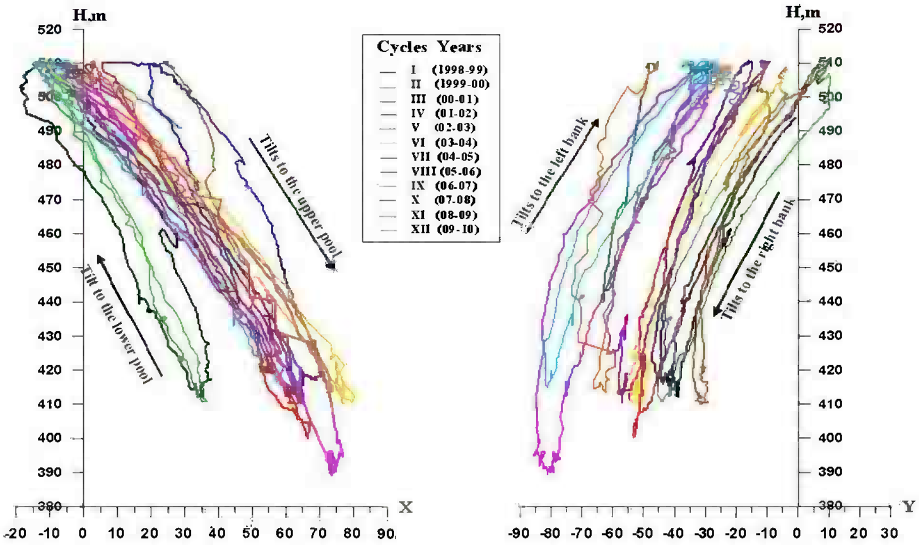


Figure 3. Left: Tilts in sec, registered in the body of Enguri High Dam, Georgia (section 12, mark 402) intwo directions, along (X) and normal (Y) to the dam crest versus water level in the lake H in meters, during12 seasonal cycles (1998-2009). Note hysteresis in load-unload response.

The interpretation of observed hysteretic stress-strain or tilt-stress diagrams (Fig.3) can be accomplished by the theory of mesoscopic elasticity (McCall&Guyer 1994, Guyer&Johnson 2009). The matter is that heterogeneous materials such as mass concrete and rocks are nonlinear and their behavior is very different from this of its homogeneous components: for example, stress-strain (or tilt) dependences manifest nonlinear hysteretic elastic behavior, namely, asymmetric response to loading and unloading of so called mesoscopic structural features (mainly compliant microcracks) to stress variation. Heterogeneous materials contain an enormous number (10^9-10^{12}) of such defects per square centimetre, which means that macroscopic elastic properties of the material depend strongly on behavior of microcracks. Thus parameters of hysteretic cycle can be used for diagnostics of material: in the absence of cracks the brittle solid manifests linear elasticity without any hysteresis, appearance of cracks leads to hysteresis and the opening of hysteresis curve increases with the number of defects.

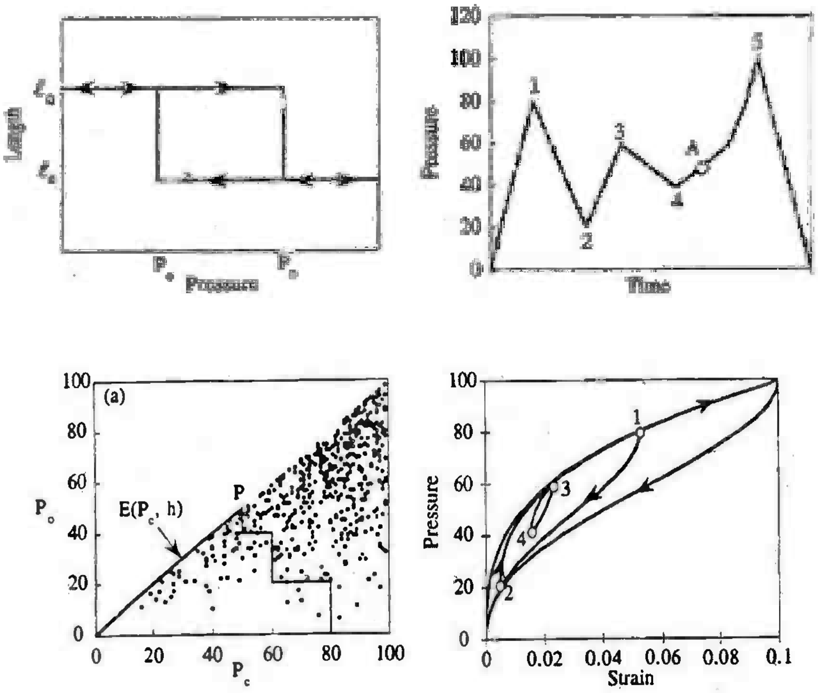


Fig.4. The approximation of hysteretic data by Preisach-Mayergoyz (P-M) phenomenological model. In the P-M model the system is represented by complex of hysteretic elastic units or hysterons, which manifest asymmetric response to loading-unloading cycle

The approximation of hysteretic data can be accomplished using the Preisach-Mayergoyz (P-M) phenomenological model. In the P-M model the system is represented by complex of hysteretic elastic units or hysterons, which manifest asymmetric response to loading-unloading cycle (Fig.4).

Comparing outputs of Preisach-Mayergoyz (P-M) model (Fig.3) with annual hysteresis loops of Enguri dam tilts (Fig.2)we can mark close similarity between model and observed data, i.e. P-M approach can be used in dam diagnostics. The successive annual Enguri tilt loops are shifted, which means that seasonal loading and unloading cycles involve the appearance of some residual strain. This shift also can be a diagnostic sign for aging effects (e.g. thermal cracking, freezing-thawing cycles, chemical processes in mass concrete or foundation rock etc.).

As a rule nonlinear contributions to well-designed and well-constructed dam strains are small, so it can be concluded that the dam design based on linear approach works quite well, but the analysis of relatively small nonlinear effects can produce promising methods of dam safety diagnostics due to high sensitivity of nonlinear systems to small external impacts.

Short-term diagnostic tools. The main short-term diagnostic tool is the analysis of the eigenfrequencies of the dam based on the power spectra of dam vibrations caused by water discharge, turbine operation or ambient seismic noise. The record of natural dam vibrations at Enguri dam shows that the dominant frequency on the crest of the dam is about 1 Hz; this is in good agreement with results of the analysis of accelerograms recorded during the Racha earthquake (2005, M=6) and numerical analysis of a typical dam.

Our data show that the vibration spectrum also covers other than 1 Hz, much lower frequencies. These LF vibrations were recorded by the network of precision tiltmeters (Applied Geomechanics). The frequency response of the device, shown in Fig. 5 demonstrates, that in principle we can register LF vibrations in the wide range 0.05-20 Hz. We found that the amplitudes and frequencies of the broadband power spectra respond clearly to changes in the state of the dam, which means that monitoring of LF vibrations is a promising technique for dam diagnostics.

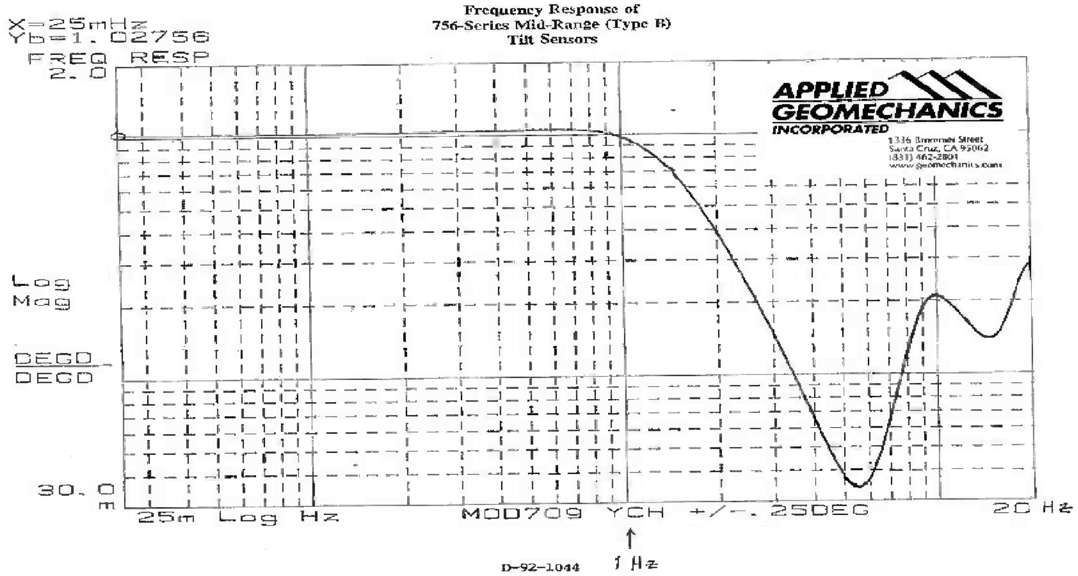


Fig.5. The frequency response of the precision tiltmeters (Applied Geomechanics).

Methods of linear and nonlinear analysis of strain and tilt time series for dam stability assessment. In order to ensure correct statistical and dynamical investigation of dam stability problem, modern methods of linear and nonlinear analysis of strain and tilt time series are used. The following time series analysis methods are used: statistical methods (moments, distribution testing), time-frequency analysis methods (power spectrum, autocorrelation function), time-frequency (wavelet transformation) and eigenvalue methods, denoising of data sets (nonlinear noise reduction), testing of memory properties of targeted process (long range correlation testing, detrended fluctuation analysis (DFA), multifractal detrended fluctuation analysis; correlation and information dimension calculation recurrence plots (RP) and recurrence quantitative analysis (RQA) (Press et al. 1996, Strogatz 2000, Marwan 2003, Matcharashvili&Chelidze 2000).

Nonlinear dynamics analysis allows revealing hidden structures (regularities) in seeming random time series. In order to test the sensitivity of selected methods and to assess effects of external influences on Earth tilt dynamics in the dam foundation, we have carried out retrospective analysis of tilt data. Namely, we considered tilt data sets of Earth crust tilt, hourly measured for 13 years of continued observation in the dam foundation (1971-1983). Tilt data sets in the following 7 time windows have been analyzed: 1) long before reservoir filling, 2) immediately before and 3) just after beginning of filling, 4) after second, 5) third and 6) fourth stage of reservoir filling and 7) long after completion of reservoir filling. Figures illustrate RQA determinism (RQA%DET) and Lempel-Ziv algorithmic complexity measure for mentioned 7 periods. Note that nonlinear dynamical properties of tilt time series after long enough regular (periodic) reservoir exploitation return to the patterns observed before the dam building and lake fill. These data confirm possibility of detection of man-made effects (i.e. diagnostics) in tilt time series.

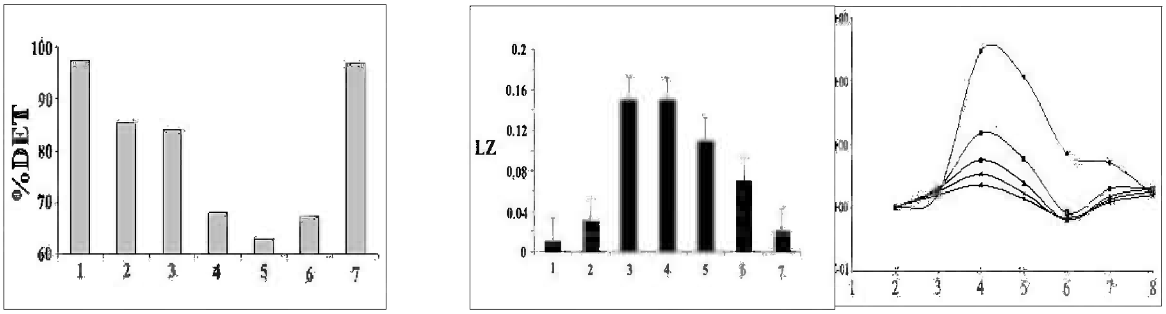


Fig.6. Left: RQA determinism measure calculated for dam foundation tilt data series for different stages of observation. Middle: Lempel-Ziv complexity measure calculated for tilt data series for different stages of observation. Right: variation of Tsallis entropy calculated for Earth tilt data series for different stages of observation. Curves from top to down correspondent to different q values from 1 to 5. Numbers on abscissa correspond to periods of observation (see text).

