ARTICLE

ASSESSMENT OF THE GEODYNAMIC SENSITIVITY OF THE METHOD OF EXPRESS CONTROL OF GROUNDWATER QUALITY

R.V. Romanov[1], O.R. Kuzichkin[2], N.V. Dorofeev[1], A.V. Grecheneva[2*], E.S. Mikhaleva[2], D.I. Surzhik[2]

[1] *Department of Electronics, Vladimir State University, 87 Gorkiy St., 600000, Vladimir, RUSSIA*

[2] *Institute of Engineering Technology and Natural Science, Belgorod State University, 85 Pobedy St, 308015, Belgorod, RUSSIA*

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ABSTRACT

The article assesses the sensitivity of the geoelectric express control method for a bipolar geoelectric installation. With an increase of the sensitivity of geoelectric measuring systems, the influence of temperature in the geological environment on measurements increases significantly and is the most significant interference-generating factor. In this regard, the article discusses the use of temperature correction algorithms. The geodynamic sensitivity of the geoelectric method for express control of the aquifer parameters was estimated based on analytical relations for the signal-to-noise ratio. The article also presents the structure of the measuring complex for geoecological monitoring. A generalized calculated geoelectric scheme based on the principle of imaginary sources, explaining the principle of the geoelectric method of express control of the aquifer, is given. To assess the sensitivity of the geoelectric method, measuring observations were conducted by the measuring complex for geoecological monitoring in the coastal zone of Lake Svyato (Nizhny Novgorod Region, Russian Federation). The data obtained show a rather high sensitivity of the geoelectric express control method to hydrogeodynamic variations in the parameters of the upper aquifer.

KEY WORDS
sensitivity, express control, groundwater monitoring, electrical conductivity

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***Corresponding Author**
Email: grecheneva_a@gmail.com

INTRODUCTION

At present, monitoring systems for controlling zones of decentralized water supply are used. The purpose of automated control systems for decentralized water supply at the local level is to constantly monitor the level regime and quality of the waters of the upper aquifer, as well as the development of measures to eliminate the causes of pollution. The basis of its construction is the geoelectric methods of express analysis of the upper aquifer by a generalized parameter - electrical conductivity [1, 2]. The choice of the electrical conductivity of water as a generalized parameter of water quality is determined by its information content and the high adaptability of geoelectric methods for monitoring this parameter in real time. In addition, this makes it possible to use distributed geoelectric measurements for hydrogeological assessment of the development of exogenous and endogenous geological processes in the study area [3, 4].

When geoecological monitoring of groundwater using geoelectric methods of express control, spatiotemporal variations of the aquifer level and groundwater conductivity are used as unified hydrogeological indicators [5]. The indicators obtained during geological monitoring make it possible to formulate an assessment of the development of negative hydrogeological processes in the territories of decentralized water supply. Modern systems of geological monitoring, built on the basis of geoelectric sounding methods, are highly sensitive to geodynamic changes in the geological environment, which leads to their high efficiency of use when monitoring the aquifer [6]. However, with increasing sensitivity of geoelectric measuring systems, the effect of temperature on measurements in the geological environment increases significantly. In this case, temperature changes in the geological environment are the most significant interference-generating factor. The temperature effect distorts the time series of the recorded data, and require mandatory temperature correction of the results of geoecological monitoring of the aquifer [7].

The aim of the work is to assess the sensitivity of the geoelectric express control method for the bipolar implementation option, taking into account the use of temperature correction algorithms.

METHODS

Principles of express control of aquifer parameters based on geoelectric methods

For the organization of geoecological monitoring of water resources, an effective approach is the use of various methods of geoelectric control [8-11]. At the same time, the measuring complex of geoecological monitoring includes an electro-locating unit, which serves to collect and process primary control data [12]. As a result of the interpretation of the sounding data, the structure depth and geoelectric parameters of the aquifer are determined. The electrolocation complex consists of a control unit for processing and analyzing data, radiating electrodes AB, sensors for measuring the electromagnetic field MN, temperature gradient sensors T1 T2 and wires.

