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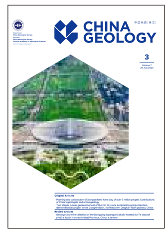

Planning and construction of Xiong’an New Area (city of over 5 million people): Contributions of China’s geologists and urban geology

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A R T I C L E I N F O

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A B S T R A C T

China established Xiong’an New Area in Hebei Province in 2017, which is planned to accommodate about 5 million people, aiming to relieve Beijing City of the functions non-essential to its role as China’s capital and to expedite the coordinated development of the Beijing-Tianjin-Hebei region. From 2017 to 2021, the China Geological Survey (CGS) took the lead in multi-factor urban geological surveys involving space, resources, environments, and disasters according to the general requirements of “global vision, international standards, distinctive Chinese features, and future-oriented goals” in Xiong’an New Area, identifying the engineering geologic conditions and geologic environmental challenges of this area. The achievements also include a 3D engineering geological structure model for the whole area, along with “one city proper and five clusters”, insights into the ecology and the background endowment of natural resources like land, geothermal resources, groundwater, and wetland of the area before engineering construction, a comprehensive monitoring network of resources and environments in the area, and the “Transparent Xiong’an” geological information platform that is open, shared, dynamically updated, and three-dimensionally visualized. China’s geologists and urban geology have played a significant role in the urban planning and construction of Xiong’an New Area, providing whole-process geological solutions for urban planning, construction, operation and management. The future urban construction of Xiong’an New Area will necessitate the theoretical and technical support of earth system science (ESS) from various aspects, and the purpose is to enhance the resilience of the new type of city and to provide support for the green, low-carbon, and sustainable development of this area.

1. Introduction

More than 50% of the world’s population lives in cities. The advancement in human society and the rapid development of science and technology have accelerated the urbanization process. Human activities have significantly influenced geologic environments, resulting in gradually deteriorating urban geologic environments and increasingly prominent geologic issues related to urban land use, resource exploitation, waste disposal, environmental protection, and disaster prevention and control. These directly affect and restrict urban development and renovation (Tang HM, 2006).

The rate of urbanization in China has reached up to 65%, giving birth to megacities such as Beijing, Shanghai, Guangzhou, and Shenzhen, significantly boosting economic and social advancement. However, the urbanization process has caused issues like high population density, environmental

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pollution, resource shortage, and traffic congestion (Wang J et al., 2019; Wang BQ et al., 2021; Xu BQ, 2023), severely restricting urban resilience and sustainable development (Pan X and Zhang SW, 2021; Floková L et al., 2023). Modern urban development, guided by new urbanism, smart growth theory, and sustainable development theory, has gradually shifted toward balanced land development and biodiverse and sci-tech cities like Freiburg in Germany and Songdo in Republic of Korea.

To address the challenges of urban development, American scholars, represented by Kaye and Legget, first coined the concept of urban geology (Kaye CA, 1968; Legget RF, 1973), holding that urban geological activities can assist in ascertaining the geological conditions underneath cities, thus contributing significantly to urban engineering construction (Hageman BP, 1963; Bobylev N, 2009; Gargiulo M et al., 2017). As urbanization continues, urban geology has garnered extensive attention. As a separate branch of geology, urban geology plays an essential role in solving urban geologic issues and accomplishing sustainable development (Jin JJ and Pan M, 2007; Lin LJ et al., 2020).

Urban geological activities have gradually shifted from initial single-factor surveys to multidisciplinary comprehensive geological surveys. The purpose is to identify the background resource endowment of cities and solve the geologic environmental issues in urban development, thus promoting the sustainable development of urban economy, society, and environment (Fang JH, 2001; Feng XM et al., 2003; Luo GY, 2005; Xu ZQ et al., 2006; Gao YF et al., 2007; He ZF, 2010; British Geological Survey, 2015; Cheng GH, 2018; Bibri SE et al., 2020; Anna WF et al., 2024).

The regional urban development strategy in China has imposed new requirements on urban geological efforts in terms of optimizing urban structural layout, expanding urban development space, advancing the construction of green cities, and enhancing urban safety guarantee (Jin JJ et al., 2007; Li LR et al., 2012; Zheng GS et al., 2016; Xu YQ, 2022). Multi-factor urban geological surveys involving space, resources, environments, and disasters are critical to intensive, intelligent, green, low-carbon, and sustainable urban development (Hao AB et al., 2017; Lin LJ et al., 2017; Zhang MS et al., 2018).

China established Xiong’an New Area in Hebei Province in April 2017, aiming to effectively relieve Beijing of the functions non-essential to its role as China’s capital and to expedite the coordinated development of the Beijing-Tianjin-Hebei city cluster. Multi-factor urban geological surveys involving space, resources, environments and disasters in Xiong’an New Area can lay an essential foundation for high-standard, high-quality construction of Xiong’an New Area. These surveys serve as both a vital means to construct Xiong’an New Area into a smart city with high ecological civilization and a practical guarantee for the whole process of the planning, construction, operation, and management of the area. Furthermore, they provide services of planning, construction, natural resource management, ecological protection, safe urban operation, and digital city construction for Xiong’an New Area, holding great significance for building this area into a demonstration base of multi-factor urban geological surveys.

From 2017 to 2021, the CGS organized China’s geologists to conduct multi-factor urban geological surveys involving space, resources, environments, and disasters in Xiong’an New Area, obtaining deep insights into the conditions of natural resources and geologic environments, a batch of exclusive, comprehensive, and high-precision survey data of natural resources and geologic environments before the construction of the area, and a series of geological survey reports. Furthermore, these surveys were accompanied by explorations and innovations in working philosophy, working methods, and result presentation. These geologists provide continuous and effective services for the planning and construction of Xiong’an New Area, with the surveys they conducted offering a demonstration and reference for multi-factor urban geological surveys in other areas.

2. Regional background

2.1. Geographic location

Xiong’an New Area resides in the hinterland of Beijing, Tianjin, and Baoding, 105 km away from Beijing and Tianjin, 155 km from Shijiazhuang, and 30 km from Baoding, enjoying great locational advantages and convenient and efficient traffic. With a planned area of 1770 km^2, the Xiong’an New Area consists of Xiongxian, Rongcheng, and Anxin counties (including the Baiyangdian water area), Maozhou and Gougezhuang towns, Qijianfang Township of Renqiu City, and Longhua Township of Gaoyang County (Fig. 1).

Xiong’an New Area manifests stable geologic conditions, excellent ecosystems, and a high resource and environmental bearing capacity. This area has a permanent population of 104.71×10^4 as of June 2017. It holds considerable potential for development given its low development degree at present, hosting general conditions for high-standard development and construction with an excellent starting point.

2.2. Geological setting

The terrain of Xiong’an New Area decreases gradually from northwest to southeast, with surface elevations ranging from 5 m to 26 m and surface gradients less than 2‰ (Fig. 1). With the Rongcheng-Xiongxian area as a boundary, the northern portion exhibits alluvial-proluvial plains composed of modern river alluvium or before-fan depression deposits, along with underlying alluvial-proluvial deposits, while the southern portion hosts alluvial-lacustrine plains formed by modern river alluvium and lacustrine deposits (Fig. 2).

Xiong’an New Area has a warm temperate, monsoon continental, subhumid and semi-arid climate, with an average annual temperature of 12.7°C and an average frost-free period of about 205 days per year. Its average annual precipitation is

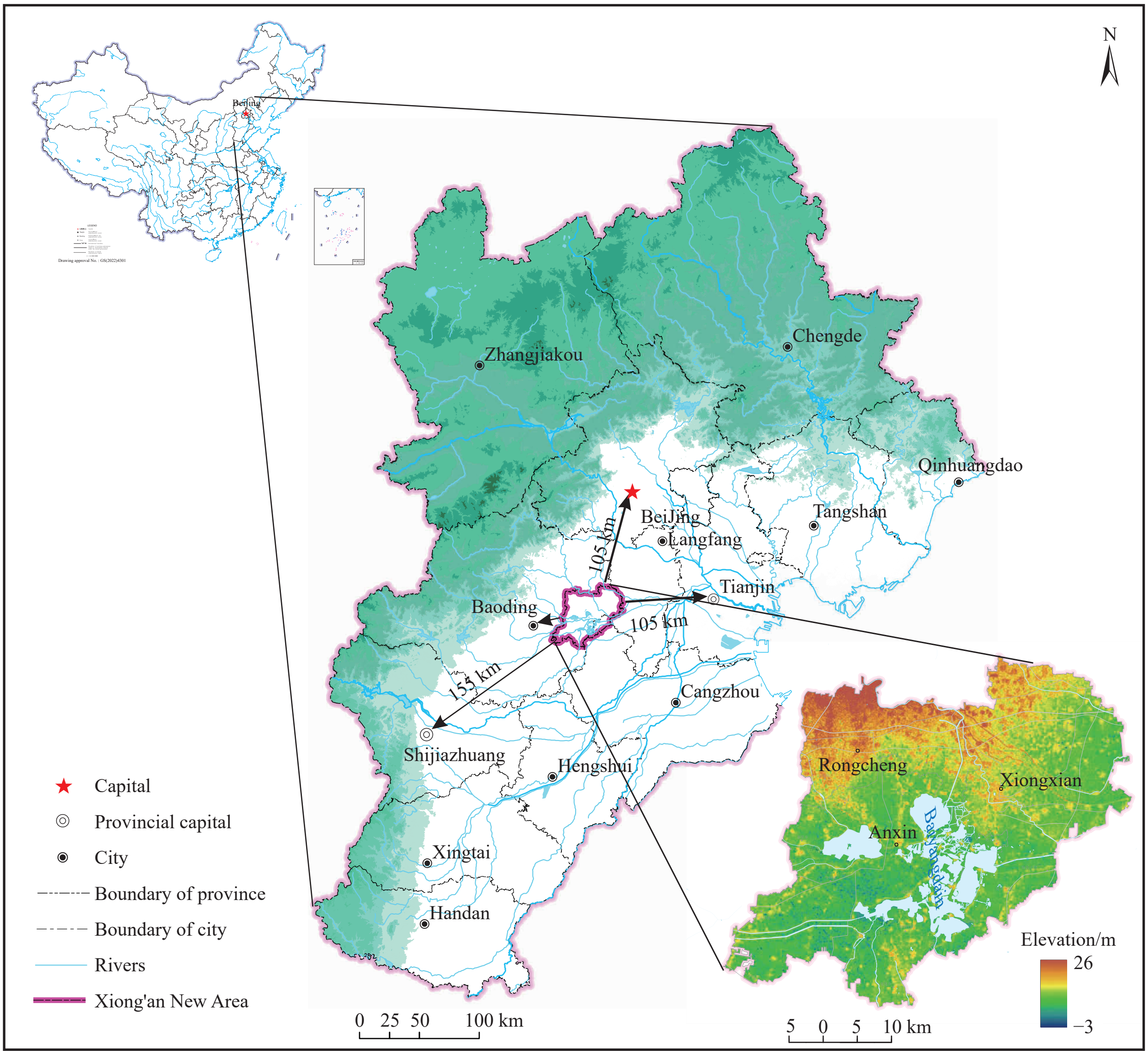

Fig. 1. Geographic location of Xiong’an New Area.

approximately 500 mm (Fig. 3), with 80% of intra-annual precipitation concentrated in July, August, and September. It has a well-developed river system comprising 10 rivers, all of which fall within the Daqing River basin (Fig. 4). The total river length and river density measure 258 km and 0.12–0.23 km/km^2, respectively. Besides, the Baiyangdian Lake, the largest lake in the North China Plain, has an area of about 366 km^2 and a maximum water storage capacity of 10.4×10^8 m^3.

2.3. Overall planning

Drawing on successful international experience, the Leading Group for Coordinated Beijing-Tianjin-Hebei Development prepared the *Planning Outline for Xiong’an New Area in Hebei* and the *2018–2035 Master Plan for Xiong’an New Area in Hebei Province*. The planning describes a scientific and reasonable spatial layout, a beautiful natural ecosystem, a green, low-carbon, and smart new city, a convenient and efficient traffic network (Fig. 5c, d), and a modernized urban security system. Overall, this area will be progressively built into a high-quality and high-level modern city that is green, low-carbon, information-based, intelligent, and suitable for living and work, thus standing as a national pacesetter of high-quality development in the new era (Figs. 5a, b, e, f, g, h).

3. Methods

3.1. Goals of geologic surveys

The geologic work in the Xiong’an New focuses on multi-factor urban geological surveys involving space, resources, environments, and disasters according to the general requirements of “global vision, international standards, distinctive Chinese features, and future-oriented goals”. The purpose is to build Xiong’an New Area into a world-class “Transparent Xiong’an”, a global pacesetter of geothermal resource utilization, and a demonstration base of multi-factor urban geological surveys and natural resource surveys and to provide whole-process geological solutions for the planning,

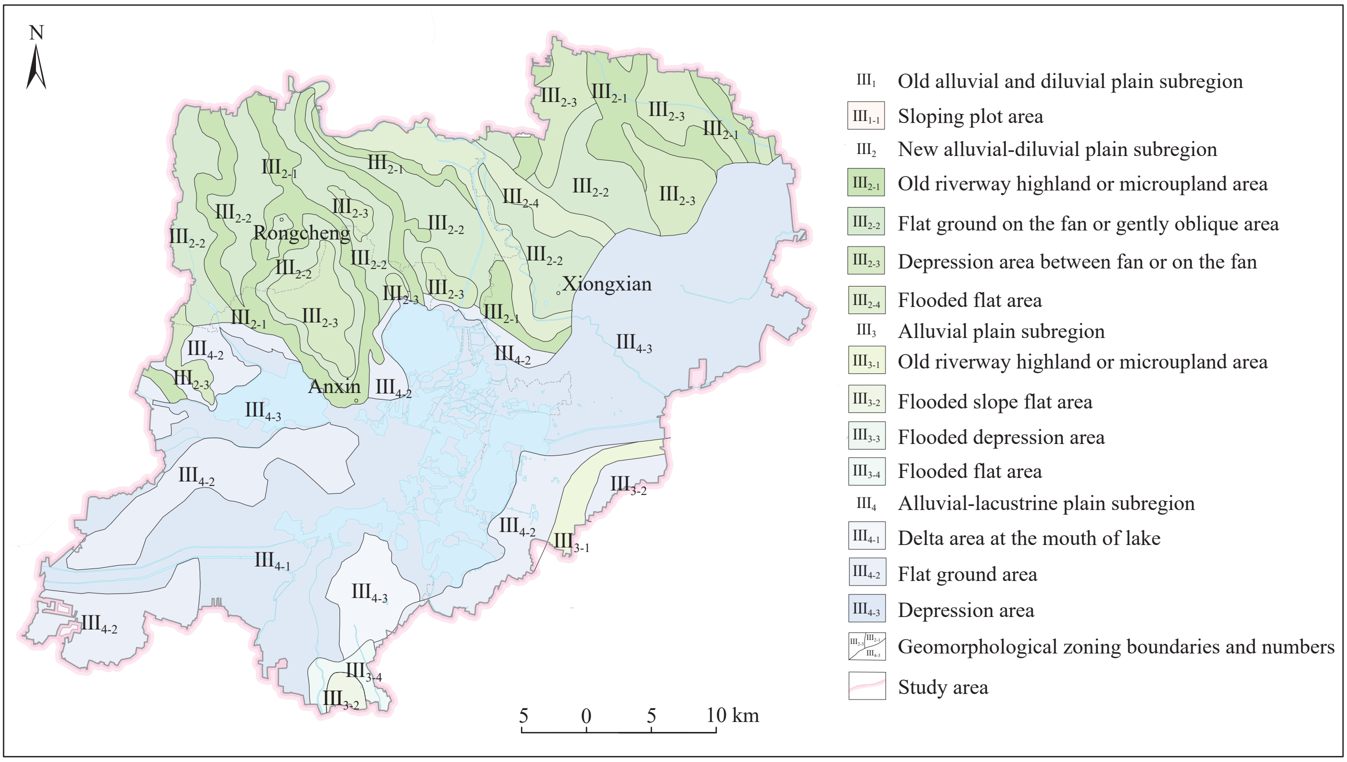

Fig. 2. Landforms in Xiong’an New Area.