Reservoir induced synchronization of seismicity. Nonlinear dynamics analysis of seismic time series in the Enguri reservoir area and water level in the lake reveals strong increase of order in earthquake occurrence during quasi-periodic load-unload regime of the lake. It is well known, that large reservoirs located in the seismically active zones are often considered as a factor, quantitatively and qualitatively influencing earthquakes generation. During impoundment or after it both the number and magnitude of earthquakes around reservoir significantly increases. After several years these changes in earthquake generation, named as reservoir induced seismicity (RIS) essentially decreases down to the level, when lesser earthquakes occur with lower magnitudes. To explain this decrease, we propose the model of phase synchronization of local seismic activity by the periodic variation of the water level - reservoir induced synchronization of seismicity (RISS). Data, presented in Fig. 7 evidence that increase of order in dynamics of daily earthquake occurrence, earthquakes temporal and energy distribution took place around Enguri high dam water reservoir (Western Georgia) during the periodic variation of the water level (WL) in the lake. Here the upper plot shows the WL time series – it became quasi-periodic after the day 4000 after beginning tiltmeter observations. The middle plot RQA %DET of daily number of earthquakes calculatedfor consecutive non overlapping 1-year sliding windows(*circles*). Averaged results of RQA %DET for 20 shuffled (*asterisks*)and phase-randomized (*triangles*) surrogates of daily numberof earthquakes in consecutive 1-year sliding windows. The lowest plot shows RQA %DET of magnitude (*black columns*) and waiting time(*grey columns*) sequences: (1) before impoundment, (2) duringflooding and reservoir filling, and (3) periodic change of waterlevel in reservoir.

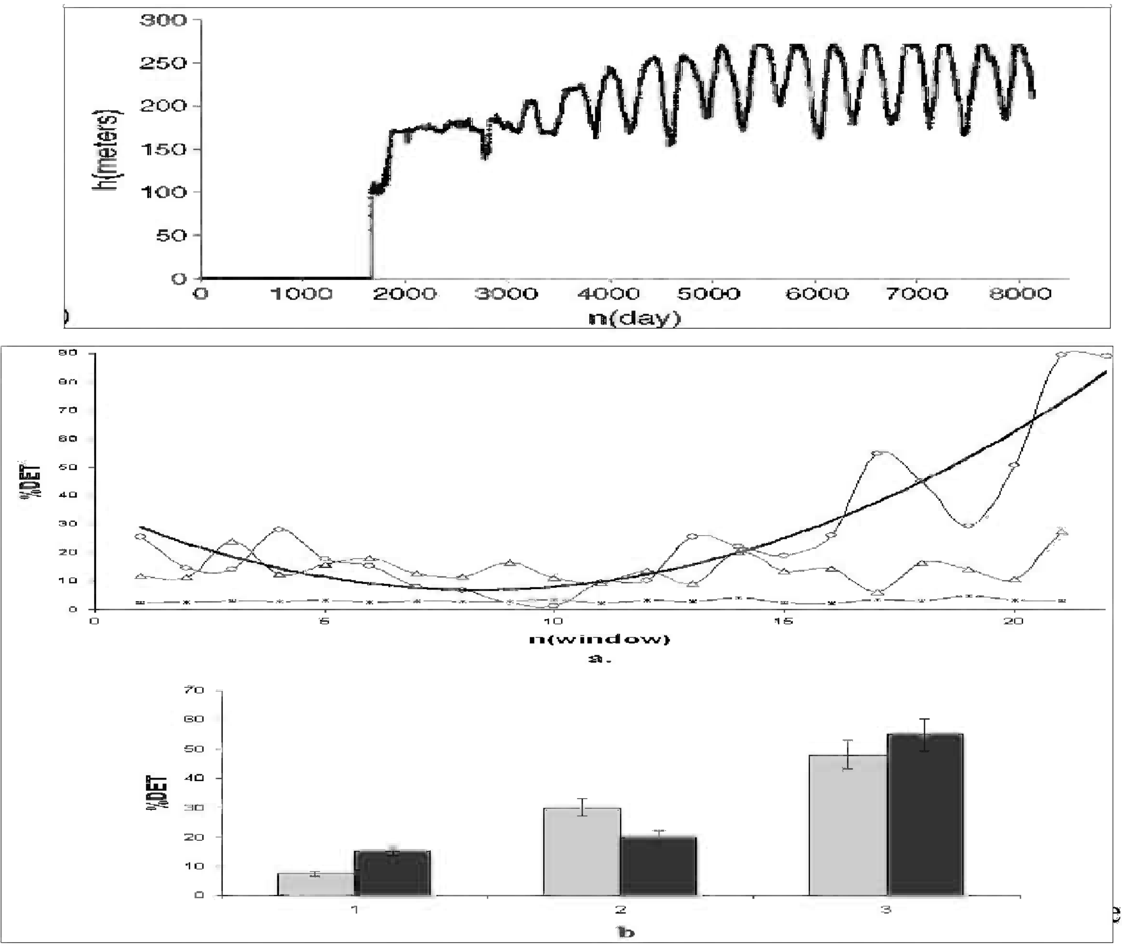


Fig. 7. The upper plot shows the WL time series – it became quasi-periodic after the day 4000 after beginning tiltmeter observations. The middle plot RQA %DET of daily number of earthquakes and its randomized version.The lowest plot shows RQA %DET of magnitude (*black columns*) and waiting time(*grey columns*) sequences for three intervals of lake exploitation. See text for details.

Based on the above analysis carried outexperimental time series, we conclude that the order in dynamics of earthquakes' daily occurrence, as well as in temporal and energy distributions increases significantly when water level variations became quasi-periodic.

*DAMTOOL- a package for operative control of engineering constructions.*DAMTOOL is a program intended for visual estimate, processing and analyzing the data of large engineering constructions' (dams, bridges etc) tilt measurements. It can be used also for analysis of any monitoring time series (strains, stresses, tilts etc). The program has 5 tabs (Data import, Data preview, Fluctuation analysis, Recurrent analysis, Tsallis Entropy).

Fig. 8 demonstrates the potential of nonlinear dynamics approach to analysis of tilt time series from April 2010 to June 2010. The upper plot shows tilt time series from April to June 2010 for one of stations of our network. The lower plot shows results of processing of the tilt record by DAMTOOL package: namely it presents RQA percent of determinism or RQA %DET (Marwan, 2003). The deviations from the normal behavior in the mid-May and June are evident even visually, but the usage of DAMTOOL allows assessing these deviations quantitatively. Note high values of and %DET during regular regime in April and first decade of May (which points to stability of monitoring data) and strong deviations in DET% due to geotechnical impact – addition of high frequency component during intensive discharge of water through dam outlet in 12.05-22.05.2010 and 01.06-11.06.2010 time intervals.

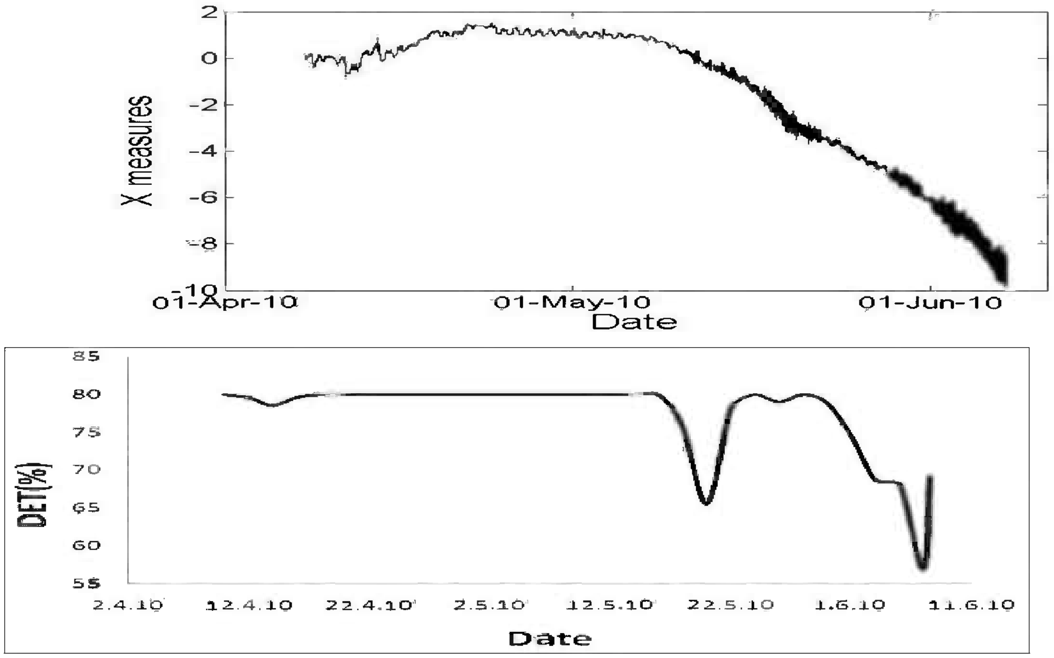


Fig. 8. The potential of nonlinear dynamics approach to analysis of tilt time series. Upper plot- original tilt time series; lower plot - RQA (% of determinism). Note high values DET during regular regime and strong deviations due to geotechnical impact (see text)

The data obtained already show very interesting long-term and short-term patterns of tilts' dynamics in the dam body, including tilt hysteresis during annual loading-unloading cycle, low-frequency dam oscillations etc, which can be used for dam diagnostics using packages DAMWATCH and DAMTOOL. The possible interpretation of hysteresis phenomena in by mesoelasticity (nonlinear elasticity) approach is suggested. It is shown that the main contribution to annual tilts hysteresis comes from the dam body tilts, thus these data are appropriate for dam damage diagnostics.The tiltmeter recordings with one minute resolution reveal many interesting details of dam behavior, which expand the spectrum of dam vibrations to low frequencies and give new diagnostic tools. Analysis of retrospective tilt data show that used methods are appropriate to detect and quantify dynamical changes in dam body behavior caused by different external and internal causes, though mechanism of some observed effects still need to be studied in detail.

3. *Flood risk assessment for different scenarios of Enguri High Dam damage.*

This work is the first step for Flood risk assessment in Georgia for Enguri High Dam, located on the Enguri River in western Georgia near the point at which the river leaves the Caucasus Mountains on its way to the Black Sea. For the modeling of flooding in case of Enguri Dam breaking has been used an important tool for simulating flood events in complex terrain a 2D flood propagation modeling program "SOBEK", which offers possibilities to quantify the dynamics of a flood event and to run different scenarios to evaluate the consequences of certain actions.

Using SOBEK the calculation of water depths and velocities, max water deep etc in case of a dam breakhas been done. The animation shows the simulation results of a dam break. The results may be used for dam breaking analysis, disaster management, evacuation planning, flood damage assessment, risk analysis and landscape, infrastructure, and urban planning.SOBEK-1D and 2D instrument for flood forecasting, like other flood modeling programs, is based on the Navier-Stokes equations.ILWIS (Integrated Land and Water Information System) a GIS / Remote sensing software also were used for modeling Enguri Dam break and flood scenario: Fig. 9shows only one small part of results.

