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The Impact of Systematized Whole-area Sponge City Construction on Groundwater Level and Safety in Beijing

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Abstract

With the systematic promotion of sponge city construction in China to alleviate the water resources management challenge, the groundwater level and water quality in the Beijing area have improved significantly. Since the demonstration construction of Sponge City was promoted in 2015, the groundwater level in Beijing has ended the downward trend of over 15 m continuous decline for nearly 20 years. At the same time, natural infiltration and natural purification also effectively ensure the water quality of rainwater infiltrating into the ground. With the rise of the groundwater level, although many underground buildings in Beijing will face new risks, the remediation of the groundwater level is still of great significance to alleviating the phenomenon of urban surface subsidence and ensuring urban water resources.

Keywords

Sponge City; Groundwater Level; Groundwater Quality; Infrastructure Construction.

1. Introduction

In the past decade, with the systematic and comprehensive promotion of sponge city construction in China, the challenges of water resources management brought by urbanization have been effectively alleviated [1]. Sponge City is to build a "breathing" water ecosystem in the city through natural accumulation, natural infiltration, and natural purification [2]. Comprehensively and systematically promoting the construction of sponge cities is of great significance to alleviating urban waterlogging, improving the water environment, and enhancing urban ecosystems' resilience [3]. At the same time, this measure has a more positive effect on lifting the groundwater level in some areas of our country [4].

By increasing urban green space, rain gardens, permeable pavement, and other measures, sponge cities enhance precipitation's absorption and retention capacity, thus effectively alleviating the frequency of urban waterlogging [5]. This way of natural retention and infiltration of rainwater resources can not only effectively reduce the runoff during heavy rain, and reduce the load of the urban drainage system, but also prevent the occurrence of flooding and effectively reduce the peak water volume of surface runoff [6]. In addition, by collecting, purifying, and storing rainwater, sponge cities realize the recycling of rainwater resources and also reduce the pressure on urban water supply.

The comprehensive and systematic promotion of sponge city construction has also significantly improved the quality of the urban water environment. Traditional urban construction mode often leads to rainwater carrying pollutants directly into rivers and lakes, resulting in water pollution. By setting facilities such as vegetation cover and constructed wetlands, sponge cities can naturally filter pollutants in rainwater and reduce the possibility of pollutants entering the water body, thereby improving the urban water environment and enhancing the resilience of the urban ecosystem [7].

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Sponge cities enhance urban biodiversity and create healthier ecosystems by restoring and increasing green spaces and wetlands in cities. This not only helps to regulate the urban microclimate and reduce the heat island effect but also provides more green leisure space for citizens and improves the livability of the city [8].

In terms of the impact on groundwater level, the systematic construction of Sponge City significantly increases the amount of rainwater infiltration and contributes to the recharge of groundwater. Most of the traditional urban ground is impermeable pavement, and it is difficult for rainwater to penetrate the ground, resulting in insufficient groundwater supply. Sponge cities enhance the permeability of surface water by increasing permeable pavement and constructing sunken green Spaces, so that more rainwater can naturally penetrate the ground and gradually replenish groundwater resources [9]. This recharge of groundwater helps to maintain the stability of groundwater level and prevent problems such as land subsidence caused by excessive exploitation of groundwater.

However, although China's sponge city construction has been promoted for more than 10 years, the specific impact of sponge city construction on the groundwater level of cities in North China is still not clear, and the correlation between the growth of the urban permeable ground area and groundwater quality is not clear [10]. Therefore, the plain area of Beijing was selected as the research object in this study, and the groundwater level height of typical cities in North China was associated with the construction time of Sponge City. Through the analysis of monitoring data, the relationship between the groundwater level height and the construction of a sponge city was found, to understand and master the improvement of water quality conditions by the construction of a sponge city. The research results have far-reaching significance for further systematically promoting the construction of sponge cities and the sustainable development of urban infrastructure.

2. Materials and Methods

2.1 Study Area

In this study, the plain area of Beijing is selected as the research object, which is the core area of Beijing capital with complete monitoring data and is suitable for analysis as a typical case, and the study area is shown in Figure 1.