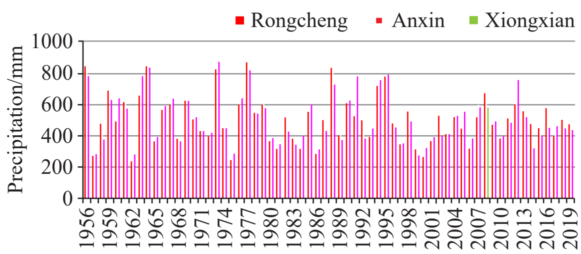

Fig. 3. Histogram showing precipitation during 1956–2019 in Xiong’an New Area.

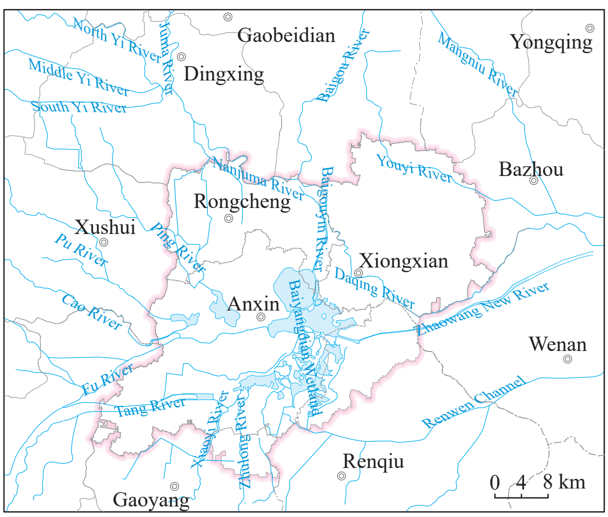

Fig. 4. River system in Xiong’an New Area.

construction, operation, and management of Xiong’an New Area.

3.2. Technical route

Focusing on the needs and major geological issues of Xiong’an New Area, the technical route is stated as follows: Planning and deploying multi-factor comprehensive urban geological surveys in a scientific manner; building a comprehensive monitoring network of natural resources and geologic environments characterized by space-ground integration, stereoscopic monitoring, and automatic sensing; establishing the “Transparent Xiong’an” geological information platform that is open, shared, dynamically updated, and three-dimensionally visualized; building an innovative service system based on urban geological surveys; serving the whole process of urban planning, construction, operation, and management, and creating a demonstration base for multi-factor urban geological surveys and natural resource surveys (Fig. 6).

3.3. Work contents

Grounded in the planning and construction needs to build Xiong’an New Area into a green, modern, smart, and ecological city with a highly efficient traffic network, as well as the principle of simultaneous commencement and gradual advancement of the initial development areas, the mid-term development areas, and the long-term control areas, the following work contents were deployed in a coordinated way: The survey, assessment, and comprehensive development demonstration of clean geothermal energy; the eco-geological survey of the Baiyangdian wetland; the survey and assessment of water resources, land resources, and engineering geology and underground space resources; the exploration of deep 3D

Fig. 5. Xiong’an New Area under construction. a, b–Xiong’an New Area before construction; c–map of the planning of the urban and rural spatial layout in Xiong’an New Area; d –map of the planning of regional rail transit and highways in Xiong’an New Area; e, f–Xiong’an New Area under construction (taken by Mou Yu, https://www.sohu.com/na/430127018_ 267106); g, h–city scale of Xiong’an New Area appearing.

geological structures; the construction of a comprehensive monitoring network of natural resources and geologic environments, and the establishment of the “Transparent Xiong’an” geological information system, among others (Fig. 7).

Primarily tasks include 1∶50000 geothermal geological survey of 2000 km^2, 1∶50000 eco-geological survey of 1300

km^2, 1∶50000 hydrogeological survey of 2000 km^2, 1∶50000 engineering geological survey of 2400 km^2, 1∶10000 engineering geological survey of 400 km^2, 1∶50000 land quality geochemical survey of 1700 km^2, interpretation of 1∶50000 remote sensing data of 2000 km^2, interpretation of 1∶10000 remote sensing data of 1200 km^2,

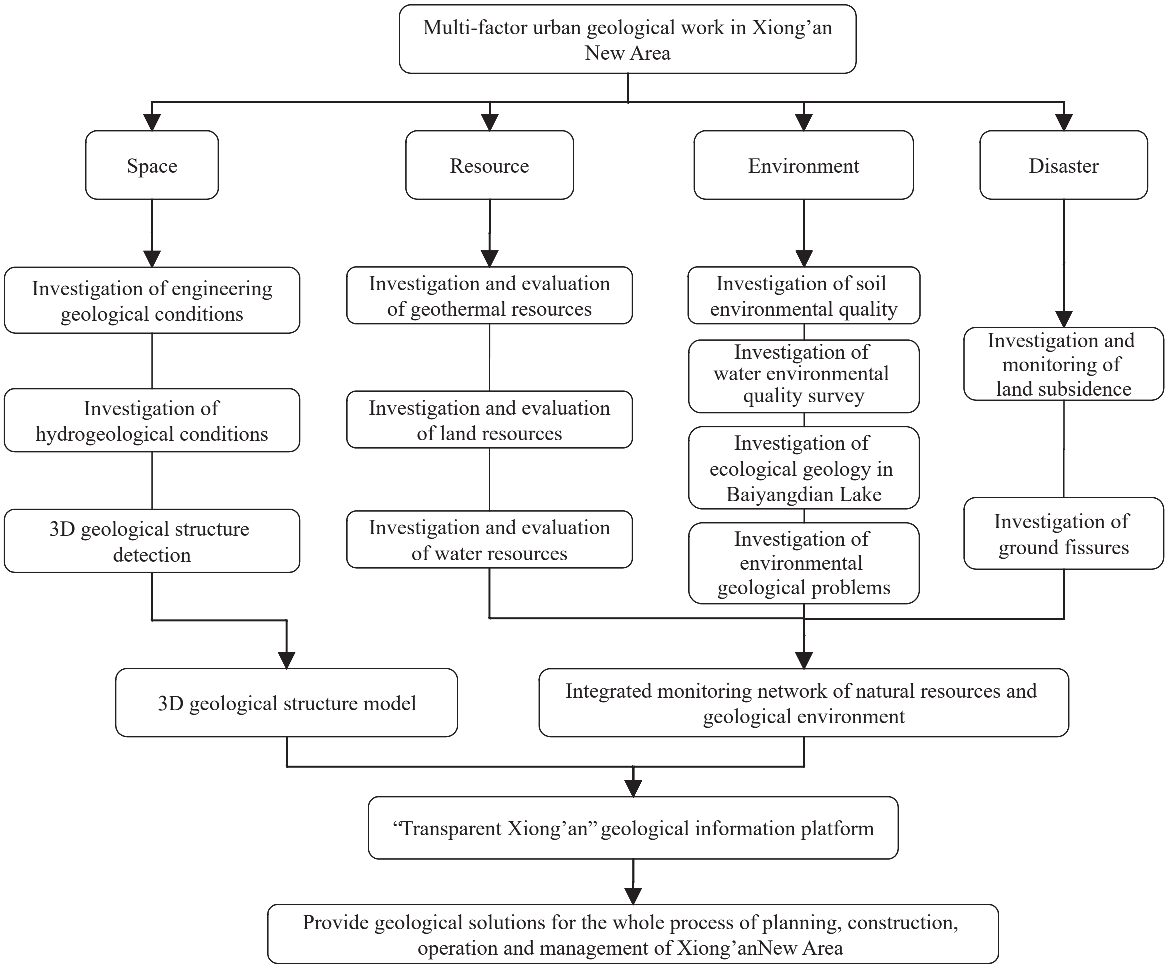

Fig. 6. Technical route of multi-factor urban geological surveys in Xiong’an New Area.

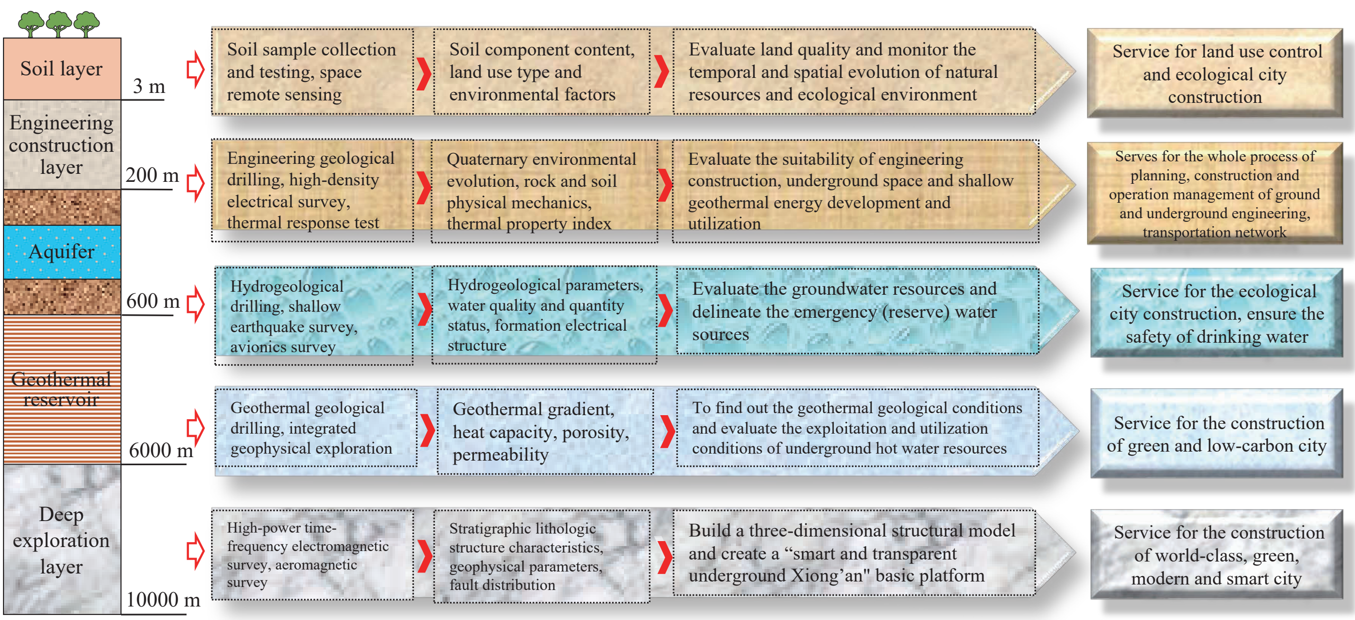

Fig. 7. Schematic diagram showing the construction of “Transparent Xiong’an”.

geothermal drilling of 65500 m, hydrogeological drilling of 13798 m, engineering geological drilling of 94914.09 m, and eco-geological drilling of 5600 m. A total of 38850 soil samples were collected. Additionally, the tasks also contain deep seismic reflection profiling of 470 km, magnetotelluric sounding of 820 km, 3D controlled source magnetotelluric sounding of 2213 points, 2D seismic exploration of 18000 physical points, and anti-interference electrical prospecting of 4000 points. The cumulative investment in these tasks totaled about 100×10^6 dollars.

4. Results

4.1. Planning and construction

Centering on the master planning and regulatory detailed planning of Xiong'an New Area, as well as the needs of engineering construction, underground space surveys and engineering geological surveys were conducted (Fig. 8), achieving insights into the engineering geological conditions of Xiong'an New Area, a 3D engineering geological structure model for "one city proper and five clusters", the extent of special soils like weak soil and liquefied sands in the area, and the assessment results of the groundwater and soil corrosiveness, site stability, and the suitability for engineering construction.

4.1.1. Engineering geological conditions

The strata at depths less than 100 m in Xiong'an New Area exhibit favorable engineering properties. Of these, the strata at depths exceeding 10 m are composed primarily of plastic to hard plastic cohesive soils and medium-dense to dense silts and sandy soils, with the characteristic values of bearing capacity generally ranging from 140 kPa to 350 kPa. The natural foundations and primary engineering construction supporting layers within the planning and construction area exhibit high bearing capacity, thus suitable for engineering construction and underground space development. Major supporting layers include the 5th and 6th (average depths: 15–20 m), 8th and 10th (average depths: 35–45 m), and 13th and 15th layers (average depths: 55–70 m), with the characteristic values of bearing capacity generally exceeding 140 kPa (Fig. 9). Three major aquifers are distributed at depths less than 50 m, where the groundwater levels deserve continuous monitoring during construction, operation, and management (Hao AB et al., 2018; Ma Z et al., 2019; Han B et al., 2020, 2023).

4.1.2. Engineering geological structure model

Using the data from 1169 engineering geological boreholes and the Xmodeling software, a 3D engineering geological structure model for strata at depths less than 100 m was constructed for Xiong'an New Area, along with one city proper and five clusters, in the following steps: Data preparation, data processing, data importing, borehole modeling, stratigraphic modeling, and model refinement and decoration (Fig. 10). The obtained model consists of 18 strata, which, corresponding to the standard engineering geological

Fig. 8. Engineering geological survey and utilization of underground space. a–construction site of engineering geological drilling; b–core catalog; c–utilization types of underground space; d–construction site of underground space.