The structure of the measuring complex for geoecological monitoring of the aquifer is shown in [Fig. 1].

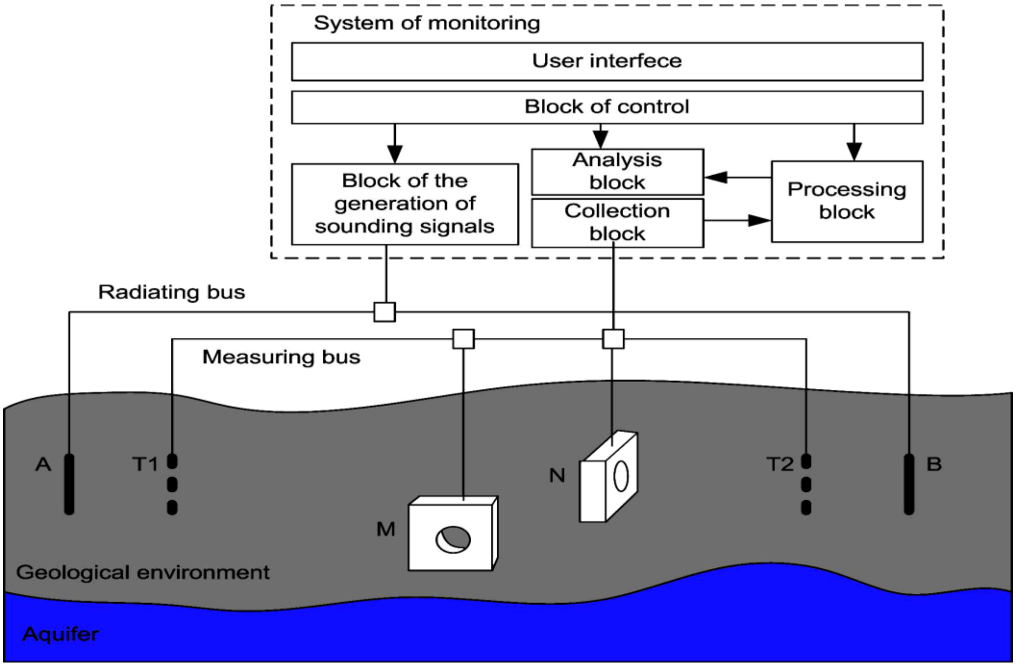

Fig. 1: The structure of the measuring complex for geoecological monitoring of the aquifer.

The parameters of the probing signal reflect the electromagnetic properties of the hydrogeological environment. Further, from the sensors M and N at the measurement points after pre-processing, an analysis of the parameters of the hydrogeological environment. To eliminate the influence of temperature interference, a gradient temperature measurement is carried out along the depth and area with temperature sensors T1,T2 [7,13]. When monitoring the geological environment, it is most rational to use non-contact transformer sensors (NTS) of the electric field [14]. They do not have galvanic contact with the medium and eliminate all kinds of excessive electrochemical noise.

[Fig. 2] shows a generalized calculated geoelectric scheme explaining the principle of the geoelectric method of express control of the aquifer, built on the principle of imaginary sources [15].

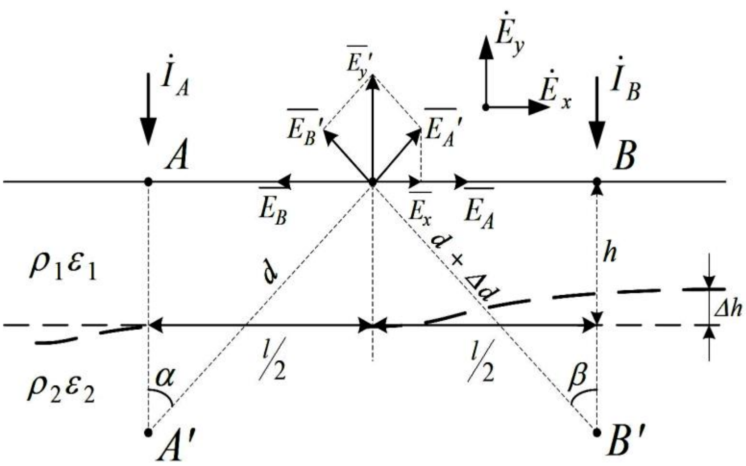

Fig. 2: Estimated geoelectric scheme.