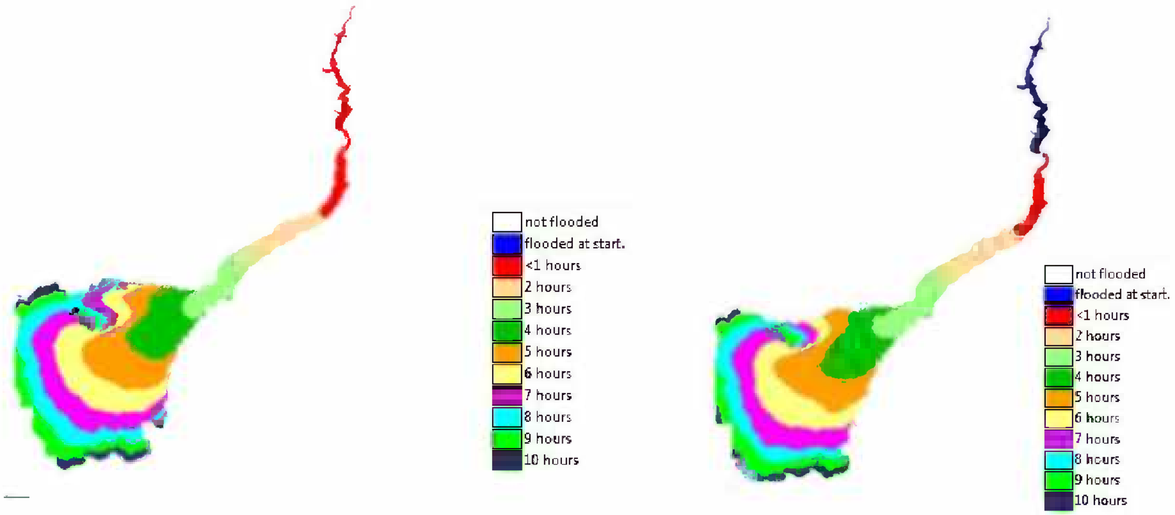


Fig. 9. Dynamics of flooding due to Enguri Dam damage for two different scenarios.

Results of calculations show that in case of dam brake the $1.1*10^9$ m^3 water would flow out downstream.The maximum velocity of the water body should be 44.0 m/s and the minimum 1.5 m/s (at 54 km from the dam). The area affected by flooding will be 1840km^2.The scenario of dam break influence on the speed velocity and propagation of the water, but difference is not large. More then 7 cities and villages in the area of the water propagation would be completely destroyed.

4. Climate Change; statistical and nonlinear dynamics predictions of regional effects

The greenhouse effect (global warming) is one of the main hazards facing the whole planet. The climate forcing is due to rising concentration of greenhouse gases (CO_2, methane, water vapor): according to different assessments, the temperature will rise by 1.4-5.8^{0}C at the end of 21-th century. This can cause a lot of devastating effects and many of them will be impossible to prevent, which means that the humankind should find some way to adapt itself to global warming.

Georgia as a whole Caucasus is prone to many negative effects, connected with climate change: the mountain glaciers can melt and partially disappear, the sea level can rise, the vast areas of land can became deserts, water resources can be seriously affected.

Despite some earlier efforts, devoted to assessment of climate change in Georgia, the results are still ambiguous. In particular, the research carried out shows that during last decades the mean temperature in the Eastern Georgia is rising and in Western Georgia it is decreasing. These conclusions are debated and there is a need to re-consider them using new data and new methods of mathematical analysis of meteorological time series. For reliable assessments new modern methods of obtaining and analysis of climate data in the past, present and future is necessary to use.

Another problem is to ascertain whether this warming is exclusively the man-made effect or it is the result of natural cyclicity in the earth climate.

Specific objective is assessment of persistence and memory characteristics of regional air temperature variation in Georgia in the light of global climate change. For this purpose longest available temperature time series of Tbilisi meteorological station (since 1890) are analyzed. Similar time series on shorter time scales of five stations in the West and East Georgia will also be used as well as monthly mean temperature time series of five stations (1906-1995) in the West and East Georgia. Both mono- and multivariate reconstruction procedures of climate change dynamics are implemented. Additionally, temporally and spatially averaged daily and monthly mean air temperature time series are analyzed. Extent of persistence in mentioned time series is evaluated.

The existing instrumental temperature data are from 1850 in Tbilisi and from 1880 in 12 meteorological stations in Georgia. These data were used in analysis of trends and for climate forecast. The detail (daily) digital data bases covering the whole observation period (1850-2010) are absent.The spatial distribution of warming (ΔT) in Georgia for 1906-1995 has been calculated in the frame of "Georgia's initial national communication under the United Nations Framework Convention on Climate Change" (1999). This study reveals the striking difference in the climate change trend between West and East Georgia.

The simplest prediction can be done by just extrapolation of time series: for example let us consider the extrapolation of 156 year Tbilisi temperature data (Fig. 6), which are best fitted by second order polynomial. The extrapolation display for the period 1850-2055 the increment $\Delta T = 2.4^0C$ with the most part of ΔT is in the last hundred years, from 1950 to 2050 and for the longer period 1850-2105, the increment $\Delta T = 4.4^0C$ with the most part of ΔT is in the last hundred fifty years, from 1950 to 2105.

It is interesting to note that this simplest extrapolation gives the assessment of temperature increment comparable with the predictions of the complicated mathematical models

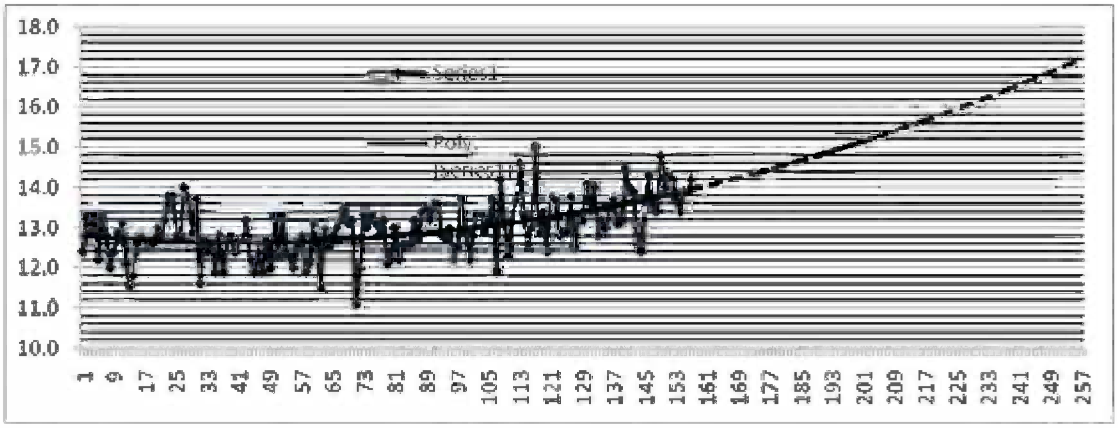


Fig. 10. Simple second order polynomial extrapolation of 156 year Tbilisi temperature data to the year 2105.

We also performed (linear) statistical assessments of future trends in climate in Tbilisi (Fig. 11) and 12 locations in Georgia, using modern methods of statistical assessments: autocorrelation, correlation fields, revealing periodicities, analysis of residuals etc.

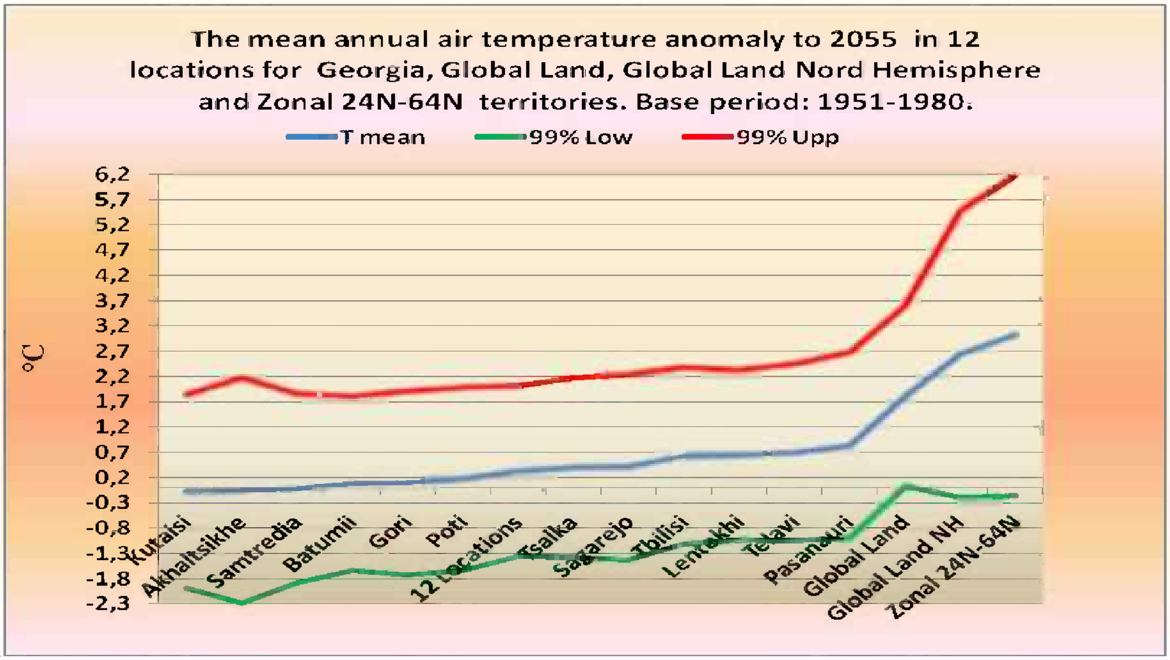


Fig.11. The mean annual air temperature change prediction for 2055 in 12 locations for Georgia, Global Land, Global Land Nord Hemisphere and Zonal 24N-64N territories

Common statistical analysis indicates to weak auto-correlation and at the same time reveals several periodicities both in original and detrended time series (Fig. 12).Extrapolation of the observed temperature trends by statistical methods predict mainly continuation of warming in the East Georgia and cooling or negligible change in the West with predominant warming in the cool periods.

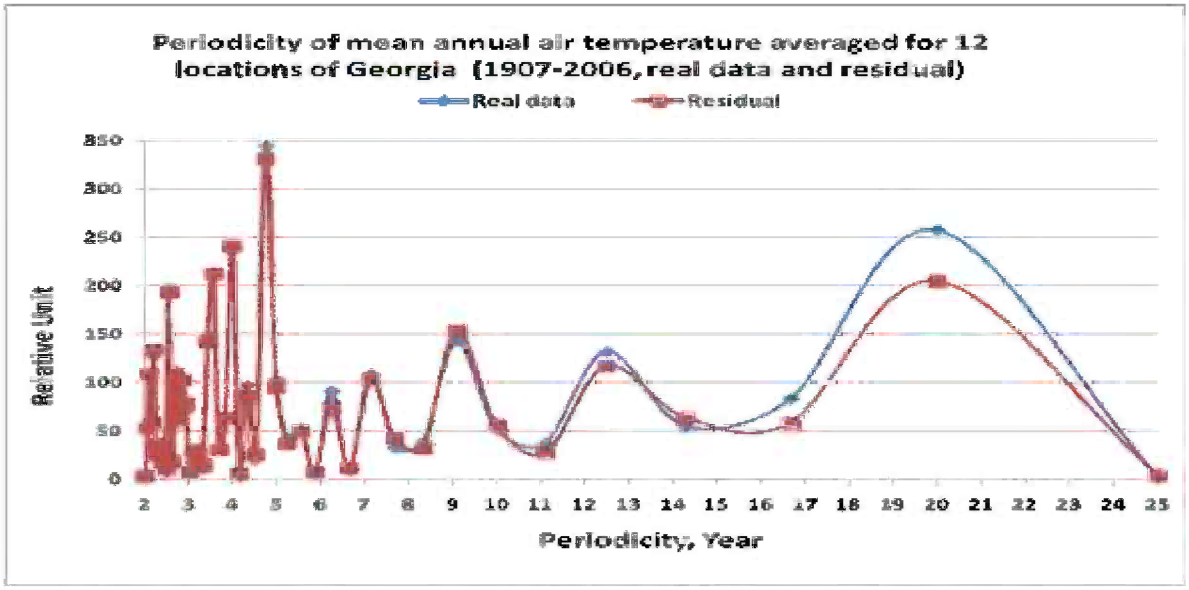


Fig. 12. Periodicities of mean annual air temperature averaged for 12 stations of Georgia (real data and residual)

Besides linear statistical methods we apply the nonlinear dynamics tool to temperature time series. Our nonlinear analysis, namely Detrended Fluctuation Analysis (DFA) shows that time series exhibit several time scales with different dynamical characteristics.

