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Increase of Order of Local Seismic Energy Release Caused by Water Level Variation in the Enguri High Dam Reservoir

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ABSTRACT. It was reported earlier that water level periodic variation in a high dam reservoir may lead to the synchronizing influence on local seismic activity. Taking into account that phase synchronization is not related to strong functional relationships, in the present study small dynamical changes in seismic activity caused by water level variation were investigated.

For this purpose the recurrence quantitative analysis (RQA) approach was used. Analysis was carried out on data sets of water level daily variation and released daily seismic energy.

It was shown that when the external influence on the earth's crust caused by reservoir water becomes periodic the extent of the regularity of earthquake daily distribution essentially increases.

Key words: *dynamics, phase synchronization, seismicity, water reservoir.*

In the present work the character of dynamical changes in the regional seismic activity under phase synchronizing influence of water level variation in a large reservoir was investigated.

Investigation of dynamical aspects of the influence of large water reservoirs on the generation of local earthquakes is one of the well recognized scientific and practical problems [1-3]. Reservoir induced seismicity (RIS) has been observed at many reservoirs. At the same time, the character of influence in the time period following the initial RIS activity is still an open problem.

In our previous research based on field and laboratory data the evidence was presented showing that the decrease of seismic energy after RIS period may be caused by the periodic variation of the water level in the large reservoir [4]. As far as we deal with the weakest form of synchrony - phase synchronization [5], in the present work we aimed to investigate the character of dynamical changes in regional seismic activity caused by the influence of water level periodic variation in the large reservoir.

The data sets of water level variation and seismic activity around Enguri high dam, used in the present study, were obtained from data bases of the M. Nodia Institute of Geophysics (Georgia). Namely, daily water level variation data were gathered at the Enguri high dam reservoir located in Western Georgia, Caucasus (42.030 N, 42.775 E) in 1973-1995. Data sets of daily occurred earthquakes and released daily seismic energy were taken for magnitude threshold $M \geq 1.6$ within 90km around the reservoir. Time series of sequences of magnitudes and time intervals between consecutive earthquakes, unevenly sampled for 1973-1995, were analyzed.

To investigate dynamical changes in target processes the Recurrence Quantitative Analysis (RQA) method was used. RQA is convenient for nonstationary