In this case, the total recorded signal at the observation point $O(x, y)$ is determined by the superposition of normal signals generated by the sources of the probing signal A and B in the surface layer with parameters σ_1, ε_1, and signals from imaginary sources A' and B'.

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Signals of imaginary sources determine the level of occurrence h , and geoelectric parameters of the aquifer σ_2, ε_2.

In accordance with the calculation scheme, the basic relations for the geoelectric field at the observation point are as follows:

$$E_y = E_A - E_B + E'_A \sin\alpha - E'_B \sin\beta,\ E_x = E'_A \cos\alpha + E'_B \cos\beta,$$
$$\alpha = arctg(l/2h),\ \beta = arctg(l/2(h - \Delta h)),\ d = sqrt(4h^2 + l^2/4). \quad (1)$$

Passing to the geodynamic parametric transfer functions of the hydrogeological section for a bipolar sounding installation [16], we obtain:

$$\dot{H}_x = \frac{K(j\omega)l}{2\pi(\sigma_1 + j\omega\varepsilon_1)d^3}(1 + (1 - \frac{3\Delta d}{d})\frac{\dot{I}_B}{\dot{I}_A}),$$
$$\dot{H}_y = (\frac{4}{\pi(\sigma_1 + j\omega\varepsilon_1)l^2} + \frac{K(j\omega)h}{2\pi(\sigma_1 + j\omega\varepsilon_1)d^3})(1 - \frac{\dot{I}_B}{\dot{I}_A}) + \frac{K(j\omega)\Delta d(3d^2 - 12h^2)}{2\pi(\sigma_1 + j\omega\varepsilon_1)d^4 h}\frac{\dot{I}_B}{\dot{I}_A} \quad , \quad (2)$$

where $K(j\omega)$ - contrast ratio.

For low-frequency methods of geoelectric control, when measuring sensors are located on the day surface of a geoelectric section, the hydrogeodynamic trend can be determined in accordance with the following relation:

$$H(\Delta d, \sigma_2) = \frac{3l\Delta dK}{2\pi\sigma_1 d^4} \quad (3)$$

Compensation of the influence of temperature interference on the parameters of the geoelectric model

When using the geoelectric method of express control of the aquifer, the geodynamic variations of individual selected layers are well described when expression (2) expressing by the transfer function of the form [17]:

$$H(j\omega, \overline{\sigma}, \overline{\varepsilon}, T) = \sum_{i=1}^{m} A_i(\overline{\sigma}, \overline{\varepsilon}, T)/(B_i(\overline{\sigma}, \overline{\varepsilon}, T) + j\omega) \ , \quad (4)$$

where the coefficients A_i and B_i are the functional dependences on the electromagnetic and spatial parameters of the media that make up the geoelectric section, is the temperature on the surface of the medium.

The electromagnetic properties of geological media (specific conductivity and permittivity) are determined primarily by the water content in the rocks that make up the geological environment. The active component of the electrical conductivity of rocks is formed due to the conductivity of the main porous structure and pore filler σ_R. In this case, the effect of temperature on the active component of the conductivity of the medium can then be described by the following linear equation:

$$\sigma = \sigma_C + \sigma_R - (\alpha_C + \alpha_R)T \ , \quad (5)$$

where α_C and и α_R are the parametric temperature coefficients.

When applying low-frequency electrical prospecting methods in geodynamic control systems, the imaginary component of the geoelectric field, which is determined by the dielectric of the water saturating the rock, should be taken into account. Moreover, the dielectric constant of water in the low frequency region is an order of magnitude higher than that of most minerals = 80 (at 20 degrees C). Numerous researches have shown that the temperature dependence of the dielectric constant of aqueous solutions is well described by a linear equation [18]:

$$\varepsilon_R = \varepsilon - \beta_R T \quad (6)$$

Mineralization determines the parametric nature of the effect of temperature on the electromagnetic characteristics of the researched geological environment, what should be taken into account when constructing processing algorithms in automated systems for express monitoring of groundwater quality.

