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Vertical Planning System Based on Urban Flood Prevention and Control: Interpretation of the Guidelines for Vertical Planning Compilation in Zhengzhou (Trial Version)

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Abstract: As global climate change intensifies, the importance of vertical planning, a key element impacting urban flood prevention and drainage safety, has become increasingly prominent. Leveraging the territorial spatial planning, Zhengzhou took substantial lessons from the July 20, 2021 torrential rainstorm and issued the Guidelines for Vertical Planning Compilation in Zhengzhou (Trial Version) (hereinafter referred to as the "Guidelines") in February 2023. This document establishes a vertical planning compilation system with "three levels, five categories" that aligns with the territorial spatial planning system. It also introduces a management and control mechanism that is flexible and resilient and adaptive to local conditions. Based on the developmental characteristics of Zhengzhou and its existing planning system, the Guidelines identify critical issues in traditional vertical planning and clarify the scope and depth of vertical planning at each level. The Guidelines explore methods and strategies for vertical planning compilation from various perspectives, including layered control, coordination of spatial-temporal elements, planning coordination, maintenance of safety baselines, and planning management. The Guidelines will promote the effective management of vertical planning, advance the improvement of Zhengzhou's territorial spatial planning system, and enhance the city's resilience and bearing capacity. **DOI:** 10.13813/j.cn11-5141/u.2024.0027-en

Keywords: transportation planning; vertical planning; compilation system; flood prevention and control; Zhengzhou

0 Introduction

Vertical planning refers to the utilization and modification of natural terrain within urban and rural construction land to meet comprehensive requirements such as road transportation, drainage and flood prevention, building layout, urban and rural environmental landscape, comprehensive disaster prevention, and economic efficiency. This process involves determining slopes, controlling elevations, and balancing earthworks [1]. Urban vertical planning directly influences the surface slope, rainwater collection, and other conditions of planned land and roads, serving as a critical foundation for the urban drainage system. Effective vertical planning can significantly enhance urban flood prevention and drainage capabilities. Conversely, poor vertical planning can produce artificial low-lying spots, reduce surface drainage capacity, increase the operational pressure on drainage networks and pumping stations, and cause waterlogging and ponding during rainfall [2].

In recent years, abnormal climatic conditions have exacerbated urban spatial safety risks, leading to frequent waterlogging issues. In 2021, the *Implementing Opinions of the General Office of the State Council on Strengthening Urban Waterlogging Control* (the State Council 2021 Document No.11) was released, emphasizing the coordinated advancement of urban waterlogging management and the enhanced vertical control through optimized urban layout [3]. The same year, in response to issues exposed during the torrential rainstorm in Zhengzhou on July 20, 2021, the General Office of the People's Government of Henan Province issued the *Implementing Plan for Urban Waterlogging Control in Henan Province*, which proposed strict requirements to implement relevant planning, incorporating drainage and flood prevention facilities, storage spaces, rainwater runoff, and vertical control during planning, construction, and management phases [4]. Leveraging the opportunity of the gradual improvement of the territorial spatial planning system, Zhengzhou drew on the experience of advanced cities and formulated the *Guidelines for Vertical Planning Compilation in Zhengzhou (Trial Version)* (hereinafter referred to as the *Guidelines*). This document focuses on constructing a city-wide vertical planning framework and coordinating vertical planning compilation to reduce urban waterlogging at its source and enhance urban resilience and safety levels.

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1 Current status of vertical planning compilation

Some cities, both Chinese and internationally, have carried out vertical planning compilation and related explorations based on their specific needs[2]. Traditional vertical planning primarily focuses on engineering to support the construction of new urban areas or centralized development zones. The core objective of vertical planning is to meet the needs of construction sites through terrain modification. It mainly relies on guidance from higher-level plans, regulatory detailed plans, and so on, combined with the current regional construction conditions and road network layout to develop preliminary plans, which are iteratively verified to meet earthwork balance and regional drainage requirements, ensuring the rationality of the planning scheme.

However, as urban construction continues, land with flat and favorable conditions has been gradually developed and saturated. Land conditions will be increasingly complex, presenting new challenges for traditional vertical planning.

1) Lack of systematic planning basis. The current *Measures for Compilation of City Planning* (Decree of the Ministry of Construction of the People's Republic of China No. 146) and its detailed rules provide insufficient guidance and constraints on vertical aspects. This results in difficulties in linking different planning outcomes, leading to a lack of vertical control basis in urban planning approval and management processes [5].

2) Lack of urban macro-level guidance. Existing vertical planning focuses only on the specific area within the planning scope and fails to systematically consider the rationality of vertical design for urban construction land from a macro perspective, limiting the effectiveness and coherence of urban vertical planning [6].

3) Inability to meet drainage needs. Vertical planning is primarily based on limited foundational data of a single area, such as current topography and river elevations, and it fails to coordinate the drainage system from a watershed perspective.

