

Application of Computer Big Data Technology in Groundwater Environment Modeling of Framed City

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Abstract. In this paper, GIS theory and method are used to establish the analysis model of groundwater dynamics, chemical field and groundwater environment evolution. The corresponding system functions are realized by programming. A discrete model of aquifer medium space is established and numerically simulated. The technical framework aims to simplify the finite element analysis process, optimize the calculation efficiency of the model, and realize the 3D visualization of the finite element numerical simulation of groundwater and the calculation results. The feasibility and effectiveness of this method are proved by a case study.

Keywords: Groundwater environment, evolutionary analysis system, spatial analysis, finite element numerical simulation.

1. Introduction

As the world's largest reserves and the largest source of fresh water after glaciers, groundwater has a significant impact on human survival and social development. The research on the formation and evolution of groundwater and the correlation between its multiple factors is of great significance for the scientific exploitation of groundwater resources, the protection of ecological environment, and the harmonious development of human and environment, and is also the focus of the research in the field of water science in the world [1]. At present, the researches on groundwater dynamic field, chemical field and ecological environment are limited to local areas, and there is a lack of research on the whole groundwater system. Using numerical simulation, "3S" and spatial analysis model, it is an important direction to study the evolution of groundwater environment in China to develop the complex mechanism of groundwater flow conditions under the dual action of natural and man-made. In the study of groundwater environment evolution, there is a huge amount of spatial information. How to organically combine various spatial analysis methods to build corresponding analytical models to realize the simulation and analysis of groundwater dynamics, hydrochemical field and groundwater environment evolution and other issues? This paper presents a GIS based analysis method of groundwater environment evolution [2]. The groundwater environment evolution analysis system based on GIS is constructed. Select representative areas to carry out empirical research, and through the case study, to test the effectiveness of the method. This paper provides technical support for revealing the evolution process of groundwater table and its response mechanism under the joint action of natural environment and human activities.

2. Design of groundwater environment detection system

2.1. System Objectives

The study of groundwater environmental evolution refers to the storage and management of groundwater environmental factors, the study of groundwater dynamic field and groundwater chemical field changes, and the assessment of the impact of groundwater environmental evolution on the ecological environment [3]. This project is based on the basic principles of groundwater environmental evolution analysis. Using spatiotemporal database, GIS, spatial analysis model and other methods, a fully functional and reliable groundwater environment evolution analysis system

was constructed. In this way, the status quo of groundwater environment, the evolution law of ecological environment and its evolution law can be accurately grasped. This lays a solid theoretical and practical foundation for the rational exploitation and utilization of groundwater resources, the protection and management of groundwater environment.

2.2. Overall system structure

The system is based on three levels as the logical framework. At the level of data support, it provides a basis for the subsequent research work. The business level is the core of the system, and the basic analysis and special research on the evolution process of groundwater resources are completed by using the spatial analysis model [4]. The present situation and evolution law of groundwater are presented in the form of graphs, maps, etc., which provides a good human-computer interaction interface for researchers. Figure 1 shows the logical structure of a groundwater detection System (figure cited in Hydrology and Earth System Sciences, 2022, 26 (2): 221-243.)

