საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 14, №3, 2020
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 14, no. 3, 2020

Geophysics

The Affectivity Assessment of the Hydrodynamic Indicator for Seismic Activities on the Basis of Local Borehole Network

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(Presented by Academy Member Tamaz Chelidze)

On the basis of the statistical analysis of the data obtained as a result of six-month continuous monitoring on the territory of Georgia we determined the relation of the rate of the water level change in the boreholes to tidal forces in the form of coefficients of long-term regression and correlation. We determined the degree of the functional relation between the values in correlation, which differ from each other for the borehole located in Kobuleti (41.436N, 44.755E) and the one in Marneuli (41.802N, 41.772E), though they are sufficiently stabile for both locations even in the case of reducing the time interval up to certain limits. However, it is especially noteworthy that further reduction (up to three days) of the time interval revealed significant "perturbations" of the regression coefficient. On the basis of the analysis conducted within the framework of this study we discovered that in the most cases the regression coefficient perturbation may be considered as a hydrogeological indicator for weak local earthquakes.

Water level, tidal variations, earthquake precursors

Recording of the geophysical precursors of earthquakes and determining the physical mechanics of their generation have been actual for many years. It is known that there are precursors, which enable to forecast the precise time, strength and location of an earthquake. Nowadays, making such a forecast is possible only by means of the joint analysis of different indicators for seismic activities. It is considered that the more are such indicators the more is the reliability of earthquake forecast. Indicators are characterized by different qualitative-quantitative manifestations during an earthquake preparation process, which is linked with a certain geological structure and the local properties of the nearby cosmic space. In this regard, the part of the Caucasus, which includes Georgia, is quite diverse. As a rule, this fact must contribute to detection of the effects connected to the increase of seismic activities.

One of above mentioned indicators is the water level, which has been observed since 2008. Nowadays, the network of the hydrogeodynamic observations in Georgia is presented by 10 observation boreholes. They were selected among many boreholes as far as they were the most sensitive to geodynamic stresses. The criteria of sensitivity were their ability to respond to the solar-lunar tidal and atmospheric pressure variations as well as their locations characterizing the main geological units.

This network enabled to reveal the hydrodynamic effects of several remote strong earthquakes that probably must be the result of the distribution of the seismic waves on a planetary scale. According to one of the models, the hypocenter depth characteristic of strong earthquakes is the main factor, which together with geological structure, enables to reveal underground hydrogeodynamic effects on long distances [1]. However, as it is shown below, besides the effects of far earthquakes, the data of the borehole observations also enable to quite effectively record the preparation processes of nearby weak and moderate earthquakes. We consider that this requires the records of tidal variations obtained by observing the water level variations in the boreholes. According to the existing data, this condition is well satisfied by the boreholes in Kobuleti and Marneuli, which are located in different geological mediums. This fact is the basis of the working hypothesis, according to which the image expressing the tidal variations is discarded by short-term spontaneous "perturbations" during an earthquake preparation process [2].

The Hydrogeodynamic Indicator for Earthquakes

The elastic properties of local geologic structures must have significant influence on the hydrologic parameters of boreholes. The anomalous variation of the water level in a borehole may generally be caused by the preparation process of a seismic phenomenon in the medium, i. e. the mechanical and thermodynamical variations taking place in the focus of the upcoming earthquake. In this case we have two mechanics of the generation of an anomaly. The first one is the wave mechanics of the distribution of the seismic process in the medium. It seems qualitatively obvious, though becomes problematic as the distance increases. Indeed, the activity of such mechanics in the borehole is more imaginable in the earthquake preparation process, but immediately after the earthquake, when shock waves are distributed in the medium. The other mechanics is the local deformation process, namely, when a deep borehole has opened the aquifer, which is located between waterproof layers at its top and bottom and is a kind of a strainmeter. It is sensitive to all kinds of deformation processes both indigenous (tidal variations, atmospheric pressure) and endogenous (an earthquake preparation process, creeps, etc.). Such deep boreholes have recorded 10-8 deformations, such as tidal variations.