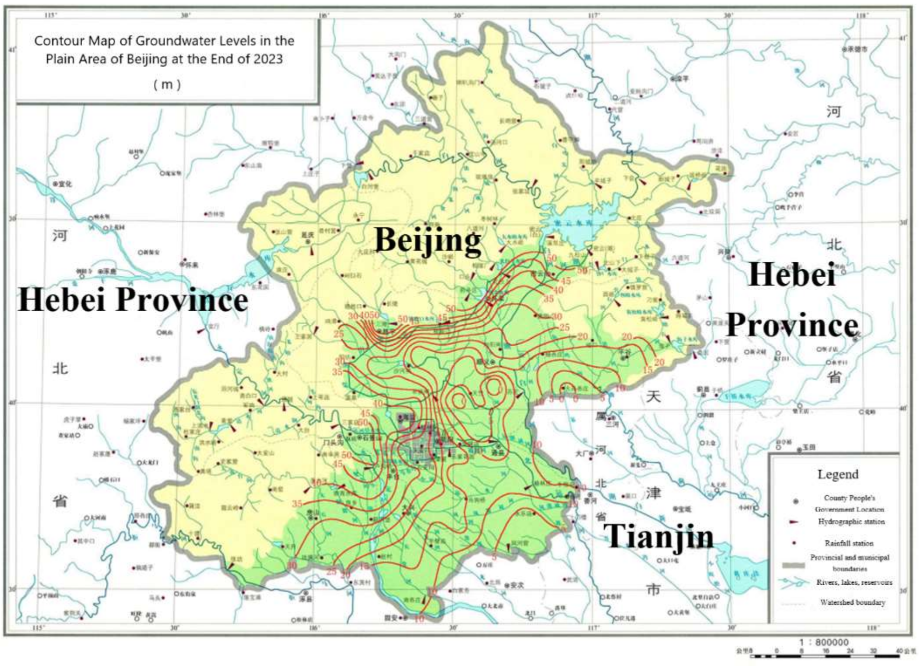

Figure 1. Contour map of groundwater level in plain area of Beijing (Image source: Beijing Water Resources Bulletin 2023)

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2.2 Data Statistics

According to the "Beijing Water Resources Bulletin" in 2023, the depth and height of groundwater level in Beijing plain area since 1978 are obtained, as shown in Figure 2.

Figure 2. The process map of groundwater depth in the Beijing Plain Area from 1978 to 2023 (Image source: Beijing Water Resources Bulletin 2023)

3. Results and Discussion

3.1 Analysis of Groundwater Level Change in Beijing

The change in groundwater level in plain areas of Beijing is a complex problem affected by many factors. Since 1978, the groundwater level in the plain area of Beijing has generally shown a downward trend. Especially in the early 2000s, due to the acceleration of urbanization, population growth, industrial development, and increased demand for agricultural water, groundwater was exploited in large quantities, leading to the further rapid decline of water level, and the decline of groundwater level entered an accelerated stage.

The decline in groundwater levels is usually due to the greater extraction than recharge of groundwater. Beijing has always been a city with a relative shortage of water resources, and groundwater was once the main source of water supply. Due to long-term overexploitation, the recharge of groundwater is difficult to catch up with the exploitation, which exacerbates the decline of groundwater level. The decline of groundwater level has more adverse effects on the environment, resulting in a series of environmental problems, including land subsidence and ecological environment deterioration, etc., and land subsidence poses a certain threat to the safety of Beijing's infrastructure.

Since the 18th National Congress of the Communist Party of China, the central government, led by General Secretary Xi Jinping, has emphasized the development concept that "lucid waters and lush mountains are invaluable assets." The Beijing municipal government has gradually recognized the severe issues related to groundwater environmental degradation and has implemented a series of measures to control groundwater extraction. These measures include increasing the supply of surface water, constructing the South-to-North Water Diversion Project, promoting water-saving agriculture and industry, and enhancing groundwater management and protection. These initiatives have, to some extent, mitigated the rate of decline in groundwater levels.

However, with the implementation of the aforementioned policies and management measures, especially following the full operation of the South-to-North Water Diversion Project, which has replaced groundwater usage with surface water, the rate of decline in groundwater levels in Beijing has been significantly alleviated. Nevertheless, groundwater levels have not yet achieved full replenishment and increase. In response to this situation, the comprehensive development of sponge city construction in Beijing has led to notable changes. By increasing surface infiltration channels and using natural percolation to recharge rainwater into the groundwater, significant improvements have been observed.

As shown in Figure 2, since the initiation of sponge city pilot projects in Beijing in 2015 as a pioneering demonstration area, the downward trend in groundwater levels has been markedly alleviated, ending nearly 20 years of continuous decline of 15 meters. With the systematic and widespread promotion of sponge city construction in Beijing, the further reduction of impervious surfaces has led to an increase in permeable surfaces, allowing the urban surface to gradually revert to pre-development conditions. Since 2015, groundwater levels in Beijing have been rising annually, reaching levels comparable to those before the year 2000 by 2023. Additionally, since 2020, there has been a significant change in precipitation patterns in Beijing. With the northward shift of precipitation belts due to global climate change, the annual rainfall in the Beijing region has increased significantly. The increase in rainfall, combined with the natural accumulation and infiltration methods promoted by sponge city construction, has further accelerated the groundwater recharge phenomenon. This further underscores the significant role of sponge city construction in the rise of groundwater levels.