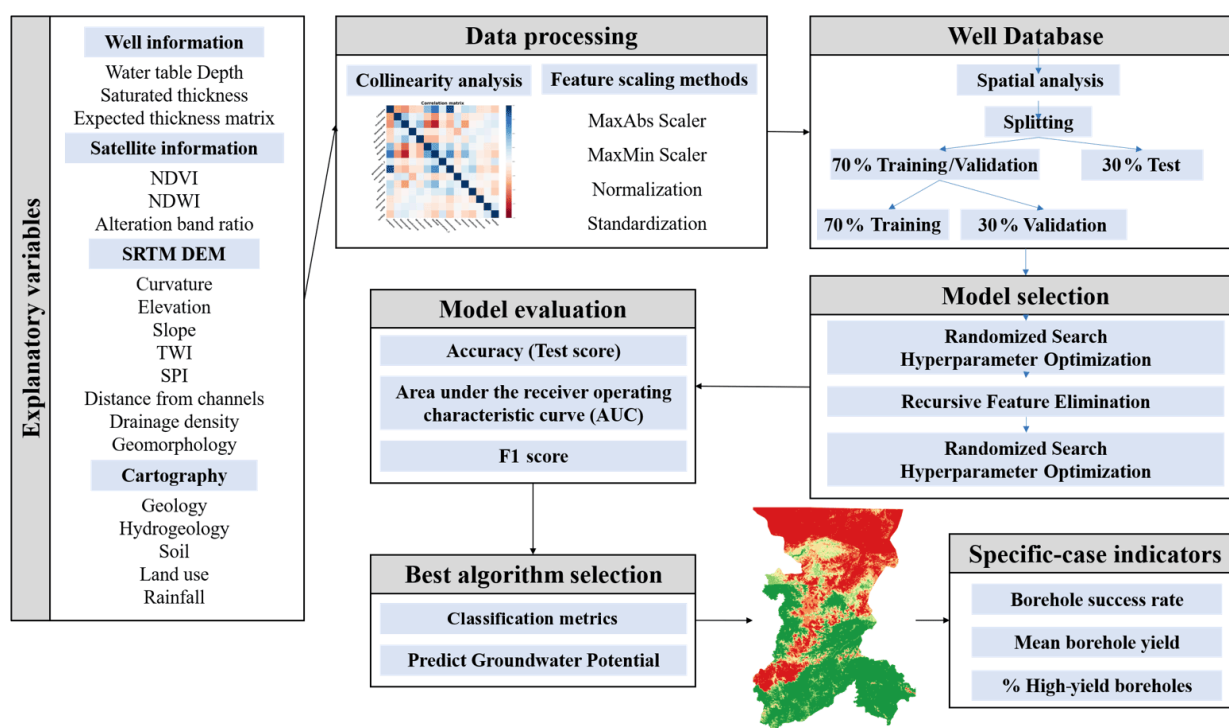


Figure 1. Logical structure of groundwater detection system

2.2.1. blishment of hydrogeological conceptual model

In view of the strong spatio-temporal continuity of pore groundwater system and its significant restriction on the hydraulic relationship between aquifers, this project intends to apply 3D geological simulation method to the conceptual model of structural hydraulics. In this way, the spatio-temporal differentiation in complex media is revealed.

2.2.2. Discrete mesh generation

In groundwater finite element numerical simulation, the division of discrete grid is the key step. The shape and size of grid elements are directly related to the accuracy and calculation speed of finite element simulation. In order to balance the accuracy and effectiveness of the solution, it is usually necessary to adjust the scale of triangular elements appropriately [5]. Make the scale between units as smooth as possible to prevent the formation of long, narrow triangles. In addition, it is also necessary to consider the limitations of the spatial spread of the water-bearing medium, such as the overflow supplement. A triangular mesh with regional adaptability is constructed by using an improved wave front propulsion method. The optimal mesh scale is obtained by considering the

hydraulic gradient, boundary conditions and aquifer structure. In this way, a new adaptive spatial discrete grid is realized.

2.2.3. Parameter extraction and initial value allocation in the mode

According to the spatiotemporal differentiation of parameters in different Spaces of the mathematical model of underground flow, it is abstracted into point, line and surface vector data for superposition to achieve the purpose of automatic extraction [6]. According to the spatial distribution of the initial water head of the target aquifer at the initial time of simulation, boundary conditions, groundwater exploitation, recharge and drainage, and the spatial distribution of hydrogeological parameters, the calculation parameters of the model are automatically assigned to the calculation units or grid nodes by combining the spatial interpolation algorithm

2.2.4. Visualization of simulation results

Through 2.5D level DEM and 3D visualization of groundwater flow field, 3D modeling of groundwater flow field is realized. The 3D spatial data model contains a series of solid elements with different shapes, which can not only reflect the actual situation in the region, but also provide an effective means for the unstable flow of underground water [7]. Each node in the grid is placed on the node of the unit, and the parameter value of each node is extracted by the corresponding algorithm, so that the parameter information is transmitted to the unit. The results of the simulation are continuously changed and fed back to the 3D solid unit. In this way, the dynamic adjustment of the three-dimensional solid unit is realized.

2.3. System function design

2.3.1. Database management and maintenance

Integrate, manage and maintain data from multiple sources on a spatio-temporal scale. The spatial data modeling of groundwater environment is realized.

2.3.2. Analytical function of underground water flow field

In order to study the dynamic evolution law of regional groundwater flow, a groundwater dynamic field analysis model is proposed. Through the analysis of the time and space evolution law of groundwater table, the dynamic evolution law of groundwater table is revealed, and the dynamic model of groundwater flow is identified [8]. The evolution law of groundwater flow movement under the action of multiple factors is analyzed.