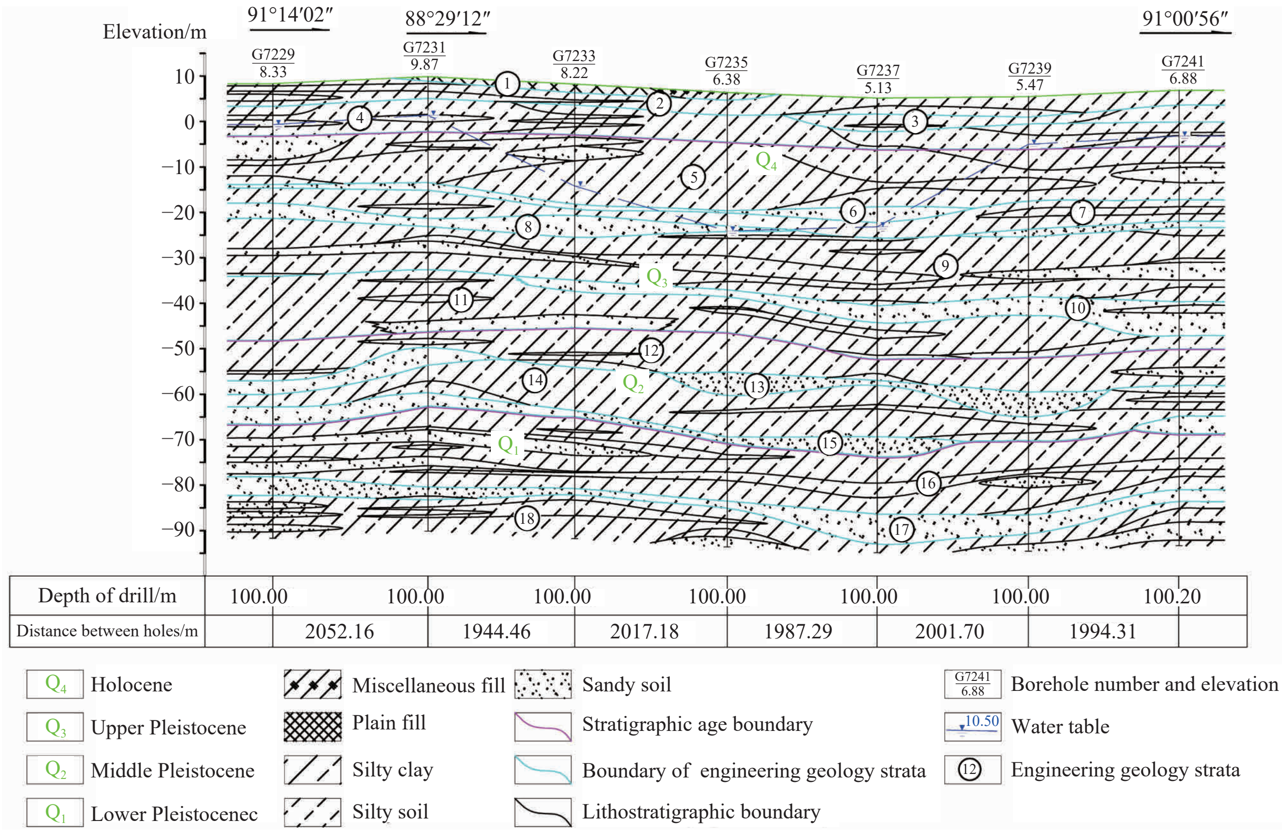

Fig. 9. Standard engineering geological section of Xiong'an New Area (after Han B et al., 2023).

strata, clearly present the distribution ranges and thickness variations of all the engineering geological strata. This model reveals the spatial distribution patterns of the strata, as well as the spatial relationships between the engineering construction supporting layers and the strata involved in underground space development within the 3D space. Additionally, this model allows for analyses and processing such as profiling and underground space excavation. Therefore, it can be employed to simulate the 3D dynamic process of tunnel and foundation excavation in urban engineering construction, thus providing a reference for the planning and construction of Xiong'an New Area (Han B et al., 2023).

4.1.3. Special soils

(i) Weak soil

No weak soil in the strict sense has been discovered in Xiong'an New Area. In this study, weak soil refers to cohesive soil with a porosity of about 1.0, moisture content exceeding or approximating 30%, and compression index above 0.4. The weak soil, dominated by silty clay, is primarily distributed in a dotted pattern within the alluvial-lacustrine deposit area. Specifically, such soil spread in the western Anxin county town and between the Zhanggang Township - Xiongxian county town in the west and the Maozhou, Liulizhuang, and Anzhou towns in the east. The weak soil covers an area of 193 km^2, accounting for 10.9% of the total area of Xiong'an New Area (Fig. 11a).

(ii) Liquefied sand

GB50011-2010 *Code for Seismic Design of Buildings* issued by the Ministry of Construction of the People's Republic of China in 2010 indicates that Xiong'an New Area has a seismic intensity of 7, and, accordingly, the design basic ground motion acceleration in this area is 0.10 g (Ministry of Construction of the People's Republic of China, 2010). However, based on the planning of Xiong'an New Area, a basic seismic fortification intensity of 8 (0.2 g) was used for assessments. The preliminary assessment indicated the absence of liquefied sands across the area. However, to ensure the safety of the new city, a detailed assessment was conducted based on current groundwater levels, revealing that earthquake-induced soil liquefaction occurs primarily in the Anxincounty town - Xiongxian county town - Zhaobeikou Town area and the Anzhou Town - Quantou Township - Liulizhuang Town area in the south. Specifically, moderate liquefaction occurs in Anxin County town, Liutong Village, and Anzhou, Duancun, and Liulizhuang towns near the Baiyangdian Lake, while severe liquefaction is distributed the area immediately adjacent to the Baiyangdian Lake (Fig. 11b).

4.1.4. Corrosivity of groundwater and soils

(i) Corrosivity of groundwater

Regarding the corrosivity of groundwater to concrete structures in Xiong'an New Area, strong corrosion is primarily identified in the Tongkou Town - Liulizhuang Town area in Anxin County, moderate corrosion in the Liulizhuang Town - Tongkou Town area in Anxin County and the Zangang Town - Shuangtang Township area in Xiongxian County, weak corrosion in the Laohetou Town - Tongkou

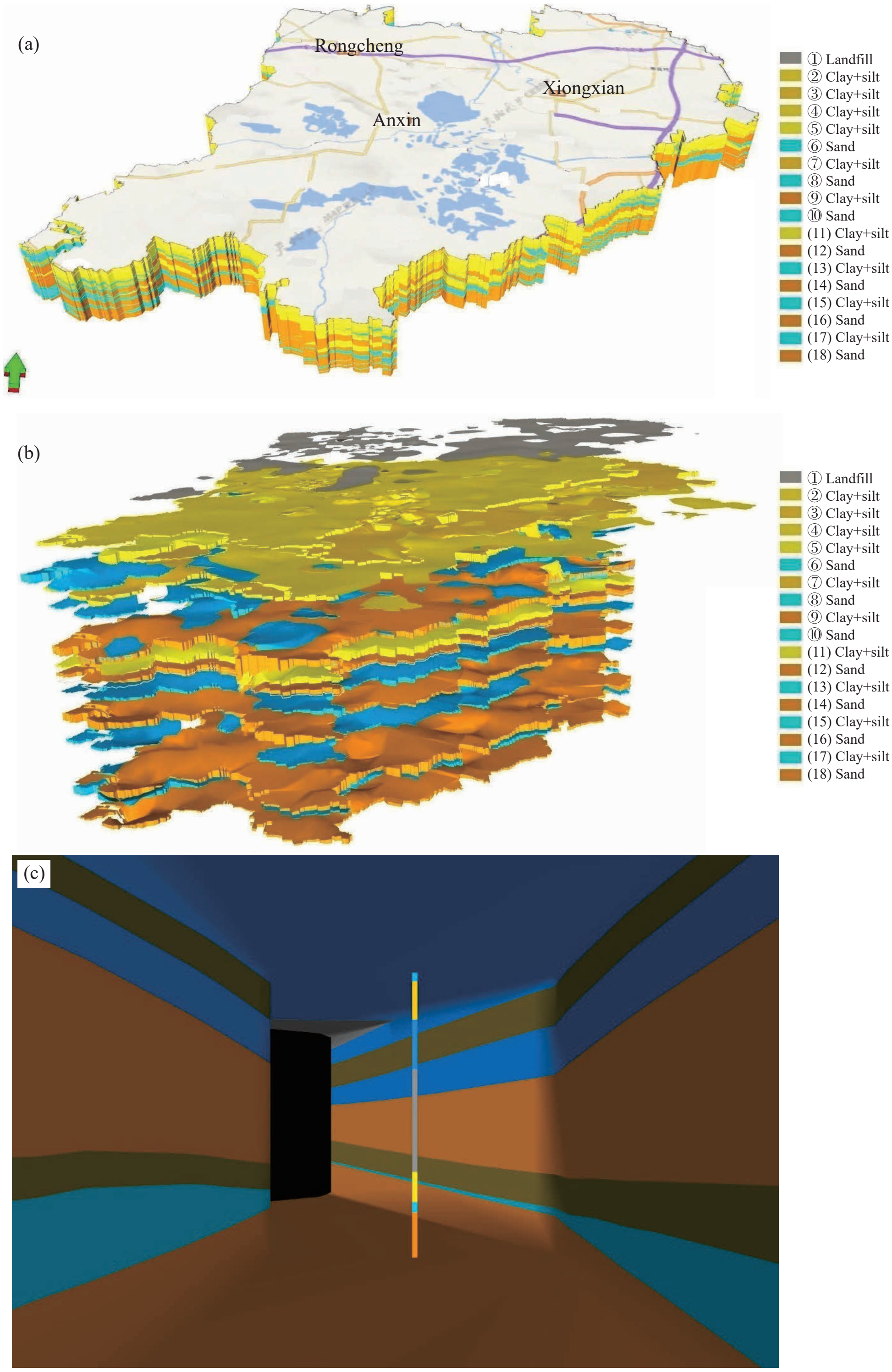

Fig. 10. 3D engineering geological structure model of Xiong’an New Area. a–geobody; b–stratigraphic exploded view; c–tunnel roaming.

Town area in Anxin County and the Gougezhuang Town - Longwan Town - Zangang Town area in Xiongxian County, and slight corrosion extensively in the northwestern portion of Xiong’an New Area.

Regarding the corrosivity of groundwater to steel bars in reinforced concrete within the study area, moderate corrosion is primarily discovered in the Liulizhuang Town - Tongkou Town area in Anxin County, weak corrosion is widespread in most of Anxin County in the southeast and to the south of the Xiongzhou Town - Zangang Town area in Xiongxian County, and slight corrosion widely spread in the north and the west, with the absence of strong corrosion.

Regarding the corrosivity of groundwater to steel structures in the study area, moderate corrosion is principally found in the Liulizhuang Town - Tongkou Town area in Anxin County and the Maozhou Town - Qijianfang Township area in Xiongxian County, and weak corrosion is widely distributed in other areas, with the absence of strong corrosion.

(ii) Corrosivity of soils

Insignificant corrosivity of soils to concrete structures is found in Xiong'an New Area. Specifically, slight and weak corrosions occur widely, moderate corrosion is primarily identified in Tongkou Town of Anxin County, along with Maozhou Town and eastern Longwan Town of Xiongxian County, and strong corrosion is scattered over the study area. Regarding the corrosion of soils to steel bars in reinforced concrete in the study area, slight corrosion is found in most areas, weak corrosion in a few areas including Shuangtang Township, Maozhou Town, and Gougezhuang Town in eastern Xiongxian County, as well as Liulizhuang Town and Longhua Township in Anxin County, and moderate corrosion merely in Maozhou Town in Xiongxian County, with the absence of strong corrosion. Concerning the corrosion of soils to steel structures in the study area, only slight corrosion is identified (Fig. 12; Xia YB et al., 2022).

4.1.5. Site stability

Regarding site stability (Ministry of Housing and Urban-Rural Construction of the People's Republic of China, 2012), Xiong'an New Area can be divided into stable zones, roughly stable zones, and zones with poor stability (Figs. 13a, b).

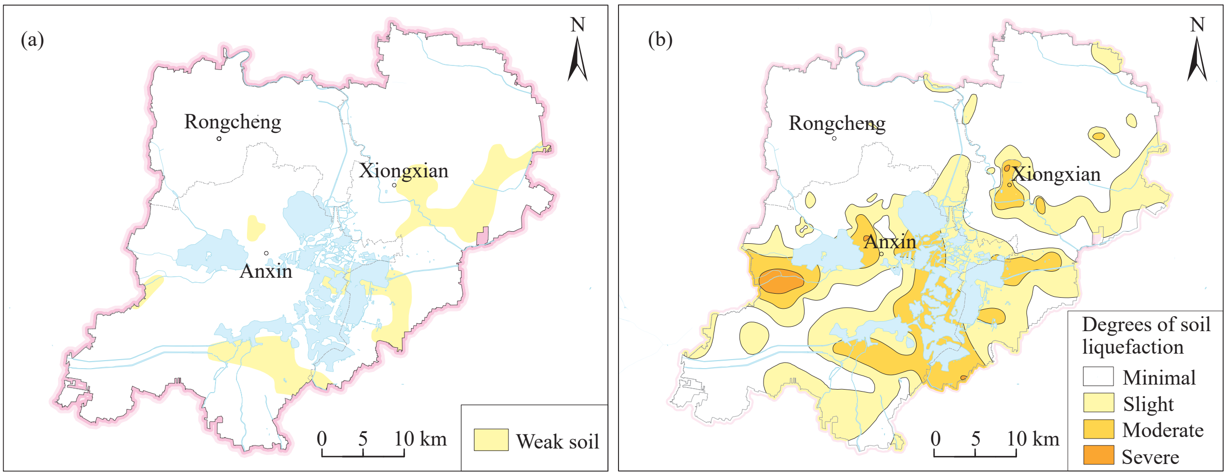

Fig. 11. Distribution of weak soil (a) and liquefied sand (b) under current groundwater levels in Xiong'an New Area.

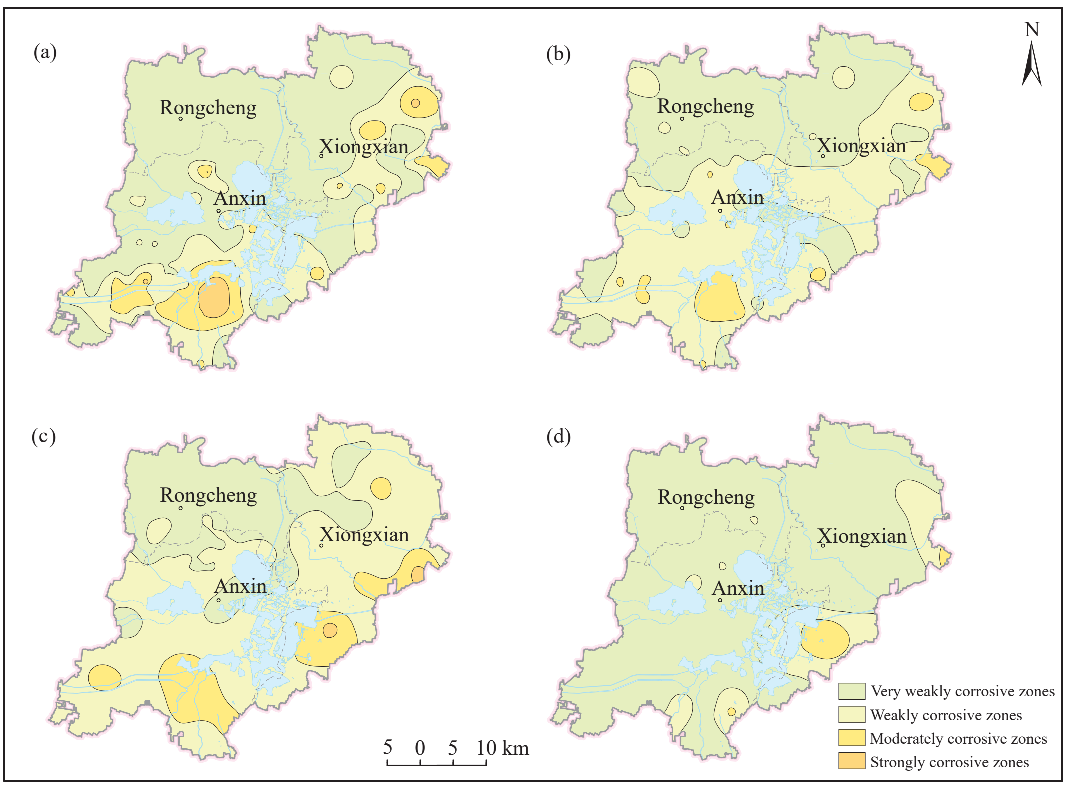

Fig. 12. Assessment results of the corrosivity of groundwater and soils in Xiong'an New Area. a–corrosivity of groundwater to concrete structures; b–corrosivity of groundwater on steel bars in reinforced concrete; c–corrosivity of soil on concrete structures; d–corrosivity of soil on steel bars in reinforced concrete.