3.2 Impact of Sponge City Construction on Groundwater Quality

Sponge city construction primarily improves groundwater quality by increasing the natural infiltration of rainwater. Sponge cities use permeable pavements, rain gardens, sunken green spaces, and bioretention facilities to not only enhance rainwater infiltration but also purify water through these low-impact development features, effectively reducing the risk of groundwater contamination. These low-impact development facilities slow down rainwater runoff and increase opportunities for rainwater to infiltrate into the ground. As rainwater passes through soil layers and vegetation, it undergoes preliminary purification. Microorganisms, plant roots, and soil particles can adsorb and degrade pollutants in the rainwater, such as heavy metals and nutrients like nitrogen and phosphorus, allowing the rainwater to recharge the groundwater with relatively cleaner quality, thereby improving groundwater quality.

Additionally, sponge city construction promotes the recycling of rainwater resources, reducing the excessive extraction of groundwater. Traditional urban drainage systems often discharge rainwater directly into drainage systems or rivers. In contrast, sponge cities emphasize the collection and utilization of rainwater. By constructing rainwater harvesting systems and using rainwater for green space irrigation and landscape watering, sponge cities not only reduce the demand for groundwater but also decrease pollutant discharge. The collection and reuse of rainwater help alleviate the pressure on groundwater extraction, thereby protecting groundwater resources.

Finally, sponge city construction also enhances the health of urban ecosystems, indirectly improving groundwater quality. The green spaces, wetlands, and vegetation systems in sponge cities not only provide effective hydrological regulation but also improve the urban ecological environment. These ecosystems increase biodiversity, provide habitats, and, through plant roots and microbial activity, further enhance groundwater purification capabilities. A healthy urban ecosystem effectively maintains groundwater quality and contributes to the overall sustainability of urban water resources.

3.3 Impact of Elevated Groundwater Level on Urban Infrastructure Construction

As groundwater levels rise in Beijing's plain areas, this will have significant and complex impacts on the city's infrastructure. While rising groundwater levels can bring environmental and resource benefits, their effects on urban infrastructure must be carefully considered.

The rise in groundwater levels helps mitigate the ground subsidence issues caused by excessive groundwater extraction. Prolonged over-extraction of groundwater has led to a decline in groundwater levels, resulting in soil compaction and ground subsidence. This subsidence has severely impacted urban infrastructure, including roads, buildings, and underground pipelines. As groundwater levels rise, increased moisture in the soil helps restore its original structure, which can slow down or reverse ground subsidence, thereby protecting and extending the lifespan of infrastructure.

However, elevated groundwater levels can pose safety risks to underground structures such as underground parking lots, subway tunnels, and underground pipelines. When groundwater levels rise significantly, the additional water pressure can affect these structures, potentially leading to leakage or structural deformation. If drainage systems and waterproofing measures are inadequate, elevated groundwater levels may cause leaks and water damage in underground structures, compromising their long-term safety. In recent years, the rising groundwater levels have led to increasingly severe leakage issues in some of Beijing's subway lines, particularly those constructed and opened after 2000. Therefore, during the design and construction of underground structures, it is essential to thoroughly consider the impact of groundwater level changes and implement effective protective measures. To address groundwater impacts on construction projects, additional drainage facilities, reinforcement measures, and waterproofing designs may need to be incorporated during the design phase. These measures could include installing drainage pipes, enhancing basement waterproofing, or using anti-permeable materials. These additional requirements can increase construction costs and potentially affect project timelines.

Additionally, rising groundwater levels may also impact the stability of roads and bridges. As groundwater levels increase, water can accumulate beneath roadbeds and bridge foundations, potentially affecting their stability and leading to issues such as erosion or weakened structural support. Thus, urban planners and engineers must monitor groundwater levels closely and adapt infrastructure design and maintenance strategies accordingly to ensure the stability and longevity of urban infrastructure in the face of changing groundwater conditions.

While the rise in groundwater levels presents certain challenges for infrastructure construction, it can also have positive effects on urban green spaces and landscapes. An increase in groundwater levels can improve moisture conditions for urban green areas, promoting plant growth and enhancing the urban greening rate. This, in turn, contributes to improving the environmental quality and aesthetic appeal of the city, positively impacting the living environment for residents.

4. Conclusion

With the comprehensive promotion of sponge city construction, groundwater levels in Beijing's plain areas have significantly increased, and the groundwater quality has benefited from the use of low-impact development facilities, maintaining high water quality standards. However, the rise in groundwater levels has a dual impact on urban infrastructure construction. While it helps alleviate ground subsidence issues and improve green space environments, it may also increase safety risks and construction costs for underground structures. To effectively address these challenges, urban planning and infrastructure construction must thoroughly consider the impacts of groundwater level changes and implement appropriate design and engineering measures to ensure the safety and sustainability of infrastructure.

In the future, although groundwater levels in Beijing have risen, the overall groundwater resources still face significant pressure. As the systematic and comprehensive promotion of sponge city construction continues, the upward trend in groundwater levels will gradually slow. Therefore, ongoing water conservation and management measures, improving water resource efficiency, and expanding the use of recycled water will remain crucial strategies for maintaining groundwater balance in the future.

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