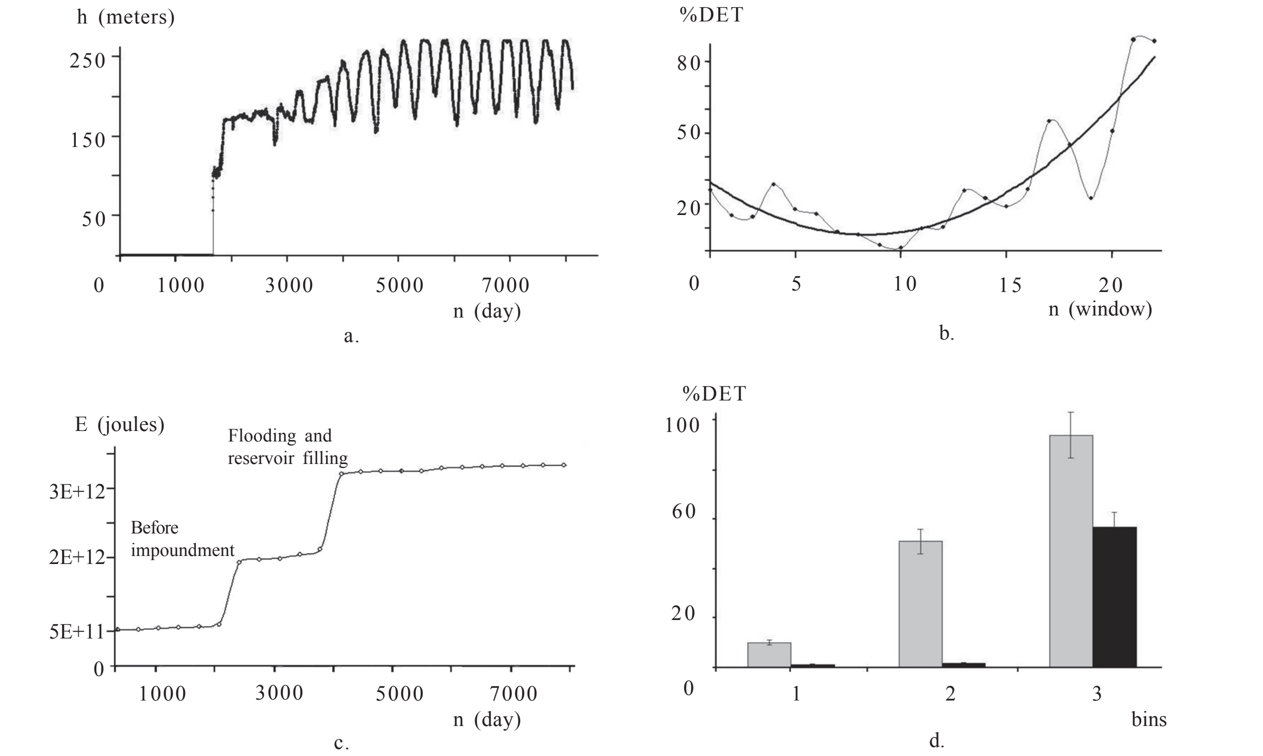

Fig. 1. a. Variation of water level in Enguri high dam reservoir above sea level in 1978-1995. b. RQA %DET of daily number of earthquakes calculated for consecutive one year sliding windows, c. Cumulative sum of released daily seismic energy. d. RQA %DET of magnitude (black columns) and interearthquake time interval (grey columns) sequences (1) before impoundment, (2) during flooding and reservoir filling and (3) periodic change of water level in reservoir.

and short real data sets [6]. In the present study recurrence determinism - *DET*(*t*) measure based on the analysis of diagonally oriented lines in the recurrence plot has been calculated [7].

According to recent publications, the dynamics of earthquake-related processes in the earth's crust are recognized as non-random, having both low and/or high dimensional nonlinear structures [8, 9]. One of the characteristic properties of processes in non-random systems, which are close to the critical state, is their high sensitivity to initial conditions as well as to relatively weak external influences. This is a general and very important property of practically unpredictable seismic processes. Indeed, insofar as we are not able to govern the initial conditions of lithospheric processes, even possibility in principle of controlling of the dynamics of seismic processes has immense scientific and practical significance. The way towards understanding such control mechanism lies through investigation of the dynamics of seismic processes, when a small external influence leads to phase synchronization.

The phase synchronization between water level periodic variation and seismic activity, observed in our previous and present studies, is recognized as the weakest form of synchrony when interacting nonlinear oscillators remain largely uncorrelated. Generally, interacting systems may have different dynamical features [5]. It is most important that, contrary to other forms of synchrony which lead to an increase of order in the behaviour of the synchronized system, phase synchronization does not require strong coupling between involved processes. This in turn means that the presence of order and character of the changes in dynamics of a phase synchronized system is not obvious.

We used RQA to investigate the character of dynamical changes in seismic process. As follows from our RQA results, when an external influence on the earth's crust caused by a water reservoir becomes periodic, the extent of the regularity of earthquake daily distribution (estimated as %DET) essentially increases (see Fig. 1b, bold line). This result was tested by comparing it with the surrogate data. It is important to mention that the influence of an increasing amount of water and its subsequent periodic variation essentially affects also the character of earthquakes magnitude and temporal distribution (see Fig. 1,c). The extent of order in the temporal (Fig. 1d, black columns) and magnitude (grey columns) distribution of the earthquakes, calculated as the value of %DET, substantially increases when the reservoir influence becomes periodic. Results of %DET calculation of corresponding surrogates are always less than 50%

of the original values (not shown here). It is interesting to note that the dynamics of earthquakes temporal and energetic distributions changes even under water level irregular variation, though not so much as under periodic variation.

Based on the results of our investigation, we conclude that the order in the dynamics of earthquakes daily occurrence, as well as in earthquake's temporal and energetic distributions increases when water level variation becomes periodic.

გეოფიზიკა

ენგურის წყალსაცავში წყლის დონის ვარიაციით გამოწვეული ლოკალური სეისმური ენერგიის გამოთავისუფლების მოწესრიგებულობის ხარისხის ზრდა

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ჩვენს წინანდელ ნაშრომებში ნაჩვენები იყო, რომ დიდ წყალსაცავში წყლის დონის პერიოდულმა ვარიაციამ შესაძლოა გამოიწვიოს ლოკალური სეისმური აქტივობის ფაზური სინქრონიზაცია. იმის გათვალისწინებით, რომ ფაზური სინქრონიზაციისას პროცესებს შორის ფუნქციონალური კავშირი სუსტია, ჩვენ ამ ნაშრომში მიზნად დავისახეთ შეგვესწავლა თუ როგორ იცვლება სეისმური პროცესის დინამიკური მახასიათებლები წყალსაცავში წყლის დონის ვარიაციის სხვადასხვა რეჟიმში.

ნაჩვენები იქნა, რომ წყალსაცავში წყლის დონის პერიოდული ვარიაცია განაპირობებს მიწისძვრების რაოდენობისა და გამოყოფილი ენერგიის განაწილების პროცესის მოწესრიგებულობის ხარისხის ზრდას.

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