2.3.3. Electric field distribution characteristics in groundwater

The analysis model of groundwater chemical field was established to analyze each element of regional groundwater chemical field. The research contents include (1) the spatial and temporal distribution characteristics and evolution characteristics of each component in the study area; (2) The spatial and temporal distribution characteristics of hadrochemical components; (3) Formation and migration characteristics of hadrochemical components; (4) Analyze the relationship between groundwater chemical composition and related factors; (5) The internal relationship between the hadrochemical components and the influencing factors; (6) Identify the evolution characteristics of groundwater chemical components.

2.3.4. Function of groundwater environmental evolution effect analysis

Research on the influence of groundwater environment evolution was carried out, and groundwater quality and groundwater pollution were evaluated. The potential ecological effects such as salinization were studied.

2.3.5. Visualization and Output functions

With the powerful visualization and output ability of GIS, various key data and information about the evolution process of groundwater environment can be displayed and output [9]. Through visual

analysis and integrated interpretation, the influence mechanism of natural and human activities on the change of groundwater level is deeply understood.

2.4. The parameters of the surface shape are obtained by using the topology reconstruction method of the grid

Pore groundwater is a water-bearing medium with spatial continuity, and its main characteristic is that it has a certain degree of planarity. This paper makes a detailed zoning of groundwater based on the existing theoretical model and experimental data. The calculated parameters are obtained by superimposing the partitioned polygon with the discrete mesh. For the same unit in multiple different hydrogeological parameter partitions, the ABC unit across the parameter partitions is shown in Figure 2 (image cited in Hydrology and Earth System Sciences, 2022, 26(23): 6147-6162). This project intends to study the structure reconstruction method of triangulation network based on subdivision constraints, and transform the original mesh subdivision into triangular mesh with subdivision boundaries to ensure the consistency of each element in the mesh. Firstly, the starting and ending positions of the line segment on the partition boundary are found. (2) Determine the area of influence formed by the three triangles affected by the line segment; (3) Remove the known triangles that already exist in the influence zone. The Delaunay method was used to redivide the system. (4) Obtain the next segment at the partition boundary, and repeat the above procedure until all segments have been experienced once.

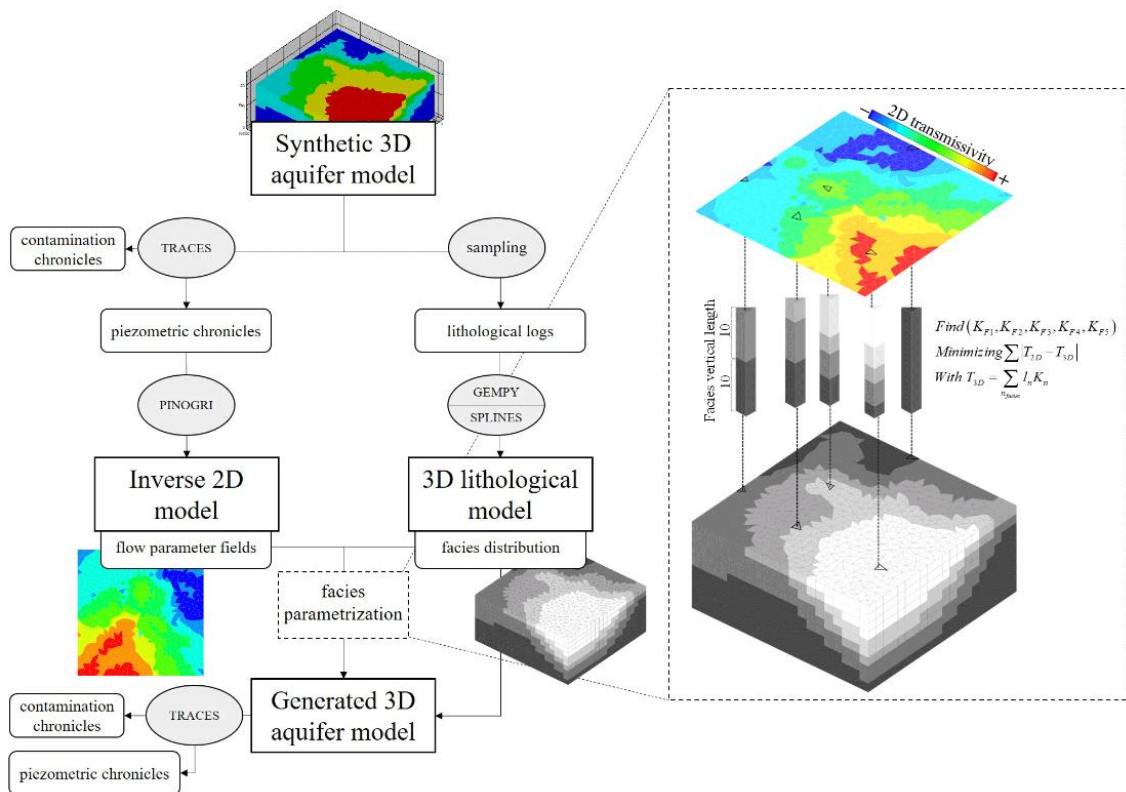


Figure 2. Schematic diagram of local reconstruction principle of triangulation network