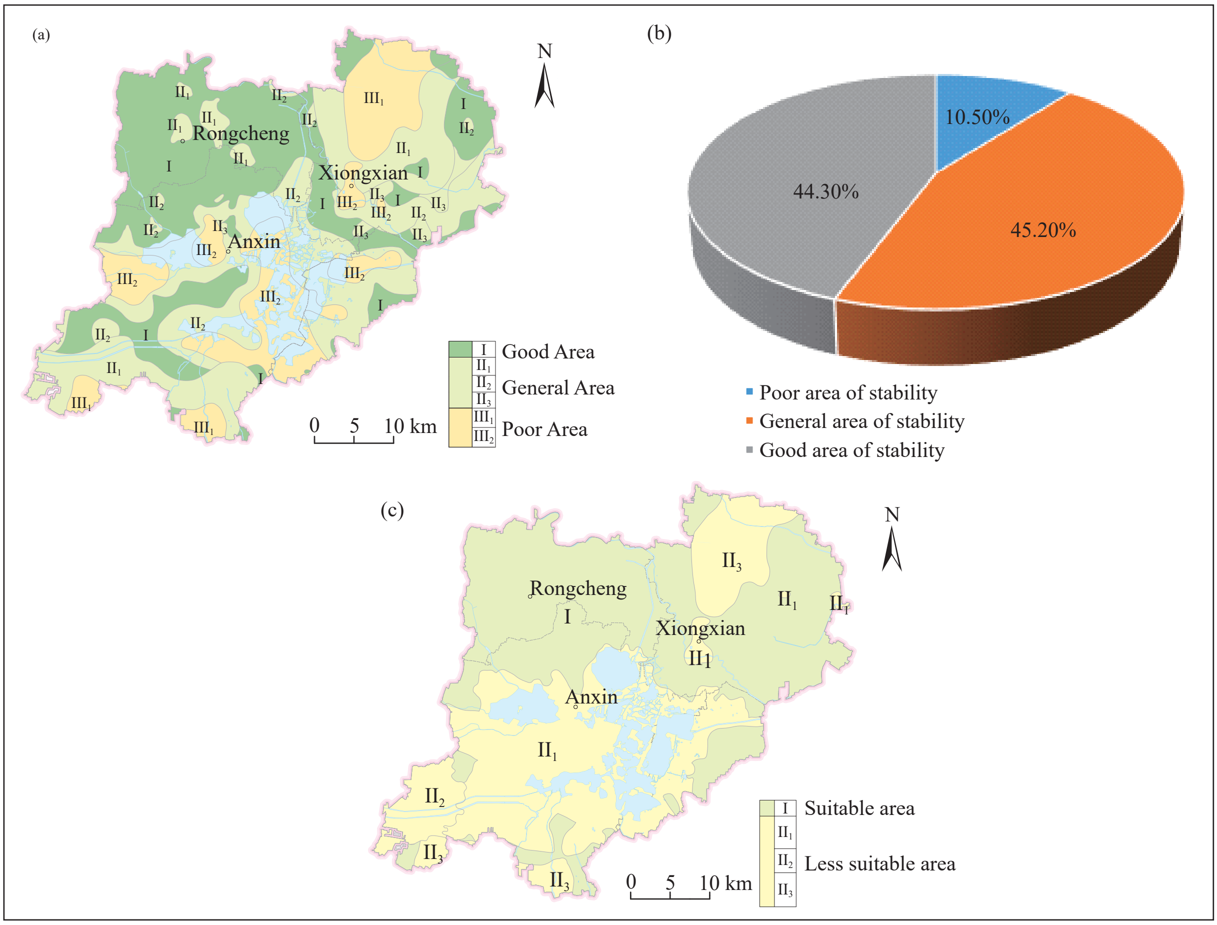

Fig. 13. Site stability zoning (a), proportions (b) of site stability zones and engineering construction suitability zoning (c) in Xiong’an New Area.

Zones with poor stability consist of zones with moderate and severe seismic liquefaction of saturated silty soils and those with land subsidence exceeding 50 mm, covering an area of 186 km^2, which accounts for 10.5% of the total area. These zones are located in the Beishakou Township - Daying Town - Mijiawu Township area, scattered areas of Anxin County, Luzhuang and Longhua townships, and Anzhou and Duancun towns.

Roughly stable zones comprise zones with slight seismic liquefaction of saturated silty soil, those with well-developed weak soil, and those with land subsidence ranging from 30 mm to 50 mm, covering an area of 799 km^2, representing 45.2% of the total area. These zones are primarily distributed in Anxin county town, Xiongzhou Town, the Zhaobeikou Town - Longwan Town area, Zhanggang and Mijiawu townships, Zangang, Gougezhuang, and Maozhou towns, and the Anzhou Town - Duancun Town - Tongkou Town - Liulizhuang Town - Qijianfang Township area. The rest of Xiong’an New Area belongs to stable zones, with an area of 785 km^2, which accounts for 44.3% of the total area.

4.1.6. Suitability for engineering construction

Based on CJJ 57-2012 *Code for Geo-Engineering Site Investigation and Evaluation of Urban and Rural Planning*, Xiong’an New Area can be divided into suitable and less suitable zones for engineering construction, as revealed by the suitability assessment (Fig. 13c).

Less suitable zones cover an area of 845 km^2, accounting for 47.8% of the total area. They exhibit weak soil and slightly liquefiable soil, land subsidence, and generally stable foundations, with groundwater levels posing minor impacts on engineering construction.

Other portions in the study area are suitable zones, exhibiting almost the absence of weak or liquefiable soils, slight land subsidence, and stable foundations, with groundwater levels posing minimal impacts on engineering construction. These zones cover an area of 925 km^2, accounting for 52.2% of the total area.

It is inadvisable to consider the water areas within the Baiyangdian area, such as its flood discharge, storage, and detention areas, to be suitable zones for engineering construction. These water areas were excluded in this study.

4.2. Natural resources

Given the needs of Xiong’an New Area for green and low-carbon urban construction and natural resource management, natural resource surveys were conducted in this area, identifying the types, quantities, and distributions of land, geothermal, groundwater, and wetland resources.

4.2.1. Land resources

By the end of 2020, six land use types had been identified in Xiong’an New Area, namely arable land, forest land, grassland, surface water bodies, construction land, and others, covering areas of 805.1 km^2 (37.27%), 344.7 km^2 (15.96%), 17.2 km^2 (0.80%), 280.1 km^2 (12.97%), 339.0 km^2 (15.69%), and 373.9 km^2 (17.31%), respectively (Fig. 14a). From 2017 to 2020, the area of arable land decreased, while the areas of forest land, construction land, and surface water bodies increased (Fig. 14b; Table 1).

4.2.2. Geothermal resources

Xiong'an New Area boasts abundant geothermal resources, which are primarily distributed in the Rongcheng, Niutuozhen, and Gaoyang geothermal fields (Fig. 15a; Table 2). From top to bottom, the geothermal reservoirs in Xiong'an New Area include porous sandstone reservoirs in Neogene Minghuazhen and Guantao formations and Cambrian Ordovician, Jixianian, and Changchengian bedrock reservoirs. Of these, the Jixianian bedrock reservoirs serve as the primary geothermal reservoirs, with burial depths ranging from 700 m to 3000 m, thicknesses from 500 m to 2000 m, and reservoir temperatures from 50°C to 123°C. These reservoirs exhibit high water volume, high water quality, and convenient reinjection conditions, rendering them suitable for large-scale centralized exploitation.

Currently, the exploitable geothermal reservoirs within depths less than 4000 m in Xiong'an New Area include the porous reservoirs in the Neogene Minghuazhen and Guantao formations, along with the bedrock reservoirs. The geothermal reservoirs in the Wumishan Formation, the Gaoyuzhuang Formation, the Cambrian Ordovician Formation, and the Guantao Formation hold geothermal resources of 5928.66×10^{16} J and geothermal fluid reserves of 376.69×10^8 m^3 (Fig. 15a). Under the production-reinjection balance, the geothermal fluids in Xiong'an New Area exhibit recoverable resources of 4.00×10^8 m^3/a and recoverable heat of 10.10×10^{16} J/a, which corresponds to 346.03×10^4 t/a of coal equivalent (Wang GL et al., 2018; Ma F et al., 2020; Li M et al., 2023; Zhu X et al., 2023).

Well D34 in Liulizhuang Town, Anxin County, with a wellhead temperature of 123.4°C, a bottomhole temperature of 131.9°C, and a vapor-water mixed flow rate of 142 m^3/h, boasts the highest temperature in North China currently. Well D35 in Duancun Town, Anxin County, exhibiting a wellhead temperature of 109.2°C, a bottomhole temperature of 116°C, and a vapor-water mixed flow rate of 250 m^3/h, has the highest production capacity in North China presently.

Presently, SINOPEC has built 53 heat exchange stations and 131 geothermal wells in Xiong'an New Area, achieving a heating area of above 7×10^6 m^2, which covers nearly 70000 residents in Xiong'an New Area. The obtained heat is equivalent to 1.42×10^6 t of standard coals, reducing carbon

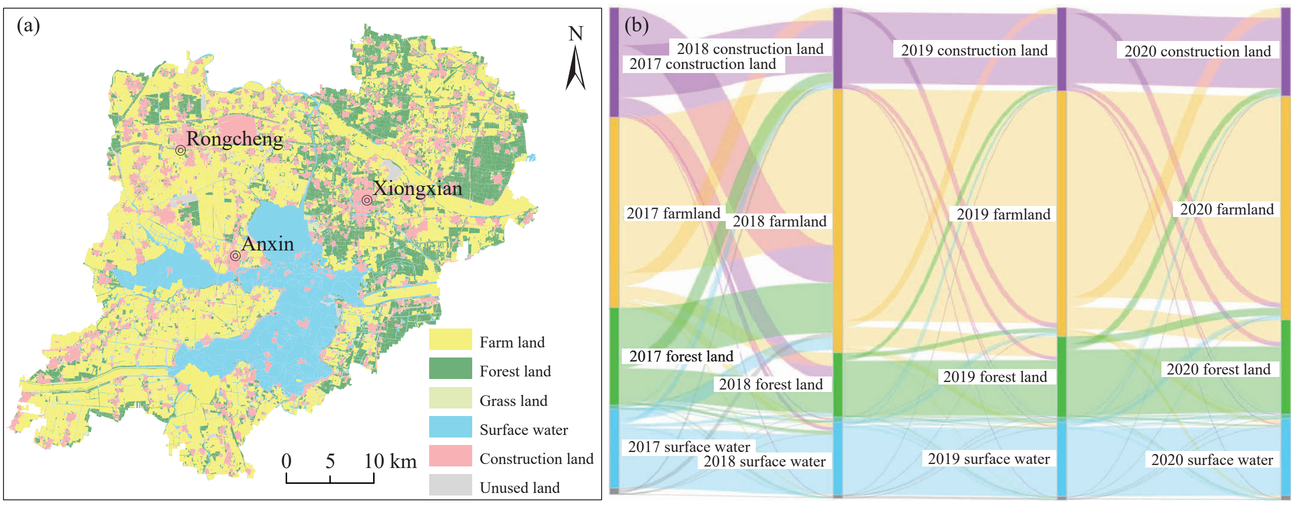

Fig. 14. Present situation (a) of land use types in Xiong'an New Area (after the remote sensing data in the 4th quarter of 2020) and Sankey diagram (b) showing changes in the areas (km^2) of land use types in Xiong'an New Area during 2017–2020.

Table 1. Remote sensing data-derived statistics of the areas of land use types in Xiong'an New Area from 2017 to 2020.

Date	Farm land/km^2	Forest land/km^2	Grass land/km^2	Construction land/km^2	Surface water/km^2
2017.3	989.4	198	21.2	289.2	258.8
2018.3	951.8	232	18.1	293	261.7
2019.3	883	290.1	16.1	300.2	267.2
2019.6	863.4	306.3	16.4	303	269.1
2019.9	836.8	333.8	18.7	299.3	269.9
2019.12	831.2	335.2	18.6	305.1	274.1
2020.3	824.1	346.2	17.5	325.1	277.7
2020.6	811.3	344.9	17.7	328.9	279.4
2020.9	810.8	345.9	17.3	336	278.3
2020.12	805.1	344.7	17.2	339	280.1

dioxide emissions of up to 3.7×10^6 t/a (Fig. 15b).

4.2.3. Groundwater resources

Xiong'an New Area hosts water resources of 1.2×10^8 m^3 (including 91% groundwater) and an average annual precipitation of 516 mm (Table 3). Groundwater in this area, dominated by pore water in unconsolidated rocks, primarily occurs in four Quaternary aquifers. Of these, aquifers Ⅰ and Ⅱ, dominated by fine sands, silts, and silty-fine sands, exhibit moderate water yield properties, with a single-well water yield ranging roughly from 1000 m^3/d to 3000 m^3/d. Aquifers III and IV, consisting primarily of fine and medium-fine sands, manifest relatively high water yield properties, with a single-well water yield varying roughly from 2000 m^3/d to 3000 m^3/d (Feng W et al., 2017). Xiong'an New Area shows a low water resource bearing capacity and low potential for water resource exploitation (Wang SQ et al., 2017).

In Xiong'an New Area, the shallow groundwater levels exhibit burial depths generally ranging from 5 m to 20 m, with an average annual recharge of 20245×10^4 m^3, while the deep groundwater levels manifest burial depths generally ranging between 25 m and 35 m, with an average annual recharge of 2203×10^4 m^3 (Fig. 16). This area hosts exploitable groundwater resources of approximately 19922×10^4 m^3/a. Since the establishment of this area in 2017, the shallow groundwater levels have remained stable and even trended upward, and the downward trend of the deep groundwater levels has gradually reduced. These are attributed to measures such as the prohibition/restriction on groundwater exploitation, south-to-north water diversion, ecological water replenishment for Baiyangdian, and planting structure adjustment (Zhang Y et al., 2018; Li HT et al., 2021; Zhao K et al., 2021).