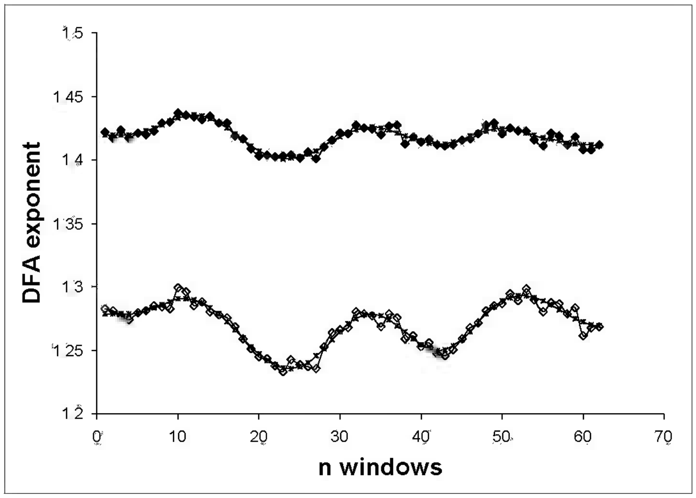


Fig.13. Smoothed by Savitzky Golay filtering DFA scaling exponents for Tbilisi (top) and Kutaisi(bottom) mean daily temperature data, 1936-2006, One year time scale. Asterisks correspond to smoothed data.

Taking into consideration that value of DFA exponent close to 1 means that investigated process is similar to white noise, it can be assumed, that daily temperature variation in Tbilisi is more regular comparing to Kutaisi for all considered time scales.The variations of DFA exponents' values reveal some periodic features. In order to better visualize suggested quasi-periodicity in scaling features of analyzed data we used Savitzky-Golay smoothing and filtering procedure for calculated DFA slope values for 3 different time scales – one year, one month to one year and one month (Fig. 13).

In addition to said above in methodology section RQA is a tool for qualitative and quantitative evaluation of nonlinear dynamical structure. It is sensitive and effective even for relatively short time series. Recurrence plots (Fig.14) shows much regular pattern for Tbilisi (East Georgia) in comparison to Kutaisi. These differences in the degree of regularity are definitely of local origin.

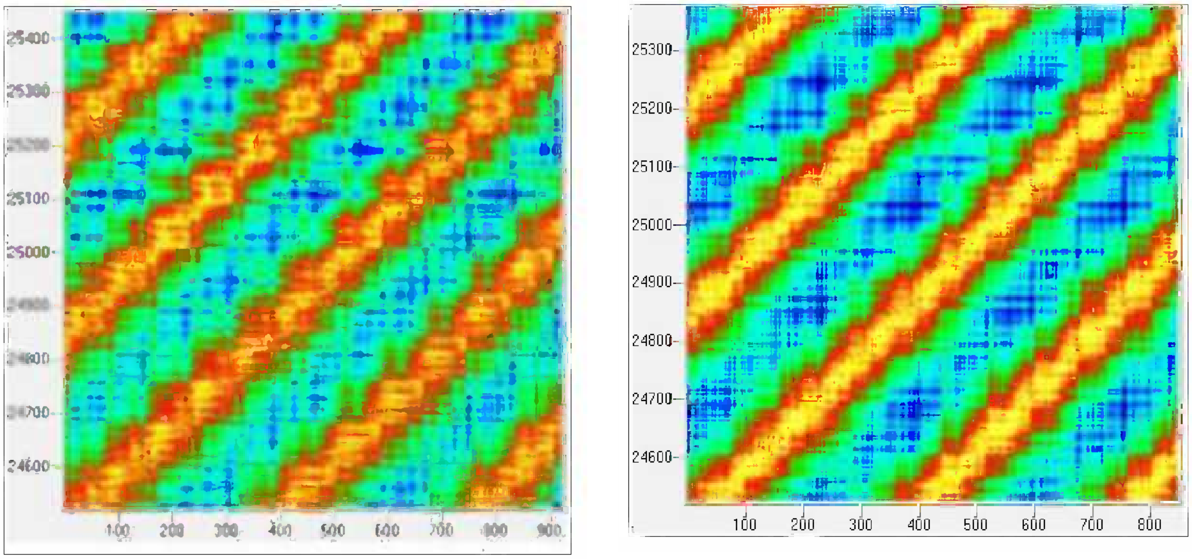


Fig. 14. Recurrence plots of Kutaisi (left figure) and Tbilisi (right figure) daily mean temperatures data, 1936-2006.

The ordering strength of temperature time series vary in time revealing existence of low-dimensional processes close enough to multi-scale quasi-periodicity (Fig. 15).The physical mechanism of such time-dependence is not clear: some of them can be connected with North Atlantic, Pacific Decadal or El Nino (NAO, PDO or ENSO) cycles.

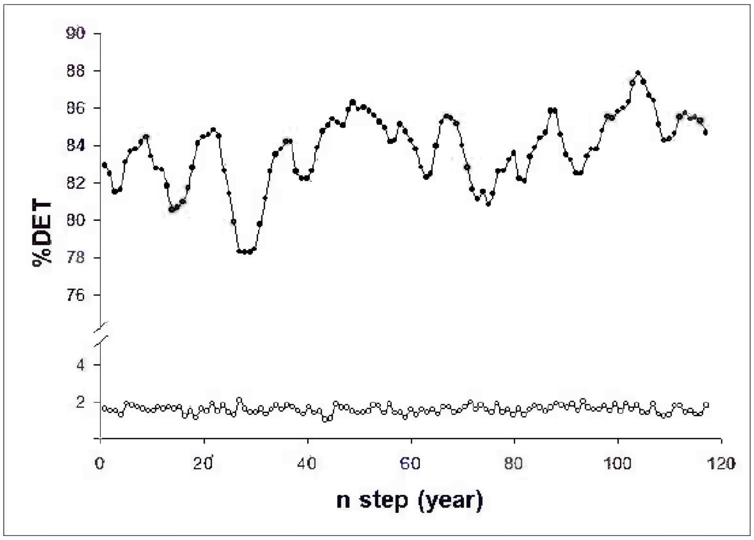


Fig. 15. Recurrence quantification analysis of daily mean temperature data Tbilisi 1981-2006, calculated for consecutive 5 year windows by one year step. Lower curve shows randomized time series.

We suppose that besides local peculiarities leading to different levels of ordering in the West and East Georgia there are some global factors leading to similar type of time-dependent dynamics in the both parts of country.For time scales larger than one year process always looks as strongly antipersistent, i.e. at this time scales stability of observed trends is questionable and inversion of observed trends is a typical feature of dynamical process.

Using nonlinear methods a small increase of temperature can be predicted in both parts of Georgia for the next 10 years and this process is not affected by different noises contained in existing data sets (Fig. 16 a).

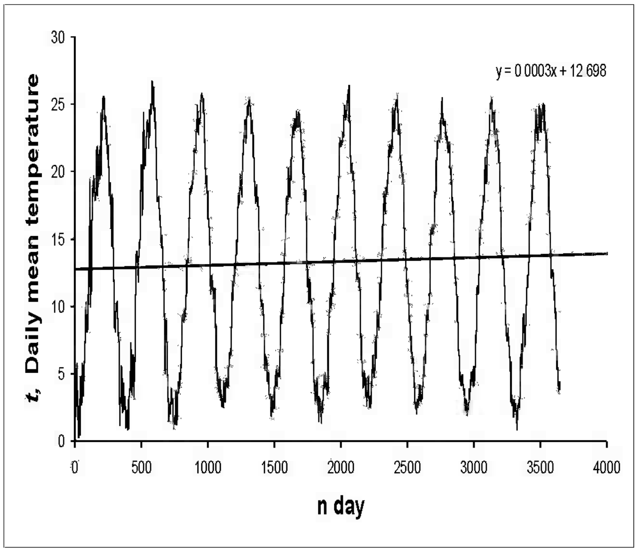


Fig. 16 a. Weak positive trend in the forecasted for 10 year Tbilisi daily mean temperatures data sets. Forecast was made based on Tbilisi mean daily temperature time series from 1881 to 2006.

The program package Drought Assessment Package Application (DAP APP) was compiled to assess the recurrence of droughts in a given area. Program package presents easy-to use friendly toolbox working with time series. Application is designed to work with TXT or DAT files which contain for example temperature or precipitationmeasures.<u>Input files should have only one column.</u>This package includes different popular instruments for data analysis:

1. Recurrent Plots (RECURRENCE PLOT tab menu) and Recurrent Quantification Analysis (RQA)
2. Detrended Fluctuation Analysis (DFA tab menu);
3. Power Spectrum and Histogram (HISTOGRAM/POWER SPECTRUM tab menu);
4. Correlation calculation (CORRELATION DIM/AUTOCORRELATION tab menu);
5. Lyapunov exponent calculation (LYAPUNOV EXPONENT tab menu);
6. Stationary test (STATIONARY TEST);

Here we show only the results on the recurrence of the droughts defined as days with temperature higher then 30^0C of various durations using Tbilisi data.We took only summer month from Tmax daily series and calculated duration of droughts (in days) with max temperature (Tmax) higher than 30 C^o in summer months.

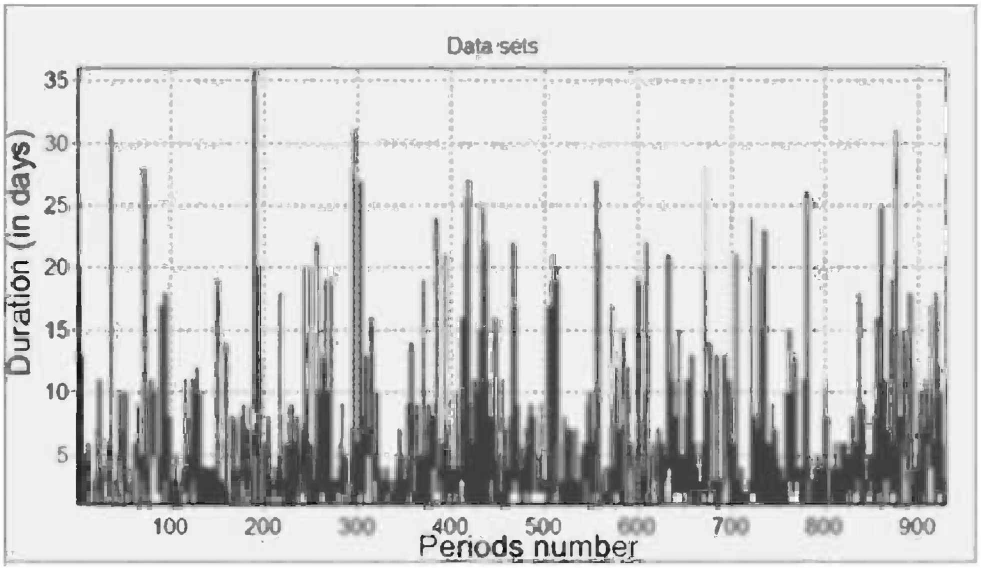


Fig.1. Duration of periods with Tmax higher 30 C^o versus period number of period with Tmax higher than 30 C^o, which can contain *m* = 2, 5,10,....35 days.