By reconstructing the grid structure, each triangle element in the generated grid occupies only a single parameter value to ensure the consistency of each element in the grid. The parameter values of the triangular body are obtained by the light method, and the hydrogeological conditions are automatically extracted [10]. Figure 3 is a comparison chart of the results of permeability factor extraction before and after performing topological restriction reconstruction of the reduced grid (image cited in Hydrology and Earth System Sciences, 2018, 22(8): 4381-4400). After the parameters are divided by the topology reconstruction grid, the coincidence between the obtained parameter values and the parameter values is improved.

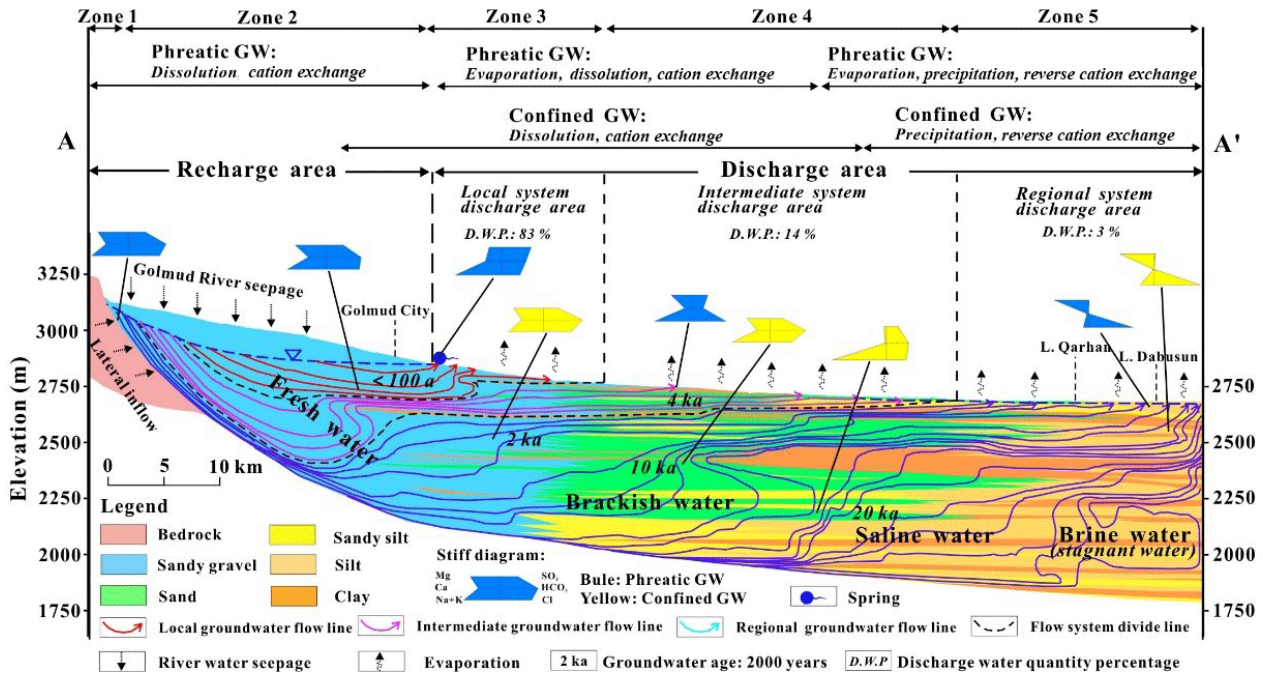


Figure 3. Comparison of permeability coefficient extraction results before and after grid reconstruction

3. Algorithm Design

3.1. Equation of continuous movement of groundwater

In general, the unsteady motion of groundwater can be described by the following continuous motion equation:

$$\frac{\partial}{\partial x} \left(S_l \frac{\partial L}{\partial x} \right) + \frac{\partial}{\partial y} \left(S_l \frac{\partial L}{\partial y} \right) + \frac{A_z}{d_z} (L_z - L) + E = R \frac{\partial L}{\partial t} \quad (1)$$

