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Algorithm for a Forecast Assessment of Negative Changes in Underground Water in the Territory of Non-Centralized Water Supply

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Abstract. The water quality of non-centralized water supply sources largely depends on the presence of active karst processes. Underground waters of karst origin are a vulnerable component of the geological environment to the influence of modern anthropogenic factors that violate natural hydrogeological and geoecological conditions. One of the indicators of the development of karst processes is the level of river runoff and mineralization of underground water. The results of the analysis of these data make it possible to increase the efficiency of geoecological monitoring systems and to increase the accuracy of forecast estimates of negative changes in groundwater in the territory of non-centralized water supply. When processing heterogeneous spatial data, it is proposed to identify anomalous deviations of parameters. An algorithm has been developed that determines the critical states of karst water vulnerability indicators. A system of equations has been compiled to find the necessary value of the indicators of vulnerability of karst waters, at which the state of underground water passes into a critical state. The paper analyzes data on the salt content and electrical conductivity of groundwater at key points and the number of karst dips. Preliminary hydrogeological work was carried out to determine the conditions of movement of karst waters associated with the lithological heterogeneity of the massif and the degree of karst formation. The results obtained can be used to improve the regional model for assessing the resources of vulnerability and protection of groundwater and forecast the activation of destructive karst processes.

1. Introduction

Underground waters of karst origin are a vulnerable component of the geological environment to the influence of modern anthropogenic factors that violate natural hydrogeological and geoecological conditions [1,2]. The water quality of non-centralized water supply sources largely depends on the presence of active karst processes [3]. One of the indicators of the development of karst processes is the level of river runoff and mineralization of groundwater. This feature of the rivers makes it possible to organize regime geoecological monitoring of the development and forecast the activation of destructive karst processes [4,5]. Also, an important role in the forecast of negative changes in groundwater in the territory of non-centralized water supply is played by the assessment of the karst hazard of the area. These estimates are given to assign a specific area to a particular category of karst hazard [4] and in the future play a significant role in obtaining a forecast assessment of changes in the geological environment.

In the presence of active karst processes and under difficult hydrogeological conditions on the territory of settlements, the state of groundwater is constantly in critical situations. Management in these conditions requires, as a rule, cardinal decisions with their implementation in the shortest possible time.

Therefore, the development of an algorithm for the formation of a predictive assessment of negative changes in groundwater in critical situations is an urgent task.

2. The main factors affecting the quality of groundwater

To assess the vulnerability of sources of non-centralized water supply, a factor O including such indicators as lithology, soil thickness, and the presence of a karst base is taken into account. The most intensive karst processes occur on river terraces, valley slopes. Factor C includes the level of river flow at hydrogeological stations, groundwater flow, sinkholes, tectonic faults and vegetation. The development of karst is also facilitated by high gradients of underground flow and groundwater outflows in river beds and coastal slopes [6,7]. For this, factor K is taken into account, which is formed on the basis of the criterion of the development of the karst network and the hydrographic network. A relatively large amount of precipitation, especially in the form of rain, and low evaporation determine the increased values of surface and underground runoff, the greater intensity of water exchange and water circulation in the near-surface horizons of rocks and, accordingly, the development of dissolution and leaching processes. Factor P takes into account the amount of liquid and solid sediments involved in feeding karst waters [8].

Among the external factors, the solubility of minerals is significantly affected by the total mineralization and chemical composition of the dissolving waters [9]. The L factor characterizes the electrical conductivity, mineralization and temperature of karst groundwater. The hydrogeochemical assessment of the intensity of the development of the karst process is carried out according to the degree of aggressiveness of groundwater in relation to karst rocks, i.e. the amount of water-soluble rock that can go into solution, and the amount of water-soluble rock carried out by groundwater per unit area [10,11].

3. Algorithm of ranking zones of control

When processing heterogeneous spatial data, it is necessary to identify anomalous deviations of parameters (total mineralization and chemical composition of groundwater) based on algorithms for ranking control zones [12]. In this case, an MxNxL matrix is created for each monitoring area, where M - longitude, N - latitude, L - depth. Since the change in the quality of underground karst waters is influenced by many parameters, correction factors should be introduced that take into account external destabilizing factors [13].

To locate near-surface irregularities in the original three-dimensional matrix A{N;M;L}, linear and nonlinear processing is carried out in order to identify sharp drops in the three-dimensional picture of the distribution of predicted estimates of changes in the geological environment. The result is a three-dimensional matrix A'{N;M;L}, the value of the elements of which is different from zero only in the areas of sharp changes. After that, threshold treatment is carried out to identify areas of negative changes in groundwater in the territory of non-centralized water supply.

4. Algorithm for formation of forecast assessment

The task of predicting a critical situation is to determine the time at which the parameters characterizing the quality of groundwater will take critical values, as well as to assess the general state of karst groundwater.