Borehole sensitivity highly depends on the geologic medium (rock elasticity, etc.) and hydrologic properties (Table 1), e.g. the Kobuleti borehole located in a sandy medium and the Marneuli borehole located in a limestone environment have different quantitative reactions to tidal forces. However, only the elasticity and shear modulus of sandstones, limestones or basalt are not the main physical properties of a nonhomogeneous environment. It is obvious that

Table 1. The main borehole parameters included in the study

N	Location	Depth (m)	Diameter (mm)	Casing string (mm)	Filter (m)	Water level (m)	Lithology	Age
1	Kobuleti	2000	225 180 135	0-10 0-58 0-205	187-640	-0.5	Tuff, andesite, basalt	E3
2	Marneuli	3505	360 270 225 127	0-80 0-1258 1258-2527 2527- 3024	1235-1600	-8.5	Gravel, dolerite, marl, argillaceous tuff, diabase, basalt	N

borehole properties are significantly determined by the deep hydrogeological structure. Despite all that the relation of the water level to the variation of the tidal forces in a borehole in any medium must stay in the limits of more or less linear elasticity. However, after interference of an additional (geodynamic) force this relation must break down. In this regard, the retrospective analysis of the observation data of many years show that the failure of the stability of the long-term trend of the water level variation in a borehole is a determining sign of its effectiveness, as a hydrodynamic indicator for nearby earthquakes. As it appeared, among the Georgian borehole network this feature is characteristic of the boreholes of Kobuleti and Marneuli, which are significantly distant from each other. Additionally, the different geological media must be the basis of certain quantitative differences between the values of the regression and correlation coefficients characteristic of the boreholes. Exactly these parameters determine the character of relationship between the variation of the tidal forces and the water level or the rate of its change in the borehole.

The Quantitative Results

The statistical analysis included the data obtained during six months (01.01.2019-31.06.2019). For both boreholes we determined long-term semiannual (actually seasonal), medium-term (one month) and short-term (three days) correlation and regression coefficients, which build up relations between the variation of the vertical component of the tidal force and the rate of change of the water level in the borehole. The comparison of the instantaneous values was made in a one-minute discretization regime. Atmospheric pressure was measured together with the water level immediately at the location of the boreholes. The values of the tidal variations were calculated by special software (Dennis Milbert TIDE programme, https://geodesyworld.github.io/SOFTS/solid.htm). We filtered the data of the water level variation in the borehole to exclude the influence of short-term random factors caused by the effect of the atmospheric pressure in order to increase the reliability of the results.

Further, we carried out an analysis of the correlative relation between the water level variation and the tidal variations. Firstly, we determined the rate of change of the water level for the data with interval n=300 minutes. It appeared that the long-term and medium-term Pirson correlation coefficients of the Marneuli borehole are constant: $r \approx 0.99$,i.e., the determination coefficient is actually absolute: $D = r2 \approx 1$. It means that in the case of the Marneuli borehole the correlation relation is a sufficiently precise approximation of the functional relation.

We also calculated the long-term correlation coefficient for the Kobuleti borehole: r=0.87, whereas the medium-term correlation coefficient varies in interval: r=(0.83-0.90). Consequently, D=(0.69-0.81). Such a high level of determination means justifiability of a linear relation between the values being in the correlation. Fig. 1a is a graphical expression of the regression equation corresponding to the Marneuli borehole (A=0.194-regression coefficient; B=-0.00004 – absolute term, Std=0.0002 – error), whereas the normal Gauss distribution curve of the relevant histogram (Fig. 1b) proves the functional relation between the values being in the correlation. Let us note that despite the different value of the regression coefficient (A=0.119, B=-0.000007, Std=0.0003), which may be considered as the result of mainly the activity of the geological factor, qualitatively, we have a similar situation for the Kobuleti borehole. Thus, we may conclude that there is quite strong relation between the tidal forces and the hydrological properties of a borehole that is proved by the smallness of errors in the relevant regression equations.

Table 2 shows the long-term and medium-term regression coefficients for both boreholes. It is noteworthy that for any time interval, among them for three-day time interval as well, the value of the statistical error is very small in all cases.