4.2.4. Wetland resources

The Baiyangdian wetland, primarily situated in Anxin County, is the largest freshwater wetland in the Hebei Plain, with a total area of around 366 km^2, an east-west length of 39 km, and a north-south width of 28 km. This wetland consists of 143 shallow lakes and more than 3700 ditches, with the water body area representing about 50% of the total area of the wetland. The natural landscape in the wetland is dominated by water, marshes, and reeds (Figs. 17a, b; Ma Z et al., 2021).

The Baiyangdian wetland primarily comprises wetland vegetation (122.04 km^2) and water areas (108.60 km^2), showing a high level of landscape fragmentation (Fig. 17c; Table 4; Zhang SF, 2022). It has substantial animal and plant

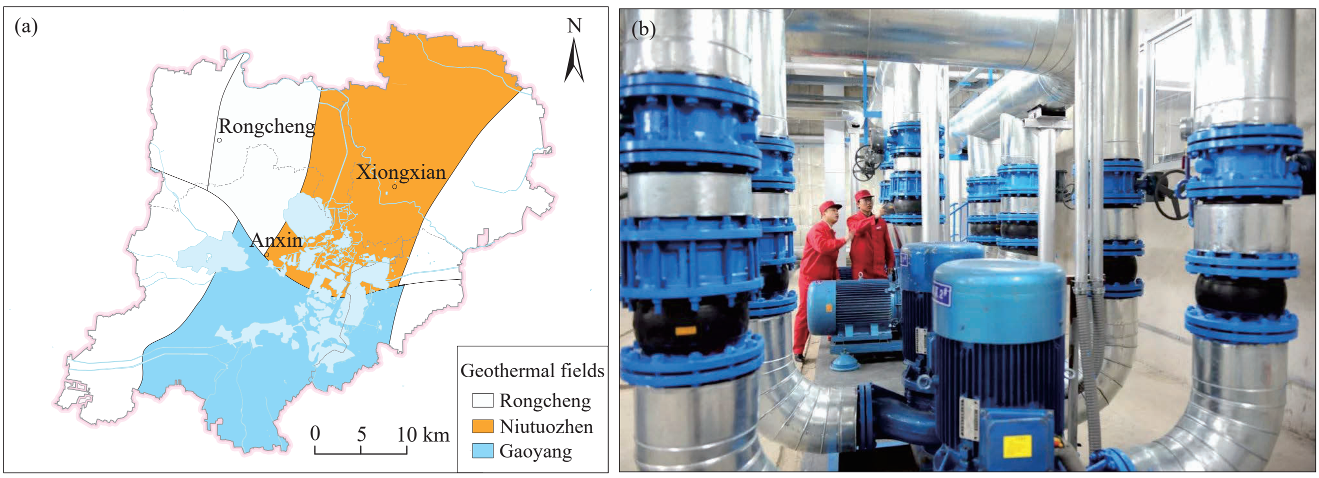

Fig. 15. Distribution (a) of geothermal fields in Xiong'an New Area (after Wang K et al., 2021) and SINOPEC's supply (b) of over 7×10^6 m^2 of geothermal heating for Xiong'an New Area (after https://www.sohu.com/a/302676388_313493).

Table 2. Statistics of geothermal resources in Xiong'an New Area.

Geothermal field	Area/km^2	Geothermal resources/J	Geothermal fluid storage capacity/m^3	Balanced conditions for harvesting and irrigation		Converted into standard coal/(t/a)
				Recoverable resources/(m^3/a)	Recoverable heat/(J/a)	
Rongcheng	309.97	1230.73×10^{16}	30.25×10^8	99.63×10^6	222.77×10^{14}	76.29×10^4
Niutuozhen	699.11	2062.62×10^{16}	124.94×10^8	140.39×10^6	354.95×10^{14}	121.56×10^4
Gaoyang	628.04	2635.31×10^{16}	221.50×10^8	160.69×10^6	432.68×10^{14}	148.18×10^4
Total	1637.12	5928.66×10^{16}	376.69×10^8	4.00×10^8	10.10×10^{16}	346.03×10^4

Table 3. Average annual water resources in Xiong'an New Area.

County	Rainfall/(mm/a)	Amount of surface water/(10^8 m^3/a)	Amount of groundwater/(10^8 m^3/a)	Total water resources/(10^8 m^3/a)
Rongcheng	518	0.0232	0.3613	0.3522
Anxin	514	0.0569	0.4797	0.4200
Xiongxian	517	0.0282	0.4667	0.4546
Total	516	0.1083	1.3077	1.2268

resources, including 47 aquatic macrophyte species dominated by lotus, reed, and water chestnut, more than 40 fish and shrimp species mainly encompassing salmon, carp, mackerel, shrimp, and river crab, and 197 bird species like great bustard, white crane, red-crowned crane, and oriental white stork based on the data as of 2021.

4.3. Ecosystems

Rooted in the needs of Xiong'an New Area for excellent natural ecosystems and the ecological conservation and restoration of Baiyangdian, the ecosystems in the Xiong'an New Area were surveyed and assessed, ascertaining the geochemistry-based soil environment quality and the quality of water and wetland environments.

4.3.1. Soil environment

Soils in Xiong'an New Area are primarily of good-to-high quality (Table 5; Fig. 18; Guo ZJ et al., 2020; Zhou YL et al., 2021a; Zhou YL et al., 2021b), and zones with clean and

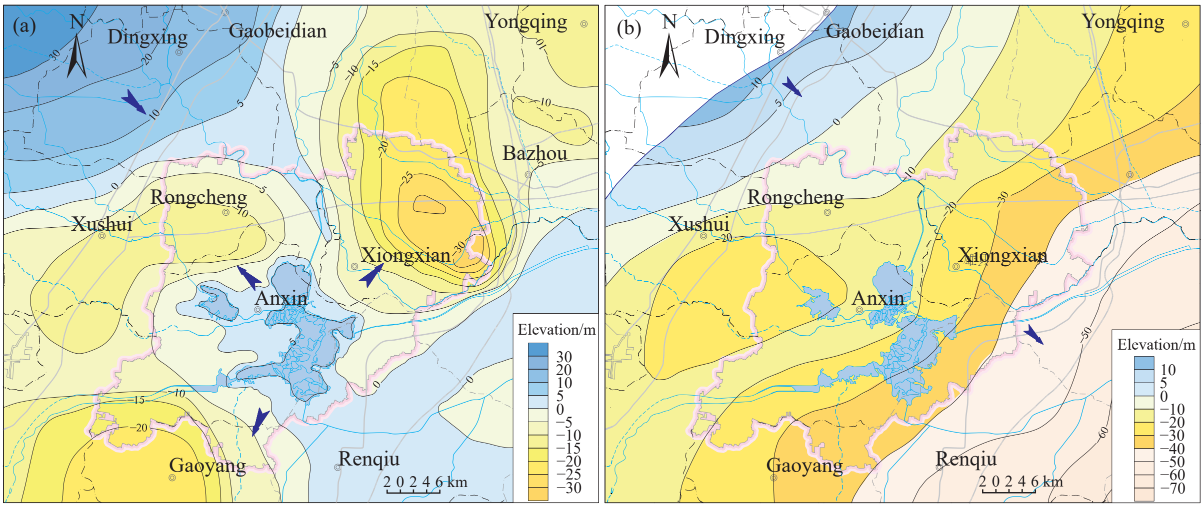

Fig. 16. Contour maps showing the shallow (a) and deep (b) groundwater levels in Xiong'an New Area in June 2021 (after Ma Z et al., 2021).

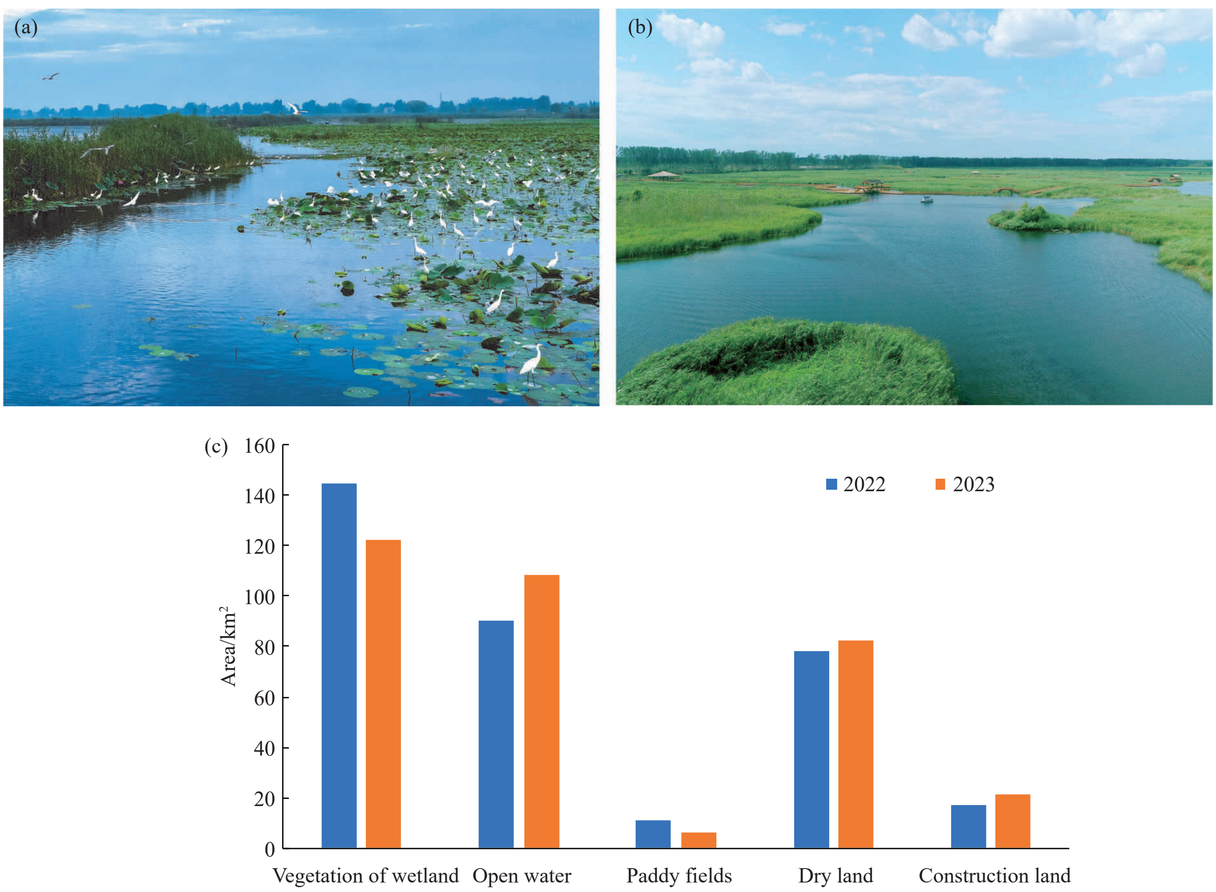

Fig. 17. Scenery of the Baiyangdian wetland. a–White cranes; b–Shaochedian; c–areas of various landscapes.

contamination-free soil environment account for greater than 99% of the total area.

The contamination-free selenium-rich arable land with an area of 569.39 km^2 has been identified (Fig. 18), with selenium content ranging from 0.3 to 3.0 mg/kg, which establishes it as a rare and high-quality arable land resource. Such arable land is distributed continuously in Xiaoli and Nanzhang towns of Rongcheng County and sporadically in Zhaili Township of Anxin County and Longwan and Shuangtang townships of Xiongxian County (Zhou YL et al., 2022).

4.3.2. Groundwater environment

The groundwater in Xiong'an New Area exhibits high and stable quality and insignificant spatiotemporal variations generally (Fig. 19), with most of the deep groundwater and more than two-thirds of the shallow groundwater fulfilling the criteria for drinking water. The high-quality strontium-rich groundwater that meets or approaches the criteria for natural mineral water (strontium concentration: > 0.4 mg/L) has been identified at 227 sites. Most of such water is shallow, with deep strontium-rich groundwater distributed in the vicinity of Laohetou Town in Anxin County.

Following the principle of high-quality water for high demand, the Jiaguang Township in northwestern Rongcheng County can be employed as the target of the backup water source in Xiong'an New Area. The estimated recoverable resources reaching up to 6×10^4 m^3/d establish this township as a large-scale water supply source (Li HT et al., 2021).

Table 4. Area statistics of land use types in the Baiyangdian wetland (1st and 2nd quarters of 2023).

Land use type	First quarter		Second quarter	
	Area /km^2	Percentage/%	Area /km^2	Percentage/%
Open water	107.55	31.54	108.6	31.85
Vegetation of wetland	125.60	36.83	122.04	35.79
Paddy fields	12.06	3.54	6.5	1.91
Dry land	75.54	22.15	82.28	24.13
Construction land	20.23	5.93	21.56	6.32
Total	340.98	100.00	340.98	100.00

Table 5. Statistics of soil quality in Xiong'an New Area.

Comprehensive classification-derived soil quality		Soil		Farmland (orchards)	
		Area/km^2	Proportion /%	Area/km^2	Proportion /%
First class	Excellent	430.59	35.31	344.23	42.99
Second class	Good	533.39	43.74	331.22	41.37
Third class	Moderate	251.12	20.59	124.13	15.50
Fourth class	Poor	2.94	0.24	0.84	0.11
Fifth class	Inferior	1.47	0.12	0.23	0.03

4.3.3. Wetland environment

(i) Sediment environment

Sediments in the Baiyangdian wetland, consisting of black and grayish-black silts with high water content, appear as

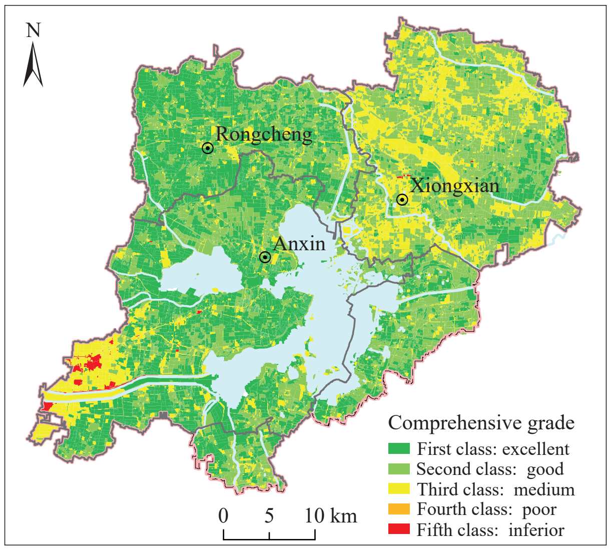

Fig. 18. Geochemical evaluation of the comprehensive grades of soil quality in Xiong'an New Area.