In accordance with the accepted horizontally layered model of the geoelectric section in accordance with (5.6), the temperature effect can be taken into account through the generalized linear dependence of the complex conductivity of the upper layer of the geoelectric section [19].

$$H(j\omega,\overline{\sigma},\overline{\varepsilon},T)=H_1(j\omega,\sigma_1,\varepsilon_1,T_0)\alpha_T\Delta T+\sum_{i=1}^{m}A_i(\overline{\sigma},\overline{\varepsilon},T_0)/(B_i(\overline{\sigma},\overline{\varepsilon},T_0)+j\omega) \quad (7)$$

Based on (5,6), we have a linear regression relation uniting the time intervals and allowing to distinguish the hydrogeodynamic trend of the aquifer, which can be given to the following form:

$$H(j\omega,\overline{\sigma},\overline{\varepsilon},T)=H(j\omega,\overline{\sigma},\overline{\varepsilon},T_0)+H_1(j\omega,\sigma_1,\varepsilon_1,T_0)\alpha_T\Delta T+\Delta H_i(j\omega,\overline{\sigma},\overline{\varepsilon},T_0) \quad (8)$$

where i is the number of measurement intervals, is the generalized temperature coefficient, is the average generalized temperature, is the temperature deviation from the average.

Based on the regression relations, assuming that the hydrogeodynamic trend is stationary within the measurement interval, for each time interval, the transfer function variations are determined by temperature waves in the surface layer of the geoelectric section. Upon receipt as a result of regime observations, N is the number of intervals for monitoring the hydrogeodynamic process; M is the number of measurement points in the control interval, the temperature correction algorithm can be built on the basis of regression analysis of the data [20].

As a result, the generalized temperature coefficient is defined as:

$$\alpha_T=\frac{\sum_{i=1}^{N}\sum_{j=1}^{M}H_{ij}\left(T_{ij}-\frac{1}{M}\sum_{j=1}^{M}T_{ij}\right)}{\sum_{i=1}^{N}\sum_{j=1}^{M}T_{ij}\left(T_{ij}-\frac{1}{M}\sum_{j=1}^{M}T_{ij}\right)}. \quad (9)$$

Where do we get the calculated value of the geodynamic variations of the transmission coefficient Δi:

$$\Delta_i=\frac{1}{M}\sum_{j=1}^{M}H_{ij}-\frac{1}{M}\sum_{j=1}^{M}T_{ij}\cdot\frac{\sum_{i=1}^{N}\sum_{j=1}^{M}H_{ij}\left(T_{ij}-\frac{1}{M}\sum_{j=1}^{M}T_{ij}\right)}{\sum_{i=1}^{N}\sum_{j=1}^{M}T_{ij}\left(T_{ij}-\frac{1}{M}\sum_{j=1}^{M}T_{ij}\right)} \quad (10)$$

Denote by, $\overline{H_M}=\frac{1}{M}\sum_{j=1}^{M}H_{ij}$ and $\overline{T_M}=\frac{1}{M}\sum_{j=1}^{M}T_{ij}$, then the geodynamic trend taking into account the temperature correction can be determined by the following relation:

$$\Delta_i=\overline{H_M}-\overline{T_M}\cdot\frac{\sum_{i=1}^{N}\sum_{j=1}^{M}H_{ij}\left(T_{ij}-\overline{T_M}\right)}{\sum_{i=1}^{N}\sum_{j=1}^{M}T_{ij}\left(T_{ij}-\overline{T_M}\right)}. \quad (11)$$

The above relations (7-10) are of a general nature, allowing one to formalize the preliminary stage of processing geoelectric data at local control levels, taking into account temperature variations in the geological section. In this case, when assessing the sensitivity of the applied control method, it should be taken into account that the regression temperature correction algorithms reduce the temperature noise to the level of white noise with intensity

$$\Delta H_T=H_1(j\omega,\sigma_1,\varepsilon_1,T_0)\alpha_T\int_M\Delta T^2\partial t(1-\mathrm{mod}\,R_T) \quad (12)$$

where is the correlation coefficient of the regression analysis of the temperature dependence.