As a result we get Tmax duration series versus period number, which is depicted on the Fig.16b. Note, that the number of periods with Tmax higher than 30 C^o are not uniform - so the X-axis shows only the number of high temperature period, which can contain *m* = 2, 5, 10,.....35. days.

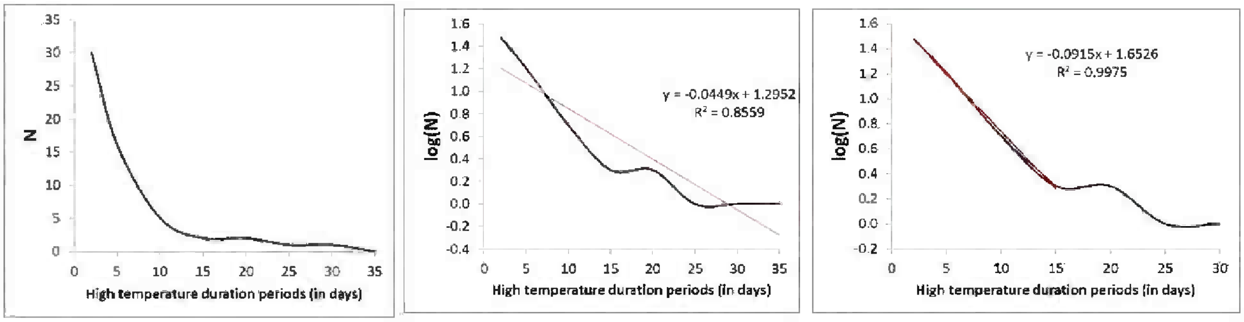


Fig. 16 b. Frequency-Intensity Estimate Plot: a) linear plot of number of droughts N in five years (i.e. drought rate) with duration more than 2days versus corresponding durations (intensity of droughts); b) the same in semilog scale - log N versus intensity with straight line approximation for all intensities; c) the same as 7b with straight line approximation for intensities from 2 to 15 days.

Frequency-Intensity Estimate Plot or plot of number *N* of droughts in 5 years (i.e. drought rate) with duration *m*more than 2, 5, 10, 15, 20, 25, 30, 35 days versus corresponding durations (intensity of droughts (Fig.2 a, b, c) of high-temperature periods was done on duration series (Fig. 1).It manifests the presence of heavy-tail i.e. different statistics for extreme events (long droughts) with duration larger than 15 days (Fig. 2 a). We observe that up to period length equal to 15 days, relationship between occurrence of high-temperature periods and period lengths is very well approximated by exponential function (Fig. 2 c) and recurrence time T_R can be accessed accurately for 15-days droughts. For example, 15 days drought reoccur as (antilog(log0.3))/5 (1/year) ≈ 2/5≈ 0.4 (1/year) or T_R = once per twoand a half years. The linear approximation for a whole semilog plot (Fig. 2 b) is much less accurate and for 15 days drought reoccurrence we get (antilog(log0.6))/5 (1/year) ≈ 4/5 ≈ 0.8 (1/year) or T_R ≈ once per year and for droughts with duration 35 days ((antilog(log(-0.35)))/5 (1/year) ≈0.45/5 (1/year) =0.09 /5 (1/year) ≈ 0.1 (1/year) or T_R ≈ once per ten years, which is less than observed data. According to observed data ((antilog(log(0)))/5 (1/year) ≈ 1/5 (1/year) or T_R ≈ once per five years.

5. *Pan-European and nation-wide landslide/debris flow susceptibility assessment*

The earth surface is not static but dynamic, and landforms change over the time as a result of weathering and surface processes (i.e., erosion, sediment transport and deposition). These changes have the potential to cause significant harm to civil engineering projects as they resulted into different hazardous processes, i.e. landslides, which are important natural geomorphic agents that shape mountainous areas and redistribute sediment]. Landslides are commonly responsible for significant losses of money and lives, and the severity of the landslide problem became worsens with increased urban development and change in land use.

In Georgia, where up to 80% of the territory is mountainous and more than 30% of settlements are located in the high mountains (above 1000 m altitude) the slope stability is recognized as the problem of high importance. Investigations, carried out in last decades, show that the negative impact of landslide activities becomes perturbing almost all over the territory of Georgia.

The goal of the project was to compile a new maps of landslide, derris-flow and rock-falls susceptibility (hazard) map following standards of Pan-European map.

The following dataset has been collected during preparation period:

1. DTM (Digital Terrain Model) – The digital elevation model of the territory of Georgia(extracted from Aster Satellite mission (ASTER: Advanced Spaceborne Thermal Emission and Reflection) (http://asterweb.jpl.nasa.gov/). From DTM data one of the main factors - the terrain's slope model was compiled (Fig. 17).

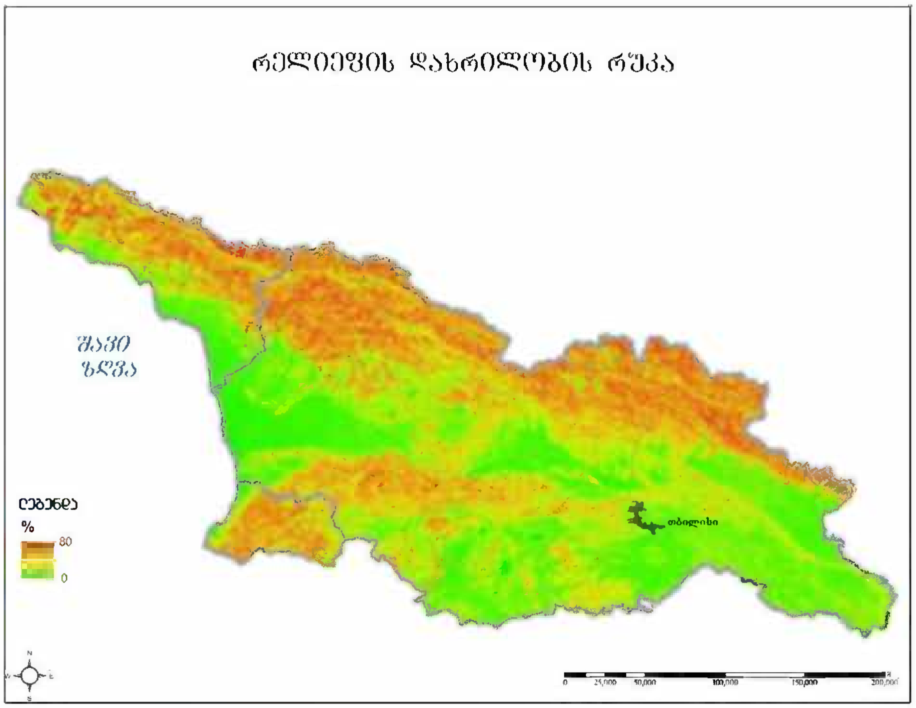


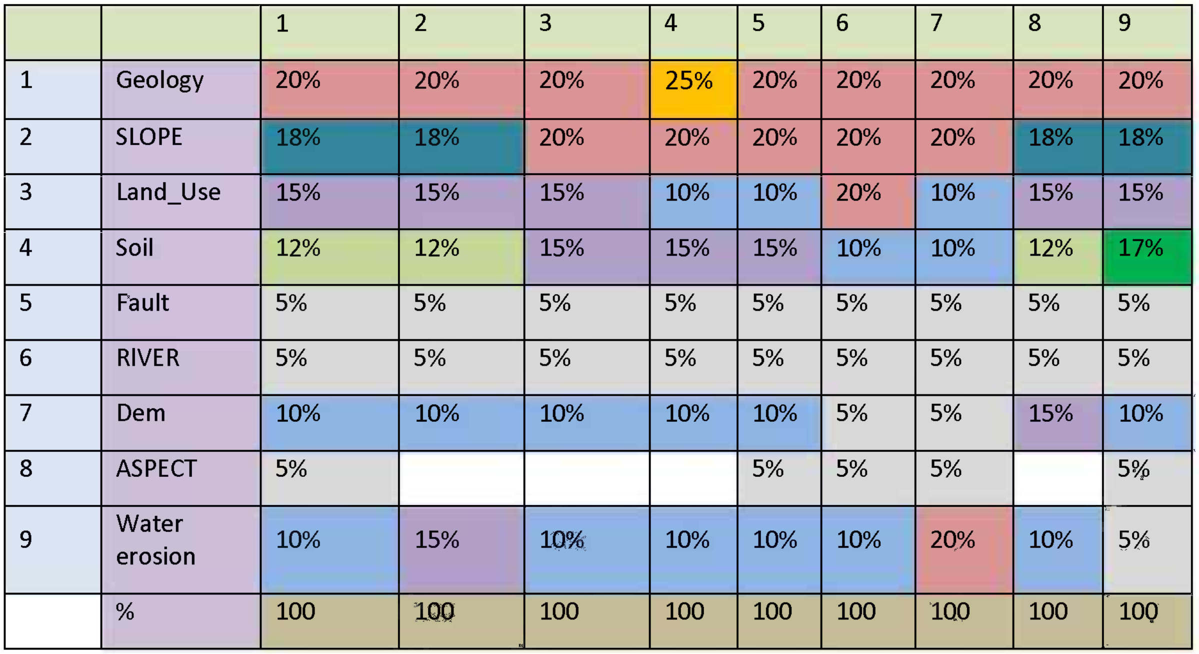
Fig. 17. The terrain's slope model of Georgia – one of the risk factors.

2. Rivers network of teritory of Georgia (the database have been extracted from 1:50 000 topographic map)
3. Engineering geological structure's map of Georgia (the database have been created based on the Engineering geological map of Georgia of 1:200 000 scale)
4. Active tectonic faults database of Georgia (created from geological map ofGeorgia 1:200 000 scale)
5. Soil types map of Georgia (1:200 000 scale database)
6. Land use database (Terra modis dataset) (http://modis.gsfc.nasa.gov/)
7. Landslide inventory databases, compiled using different sources (around 500 events).

The next step, after data colection and processing is parametrisation of the factors' maps. For this goal the analysis of different factors' maps have been carried out. For this goal the expert judgment and knowledge have been used. Each factor map was classified and for each classes the value from 0-to 100 have been graded, where 0-is absence of the class to produce mass movement and 100 is the highest value of formation which should produce mass movement.

The parameterized maps have been reworked into raster type maps with 30m resolution and methodology have been tested using all (9) parameters. The combining of the selected parametrical maps carried out usingArc-Gis. The maps have been combined using different types of weight of each parameter. In the table 2 the numbers of models are shown with parameter's weights for landslides.

Table2.Model parameterization of factors' weights for landslides(%).



