Method of determining early warning water level for controlling regional urban land subsidence

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Keywords: land subsidence, early warning groundwater level, pumping, recharge, urban plan

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Abstract

Urban land subsidence is mostly caused by excessive groundwater exploitation, dewatering, and soil disturbance caused by engineering construction. The control of groundwater level in urban areas is helpful to slow down the surface subsidence. However, the superposition effect of engineering construction on the consolidation of shallow soil caused by the drainage of shallow groundwater and the settlement of buildings after construction are mixed and become more obvious. How to warn in early stage and control land subsidence is very important. With Ningbo City as background, the methods to determine early warning groundwater based on geological zones and land subsidence control zones were discussed. The correlation between groundwater level, land subsidence and engineering construction was analyzed, and the evolution of groundwater seepage field was correlated with the future urban planning and construction of Ningbo, together with the control zoning of land subsidence, so as to determine the early warning water level.

Introduction

Urban construction, urban operation, urban emergency water supply and pipe network leakage cause abnormal groundwater level, and abnormal groundwater level may cause land subsidence, ground collapse and other disasters. Due to the interaction between groundwater and land subsidence through fluid-structure coupling, using groundwater level to warn urban land subsidence is an urgent problem to ensure the safety of Ningbo city. Based on the evolution chain of urban operation safety-groundwater level-land subsidence. Combined with the construction of groundwater water-land subsidence observation network, taking urban elevation safety as control target, the early warning safe water level is proposed.

Tosi et al. (2009) revealed the mechanism of shallow soil settlement caused by urban building load based on GPS and InSAR data. Gayarre et al. (2020) used the method of dialectical logic reasoning to discuss the interaction between urban land subsidence and buildings. Truong-Hong et al. (2013) used ground 3D laser scanning technology to study the influence of building detail load changes on settlement, and demonstrated that different building structures would lead to different deformation results. In order to analyze the coupling relationship between groundwater and land subsidence, Zhang et al. (2022) used GRACE-FO data and GLDAS data to inversely show the time series of groundwater changes in the Beijing-Tianjin-Hebei region from 2016 to 2019. Then, MCTSB-InSAR technology was used to invert the settlement change time series of the same period in this area. The variation sequence and trend line of ground water and land subsidence were obtained by experiments, and the inelastic storage coefficient was introduced to analyze the change rule of the influence of ground water on land subsidence. Tian et al. (2022) took the plain area of Chaobai River Basin as an example, comprehensively used synthetic aperture radar interferometry technology, stratification standard and groundwater stratification monitoring technology to conduct three-dimensional monitoring of regional land subsidence and groundwater, and proved the response characteristics of "land subsidence" to the rising process of groundwater level. On the basis of fully discussing the role and characteristics of engineering factors in regional land subsidence in Ningbo Plain, Zhang et al. (2013) established a fully coupled dynamic land subsidence equation under the dual action of groundwater extraction and regional building load with the variation of parameters with stress and strain based on the finite difference method. The comparative study of measured data and simulation results showed that the model had a good fitting relationship, and predicted the development trend of land subsidence from 2012 to 2015. After ignoring the group well effect, Wu et al. (2016) introduced such as drainage with effective stress principle of unsaturated soil, at the same time, considering the seepage force produced by dewatering eventually caused adding the difference variation sequence stress component exists in the horizontal direction, layered summation method was used to calculate the drawdown funnel curve and drainage soil and saturated soil vertical settlement and superposition after smoking precipitation well weeks after final total subsidence on the surface of the earth.

In this paper, Ningbo city center was selected as the demonstration area. The early warning water level was proposed for different land subsidence control zones. The research results have certain reference significance for Ningbo city planning.

Methods

Groundwater warning and zoning control model for urban safety

Utilization of underground water level running safety-chain of ground settlement evolution, combining with the construction of underground water level, land subsidence observation network, with the medium of underground water level, from the engineering measure to partition a given security water level warning value, city scale early warning model results can access Ningbo related geological environment monitoring application, further perfecting the urban groundwater monitoring and early warning technology system.