$(t \geq 0, (x, y) \in U)$

Initial conditions:

$$L(x, y, 0) = L_0(x, y) \quad (2)$$

Boundary conditions:

$$\begin{cases} L | \Theta_1 = \delta(x, y, t) & (t \geq 0) \\ S \frac{\partial L}{\partial n} = p(x, y, t) & (otherwise) \end{cases} \quad (3)$$

Where: A_z is the overflow recharge coefficient; d_z is the vertical distance through which the overflow passes; S_l is the water conductivity coefficient in the horizontal direction of aquifer; E is the vertical recharge water quantity of aquifer per unit time and per unit area (outflow is represented by negative value); R is the water storage coefficient of aquifer; L_z is the water head; L is the water head to be calculated; U is the seepage zone, which is the research area surrounded by the first-class boundary Θ_1 and the second-class boundary Θ_2 . $L(x, y, 0)$ is the two-dimensional spatial distribution function of water head at the initial time. $L_0(x, y)$ is the initial water head at any

position; p is the inflow flow per unit width on the boundary (the outflow is negative); n is the external normal direction; t is the simulation period; $\delta(x, y, t)$ is the groundwater level at position (x, y) at the specified time t ; S is the coefficient of water conductivity.

3.2. Construction of adaptive spatial discrete grid based on improved Frontier Propulsion Method (AFT)

Taking the water level DEM as the background grid, the mapping relationship between the hydraulic gradient and the element control size was established, the maximum element size l_{\max} and the minimum element size l_{\min} were predicted, and the maximum hydraulic gradient H_{\max} and minimum hydraulic gradient H_{\min} were calculated [11]. The relationship between the hydraulic gradient H_i and the corresponding element size l_i can be approximated as follows:

$$l_i = l_{\max} + \frac{l_{\min} - l_{\max}}{H_{\max} - H_{\min}} (H_i - H_{\min}) \quad (4)$$

3.3. Three-dimensional visualization of groundwater flow rate

The output result of groundwater flow simulation is the water level of each compute node in the discrete grid, and the groundwater flow simulation results are generally visualized in the form of three-dimensional flow field. According to the characteristics of groundwater seepage, the data source of three-dimensional flow field is groundwater seepage velocity, and its direction represents the direction of groundwater flow. For two-dimensional finite element numerical simulation of groundwater flow, the velocity at each grid node can be synthesized by the velocity component v_i, v_j in the direction X, Y . According to Darcy's law, the seepage velocity in a certain direction is proportional to the hydraulic gradient at the node position.

$$v = a_b \frac{\partial L}{\partial b} \quad (5)$$

Where: v is the seepage velocity; L is the water level field; b is a seepage direction; a_b is the permeability coefficient along the b direction. The key to calculate the seepage velocity is to obtain the expression of function L representing the spatial distribution of water level. For a node i , the water level surface in a certain range around it is regarded as a quadric surface, whose expression is

$$L_i(x, y) = \lambda_0 + \lambda_1 x + \lambda_2 y + \lambda_3 x^2 + \lambda_4 xy + \lambda_5 y^2 \quad (6)$$

x, y, z is the projection of the spatial position coordinates on the three coordinate axes; $\lambda_0, \lambda_1, \dots, \lambda_5$ is the coefficient. There are at least 6 discrete grid nodes in this range, and the error equation matrix of these 6 compute nodes is listed:

$$v = M\Lambda - F \quad (7)$$

Among

$$v = \begin{pmatrix} v_1 \\ \vdots \\ v_6 \end{pmatrix}, M = \begin{pmatrix} 1 & \bar{x}_1 & \bar{y}_1 & \bar{x}_1^2 & \bar{x}_1\bar{y}_1 & \bar{y}_1^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & \bar{x}_6 & \bar{y}_6 & \bar{x}_6^2 & \bar{x}_6\bar{y}_6 & \bar{y}_6^2 \end{pmatrix} \quad (8)$$

$\bar{x}_1, \bar{x}_2, \dots, \bar{x}_6, \bar{y}_1, \bar{y}_2, \dots, \bar{y}_6$ is the estimated value; F_1, F_2, \dots, F_6 is the error value. According to the adjustment theory, the solution of coefficient matrix Λ is obtained as

$$\Lambda = (M^T Q M)^{-1} M^T Q F \quad (9)$$

Q is the weight matrix. From this, $L(x, y)$ expression can be obtained, and the partial derivative of X, Y direction can be obtained respectively, and the groundwater seepage velocity at node i can be obtained by combining the corresponding permeability coefficient of the node. The more nodes taken, the smoother the surface and the better the fitting effect. The "spines" were selected to represent the flow vector, the color represented the flow velocity, and the length of the vector was set as a fixed value to obtain the components of the water fluid unit in the X and Y directions, which were imported into the 3D GIS platform for visualization.