		1	2	3	4	5	6	7	8	9
1	Geology	20%	20%	20%	25%	20%	20%	20%	20%	20%
2	SLOPE	18%	18%	20%	20%	20%	20%	20%	18%	18%
3	Land_Use	15%	15%	15%	10%	10%	20%	10%	15%	15%
4	Soil	12%	12%	15%	15%	15%	10%	10%	12%	17%
5	Fault	5%	5%	5%	5%	5%	5%	5%	5%	5%
6	RIVER	5%	5%	5%	5%	5%	5%	5%	5%	5%
7	Dem	10%	10%	10%	10%	10%	5%	5%	15%	10%
8	ASPECT	5%				5%	5%	5%		5%
9	Water erosion	10%	15%	10%	10%	10%	10%	20%	10%	5%
	%	100	100	100	100	100	100	100	100	100

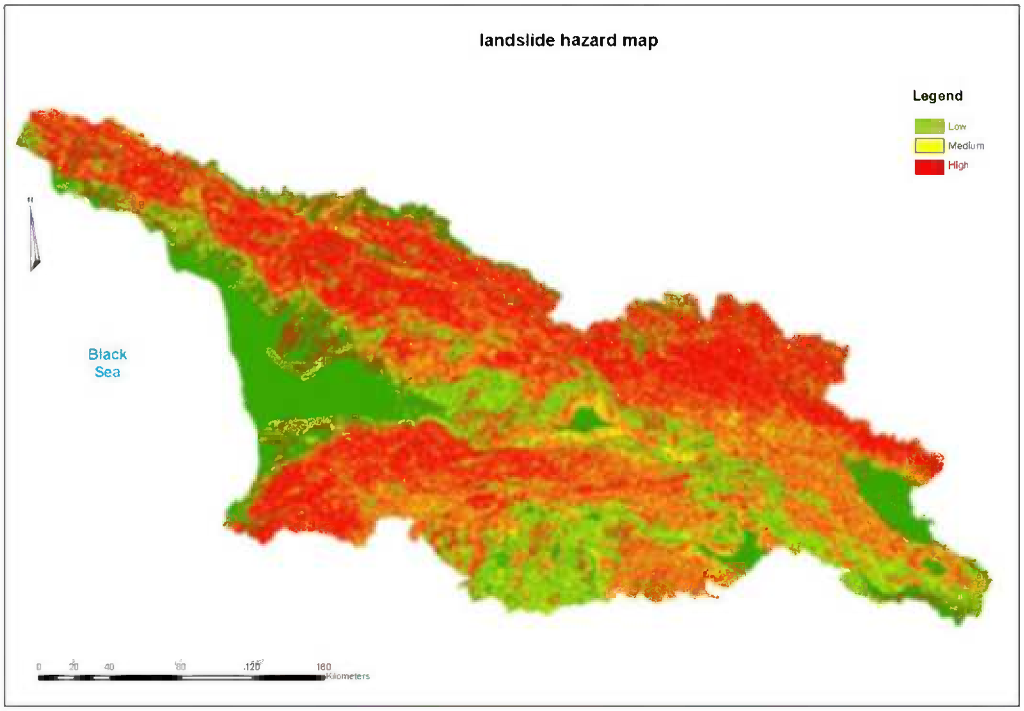


Fig. 18. Landslide susceptibility map of Georgia.

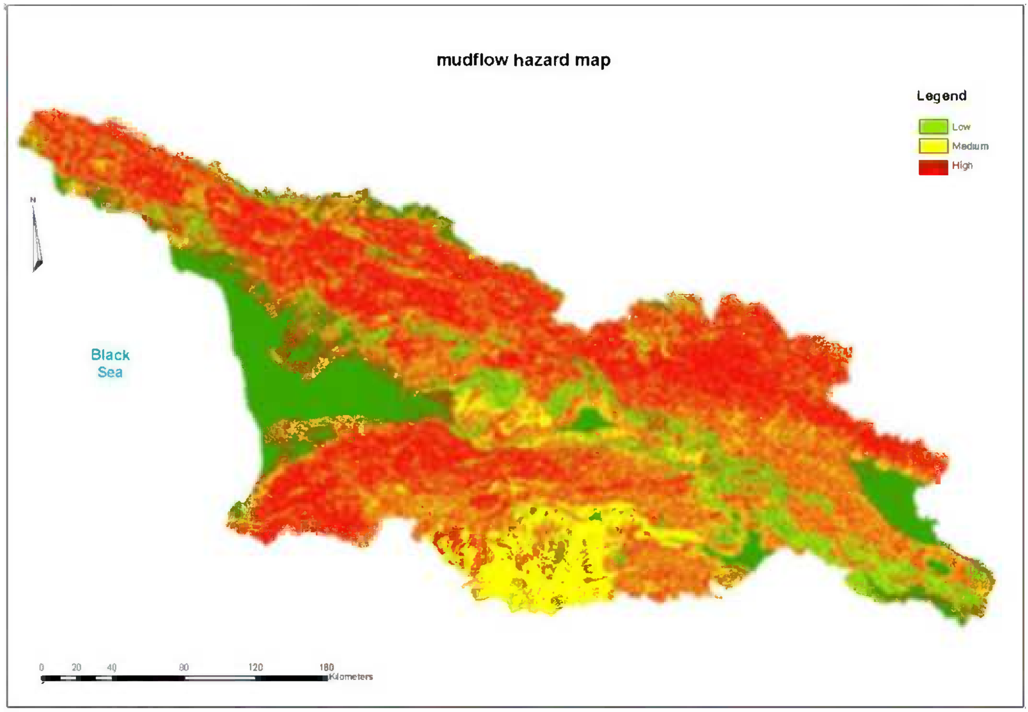


Fig. 19. Mudflow susceptibility map of Georgia.

The resulting prognostic maps 18, 19 are much more detailed than previous ones and are in good correlation with the data on occurred events (Fig. 20).

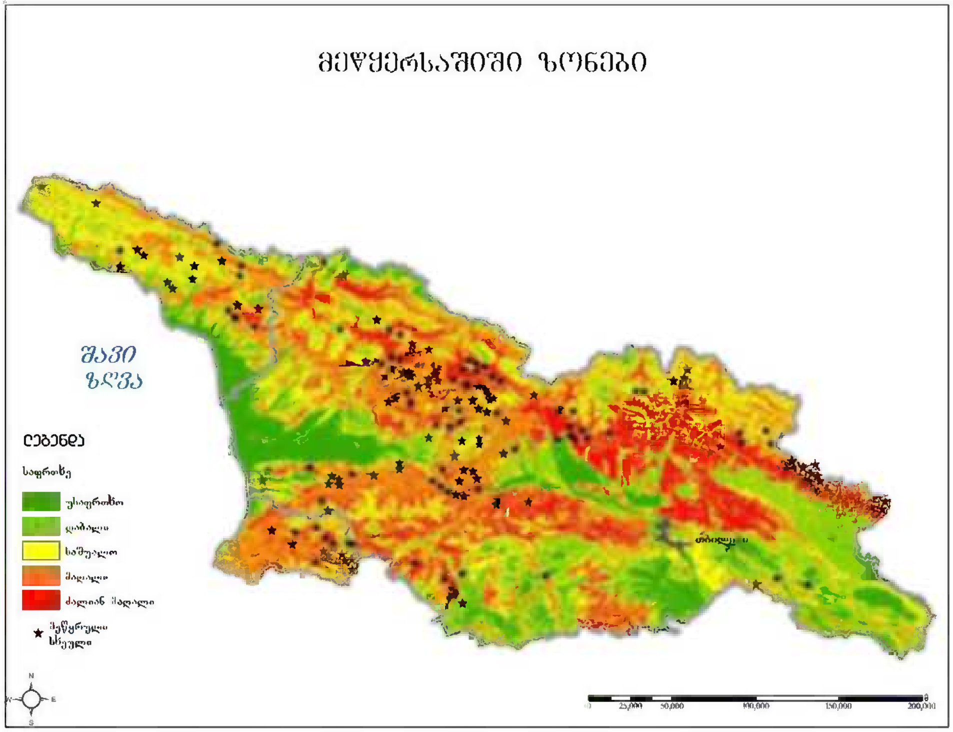


Fig. 20. Landslide susceptibility map in combination with occurred landslide events dataset.

6. *European Landslide Hazard Maps including Triggering factors: precipitation and seismic hazard (preliminary results)*

As a rule compilation of theoretical landslide/debris-flow hazard maps is founded on the analysis of several permanent factors, such as the slope of the hill, mechanical properties of geological formations etc. These factors are stationary and do not take into account impact of such important triggering agent, as precipitation. On the other hand it is well known that the occurrence of landslides/debris-flows critically depends on the precipitation, which usually is considered as one main triggering factor. The impact of triggering agent can be implemented into mass-movement stationary hazard assessment merging, for example, standard landslide hazard map with a long-term (100 years long rx5 days) rainfall data; precipitation intensity map for 100 years is practically a stationary map. Of course, it is necessary to establish some gradation rule, characterizing hazard increment with a long-term rain intensity and duration (thresholds).

*Stationary Forecast for triggering factor (precipitation).*This approach uses the long-term (e.g. for 100 years) local precipitation or soil wetness data as an additional quasi-stationary factor (Fig. 21), which can be added to a standard list of factors: slope, geology, etc, which are used in compilation of standard landslide/debris-flow (Fig. 18). For inclusion of precipitation triggering effects we use the map of maximum 5-day precipitation for 100 years return period in Georgia (Atlas of Natural Hazards and Risks in Georgia. 2012).

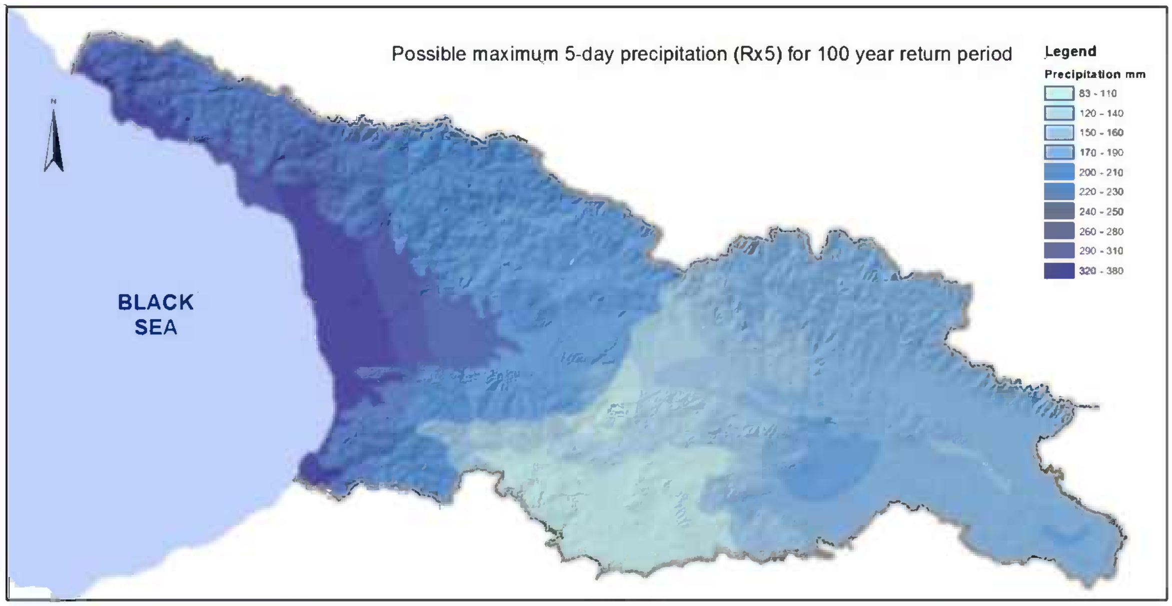


Fig. 21. Map of maximum 5-day precipitation for 100 years return period in Georgia.

Fuzzy Logic (FL) Approach. First we choose the fuzzy sets (linguistic terms)that describe the linguistic variable precipitation:low, medium, high, very high. For linguistic variable landslide let be low, medium and high.

The next step is to construct IF - THEN fuzzy rule base, where IF-part includes two variables - precipitation and landslide. They are input variables and the one output variable is hazard. The following case - IF precipitation is variable “medium” and landslide variable is “low’ - THEN hazard is low - is one example of such rule.

The above approach was first used for compilation of the stationary map of landslide hazard map of Georgia (Fig. 18) merged with the average multi-year distribution of the maximum amount for 5-day precipitation 100 years' return period maps of precipitation in Georgia, which also can be considered as a stationary map (Fig. 21). The multi-year, everyday measurement data of precipitation, obtained from the 83 meteorological stations, has been used for calculation of fuzzy logic rules for 100 years periods.

As a result of fuzzy merging stationary maps of landslide hazard and precipitation the stationary map of landslide and mudflow hazards taking into account triggering factor - precipitation - was compiled (Fig. 22).