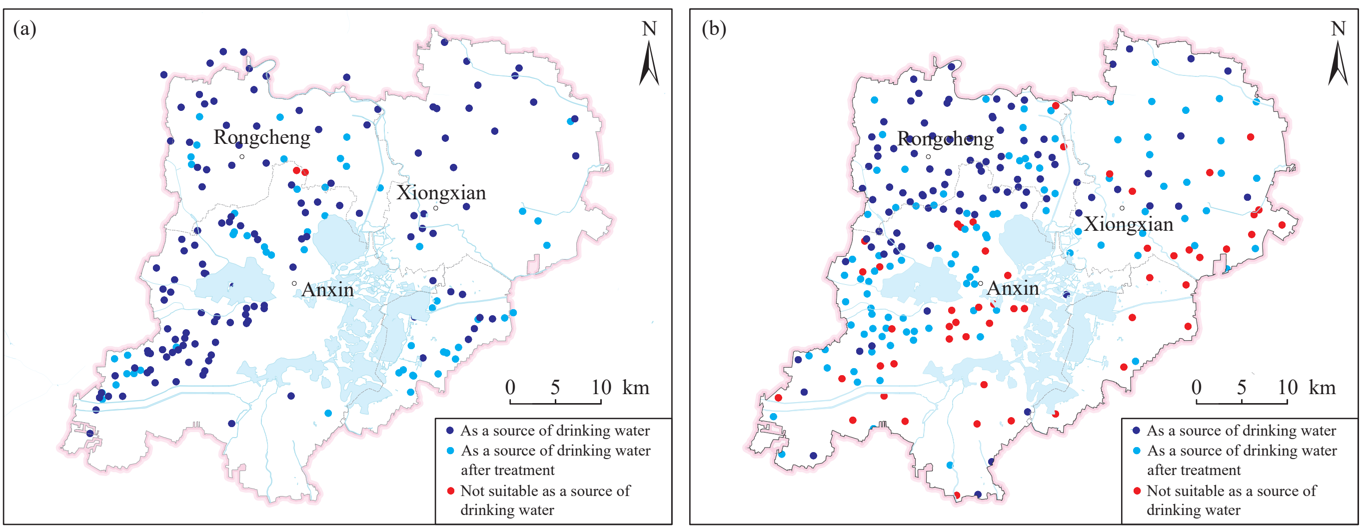

Fig. 19. Quality assessment maps of shallow (a) and deep (b) groundwater in Xiong'an New Area in 2020 (after Li HT et al., 2021).

fluid-plastic to soft plastic forms, with grayish-black to khaki silty clay underlying.

Sediments in Shaochedian, Zaozhadian, and Xiaobaiyangdian exhibit thicknesses ranging from 0.04 m to 0.49 m (average: 0.21 m), from 0.04 m to 0.27 m (average: 0.09 m) in, and from 0.04 m to 0.60 m (average: 0.16 m), respectively. Additionally, sediments near the docks and villages of Xiaobaiyangdian are relatively thick, reaching up to 0.20–0.80 m (Ma Z et al., 2022; Yin DC et al., 2022).

The sediments in Baiyangdian are of good quality generally. However, over-limit heavy metals dominated by cadmium, along with arsenic, copper, lead, and zinc, are identified locally. Of these, the nitrogen and phosphorus contents generally exceed the averages in lakes in the plain areas of eastern China, posing an endogenous release risk. The arable land in the Baiyangdian area has clean topsoil, with negligible heavy metal contamination but high nitrogen and phosphorus contents (Mao X et al., 2021; Yin DC et al., 2023). In the initial stage of returning farmland to wetland, water eutrophication risks caused by nitrogen and phosphorus release were observed in areas such as Mapangdian, southern Fanyudian, eastern Shaochedian, and southwestern Zaozhadian, covering a total area of 45.26 km^2 (Fig. 20a; Yin DC et al., 2022, 2023).

(ii) Groundwater environment

In the Baiyangdian area, groundwater at depths ranging from 20 m to 60 m primarily exhibits quality of class V (Fig. 20b), with primary over-limit components including manganese, total hardness, iodides, and total dissolved solids (TDS). Groundwater at depths ranging from 80 m to 120 m predominantly demonstrates quality of class III/IV, with over-limit components including manganese, total hardness, TDS, and sulfates. Groundwater in this area exhibits relatively stable quality, with minimal interplay with surface water.

The Baiyangdian area generally exhibits severe seepage, with a quantity of seepage of 3470×10^4 m^3/a currently. High seepage rates can be observed in the periphery of Shaochedian and to the east of Chiyudian-Fanyudian. The quantity of seepage increases by 17.6% in the case of ecological desilting at a depth of 0.5 m. The degradation of the Baiyangdian area is attributed directly to decreased natural flow. However, the underlying causes prove to be anthropogenic factors, including decreased runoff in mountains and piedmont reservoir interception, as well as the drying up of springs and increased river seepage in the piedmont overflow zone caused by groundwater exploitation in the plain area (Wang YS et al., 2021; Zhu H et al., 2021).

4.4. Urban geological safety

4.4.1. Regional structures

Xiong'an New Area spans two second-order tectonic units on the first-order Sino-Korean paraplatform: the Yanshan platform fold belt and the North China fault depression. This area contains two third-order tectonic units, namely the Jizhong platform depression (III_2^{12}) and the Jundushan magmatic rock belt (III_2^5), and six dominant fourth-order tectonic units, namely the Langfang fault depression (IV_2^{37}), the Niutuozhen fault uplift (IV_2^{38}), the Wuqing-Baxian fault depression (IV_2^{39}), the Baoding fault depression (IV_2^{40}), the Gaoyang fault uplift (IV_2^{41}), and the Raoyang fault depression (IV_2^{42}) (Fig. 21a; Table 6).

4.4.2. Dominant faults

Existing seismic activity indicates that Xiong'an New Area lies in a tectonically stable region, hosting six major faults, namely the Niudong (F1), Xushui-Anxin (also known as Xushuinan; F2), Baoding-Shijiazhuang (F3), Laohetou (F4), Gaoyang-Boye (F5), and Rongdong (F6) faults, all of which are inactive faults (Fig. 21b).

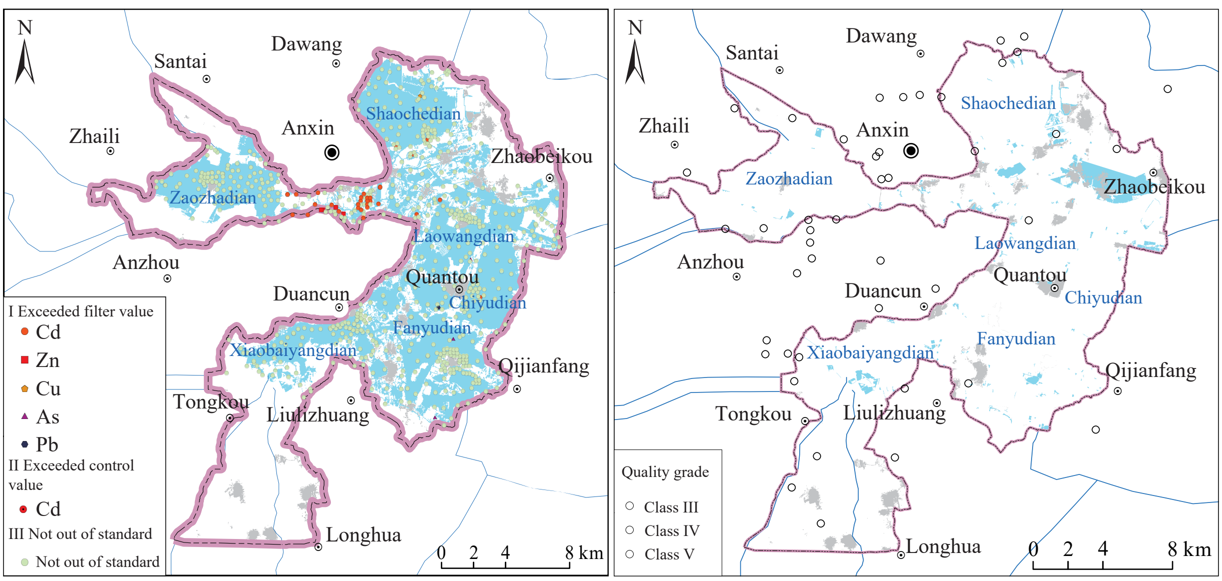

Fig. 20. Comprehensive assessment of the sediment environment quality (a) and quality assessment of shallow groundwater in the periphery (b) of the Baiyangdian area.

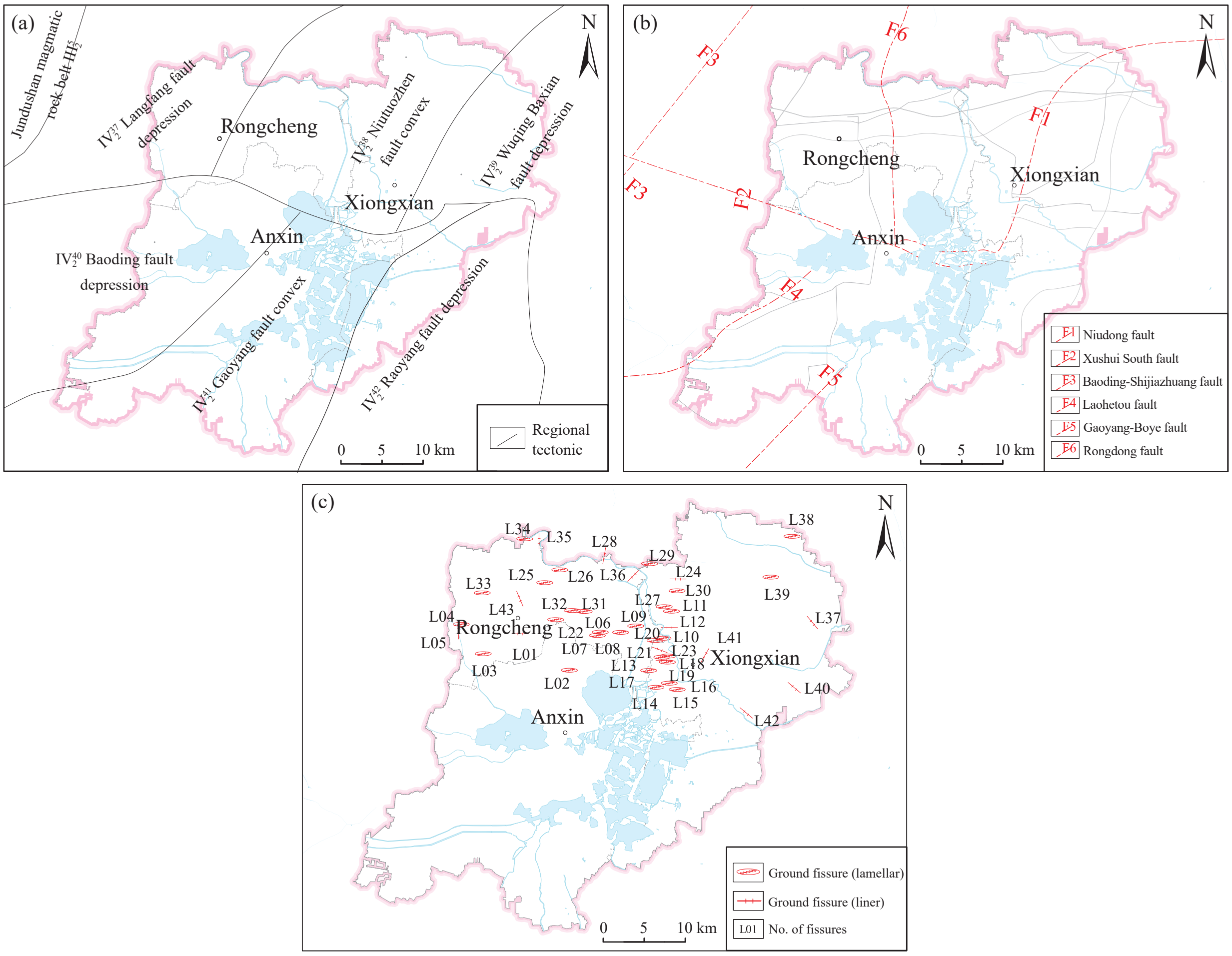

Fig. 21. Distribution of factors of urban geological safety in Xiong’an New Area. a–regional structures; b–faults; c–ground fissures.

Table 6. Characteristics of fourth-order tectonic units in the Jizhong platform depression.

No.		Name	Strike	Overburden	Bedrock
Jizhong platform depression III212	IV237	Langfang fault depression	NE-NNE	Q, N, E	Mz
	IV238	Niutuozhen fault uplift	NE	Q, N	Pz, Jx
	IV239	Wuqing-Baxian fault depression	NNE	Q, N	J+K
	IV240	Baoding fault depression	NE	Q, N, E	Mz
	IV241	Gaoyang fault uplift	NE	Q, N, E	Pz, Jx
	IV242	Raoyang fault depression	NNE	Q, N, E	Pz, Jx

4.4.3. Earthquakes

No earthquakes of magnitude 3 or higher have occurred in Xiong’an New Area since 1970, as indicated by reports derived from contemporary seismic monitoring systems. Furthermore, no catastrophic earthquakes of magnitude 6 or higher have ever occurred in this area according to statistics for historical earthquakes. Four destructive earthquakes of magnitude 5 to 6 once occurred within and around Xiong’an New Area: The Gaoyang earthquake on August 9, 1144, the Baoding earthquake on July 19, 1624, the Xiongxian earthquake on September 1, 1679, and the Wen’an earthquake on July 4, 2006.

4.4.4. Land subsidence

Xiong’an New Area is located in the southern portion of the Xiongxian-Gu’an subsidence zone and the northern portion of the Gaoyang-Renqiu subsidence zone. Subjected to the two subsidence centers, the land subsidence in this area primarily occurs in the south and north parts. Of these, northern land subsidence is distributed in the Daying Town - Baishakou Township area in Xiongxian County, connected to the Gu’an and Bazhou subsidence zones, while the southern land subsidence is distributed in the Luzhuang Township - Laohetou Town and Longhua Township - Liulizhuang Town areas in Anxin County, connected to the Gaoyang subsidence zone.

Xiong’an New Area has witnessed a gradually downward trend in land subsidence since 2017, with a land subsidence area of about 1695.33 km^2 (95.78% of the total area) by the end of 2022. The land subsidence in this area is generally dominated by slight and moderate subsidence, with maximum annual subsidence measuring 101 mm.

From 2018 to 2022, slight and moderate subsidence (annual land subsidence <30 mm) in Xiong’an New Area accounted for greater than 60% of the total subsidence area. In contrast, severe and extremely severe land subsidence (annual land subsidence >50 mm) decreased significantly in this period, with the subsidence rate slowing down. Of these, the severe land subsidence (annual land subsidence: 50–80 mm) accounted for 6.00% of the total area in 2018, which decreased to 2.26% in 2022, while the extremely severe land subsidence (annual land subsidence > 80 mm) accounted for 2.08% of the total area in 2018, which decreased to 0.11% in 2022. Compared to 2018, 2022 saw a decrease of approximately 25.3% in the maximum annual land subsidence (Table 7).