Analysis of urban land subsidence regionalization and prevention and control index

To collect land subsidence zoning and land subsidence prevention and control planning in Zhejiang Province and Ningbo City, The characteristics of human engineering activities and geological environment are analyzed for each zoning management area. Besides, the land subsidence control indexes are extracted for each land subsidence zone.

Spatio-temporal analysis of urban land subsidence and groundwater level monitoring network

To collect and quantitatively analyze the spatio-temporal coverage of the land subsidence monitoring network and groundwater level monitoring network in Ningbo City, conduct interpolation analysis on the relationship between land subsidence and groundwater level under the accuracy of the existing network. Based on the integration degree of existing land subsidence monitoring points and groundwater level monitoring points, the possible error of interpolation analysis and the elimination method are studied.

Analytical methods for controlling water level in monitoring Wells

In the process of urban construction in recent years, foundation pit dewatering in the development of underground space has the greatest impact on land subsidence. Foundation pit dewatering causes the variation of water level of aquifer with submersible and confined water. The mining data of monitoring wells are systematically sorted out. Based on the data of existing ground subsidence monitoring points and groundwater level monitoring points, the corresponding relationship between groundwater level and land subsidence at each monitoring well is established by least square fitting, and the land subsidence value at each monitoring well is studied. Then, the typical deep well is related to the representative geological unit, and the control water level of the monitoring well is determined by using the quantitative relationship between land subsidence and groundwater level according to the defined index of land subsidence zoning.

Results

The above methods include several parts. However, the key element of the method is the determination of early warning water level through the threshold of land subsidence. The key result of the method is to obtain the relationship between groundwater level and land subsidence, and obtain the early warning ground water level by input the threshold of land subsidence through the trend relationship between groundwater level drawdown and land subsidence.

Urban land subsidence regionalization and prevention and control indicators

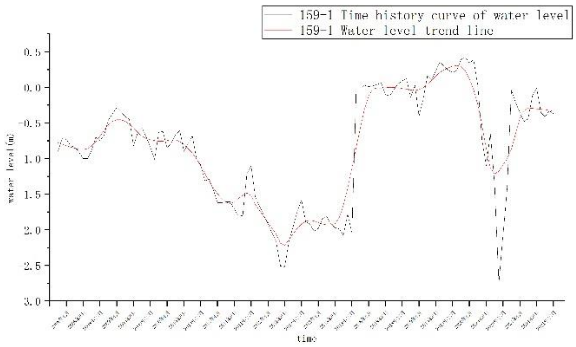
Based on the existing basic data collection and field investigation of land subsidence in Ningbo, this paper further summarized the characteristics of land subsidence, compiled the prone degree map of land subsidence and the risk zoning map of land subsidence, and strengthened the risk control of urban geological safety.

Spatio-temporal analysis results of urban land subsidence and groundwater level monitoring network

By inputting the data of land subsidence monitoring points from 2015 to 2020 into Surfer, the land subsidence rate contour map of Ningbo City from 2015 to 2020 can be obtained according to its built-in Kriging interpolation method. Then interpolated by residuals command in Surfer, the land subsidence value at each water level monitoring well can be calculated.

Monitoring well control water level analysis results

As shown in Figure 1 and Figure 2, according to the water level data recorded from 1980 to 2022 in the data collection table of groundwater level monitoring wells, the variation of water level of each monitoring well in the phreatic aquifer, confined aquifer Ⅰ and confined aquifer Ⅱ can be obtained by entering Origin software, and the dynamic evolution law of water level can be obtained. According to the completed time history curve of groundwater level, the trend line was added to filter, and the variation trend of water level in each monitoring well was analyzed and the water level was controlled. According to the chart of water level variation, firstly, the abnormal water level over the years can be analyzed and obtained, which provided a more complete basis for determining the variation of monitoring well location data caused by foundation pit dewatering. Secondly, the trend line of water level of monitoring well can be obtained by fitting water level data, and the trend of water level change can be obtained. Third, according to the historical data combined with the land subsidence value and the general situation of typical geological zones, the monitoring well water level warning index can be given.