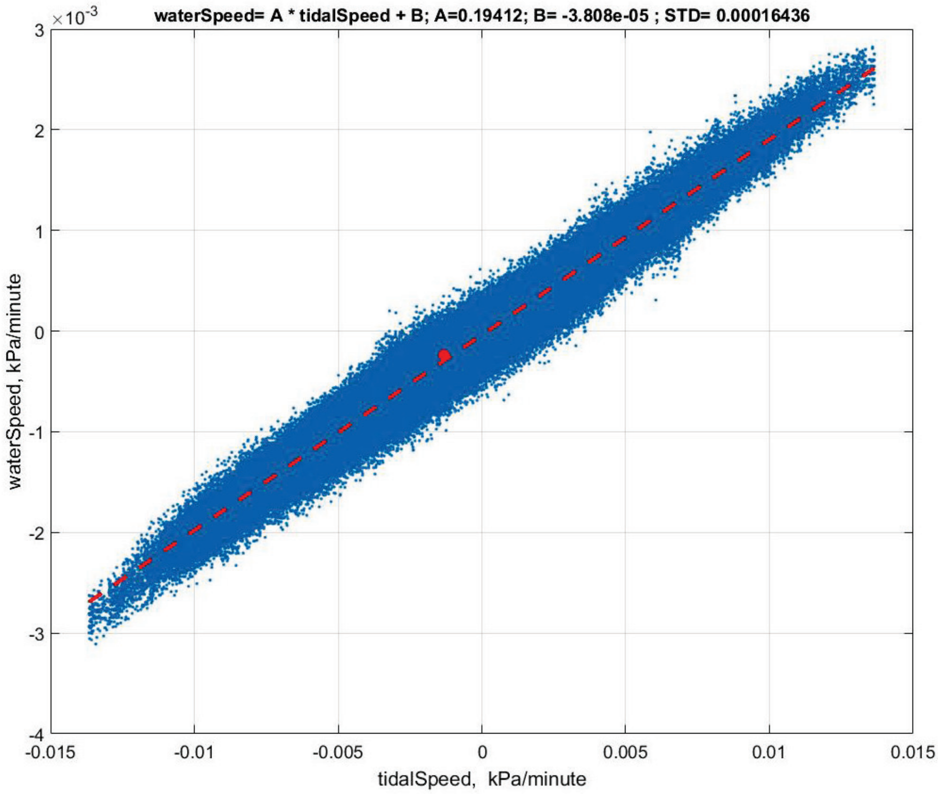

Fig. 1a. On X axis is the tidal force change (kPa) and on Y axis the water level change (kPa).

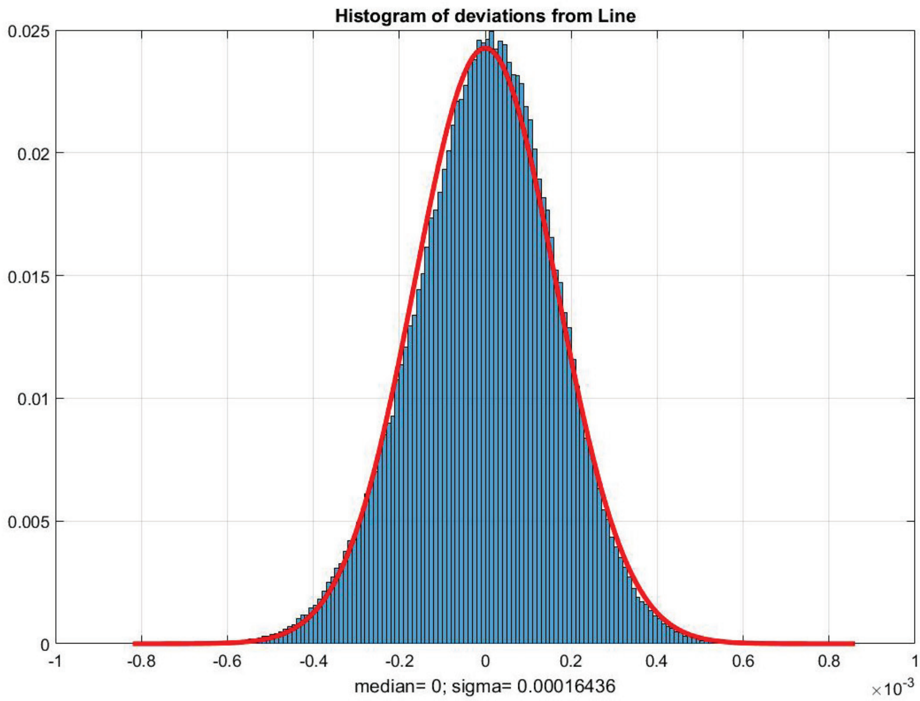

Fig. 1b. The histogram corresponding to Fig. 1a.