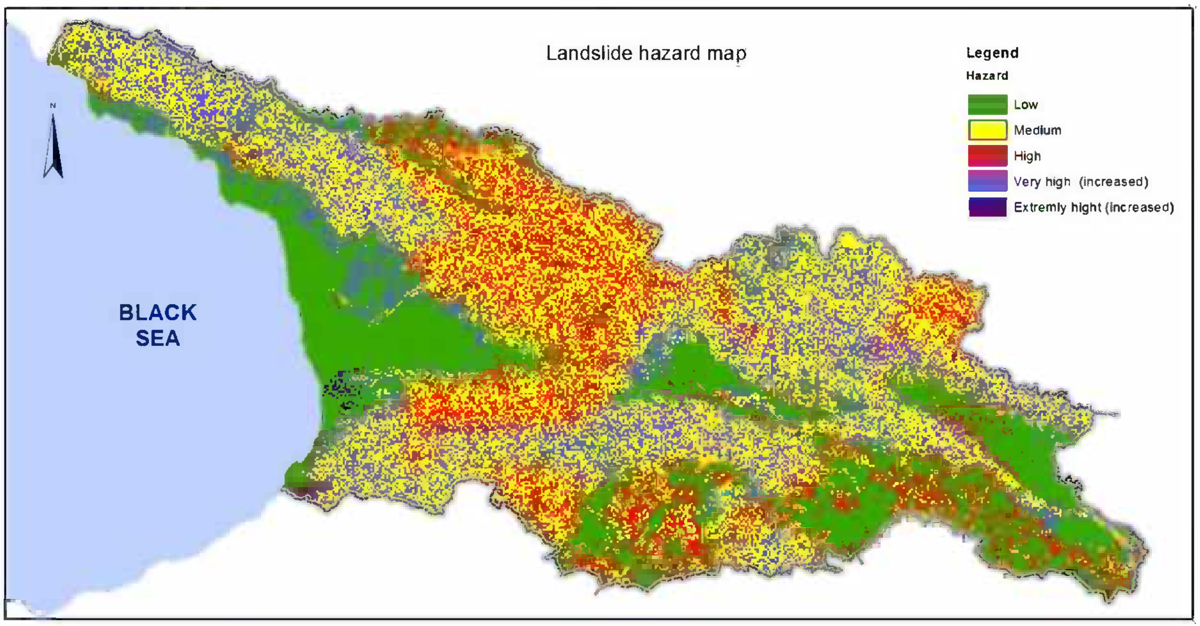


Fig. 22.Landslide hazard map of Georgia including precipitation factor (preliminary version)

It is evident that taking into account precipitation factor changes configuration of hazardous zones, namely, due to precipitation factor some hazardous zones are upgraded from $n$to $(n+1)$grade higher hazard zone (i.e. middle hazard to high hazard etc). In the landslide hazard map two more gradation –"very high" and "extreme hazard" was added, which take into account precipitation factor.

At present the center works on development of a new debris flow/landslide hazard maps, which will take into account very important factor: precipitation (intensity and duration) more exclusively as well as the seismic impact. In the former problem the space data on precipitation will be used.

7. *Cost-effective telemetric monitoring and early warning complex systems (arrays) with high-tech elements for signaling mass-movement (preliminary results).*

The cost of precise enough monitoring/early warning system (EWS) equipment is as a rule very high (of the order of hundreds of USD) and it is practically impossible for developing countries to purchase even one system. If we take into account that the number of mass-movement dangerous sources is huge - only in Georgia there are 40000 of potential debris flow/landslide sources - the financial expenses are unaffordable. Thus, the multitude of dangerous sources, a need of covering the source area by many sensors, expensiveness of supporting personnel for a long period at potential mass-movement areas, growing number of exposed vulnerable objects and limited resources of developing countries, which are most prone to mentioned hazards, call for developing cost-effective and the same time accurate automatic monitoring/early warning telemetric systems. The network approach is important, as the mass-movement in the debris flow/landslide area is as a rule very heterogeneous and with a small number of sensors the system can miss the initiation of dangerous event.Fusion of these apparently conflicting concepts (cost-effectiveness and accuracy) became possible due to the progress of modern high-tech systems.

The main ideas in developing our EWS are: Cost-effectiveness and low power consumption; choosing informative parameters to monitor; modern sensors; micro-board for acquiring and processing information from sensors; autonomous power source; telemetric signal transmission system; analysis/decision making system.

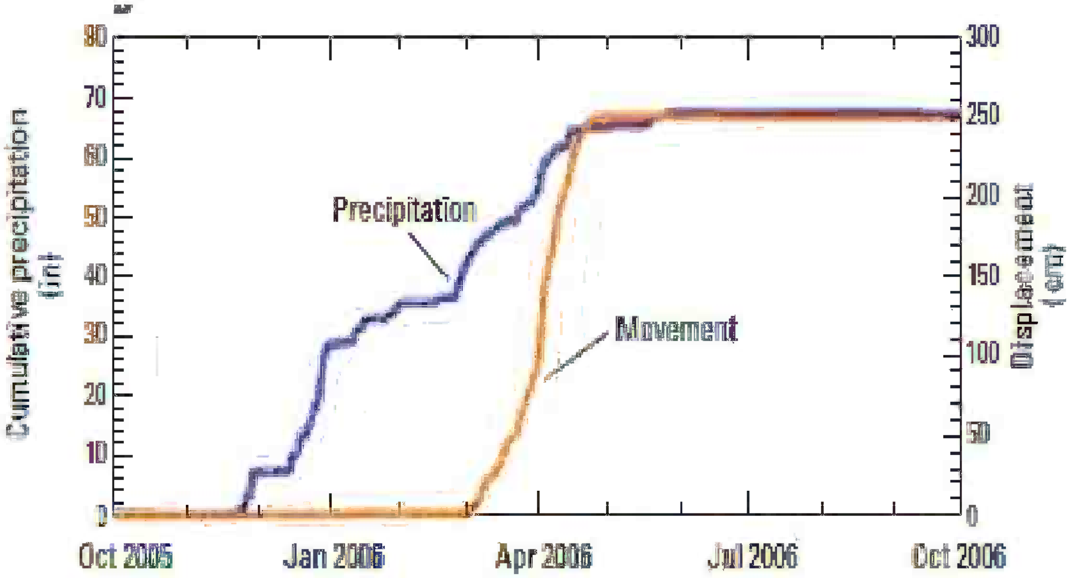


Fig. 23. The results of monitoring precipitation and mass-movement (U.S. Highway 50, California, http://landslides.usgs.gov/monitoring/hwy50/yearly.php), which show that before initiation of movement there is intensive precipitation (it can serve as long-term precursor). After exceeding threshold precipitation the mass movement is initiated.

The choice of precursory physical field is important: the precursors should be informative for diagnostics and easily measurable. The results of monitoring (U.S. Highway 50, California, http://landslides.usgs.gov/monitoring/hwy50/yearly.php), show that before initiation of movement there is intensive precipitation (it can serve as long-term precursor). After exceeding some threshold value of precipitation the mass movement is initiated (Fig.23).

Accordingly, the suggested debris flow/landslide EWS network includes monitoring of two main factors, leading to mass-movement: humidity/pore pressure/conductivity of the soil (as a relatively long-term precursor, after which will be issued long-term alarm - WATCH) and displacement/acceleration/acoustics caused by initiation of mechanical motion (as a short-term precursor, after which will be issued short-term alarm - DANGER).

Humidity sensor: The principle is to monitor the difference in ultrasonic wave amplitudes in mutually normal directions depending on the soil humidity. For this the signal from the ultra-sound wave (USW) transducer is received by two USW sensors, disposed frontally and normally to the direction of the emitted wave (Fig. 24). In water the amplitudes in both directions are the same, as the pressure is distributed uniformly in the volume. In the water-saturated soil we expect to obtain the similar behaviour in contrast to dry environment, where the amplitudes in these two directions are expected to differ significantly. The USW method was chosen because, conductivity sensors, though very sensitive, are unstable due to the electrodes' degradation/corrosion.

Mechanical motion sensors: MEMS:" Micro-electromechanical Systems (MEMS) are miniature devices comprising of integrated mechanical (levers, springs, deformable membranes, vibrating structures, etc.) and electrical (resistors, capacitors, inductors, etc.) components designed to work in concert to sense and report on the physical properties of their immediate or local environment, or, when signalled to do so, to perform some kind of controlled physical interaction with their immediate or local environment.

MEMS-based solutions yield product cost advantages for a given functionality; employing MEMS devices usually results in a reduced price for a given product, and MEMS components typically demonstrate less power consumed per a given function than do other, macro-based solutions; and the fact that MEMS device and product reliability is as good as any reliability can be." The MEMS chips, upgraded to full-scale accelerometers are shown in Fig. 24.

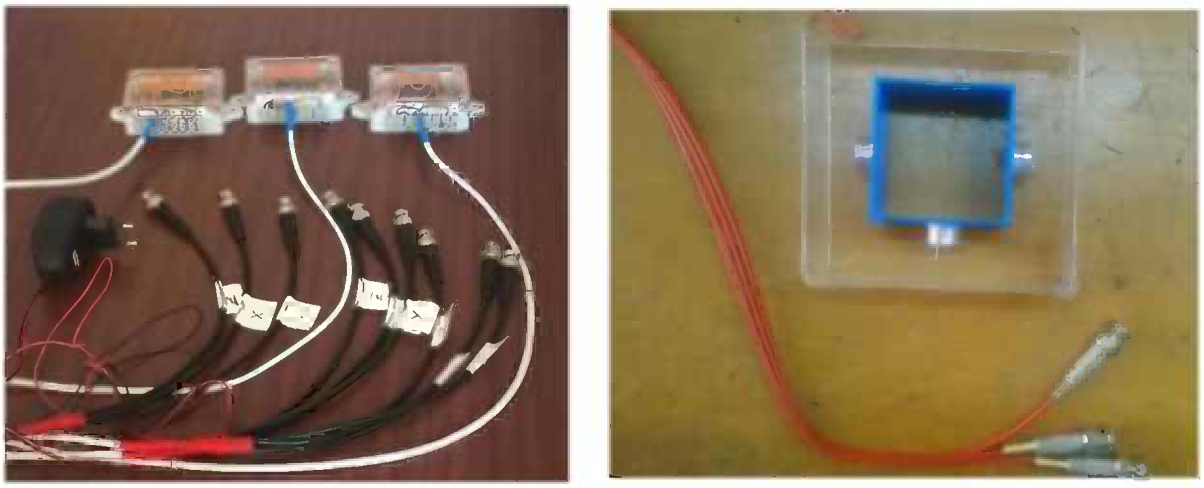


Fig. 24. Left: Array of Micro-accelerometers with MEMS sensors; right: Soil Humidity sensor: cell, USW transducer and USW receivers.

Laboratory testing of humidity sensor: Testing soil (sand) wetness using orthogonally oriented USW ratio, f=40 KHz. USW amplitudes in orthogonal directions in dry and fully saturated soil differ significantly from 1:5 for dry to1:2 for saturated state; to us, this is the state, when the long-term alarm (WATCH) should be declared (Fig. 25)

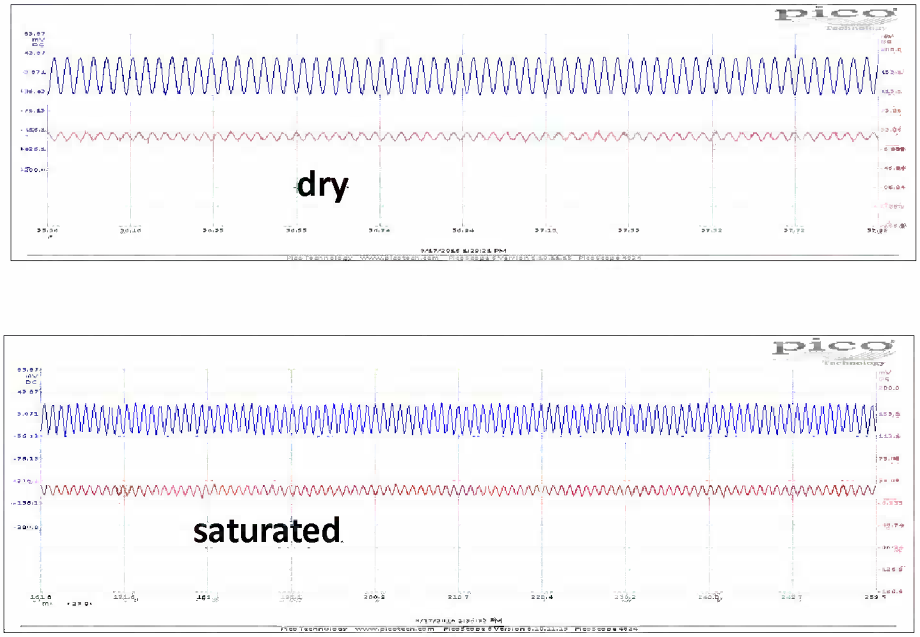


Fig. 25.USW amplitudes in orthogonal directions in dry (upperplot) and fully saturated (lower plot) soil.