As a rule, critical values are determined using the method of expert estimates and the results of processing experimental data [14]. Let's take an approach, the essence of which is that the critical states of the indicators of vulnerability of karst waters $U_I=\{O,C,K,P,L\}$ are proportional to their potentials. Indicators of groundwater quality can go into a critical state if the potential of indicators of vulnerability of karst waters U_I is reduced to the value of U_{min}. To find the necessary value of indicators of vulnerability of karst waters U_I, at which the state of underground water passes into a critical state, a system of equations is compiled. When solving the system, the maximum of the function (Φ) is found under the constraints:

$$\begin{cases} \Phi = \max\left\{ \dfrac{U_{\min}}{\sum\limits_{i=1}^{n} m_i^{(0)} \cdot K_U} \right\}; \\ U_i - U_i(K_p \cdot m_i) = 0; \\ \sum\limits_{i=1}^{n} \left[U_i \cdot \dfrac{m_i \cdot K_U}{\sum\limits_{i=1}^{n} m_i^{(0)} \cdot K_U} \right] - U_{\min} = 0; \\ \left\{ \dfrac{\sum\limits_{i=1}^{n} m_i \cdot K_U}{\sum\limits_{i=1}^{n} m_i^{(0)} \cdot K_U} \right\} - 1 = 0; \\ m_i^k - m_i^0 (1 - U_i) = 0. \end{cases} \tag{1}$$

where U_I – the required value of the indicators of the vulnerability of karst waters;

U_{min} – the required value of the indicators of the vulnerability of karst waters at which a critical situation may arise;

n – number of observation points;

$m_i^{(0)}$ – the initial value of the i-th indicator;

m_i^k – critical value of the i-th indicator;

m_i – the number of the i-th element of the indicator;

K_U – the relative importance of the i-th element of the indicator;

K_p – the relative importance of the i-th unit of the influencing indicator;

Additionally, the following restriction is taken into account:

$$U_{\min} = \sum U_I \cdot P \tag{2}$$

where P – the relative importance of the indicator, influencing the transition to a critical state.

Normalizing equation:

$$U_{\min} = U_1 \cdot \frac{E_1}{E_\Sigma} + U_2 \cdot \frac{E_1}{E_\Sigma} + \ldots + U_n \cdot \frac{E_n}{E_\Sigma} \tag{3}$$

where $E_1, E_2, \ldots, E_n$ – potential of each indicator of karst water quality;

E_Σ – total potential of karst water quality indicators.

As a result of solving the above system of equations on the basis of the obtained values of the parameters of the quality of karst waters, a predictive estimate of the transition to a critical state can be formed.

5. Measurement results

The study area was the village of Chud, located on the right bank of the Oka River in the northwestern part of the Navashinsky district of the Nizhny Novgorod region, where non-centralized water supply is used for water users. The territory is subject to karst-suffusion processes [15,16]. As an assessment of the development of karst processes in the study area, a generally accepted method was used for the presence and prediction of surface karst manifestations [7]. Most of the craters, which are not more than 50 years old, are located in the zone of influence of the Oka river on groundwater, as well as on the state of karst rocks In this regard, it can be considered that during the year the greatest impact on the sinkhole has a period of spring floods on the Oka river [17,18].

To obtain data on the electrical conductivity and mineralization of groundwater in the study area from March to September 2020. regime observations were carried out at eight points using a two-pole equipotential installation [19]. The data were verified with a COM 80 conductometer. The salt content and electrical conductivity were evaluated ‘figure 1’. To reduce the measurement error, the selected water samples were brought into a certain temperature range (19-21 °C).