4.4.5. Ground fissures

A total of 78 ground fissures are found in Xiong'an New Area (Fig. 21c). With the Santai Town - Dawang Town - Zhaobeikou Town area as a boundary roughly, these fissures are extensive in the north but sporadically distributed in the south. They are primarily concentrated in the vicinity of Rongcheng County, at the junctional of Rongcheng and Dingxing, Gaobeidian, and Xiongxian, at the junction of Xiongxian and Renqiu, and on sides of the Daqing and Nanjuma rivers.

The ground fissures consist of 47 linear fissures and 31 platy collapse pits. Of these, the linear ground fissures are small, with cracking lengths less than 100 m mostly (except for two with cracking lengths exceeding 100 m), widths ranging from 0.2 m to 6.7 m, and subtle regularity in the extension direction. The platy collapse pits demonstrate lengths and widths ranging from 1.3 m to 11.9 m and from 0.3 m to 5.2 m, respectively.

4.5. Digital city

Achievements in digital city construction include a comprehensive monitoring network of natural resources and environments, the online 3D integrated presentation of surface and subsurface structures, and a high-level "Transparent Xiong'an" geological information platform. Of these, the monitoring network, characterized by space-ground integration, stereoscopic monitoring, and automatic sensing, provides effective support for the management and control of natural resources and territorial space in Xiong'an New Area.

4.5.1. Comprehensive monitoring network of natural resources and environments

To address the major resource and environmental issues in Xiong'an New Area, a comprehensive monitoring network of natural resources and environments, characterized by space-ground integration, stereoscopic monitoring, and automatic sensing, was established using advanced technologies like high-resolution remote sensing, layered groundwater monitoring, and vorticity-related monitoring by referencing relevant international standards. This monitoring network has been put into operation, achieving accurate and dynamic monitoring of six resource and environmental components: groundwater, geothermal energy, forest land, grassland, wetland, and land subsidence (Fig. 22; Ma Zhen et al., 2021, 2022).

Table 7. Statistics of land subsidence in Xiong'an New Area during 2018–2022.

Annual subsidence/mm	Year				
	Area in 2018/km^2	Area in 2019/km^2	Area in 2020/km^2	Area in 2021/km^2	Area in 2022/km^2
10–30	264.74	633.81	775.84	65.85	527.76
30–50	149.46	170.63	284.83	50.49	150.23
50–80	110.62	106.12	165.14	6.32	39.98
⩾80	36.75	5.22	87.14	0.00	2.07
Maximum	135.18	168.88	233.37	179.05	101

4.5.2. 3D geological structure

The multi-level and multi-scale 3D geological structure with a burial depth range from 0 m to 10000 m of Xiong'an New Area has been identified. Based on integrated geological, geophysical, and drilling data, the 3D geological structure involves soil layers, engineering construction layers, underground aquifers, underground geothermal reservoirs, and deep exploration layers, forming a deep 3D geological structure model of Xiong'an New Area (He DF et al., 2018; Ma Y et al., 2020; Fig. 23a).

4.5.3. "Transparent Xiong'an" geological information platform

The Geological Big Data Center of Xiong'an New Area has been established, achieving the integrated management and services of geological data on engineering geology, geothermal energy, ecological geology, hydrogeology, land quality geochemical survey, and comprehensive geologic environment monitoring.

The "Transparent Xiong'an" geological information platform has been constructed to integrate the surface and underground geological information. The 3D geological structure model, involving burial depths ranging from 0 m to 10000 m, of Xiong'an New Area allows for the transparent presentation of subsurface geology like deep geological structures, geothermal reservoirs, aquifers, and engineering geological layers (Fig. 23b).

Eight special service systems have been developed: Transparent Xiong'an, underground space, geological safety, engineering geology, geothermal energy, groundwater, land quality, and geological big data. The online deployment and trial run of the "Transparent Xiong'an" digital platform was completed on "Xiong'an Cloud", laying the foundation for the application of geological achievements to services for the planning, construction, operation, and management of Xiong'an New Area.

5. Service effects and experience

The results from multi-factor urban geological surveys allow for the preparation and delivery of more than 30 research reports and technical documents focusing on planning, geothermal resource management, soil contamination control, ecological restoration in Baiyangdian, groundwater resource control, land subsidence prevention and control, and digital city construction, yielding remarkable service effects.

5.1. Service effects

5.1.1. Services for planning and construction

Using the survey results and available data on geothermal

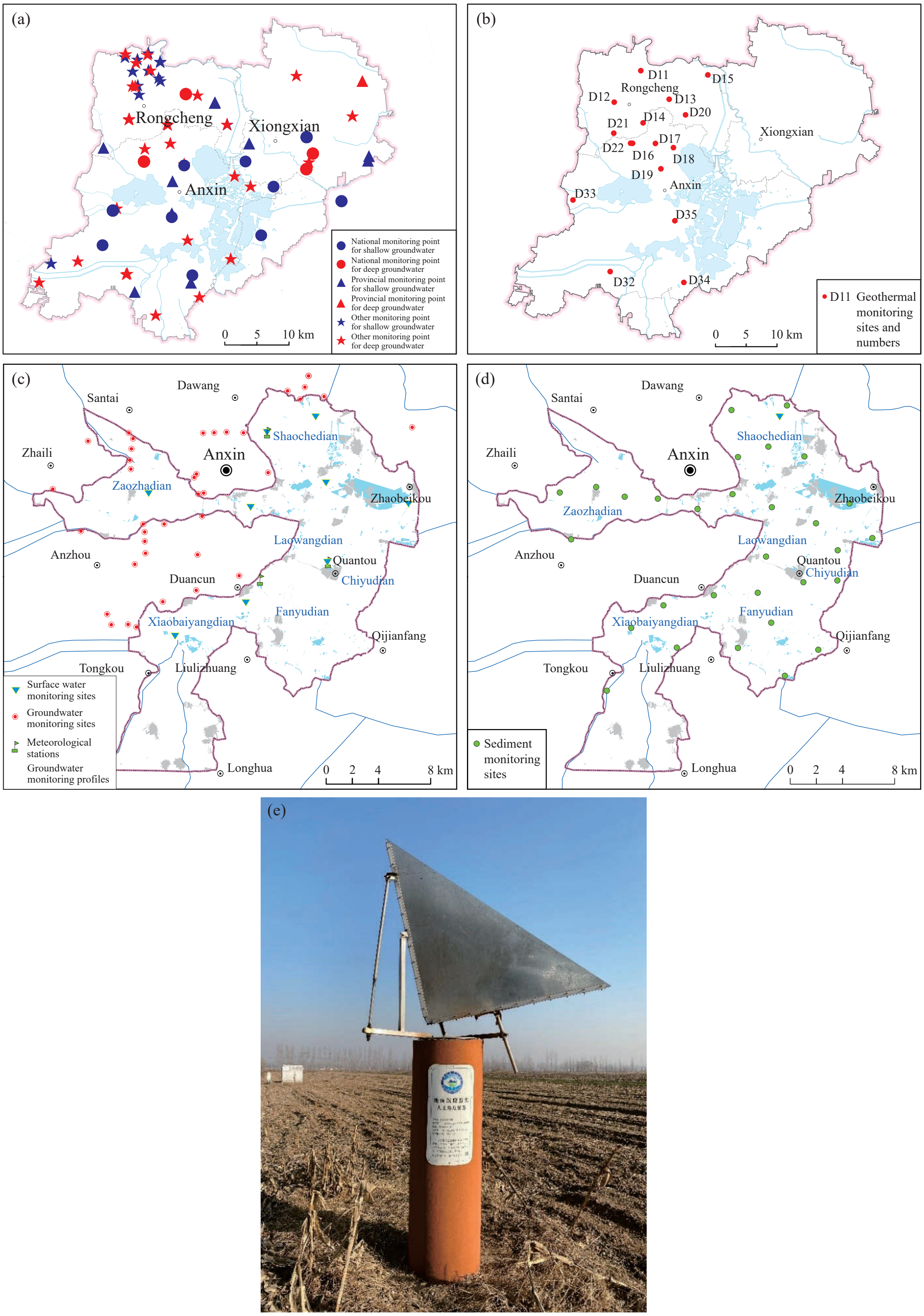

Fig. 22. Comprehensive monitoring network of natural resources and environments in Xiong'an New Area. a–groundwater monitoring sites; b–geothermal monitoring sites; c–meteorological and hydrological monitoring sites in the Baiyangdian wetland; d–sediment quality monitoring sites in the Baiyangdian wetland; e–corner reflector at a land subsidence monitoring site.

resources, water resources, land resources, engineering geology, underground space resources, ecological geology in Baiyangdian, the *Geological Survey Report for Supporting and Serving the Master Plan of Xiong'an New Area* and relevant atlas (Fig. 24) have been prepared and delivered, thus providing authoritative geological data for the preparation of the master plan. One conclusion in the report stating that Xiong'an New Area possesses stable geological conditions has been written into the master plan. Meanwhile, three suggestions, namely the optimization of urban cluster layout, the layered multi-functional exploitation and utilization of underground space, and the assessment and avoidance of soil liquefaction risk, have been adopted.

Data on the spatial distributions and mechanical properties of rock and soil masses, along with data on groundwater levels, have been available for underground space development, integrated pipeline corridor planning, and earthwork reuse in critical zones like Rongdong. The anti-floating groundwater levels along the express line linking Xiong'an New Area with the Beijing Daxing International Airport have been investigated, with the recommended anti-floating groundwater levels at sites along this line having been proposed. Furthermore, it has been demonstrated that large-scale, intensive excavation of underground space affects the water quality, groundwater recharge, and geological stability along the Xiong'an-Xinzhou High-Speed Railway.

5.1.2. Services for the exploitation and management of geothermal resources

The proposition of the innovative zoning of geothermal exploration and exploitation rights contributes to the whole-process services for the development, management, and supervision of geothermal resources in Xiong'an New Area. An assessment with controllable accuracy was performed for geothermal reserves in the Rongdong zone, promoting the smooth granting of geothermal exploitation rights of the first large zone in Xiong'an New Area.

Relevant technical codes of practice have been prepared, including the *Technical Code of Practice for Prefeasibility Exploration of Geothermal Resources in Xiong'an New Area (Trial)*, the *Technical Code of Practice for Geothermal Production and Reinjection Wells Monitoring in Xiong'an New Area (Trial)*, and the *Technical Code of Practice for Geothermal Dynamic Monitoring System and Specialized Monitoring Wells in Xiong'an New Area (Trial)* (Fig. 25a), providing support for the scientific and standardized management of geothermal resources.

5.1.3. Services for the control of contaminated land and the restoration of ecosystems in Baiyangdian

To meet the needs of the Ecosystem Bureau of Xiong'an New Area, soil quality geochemical survey reports of Xiong'an New Area have been prepared, and the soil quality at the periphery of key supervised enterprises has been assessed based on geochemical survey data. These provide detailed data for the control of heavy metal contamination in the soils of Xiong'an New Area, directly serving the control and law enforcement of soil contamination.

Some suggestions have been proposed for the Baiyangdian wetland, including (1) the extent and depth of ecological desilting, as proposed based on the investigated thicknesses and distributions of contaminated sediments formed since the 1980s; (2) returning farmland to wetland put forward based on the water and soil quality assessment and the lake eutrophication risk under the condition of water level restoration; (3) coffer dam removal and ecological water

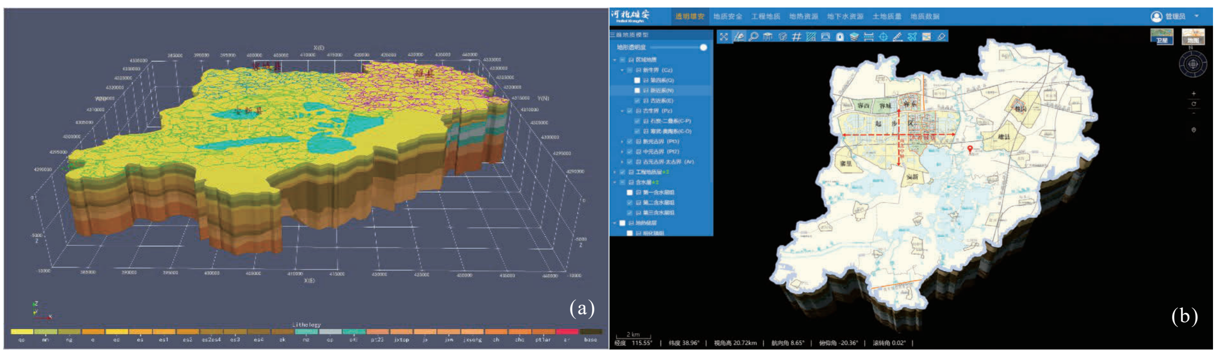

Fig. 23. 3D geological structure model (a) of Xiong'an New Area (burial depth range: 0–10 km) and "Transparent Xiong'an" geological information platform (b).

Fig. 24. China Geological Survey transferring geological survey data to Xiong'an New Area. a–transferring geological survey data; b–geological survey atlas; c–reports for the master plan of Xiong'an New Area.

allocation given the hydrodynamic impacts on water quality (Fig. 25b).

Based on the sediment environment quality and the endogenous release risk of nitrogen and phosphorus, ecological desilting of 78.1 km^2 is recommended (Fig. 25c). Based on the vertical distribution patterns of contamination with heavy metals, nitrogen, and phosphorus, suitable desilting depths are determined at 0.2–0.8 m, corresponding to a total desilting volume of 2190×10^4 m^3, and priority should be given to areas with over-limit heavy metals, such as Nanliuzhuang.

5.1.4. Services for land subsidence prevention and control and groundwater resource management

Scientific results on land subsidence prevention and control and groundwater resource management include: (1) Geoscientific recommendations on the construction of the Beijing-Xiong'an high-speed railway and the safe operation of the Tianjin-Baoding high-speed railway, as proposed based on the land subsidence monitoring data of Xiong'an New Area; (2) layerwise marks for land subsidence, which has been integrated into the construction of both the leveling origin of Xiong'an New Area (Fig. 26) and the urban municipal infrastructure, thus boosting the co-construction and sharing with the deformation monitoring of high-speed railways; (3) the assessment and analytical results of groundwater resources and the variation patterns of groundwater levels and water quality in Xiong'an New Area, providing fundamental data for the scientific management of water resources and the efficient control of groundwater exploitation in the area.

