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

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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 geoeological 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 geoeological 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.

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 geoelectrical 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 geologic 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 geoeological 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 geoelectrical 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 geoelectrical 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.](image)

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.](image)

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 \( \sigma_1, \varepsilon_1 \), and signals from imaginary sources \( A' \) and \( B' \).
In this case, the effect of temperature on the electromagnetic field at the observation point are as follows:

$$E_y = E_A - E_B + E'_A \sin \alpha - E'_B \sin \beta, \quad E_x = E'_A \cos \alpha + E'_B \cos \beta,$$

$$\alpha = \arctg(1/2h), \quad \beta = \arctg(1/2(h - \Delta h)), \quad d = \sqrt{4h^2 + l^2/4}. \quad (1)$$

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

$$\hat{H}_x = \frac{K(j\omega)h}{2\pi(\sigma_1 + j\omega \varepsilon_1)ld^3(1 + (1 - \frac{3\Delta d}{d}) \frac{l}{I_\alpha})},$$

$$\hat{H}_y = \left( \frac{4}{\pi(\sigma_1 + j\omega \varepsilon_1)d^3} \right) + \frac{K(j\omega)h}{2\pi(\sigma_1 + j\omega \varepsilon_1)ld^3(1 - \frac{l}{I_\alpha})} + \frac{K(j\omega)ld(3d^3 - 12h^3)}{2\pi(\sigma_1 + j\omega \varepsilon_1)ldh} \frac{l}{I_\alpha}$$

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 hydrodynamic trend can be determined in accordance with the following relation:

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

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 the transfer function of the form [17]:

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

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, $T$ 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 $\sigma_R$. 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 $\alpha_C$ and $\alpha_R$ 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].

The electromagnetic field is described by the Laplace equation:

$$\nabla \cdot \mathbf{D} = \rho \quad (7)$$

$$\nabla \times \mathbf{H} = \mathbf{J} \quad (8)$$

where $\mathbf{D}$ and $\mathbf{H}$ are the electric and magnetic fields, respectively, $\rho$ is the electric charge density, and $\mathbf{J}$ is the current density.
Assessment of the geodynamic sensitivity of the geoelectric method of express control of the parameters of the aquifer

The 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 \( \Delta \delta_i = \{ \Delta h, \Delta d, \Delta \sigma \} \) are also equal to zero on average. Suppose that the largest allowable parameter changes during measurements are equal \( \Delta \delta_{\text{im}} \). Then the signal-to-noise ratio can be written as

\[
D_k = (\Delta \delta_{\text{im}})^2 / D[\Delta \delta_i]
\]

where \( D[\Delta \delta_i] \) is the dispersion of noise in hydrogeodynamic parameters, determined by the noise.
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:

\[
D[\xi] = \frac{1}{\tau} \left( H_1(\sigma_I, T_0) \alpha_T \int_{t=0}^{T} \Delta T^2 \partial_\tau (1 - \text{mod} R_T) - \bar{H}_1(\sigma_I, T_0))^2 \partial_\tau \right) \quad (14)
\]

RESULTS AND DISCUSSION

Results of experimental studies and conclusions

Hydrogeological monitoring was carried out in the coastal zone of Lake Svya-to. 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 Svya-to 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 Svya-to 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.
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 |
|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| $D_\sigma$ dB | 32 | 33.5 | 33.6 | 34.2 | 35 | 34.6 | 33.9 | 34.7 | 35.3 | 36.7 | 37 | 38.3 | 39.1 | 40 | 41.2 |
| $D$ dB | 37 | 36.4 | 36.3 | 35 | 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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