Table 2. Variations of coefficient A for Marneuli and Kobuleti in 2019

Time interval	Marneuli	Kobuleti
Long-time characteristic value (January-June)	0.194	0.119
January	0.200	0.118
February	0.193	0.119
March	0.191	0.127
April	0.189	0.123
May	0.192	0.117
June	0.195	0.113

28 earthquakes appeared in the probable area of the reaction of the Marneuli borehole, though the borehole reacted only to 15 of them. According to three-day data we revealed 17 cases of regression coefficient perturbation. In four cases of them the seismic sources were not registered in the probable areas. As shown in Table 3 the other 13 cases of the regression coefficient perturbations are probably connected with weak or moderate earthquakes (M=3.7-2.2) with short hypocentre distances. The occurrence times of the most of them are quite delayed in regards to the lower limit of the three-day interval. In this case the regression coefficient perturbation can be considered as an earthquake precursor. However, to assert its universality for all cases is incorrect.

Table 3. Marneuli.A=0.194, B=-0.00004, Std=0.0002. Marneuli more 5%, distance 200 km, A use 3 days, 300 minutes

N	dateStart	DateQuake [UT]	A	LatN [dg]	LongE [dg]	Magnitude	Depth [km]	Distance [km]
1	13/03/2019 00:00	14/03/ 05:51	0.206	40.26	45.05	2.2	10	133
2	25/03/2019 00:00	25/03/ 20:28	0.204	42.09	45.71	3.3	5	107.5
3	25/03/2019 00:00	26/03/ 09:31	_____	41.79	45.78	3.5	10	93.9
4	31/03/2019 00:00	01/04/ 16:09	0.181	41.22	43.76	2.3	2	86.5
5	31/03/2019 00:00	01/04/ 17:34	_____	42.08	45.87	3.6	2	117
6	31/03/2019 00:00	02/04/ 18:44	_____	43.17	44.98	3.6	10	194
7	24/04/2019 00:00	24/04/ 07:15	0.211	40.12	46.19	3.4	10	190
8	24/05/2019 00:00	24/05/ 16:28	0.205	41.37	44.03	3.5	2	60.9
9	08/06/2019 00:00	08/06/ 20:33	0.215	42.55	46.1	3.7	10	166
10	11/06/2019 00:00	12/06/ 08:44	0.173	41.73	43.13	3.6	2	139
11	11/06/2019 00:00	12/06/ 08:45	_____	41.77	43.12	3.3	1	140.9
12	11/06/2019 00:00	13/06/ 23:29	_____	40.68	44.78	2.5	10	84.1
13	26/06/2019 00:00	28/06/ 20:01	0.175	41.25	45.75	3.1	2	85.6

According to the working hypothesis the short-term perturbation by not less than 5% of the long-term value characteristic of the regression coefficient is the hydrogeodynamic indicator for a seismic phenomenon. Consequently, Table 3 shows the statistical results of the division of the long-term data array of the Marneuli borehole into a three-day array. It shows the statistical information corresponding only the cases when a local (regional) earthquake was recorded, and the value of the short-term regression coefficient differs from the long-term value characteristic of the borehole by not less than 5%: A=0.1935.

During six months there occurred 59 earthquakes in the radius of 200 km from the Marneuli borehole.

Table 4 corresponding to the Kobuleti borehole is qualitatively similar to Table 3, though there is a quantitative difference, namely, here we have 36 cases of regression coefficient perturbation, among which 20 cases were probably connected with earthquakes. There occurred 42 earthquakes in the radius of 200 km distance from this borehole and in 22 cases the borehole did not react to the seismic phenomena.