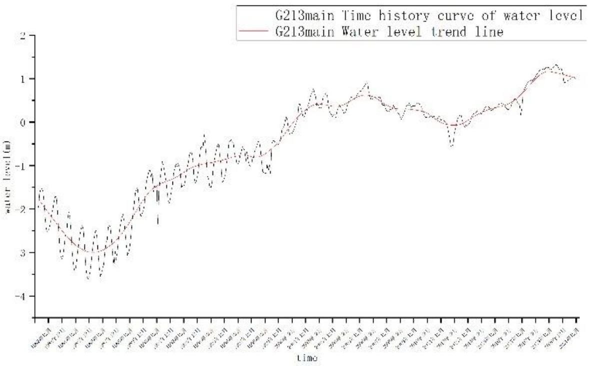


Figure 1 Time history curve and trend line of water level in 159-1 Figure 2 Time history curve and trend line of water level in G213 main

The mining data of deep wells were systematically sorted out. Based on the data of existing land subsidence monitoring points and groundwater level monitoring points, the corresponding relationship between groundwater level and land subsidence at each monitoring well was established by least square fitting, and the land subsidence value at each monitoring well was studied. Then, the typical deep well was related to the representative geological unit, and the control water level of the monitoring well was determined by using the quantitative relationship between land subsidence and groundwater level according to the defined index of land subsidence zoning.

Taking well Measure 13-I as an example, the output value was the water level variation, and the input value was land subsidence. The quantitative relationship between the two was obtained. According to (Equation 1), the control water level of the well can be determined (Fig. 3).

$$y = -9.08022 \times 10^{-4} e^{\frac{x+8.40138}{0.96633}} + 0.14091 \quad (1)$$

Taking well G216 vice as an example, the output value was the water level variation, and the input value was land subsidence. The control water level of the well can be determined (Fig.4).

$$y = 0.0011 e^{\frac{-x}{4.91407}} + 0.03682 \quad (2)$$

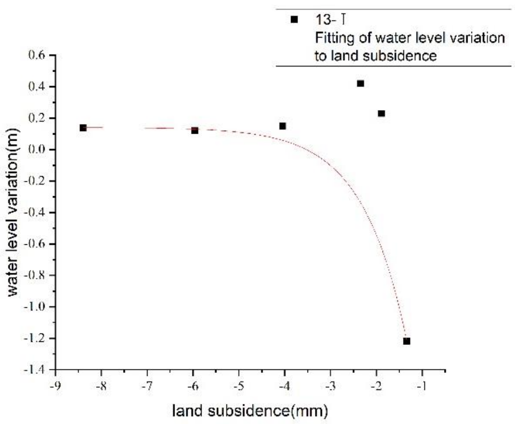


Figure 3 Fitting of 13-I

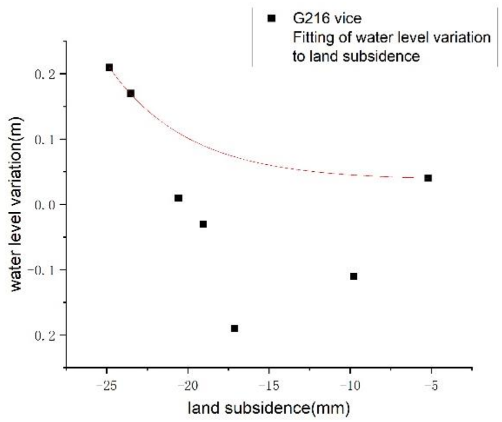


Figure 4 Fitting of G216 vice

Conclusions

The establishment of the groundwater level early warning index needed the municipal data of Ningbo city. After collecting the data, the evolution chain of urban operation safety, groundwater level and land subsidence was established. By establishing urban land subsidence zoning and prevention and control indicators, the land subsidence control indicators of different geological areas were given. The land subsidence value at the water level monitoring well was obtained based on the spatio-temporal interpolation analysis of urban land subsidence and groundwater level monitoring network. Then the trend line was added to the time history curve of the groundwater level which has been made to filter, and the fluctuation range and trend of the monitoring well water level were obtained. The groundwater level and land subsidence were fitted to establish the quantitative relationship between the groundwater level and land subsidence at each monitoring well. The land subsidence control index in different geological areas was taken as the input value, and the early warning value of groundwater level was obtained from the output.

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