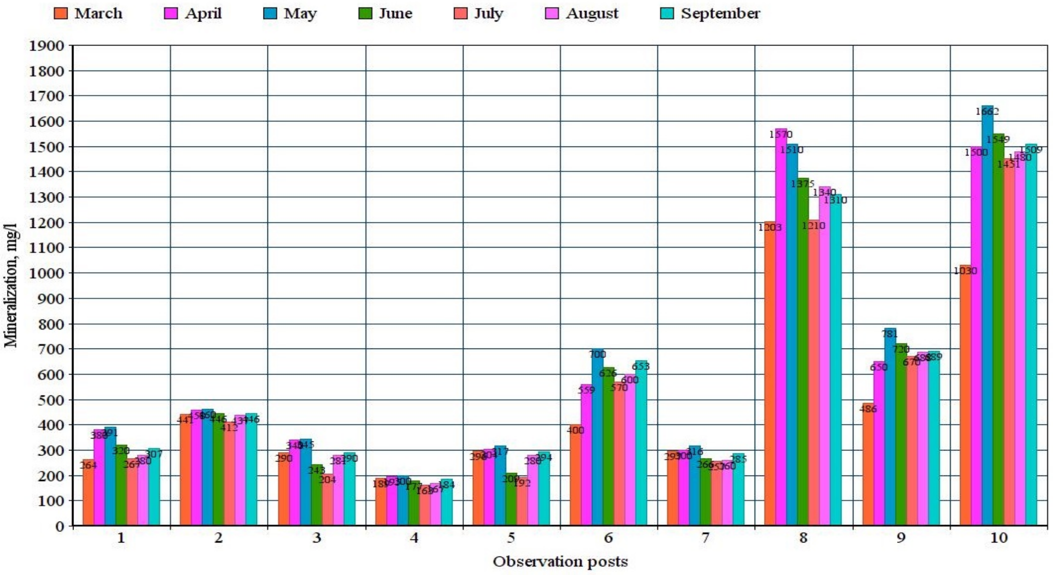

Figure 1. Results of observations on the territory of the village of Chud.

According to these calculations, in the study area, the waters are predominantly hydrocarbonate-sulphate, calcium-sodium and magnesium-calcium, fresh with a mineralization of 0.05-0.9 g / l, which in some places rises to 1.1-1.5 g / l due to movement of melt water and precipitation. The degree of aggressiveness of groundwater in relation to karst rocks makes it possible to judge the extent of the development of karst processes in a given area [20].

The actual state of groundwater in the study area is characterized by electrical conductivity and mineralization, which change over time as a result of external conditions, such as the rise of water in rivers and the activation of karst processes. The state of karst groundwater becomes critical if at least one of the parameters becomes critical. On the basis of forecasting the processes affecting the state of waters, the time and conditions for the transition of the system to a critical state are determined. The prediction interval was taken for 30 days, the prediction was performed in increments of 1 day. Based on the results of the calculations, a graph of the integral and differential functions of the transition time of the system to the critical state was built ‘figure 2’.

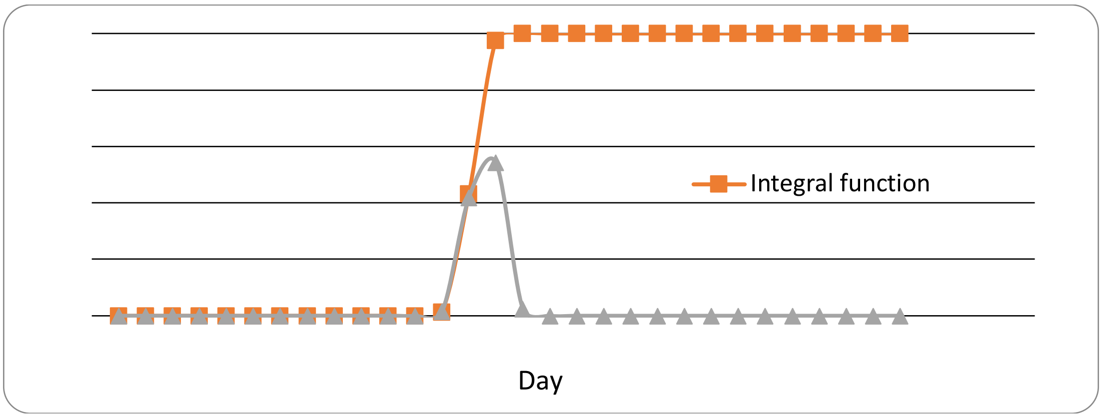

Figure 2. The graph of the integral and differential functions of the time of transition of the system to the critical state.

Critical condition may occur in 13-15 days. With the development of karst processes in this area, the use of wells for drinking water supply during the spring and autumn dry season is unsafe for the population.

6. Conclusion

Since it is quite problematic and economically unreasonable to monitor the quality of groundwater throughout the study area, during the processing of heterogeneous spatial data, it is necessary to apply an algorithm for ranking control zones with the allocation of anomalous deviations of parameters. At the same time, correlations are distinguished between hydrogeological parameters and indicators of the activity of karst processes in the controlled area of non-centralized water supply. An algorithm has been developed that determines the critical states of the indicators of the vulnerability of karst waters. A system of equations has been compiled to find the required value of indicators of the vulnerability of karst waters, at which the state of groundwater passes into a critical state. As a result of solving the system of equations on the basis of the obtained values of the parameters of the quality of karst waters, a predictive estimate of the transition to a critical state can be formed.

The paper analyzes data on the salt content and electrical conductivity of groundwater at key points and the number of karst sinkholes depending on the dynamics of the river water level. On the basis of forecasting the processes affecting the state of waters, the time and conditions for the transition of the system to a critical state are determined. Based on the results of the calculations, a graph of the integral and differential functions of the transition time of the system to the critical state was built. The results obtained can be used to improve the regional model for assessing the vulnerability and protection of groundwater resources and predicting the activation of destructive karst processes.

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