5.1.5. Services for digital city construction

The "Transparent Xiong'an" geological information platform provides vigorous support for the construction of the twin city — "Digital Xiong'an". Achievements in the digital city construction include (1) the trial operation of the "Transparent Xiong'an" geological information platform on the "Xiong'an Cloud" under the joint support from organizations such as the Reform and Development Bureau and the Xiong'an Digital Group; (2) a 3D data exchange plug-in, which integrates the 3D geological structure model into the Building Information Modeling (BIM) platform of the Xiong'an New Area; (3) an indicator system for geological approval and filing of phases of master planning, detailed planning, design, construction, and completion; (4) the *Data Delivery Standard of the BIM Management Platform for the Planning and Construction of Xiong'an New Area (Trial; Geology)*, which provides regulations and rules for the integration of geological work into the primary process of urban management.

5.2. Experience and practice

A quadripartite mechanism of coordination between the China Geological Survey and the Xiong'an New Area Management Committee, the Department of Natural Resources of Hebei Province, and the Hebei Bureau of Geology and Mineral Resources Exploration has been established. This forms the unique "Xiong'an Model" where geological work supports modern urban planning, construction, and operation, providing demonstration and experience for conducting multi-factor urban geological surveys in other cities in China.

5.2.1. Business coordination mechanism

A business coordination mechanism has been established for solid top-level design. As mentioned above, a quadripartite mechanism of coordination has been built, accompanied by the establishment of a united headquarters and Xiong'an Urban Geological Research Center. The purpose is to coordinate the overall design and planning of the geological survey work in Xiong'an New Area and to unify the work deployment in order to ensure smooth advancement.

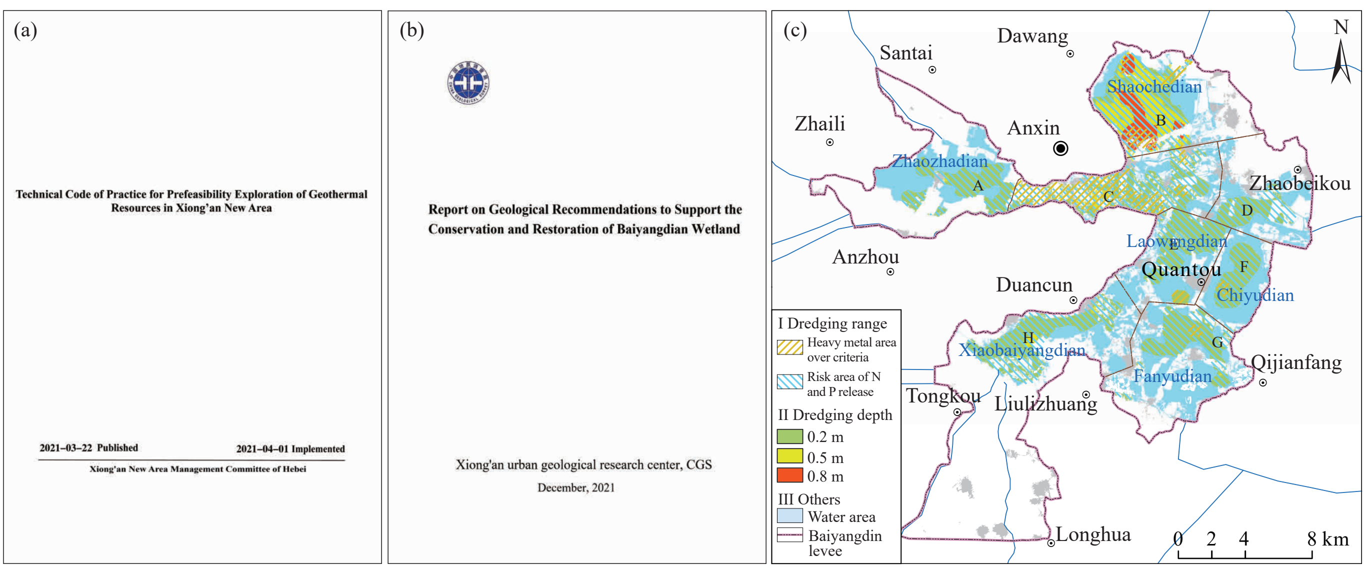

Fig. 25. Technical codes of practice for geothermal resources in Xiong'an New Area. Reports on the ecological conservation and restoration (a, b) and suggestion on ecological desilting (c) in the Baiyangdian area.

Fig. 26. Construction (a) and completion (b) of layerwise marks for land subsidence in Xiong’an New Area.

5.2.2. Communication of requirements

A continuous communication stream has been established with the Xiong’an New Area Management Committee to clarify the needs of geological work, achieve accurate planning, and provide application service products, thus ensuring effective geological surveys for serving the planning, implementation, supervision, usage regulation, and ecological conservation and restoration of Xiong’an New Area.

5.2.3. Innovation in working methods

Innovation in working methods and the construction of technical systems have been highlighted. A working methodology has been formed for the entire process of urban planning, construction, operation, and management, consisting of a set of high-quality data and report results, a set of high-standard technical norms and standards, a high-precision geological information platform, a total-factor natural resource monitoring network, an improved technical method system, and an efficient work management mode.

6. Prospects

6.1. Issues and challenges

Significant advances have been made in the construction of infrastructure, the surface water system, the “Millennium Forest” project, and Baiyangdian’s ecological protection and restoration in Xiong’an New Area (He ZT, 2023; Figs. 5g, 5h). By 2035, Xiong’an New Area will be basically built into a high-level modern socialist city that is green and low-carbon, open and innovative, information-intelligent, livable and workable, with strong competitiveness and influence, and where human beings live in harmony with nature. The functions of the city tend to be perfected, the transport network is convenient and efficient, the modern infrastructure system is complete, the innovation system is basically formed, the high-end high-tech industries lead the development, the high-quality public service system is basically formed, and the ecological environment of Baiyangdian and the air quality of the region are fundamentally improved. The Beijing’s non-capital functions will be effectively undertaken , the level of openness and international influence continues to improve, the modernisation of urban governance capacity and social management will be realized. The “quality of Xiong’an” plays an obvious role in leading the country's high-quality development, which will be a new engine of the modern economic system. However, the future development of this area still faces geological and environmental issues and challenges such as resource shortage, environmental pollution, ecological damage, and geological safety issues (Xia J and Zhang YY, 2017; Wang YJ et al., 2020; Shen CY et al., 2023).

(i) Groundwater level fluctuations, caused by climate change and human engineering activities, will affect urban safety. On the one hand, foundation pit dewatering will cause groundwater overexploitation in local areas, leading to a significant drop in the local groundwater level. On the other hand, measures such as south-to-north water diversion, ecological water replenishment in Baiyangdian, and prohibition/restriction on groundwater exploitation will contribute to a significant rise in the regional groundwater level. All these will result in groundwater level fluctuations, which will alter the initial stress state and soil structure, cause ecological harm and engineering accidents, and induce environmental and geological issues attributed primarily to human activities or exogenic geological processes. Additionally, flooding occurs frequently in this area due to its low relief, further damaging the natural ecosystem and causing serious financial loss and numerous social issues.

(ii) A rapid population inflow will reduce the local environmental and resource bearing capacity, which is caused primarily by insufficient water recharge. The surface water in Xiong’an New Area exhibits inferior quantity and quality, and deep groundwater has a lower salinity and higher quality than shallow groundwater (less than 150 m) in this area. It is challenging to meet the enormous demand of social and economic development for water resources even in wet years. Meanwhile, significant ecological water replenishment is required to improve Baiyangdian's water environment quality. Consequently, the future construction of Xiong’an New Area will face both water shortage and wetland degradation under the sustainable social development plan of building the city based on water resources (Liu JG et al., 2019).

(iii) The construction of Xiong’an New Area will inevitably cause environmental pollution, including air, soil, and water pollution, all of which are secondary issues that cannot be avoided under intensive human activities and extensive infrastructure construction. A century of smelting has led to heavy metal contamination in soils in the southwestern portion of Xiong'an New Area. Smelting operations are identified as the primary cause of excessive chromium, zinc, cadmium, and lead in soils in this area, posing serious risks to public health, especially for children (Wang CY et al., 2021). Furthermore, the sewage and wastewater from businesses and factories will be dumped into rivers and then enter the Baiyangdian area. This will result in varying degrees of water pollution, a decline in biodiversity, and significant ecological harm (Liu WH et al., 2018; Liu B et al., 2020).

(iv) Xiong'an New Area suffers geological defections that affect geological safety, including land subsidence, fissures, and concealed faults. Around 80 ground fissures have been identified in this area. They are widely distributed in certain areas, being concentrated in the vicinity of Rongcheng County. There are primarily two subsidence centers in the north and south of Xiong'an New Area. It is essential to monitor the changes in both ground fissures and land subsidence regularly and to investigate their formation mechanisms. Additionally, Xiong'an New Area hosts concealed faults, with major concealed faults posing minimal sliding instability risks and being capable of maintaining stable structures under the current in-situ stress (Shang SJ et al., 2019). Despite a generally low degree of soil liquefaction in this area, it is necessary to conduct real-time observation of both the dynamic changes in in-situ stress and the potential trend and sliding instability risk of the major concealed faults.

6.2. Opportunities

Issues and challenges also mean opportunities for China's geologists and urban geology, which have long played a critical role in addressing the ailments of the cities (also known as "big city disease") and achieving low-carbon, green, and sustainable urban development objectives.

The fast expansion of Xiong'an New Area has posed various issues and challenges, which might inspire China's geologists and research institutes to be more creative and innovative in their study. Urban geology, paying increasing attention to the relationship between human activities and the earth system, will help address issues such as resource shortage, environmental pollution, ecological damage, and geological safety issues, thereby supporting the resilient and sustainable development of Xiong'an New Area.

Therefore, China's geologists and urban geology can provide support for the formulation and implementation of pertinent policies, assist in understanding the changes and trends in the background environment for safe urban operation, and contribute to the achievement of green, low-carbon, resilient, and sustainable Xiong'an New Area characterized by the "harmony between human and nature".

6.3. Discussion

The future development of Xiong'an New Area will still rely heavily on China's geologists and urban geology, especially in the fields of engineering construction, natural resource management, ecological conservation, and urban safety. Given the development of urban geology and the future challenges faced by Xiong'an New Area, it is necessary to conduct further study and investigations of four aspects:

(i) Building a multi-scale 3D model of the underground space in Xiong'an New Area while paying close attention to the effects of intensive human engineering operations on the earth system. Given the gradual rise in the groundwater level in the area, it is necessary to predict the trends of the groundwater levels, calculate the anti-floating groundwater levels at construction sites, and assess seismic liquefaction in Xiong'an New Area based on the groundwater level monitoring results. Meanwhile, it is necessary to investigate the reciprocal feedback mechanisms behind the interactions between the geological environment and human engineering activities, especially the relationships between soils/groundwater and human engineering construction.

(ii) Estimating the future water needs of Xiong'an New Area under various growth scenarios. There is a lack of systematic studies on the prediction of the future water consumption intensity indices and water needs in Xiong'an New Area (Lv LH et al., 2021). Given the uncertainties of the future development of the area, it is necessary to calculate the water consumption intensity indices of living, production, and ecology, as well as the water demand, under various development scenarios of this area by referring to the water use efficiency of new areas and developed cities across the world. The purpose is to provide support for the water resource management of the area.

(iii) Improving the comprehensive monitoring network of natural resources and environment in Xiong'an New Area to achieve the integrated management and analysis of multi-level and multi-factor monitoring data on surface and subsurface conditions. This involves the continuous and dynamical monitoring of air quality, groundwater level, water quality, soil quality, and the spatial distribution of forest land, grassland, and wetland. It is necessary to optimize the "Transparent Xiong'an" geological information platform to achieve comprehensive analysis, query statistics, and early warning services, improve emergency response plans, and provide support for the safe urban operations and natural resource management of Xiong'an New Area.

(iv) Building the monitoring networks of the in-situ stress, land subsidence, and ground fissures in Xiong'an New Area to understand the future activity and instability risk of concealed faults, as well as key indicators of land subsidence and ground fissure development. It is necessary to monitor the dynamic changes in in-situ stress, land subsidence, and ground fissures, keep an eye on the impacts of fault activity in typical areas with strong earthquake risk in North China, and pay attention to the activity trend and sliding instability risk of major concealed bedrock faults. Additionally, a predictive model for land subsidence shall be established to understand the trends of land subsidence and ground fissures, with the purpose of guiding the safe operation of Xiong'an New Area (Yue GF et al., 2021).

7. Conclusions

(i) China Geological Survey has carried out surveys of land, geothermal resources, groundwater, underground space, ecology, and 3D geological structures in Xiong'an New Area, as well as establishing the "Transparent Xiong'an" geological information platform and the comprehensive monitoring network of natural resources and environment. China's geologists and urban geology have gained numerous achievements in supporting and serving the planning, construction, natural resource management, ecological protection and restoration in Baiyangdian, urban geological safety, and digital city construction of Xiong'an New Area.

(ii) China's geologists have created a comprehensive multi-factor, interdisciplinary, and multi-technology methodology for geological survey evaluation and quality monitoring, along with a working mechanism characterized by "four-party cooperation, communication of service and requirements, and overall integration". They have established a "Xiong'an Model" for multi-factor urban geological surveys to serve the entire chain of planning and construction. Furthermore, they have introduced innovative working methods and developed seven working standards on geothermal resources, engineering geology, and database construction. All these provide an exemplary role and experience for other cities in China to conduct multi-factor urban geological surveys.

(iii) The future development of Xiong'an New Area still faces geological and environmental issues. In the future, China's geologists and urban geology should fully utilize their disciplinary advantages to provide theoretical and technical support and enhance urban resilience using unique methods and technologies such as remote sensing, exploration, and monitoring. The purpose is to achieve the green, low-carbon, and sustainable development of Xiong'an New Area. Furthermore, it is necessary to carry out research on theoretical systems such as the mutual feedback mechanism behind interactions between human activities and the earth system. Interdisciplinary research, which involves coordination between experts from multiple fields and disciplines, is required in the future.

(iv) The Chinese Government has rolled out a series of policy documents to promote in-depth urban geological work, safeguard urban safety, and enhance modern urban governance. For instance, the policies highlight geological safety during urban engineering construction and resource exploitation, as well as improvements in the mechanisms and abilities of risk prevention and control. Emphasis is also placed on active fault identification, the environmental monitoring of sites with earthquake risks, earthquake catastrophe prediction in newly constructed zones, and multi-scale and multi-accuracy earthquake risk assessment. According to relevant policies, a groundwater monitoring system should be built to strictly regulate groundwater exploitation and to effectively observe, prevent, and control land subsidence. These policy documents impose higher requirements for urban geological work and also present new opportunities for China's geologists to carry out urban geological studies in the future.

CRediT authorship contribution statement

Zhen Ma and Liang-jun Lin conceived the presented idea. Bo Han prepared the original manuscript, and Hong-wei Liu modified the manuscript. Yi-hang Gao collected relevant data and provided figures and tables in the manuscript. Yu-bo Xia, Hai-tao Li, Xu Guo, Feng Ma, Hong-qiang Li, Yu-shan Wang, and Ya-long Zhou provided part of the data and put forward suggestions and opinions on the structure of the manuscript and reviewed the findings of this work. All authors discussed the results and contributed to the final manuscript.

Declaration of competing interest

The authors declare no conflicts of interest.

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