4. Achieve results

According to the function of the system and the standard of database construction, the data collected and sorted in the early stage of the study are processed. The spatial database of groundwater resources is constructed, and it is managed and maintained. This method uses the toolset based on Arc Toolbox to construct the analytical content of groundwater dynamic field, and will be implemented as a tool set. The corresponding analytical menu or tool group key of each parsing mode, the user sets the mode in this mode and the ESRI mode, but its interface is better and easy to use. The study focuses on the spatial distribution characteristics of groundwater chemical components, regional hydrochemical types, the correlation between major ions, and the main controlling factors of the formation and evolution of groundwater chemical fields. In view of the negative ecological and environmental impacts caused by the evolution of groundwater environment, this project has carried out a lot of research work from the aspects of groundwater quality assessment, groundwater pollution and formation mechanism.

5. Conclusion

A 3D visualization model of groundwater - water system was established. Groundwater dynamic field analysis, groundwater chemical field analysis and groundwater environment evolution impact analysis models were established based on ArcGIS model Builder. Compile programs for database management, thematic analysis and visual display. According to the spatial variation of the groundwater water-bearing system, the contour map of the top and bottom of the aquifer and the water-retaining layer is drawn, and the elevation is numerically assigned. This gives elevation information for its top and bottom.

References

- [1] Xu Tian-Fu, Chen Jing-Yi, Feng Bo, et al. Potential groundwater environmental problems in the exploitation of geothermal resources. Journal of Jilin University: Earth Science Edition, vol. 53, pp.1149 - 1162, April 2022.
- [2] Wei Binggan, Yin Shuhui, Yang Linsheng, et al. Response of arsenic in shallow groundwater to surface environmental change: research status and future. Journal of Hydrology, vol. 41, pp.44 - 48, March 2022.

- [3] Zhang Wei, Bao Xue-ying. Study on evaluation of environmental negative effects of tunnel groundwater based on support vector regression. *Railway Standard Design*, vol.65, pp.148 - 153, September 2021.
- [4] Fang Yuan, Wang Jing, GAO Shichang, et al. Groundwater environmental monitoring methods and water pollution research. *Environmental Science and Management*, vol. 48, pp.151 - 155, April 2022.
- [5] Wang Wanjin, Chu Jinglong, Cui He, et al. Environmental pollution characteristics and pollution control of groundwater in electrolytic manganese slag reservoir in karst mountain area. *Mining and Metallurgy*, vol.32, pp.110 - 118, April 2023.
- [6] Luo Jian-Nan, Li Xue-Li, Wang He, et al. Groundwater pollution source inversion identification based on local-global hybrid adaptive alternative model. *Chinese Journal of Environmental Sciences*, vol.43, pp. 3664 - 3671, July 2022.
- [7] Zhang Shuai, Xie Fei, WANG Xianghua, Li Bing. Investigation and monitoring of groundwater environment in chemical industry park. *Environmental Monitoring Management and Technology*, vol. 34, pp.60 - 63, June 2022.
- [8] Liu Dawei, Jiao Xun, Wan Bo, CHAI Juan-Fen, LIU Dan, ZHANG Wen-Jing. Research progress on the behavior of disinfectant by-products in groundwater environment. *Journal of Applied Chemical Engineering*, vol.51, pp.3354-3361, November 2022.
- [9] Qiao Guobin, QIAO Hongxia, LU Chenggong. Study on mechanism of galvanic corrosion of reinforced concrete in underground water environment of Lanzhou Metro. *Materials Review*, vol.36, pp.6-12, September 2022.
- [10] Shi Wei, Li Jianhua, Wang Wei, et al. Analysis of the influence of underground space on groundwater environment and its controlling factors. *Journal of Underground Space and Engineering*, vol. 18, pp.110 - 114, February 2022.
- [11] Yu Xiangying, Zhang Yongbo, Zhu Qing, et al. Study on groundwater environmental monitoring network in Guangdong for water source protection and pollution monitoring. *China Environmental Monitoring*, vol.37, pp.98 - 108, May 2021.