Table 4. Kobuleti . A=0.119, B=-0.000007, Std=0.00033)
Kobuleti more 5%, distance 200 km, A use 3 days, 300 minutes

N	dateStart	DateQuake	A	LatN [degree]	LongE [degree]	Magnitude	Depth [km]	Distance [km]
1	12/01/2019 00:00	14/01/2019 10:29	0.135	42.51	43.23	3	10	144
2	02/02/2019 00:00	04/02/2019 05:10	0.111	40.27	41.05	2.3	7	181
3	08/02/2019 00:00	09/02/2019 23:00	0.128	41.73	41.94	2.5	21	16.1
4	14/02/2019 00:00	14/02/2019 16:45	0.097	40.93	42.66	2.4	10	122
5	17/02/2019 00:00	19/02/2019 10:59	0.126	41.28	43.62	3	10	164
6	20/02/2019 00:00	20/02/2019 15:07	0.126	40.09	41.45	2.6	9	192
7	23/02/2019 00:00	25/02/2019 21:18	0.139	40.55	42.54	3.2	7	153
8	13/03/2019 00:00	15/03/2019 03:46	0.110	40.28	41.03	2.5	5	180
9	06/04/2019 00:00	06/04/2019 01:46	0.128	40.69	42.47	2.8	7	137
10	06/04/2019 00:00	06/04/2019 13:57	_____	40.78	42.81	2.4	7	143
11	06/04/2019 00:00	07/04/2019 17:37	_____	42.63	43.40	3.8	2	163
12	06/04/2019 00:00	07/04/2019 23:03	_____	41.49	43.37	2.8	2	137
13	09/04/2019 00:00	09/04/2019 02:59		41.53	43.67	2.6	2	161
14	09/04/2019 00:00	11/04/2019 09:12	0.133	40.54	41.73	2.3	8	140
15	24/05/2019 00:00	24/05/2019 16:28	0.094	41.37	44.03	3.5	2	194
16	24/05/2019 00:00	26/05/2019 08:48	_____	41.5	41.69	2	7	34.3
17	11/06/2019 00:00	12/06/2019 08:44	0.110	41.73	43.13	3.6	2	113
18	11/06/2019 00:00	12/06/2019 08:45	_____	41.77	43.12	3.3	1	112
19	23/06/2019 00:00	23/06/2019 14:49	0.093	40.94	39.83	2.1	18	188
20	23/06/2019 00:00	25/06/2019 22:39	_____	41.43	42.74	2.8	2	90.5

Conclusion

The work considers the water level variation in the boreholes in Kobuleti and Marneuli as hydrogeodynamic indicators for upcoming nearby earthquakes. The method is based on the determination of the relation of the water level change rate in a borehole to the tidal variations and observations on the regression coefficient value variation. The recorded deviations are probably the reactions of the boreholes to the preparation processes of nearby weak and moderate earthquakes. The basis of the conclusion is the statistical analysis of the six-month data array of the Kobuleti and Marneuli boreholes and short-term (three-day) data obtained as the result of its processing. Namely, the probability of the reactions of the boreholes to upcoming earthquakes is ≈ 45%.This result is noteworthy as taken into account that for today more than two dozens of earthquake precursors with different natures are being considered and none of them can forecast precise time and place of an earthquake occurrence [3]. The given method, which is sufficiently simple, can be also used for boreholes sensitive to other deformation processes (tidal variations). However, we should note that our method is not correct for especially seismically active zones (e.g., the boreholes in Oni and Ajameti).

The authors as recipients of Research State Grant №FR17_633 („Study of geodynamical processes evolution and forecasting") thank the Shota Rustaveli National Science Foundation of Georgia (SRNSFG), Tbilisi/Georgia.

გეოფიზიკა

სეისმური აქტივობის ჰიდროგეოდინამიკური ინდიკატორის ეფექტურობის შეფასება ჭაბურღილების ლოკალური ქსელის მონაცემებით

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მიწისძვრების ჰიდროგეოდინამიკური ინდიკატორების რაოდენობრივი მახასიათებლები დამოკიდებული უნდა იყოს გეოლოგიურ გარემოზე. ამ ეფექტის ცხადად წარმოჩენა შესაძლებელი აღმოჩნდა საქართველოში მოქმედი ჰიდროგეოდინამიკური მონიტორინგის ქსელში შემავალი ორი ერთმანეთისაგან საკმაოდ დაშორებული, ქობულეთისა (41,436N, 44,755E) და მარნეულის (41,802N, 41,772E) ჭაბურღილების საშუალებით.

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Received January, 2020