Differentialaccelerometry. In complex with displacement and soil wetness measurements the method of *differential accelerometry* will allow us monitoring of landslide/debris flow motion initiation processes. For this one accelerometer is be grounded in the stable area and the other one (or the array of accelerometers) – on the potential landslide body. The differential signal between fixed and moving devices can be used for early warning on initiating disaster (Fig. 26).

Fig. 26. Left: Both accelerometers are rigidly connected during motion – no differential signal.; right: differential signal between fixed and moving sensors (maximal displacement difference between sensors - 1mm)

*Testing accelerometers and acoustic sensors on Burridge-Knopoff model:*The well known theoretical Burridge-Knopoff model of seismicity is applicable also to landslide motion. Accelerometers are fixed on the sliding blocks connected by springs (Burridge-Knopoff model) and placed on the lower fixed block. The fixed block can be horizontal or inclined to model landslide motion (Fig. 27). Fig. 28 presents the results of testing a simple Burrridge-Knopoff model on one block-horizontal system: recordings of acceleration, acoustic emission (AE) and the pulling force on the spring (see location of the sensors in Fig. 27)

Fig. 27. The array of three accelerometers fixed on the three sliding blocks connected by springs (Burridge-Knopoff model) and placed on the lower fixed inclined block. Two AE sensors are mounted on the fixed block.

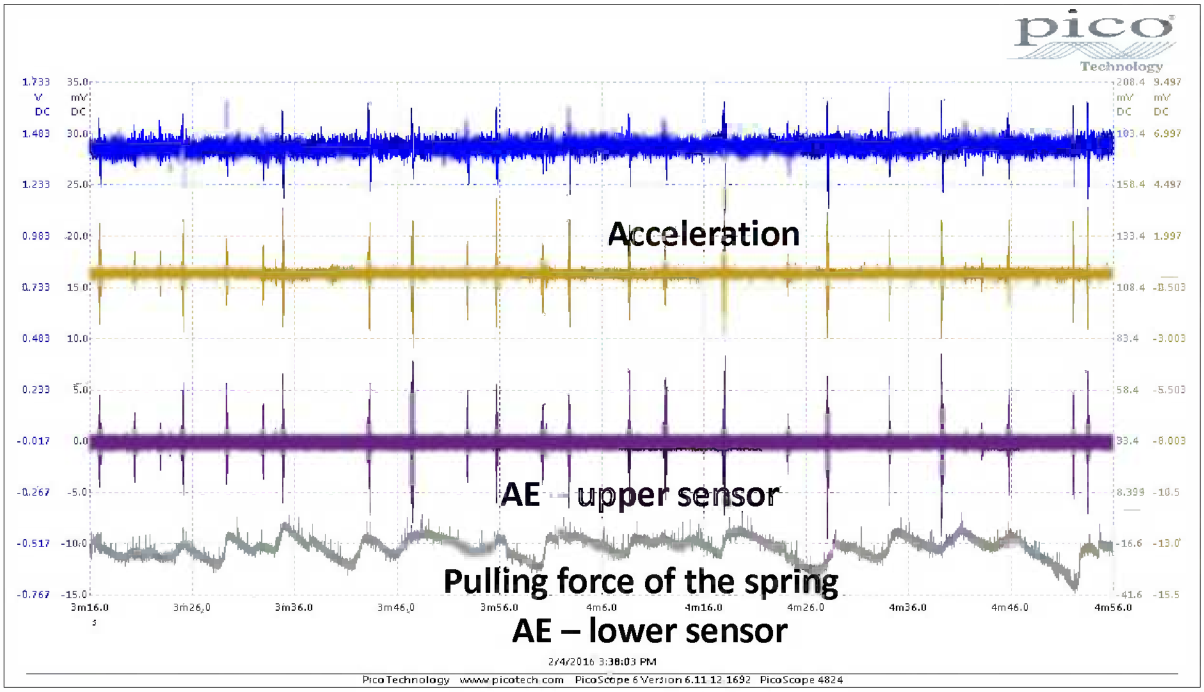


Fig. 28.Burrridge-Knopoff model–one block-horizontal system: recording of acceleration, acoustic emission(AE) and the pulling force on the spring (see location of the sensors in Fig. 27)

8. *Activity related to risk culture and public safety*

A supplementary textbook for Universities "Geophysical Methods in Ecology and Catastrophe Management" in Georgian was prepared and published in 2003 (author T. Chelidze).

In 2013 were edited and printedpopular brochures in Georgian: “Surviving disasters: a pocket guide for citizens” and “Basic knowledge on nuclear hazards: lessons of Chernobil and Fukusima”**(**Fig. 29).

EURΟPA

European Centre for Technological safety, Kiev

European Interregional Scientific and Educational Centre on Major Risk Management, Yerevan

European Centre on Geodynamical Risks of High Dams, Tbilisi

European University Centre for Cultural Heritage, Ravello

KNOW HOW TO DEAL WITH EMERGENCIES:
What you need to know;
What needs to be done.

Виктор Поярков

BASIC KNOWLEDGE ON NUCLEAR HAZARDS:
LESSONS OF CHERNOBIL AND FUKUSIMA

EUROPA 2013

თ. ჭელიძე

გეოფიზიკური მეთოდები ბუნების დაცვაში

თბილისი 2004

Fig. 29. Title pages of popular brochures in Georgian: “Surviving disasters: a pocket guide for citizens” and “Basic knowledge on nuclear hazards”**.**

The brochures have been distributed to a wide audience: teachers of high schools, Universities professors, students, governmental authorities, etc.

A web-page on “Hazards and Risks of Large Dams” has been compiled and implemented into the web-site “Be Safe Net”

9. Publications of the Centre

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Influence of periodic variations in water level on regional seismic activity around a large reservoir: Field

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ევროპის საბჭოს დიდი კატასტროფების შეთანხმების საქართველოს სპეციალიზირებული ცენტრი 20 წლისაა

რეზიუმე

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1995 წლის ნოემბერში ევროპის საბჭოს დიდი კატასტროფების შეთანხმებაში მონაწილე ქვეყნების მუდმივი წარმომადგენლების შეკრებაზე განხილულ იქნა საქართველოს წინადადება საქართველოში “მაღლივი კაშხლების გეოდინამიკური რისკის” სპეციალიზირებული ცენტრის შექმნის თაობაზე.

წინადადება განიხილეს და მოიწონეს ევროპის საბჭოს ექსპერტებმა ფრანგმა პროფესორებმა ა.გუბემ და ჟ. ბენამ, რის შედეგად 1996 წ. დეკემბერში საქართველოს გარემოს დაცვის სამინისტროს გადაწყვეტილებით საქართველოს მეცნიერებათა აკადემიის გეოფიზიკი სინსტიტუტთან შეიქმნას პეციალიზირებული ცენტრი. ამჟამად ცენტრს აქვ სარასამთავრობო იურიდიული პირის სტატუსი.

ევროსაბჭოს დიდი კატასტროფების შეთანხმების მცირე გრანტებით შესრულდა 20-ზე მეტი პროექტი, მათ შორის აღსანიშნავია:

- შეიქმნა ენგურის მაღლივი კაშხლის საერთაშორისო პოლიგონი (Enguri Dam International Test Area – EDITA),
- შეიქმნადა 2010 წლიდან უწყვეტად მუშაობს რეალურ დროში მოქმედი დიდი საინჟინრო ობიექტების დეფორმაციების ავტომატური ტელემეტრული მონიტორინგის სისტემა ენგურჰესზე
- ქართველ, აზერბაიჯანელ და სომეხ კოლეგებთან თანამშრომლობით გამოიცა სამხრეთ კავკასიის ბუნებრივი კატასტროფების GIS ატლასი, რომელშიც მოცემულია სეისმური, მეწყრული, ღვარცოფების, ზვავების საშიშროების რუკები.
- შეფასდა გვალვების განმეორადობა და კლიმატის ცვლილება საქართველოში
- განხორციელდა ენგურის კაშხლის შესაძლო დაზიანებით გამოწვეული დატბორვის მოდელირება თანამედროვე კომპიუტერული პროგრამებით
- შედგენილ იქნა ენგურის კაშხლის რაიონის სეისმური საშიშროების, პიკური და სპექტრული აჩქარებების რუკები, შესწავლილ იქნა ენგურის რეზერვუარის შექმნითა და ექსპლუატაციით გამოწვეული ე.წ. ინდუცირებული სეისმურობა.

- საფრანგეთ-ევროპის გეომორფოლოლოგიურ ცენტრთან თანამშრომლობით შეიქმნა საქართველოს მეწყრული და ღვარცოფული საშიშროების რუკები პან-ევროპული სტანდარტით.

ГРУЗИНСКОМУ СПЕЦИАЛИЗИРОВАННОМУ ЦЕНТРУ СОГЛАШЕНИЯ ПО БОЛЬШИМ КАТАСТРОФАМ СОВЕТА ЕВРОПЫ - 20 ЛЕТ

Челидзе Т.Л., Абашидзе В.Г., Мачарашвили Т.Н., Цагурия Т.А..Цамалашвили Т.О.,
Амиранашвили А.Г., Жукова Н.Н., Челидзе З.Т., Варамашвили Н.Д.

Реферат

В ноябре 1995 года на собрании постоянных представителей стран-участников соглашения по большим катастрофам Совета Европы было рассмотрено предложение Грузии о создании в Грузии Специализированного центра «Геодинамический риск высоких плотин».

Предложение было рассмотрено и одобрено экспертами, французскими профессорами А. Губе и Ж. Бена, после чего в декабре 1996 года по решению Министерства Охраны окружающей среды Грузии при Институте геофизики АН Грузии был создан Специализированный центр. В данное время Центр имеет статус внегосударственного юридического лица.

По малым грантам соглашения по большим катастрофам Совета Европы выполнено свыше 20 проектов, среди которых необходимо отметить:

- создан международный полигон высокой плотины Ингури-(Enguri Dam International Test Arec – EDITA);
- на Ингури ГЭС создана и с 2010 года непрерывно работает действующая в реальном времени система автоматического телеметрического мониторинга деформаций больших инженерных объектов;
- в сотрудничестве с грузинскими, азербайджанскими и армянскими коллегами издан атлас GIS естественных катастроф Южного Кавказа, в котором представлены карты сейсмических, оползневых, селевых, лавинных опасностей;
- оценена повторяемость засух и изменения климата в Грузии;
- с помощью современных компьютерных программ осуществлено моделирование затопления, вызванного возможным повреждением плотины Ингури;
- составлены карты сейсмической опасности, пикового и спектрального ускоркений для района плотины Ингури, изучена т.н. индуцированная сейсмичность, вызванная созданием и эксплуатацией резервуара Ингури;
- в сотрудничестве с геоморфологическим центром Франции-Европа в паневропейском стандарте создана карта оползневых и селевых опасностей Грузии.