Assessment of geodynamic sensitivity

Assessment of the geodynamic sensitivity of the geoelectric method of express control of the parameters of the aquifer can be carried out on the basis of analytical relations for the signal to noise ratio. Assuming that after temperature correction the interference $\xi(t)$ is stationary and has an average value of zero. In this case, the deviations of the measured parameters $\Delta\delta_k=\{\Delta h,\Delta d,\Delta\sigma\}$ are also equal to zero on average. Suppose that the largest allowable parameter changes during measurements are equal $\Delta\delta_{km}$. Then the signal-to-noise ratio can be written as

$$D_k=(\Delta\delta_{km})^2/D[\Delta\delta_k] \quad (13)$$

where $D[\delta_k]$ is the dispersion of noise in hydrogeodynamic parameters, determined by the noise.

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Under the assumption that the observation interval is determined by the assumed width of the spectrum of hydrogeodynamic processes. In this case, the noise dispersion is determined in accordance with equation (12), and for low-frequency methods of express control it has the following form:

$$D[\xi] = \int_{t=0}^{\tau} (H_1(\sigma_1, T_0)\alpha_T \int_{t=0} \Delta T^2 \partial t(1 - \mathrm{mod}\, R_T) - \overline{H}_1(\sigma_1, T_0))^2 \partial t \quad (14)$$

RESULTS AND DISCUSSION

Results of experimental studies and conclusions

Hydrogeological monitoring was carried out in the coastal zone of Lake Svyato. This is a large karst lake in the study area of the Nizhny Novgorod region up to 20 m deep. It was formed as a result of the merger of several karst sinkholes. Steep coasts 2-3 meters high are strongly indented by many capes and bays. There are several large islands on the lake. The lake is flowing, the bottom is sandy with a thick layer of silt, with water transparency up to 3 meters. The observations were carried out from May 1, 2017 to October 25, 2017 in the area of the location of the well of the water supply of the tourist camp. The first horizon of the study area refers to Quaternary and alluvial sands, the second to fractured and destroyed rocks of the Kazan and Sakmara tiers. Quaternary alluvial deposits of the second floodplain of the Teshi River pass on the research site. In the upper part of the stratum, the sands are fine-grained, with a depth turn into different-grained. The water at the source of lake Svyato and in the lake itself is characterized by very low mineralization. According to the analysis, its mineralization is 0.01 g/liter. The chemical composition of the water is sulfate-calcium-magnesium. In the samples of water from the well (depth 18 m) on the territory of the Svyato Lake, the water is fresh, aggressive towards sulfates and carbonates. According to the chemical analysis of water horizon sulfate-calcium-sodium. The mineralization of the aqueous solution is 0.07 - 0.26 g/liter. According to these calculations, in the coastal zone of the lake, groundwater is aggressive towards carbonate and not aggressive towards sulfate rocks.

As can be seen from the data presented during the entire observation period, the piezometric level of karst waters is very close to the level of ground above-karst waters (figure 3). Moreover, in the observed period, there is an excess of the levels of above-ground karst water over the piezometric pressure of karst water, together with a rise in the general level of the first aquifer. This difference according to observations ranged from 0.7 to 1.6 meters.

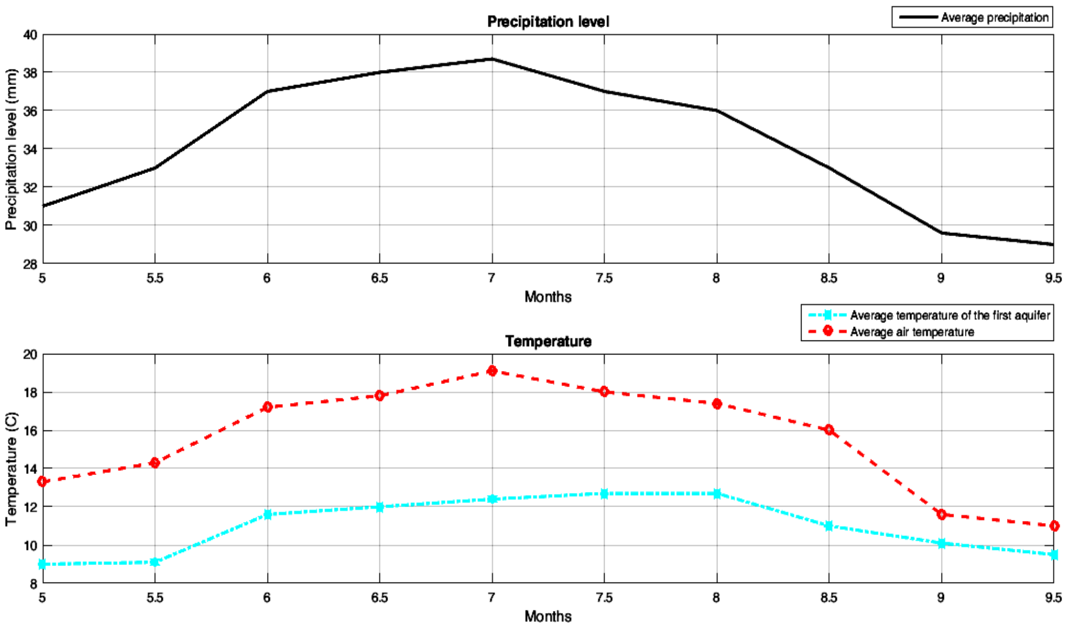

Fig. 3: Data from hydrogeological observations and average temperature.

Data on average temperature are obtained on the basis of regression processing of geoelectric signals, on the basis of the above algorithms obtained using a two-pole electrical complex of express control. The measuring geoelectric system was placed as follows. Radiating electrode A was removed from the lake by a distance l1 = 5meters; the first and second blocks of the proximity transformer sensor (NTS1 and NTS2) are located at a distance of l3 and l4 from the radiating electrode (provided that l3 = l4 = 30metres); electrode B is installed at the greatest possible distance l2 = 250 meters from the radiating electrode A. 16 daily intervals were treated [Fig. 4].

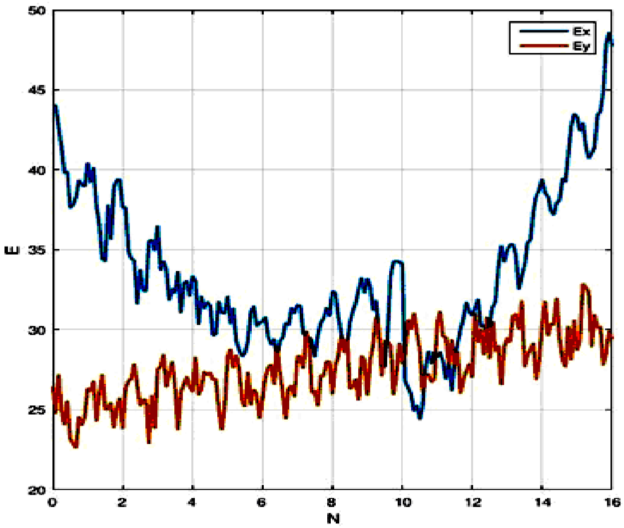

Fig. 4: Data of operational observations of a bipolar geoelectric complex of express control.

[Table 1] shows the data on the assessment of sensitivity at 16 measurement intervals.

Table 1: Data for determining the sensitivity of the geoelectric express control method

№	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
D_σ dB	32	33,5	33,6	34,2	35	34,6	33,9	34,7	35,3	36,7	37	37,8	38,3	39,1	40	41,2
D dB	37	36,4	36,3	35	33	33	33,3	34,3	34,8	37,1	37	38,2	38,4	39,1	39	39,4

CONCLUSION

The data obtained show a rather high sensitivity of the geoelectric express control method to hydrogeodynamic variations in the parameters of the upper aquifer. At the same time, the average sensitivity of a bipolar geoelectric express control system is 0.32% in conductivity, and 0.45% in terms of probability of correct detection of 0.95. It should be noted that an increase in the sensing poles makes it possible to obtain more accurate information about the hydrogeological variations of the studied hydrogeological zone.

CONFLICT OF INTEREST

There is no conflict of interest.

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FINANCIAL DISCLOSURE

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REFERENCES

[1] Belyustin AA. [2015] Potentiometry: physicochemical fundamentals and applications. St. Petersburg: Publishing House, 336, RU.

[2] Budnikov GK, et al. [2003] Fundamentals of modern electrochemical analysis. World Binom LZ, 592.

[3] Sharapov RV, Kuzichkin OR. [2014] Geodynamic monitoring in area of nuclear power plant. Applied Mechanics and Materials, 492:556-560.

[4] Dorofeev NV, et al. [2017] Spatio-temporal data processing of automated geodynamic monitoring system. Proceedings of the 2017 IEEE 9th International Conference on Intelligent

Data Acquisition and Advanced Computing Systems: Technology and Applications, IDAACS, 1:231–237.
[5] Romanov RV, Kuzichkin OR, Tsaplev AV. [2015] Geoecological Control of the Aquifer in the Decentralized Water Supply Systems of the Local Level. 8th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems, 42–46.
[6] Yakubovsky YuV, Renard IV. [1991] Electrical Intelligence. 3rd Edition. Moscow, RU, 358.
[7] Kuzichkin OR, Tsaplev AV. [2007] Temperature correction of the results of geomonitoring studies based on parametric models of media. Design and technology of electronic means. 2:39–43.
[8] Zhdanov MS. [1986] Electrical Intelligence: Textbook for universities. Moscow, RU
[9] Zhdanov MS. [2007] The theory of inverse problems and regularization in geophysics. Scientific world, RU.
[10] Khmelevskoy VK. [1984] Electrical intelligence. Publishing House of Moscow State University, 422.
[11] Gavrilov VA, et al. [2006] Experience of integrated well geophysical observations in order to monitor the state of the geomedium. Earth Science Series, 2(8):43-53.
[12] Grecheneva AV, Kuzichkin OR, Romanov RV, Bykov AA. [2017] Analysis of influence of endogenous factors on results of geoecological express-control of water resources. Journal of Engineering and Applied Sciences, 12(24):6852-6857
[13] Kuzichkin OR, et al. [2017] Geodynamic monitoring of development of a karst on the basis of georadar sounding. Proceedings of the 2017 IEEE 9th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, IDAACS 2017, 1:227-230
[14] Orekhov AA, Dorofeev NV, Romanov RV. [2013] Technical diagnostics in blocks transformer sensors geodynamic control systems. Mechanical engineering and life safety, 2(16): 29-32.
[15] Tsaplev AV, Romanov RV, Kuzichkin OR. [2015] Estimation of bias currents in the electrolocation monitoring system of the upper aquifer. 15th International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM Albena; Bulgaria, 18(24):213-220.
[16] Bykov AA, Kuzichkin OR. [2014] Regression prediction algoritm of suffusion processes development during geoelectric monitoring. Advances in Environmental Biology, 8:1404-1410.
[17] Kuzichkin OR. [2009] Approximation of equivalent transfer functions of a geoelectric section in geodynamic control. Methods and devices for transmitting and processing information, 11:172-177.
[18] Recommendation of the International Telecommunication Union. [2018], Electrical characteristics of the earth's surface. P series Radio wave propagation Geneva. https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.527-4-201706-I!!PDF-R.pdf
[19] Kuzichkin O, Chaykovskay N. [2011] Spectral processing of the spatial data at geoelectric monitoring. International Conference on Multimedia Technology, IEEE ICMT, Hangzhou, China, 765-768.
[20] Tsaplev AV, Kuzichkin OR. [2012] The use of regression processing to compensate for temperature interference in geoelectric control systems. Radio industry, 2:147-153.