4) Lack of effective guidance for built-up areas. Due to historical constraints, areas with poor vertical conditions and flood risks are mostly concentrated in urban built-up areas, while the existing vertical planning mainly focuses on undeveloped new urban areas, lacking effective guidance for built-up areas.

5) Insufficient control of critical nodes. Major municipal infrastructure such as water plants, substations, and transportation hubs are crucial for urban safety and stability. However, vertical planning has failed to provide precise vertical control requirements for these critical urban nodes.

6) Difficulty in earthwork balance. With the increased intensity of underground space development in cities, large amounts of excavated earth find no place to pile up. Due to environmental policies and economic costs, the current approach is to create a landscape filled with excavated earth, which affects natural terrain and drainage conditions.

2 New requirements for vertical planning in the new context

2.1 Requirements for improving territorial spatial planning system

Since the issuance of the *Several Opinions of the Central Committee of the CPC and the State Council on Establishing the System of Territorial and Spatial Planning and Supervising its Implementation* (the General Office of the CPC Central Committee 2019 Document No.18) in May 2019, overall reforms of the territorial spatial planning system have been initiated. Specialized planning must be conducted under the guidance of territorial spatial planning. In addition, it is necessary to establish a robust transmission mechanism for the implementation of plans to ensure their effective execution.

Currently, the *Zhengzhou Territorial Spatial Master Plan* (2021–2035) is in the approval stage. To implement the requirements set forth by the Central Committee of the Communist Party of China and the State Council to improve the territorial spatial planning system and enhance the awareness of a unified approach and a systemic perspective, Zhengzhou City should simultaneously advance the specialized planning compilation that includes vertical planning, ensuring alignment with the territorial spatial planning to achieve integrated "one map" management across all levels and types of planning.

2.2 Requirements for enhancing urban resilience and safety

Global climate change has led to increasingly frequent extreme weather events, posing significant threats to urban safety and the lives and property of residents. The 19th National Congress of the Communist Party of China explicitly identified climate change as a non-traditional security threat faced by humanity. The *Outline of the* 14*th Five-Year Plan for Economic and Social Development and Long Range Objectives through the Year 2035 of the People's Republic of China* (hereinafter referred to as the 14*th Five-Year Plan*) emphasizes the need to strengthen the observation and assessment of the impacts of global warming on vulnerable areas in China and to enhance the capacity of urban and rural construction, agricultural production, and infrastructure to adapt to climate change [7].

Research indicates that the uncoordinated vertical relationship between terrain and river channels is a significant factor contributing to flooding [8]. By systematically analyzing urban waterlogging risks, establishing a vertical planning compilation system, and refining vertical control requirements, cities can address urban waterlogging issues at their source, thereby improving urban disaster prevention and mitigation capabilities.

2.3 Requirements for developmental transformation of mega-cities

Zhengzhou, as a mega-city, is currently undergoing a phase of developmental transformation. The *14th Five-Year Plan* underscores the importance of enhancing risk prevention and control in the governance of mega-cities and promoting a shift in urban development from scale expansion to quality improvement, aiming for high-quality and sustainable development [7].

As a national central city supporting the strategic layout of the country and the core engine of the Central Plain Urban Agglomeration and the Zhengzhou Metropolitan Area, Zhengzhou needs to adhere to a people-centered approach. This involves comprehensively enhancing urban quality, promoting an inclusive, intensive, and green development model, focusing on urban resilience and safety, improving vertical infrastructure conditions, and addressing the public's demand for safe and livable urban environments.

3 Construction of vertical planning compilation system

Based on the "five levels and three categories" framework of territorial spatial planning and integrated with Zhengzhou's existing planning management system, the *Guidelines* establish a vertical planning compilation system comprising three levels and five categories: specialized planning level (specialized vertical planning), zoning planning level (zoning planning), and detailed planning level (regulatory detailed planning, construction detailed planning, and comprehensive road and pipeline planning) (Fig. 1). This system is closely aligned with territorial spatial planning, ensuring vertical transmission and systematically formulating methods and content requirements for vertical planning compilation at each level to facilitate planning control at various stages.

3.1 Specialized planning level

The scope of the specialized vertical planning in Zhengzhou covers the entire municipal territory. It considers the regional topography, geomorphology, and watershed divisions while aligning with urban growth trends. The central cluster and four suburban clusters (Xingyang–Shangjie cluster, Nanlonghu cluster, Xinzheng cluster, and Zhongmou cluster) are designated as key research areas, while each of the three distant suburban clusters (Xinmi cluster, Gongyi cluster, and Dengfeng cluster) is to develop its own specialized vertical planning (Fig. 2).

The specialized planning focuses on macro-strategic and baseline control, emphasizing the formulation of major technical standards and control requirements, defining the elevation of control points, identifying significant landmarks, landscapes, and facilities, and proposing effective protection and control measures. It also explores strategies for earthwork balance at the urban scale.

3.2 Zoning planning level

Vertical planning is an essential component of the territorial spatial zoning planning compilation in Zhengzhou. For key development areas such as new urban development zones and cooperative construction areas, regional vertical planning compilation is carried out in line with construction requirements.

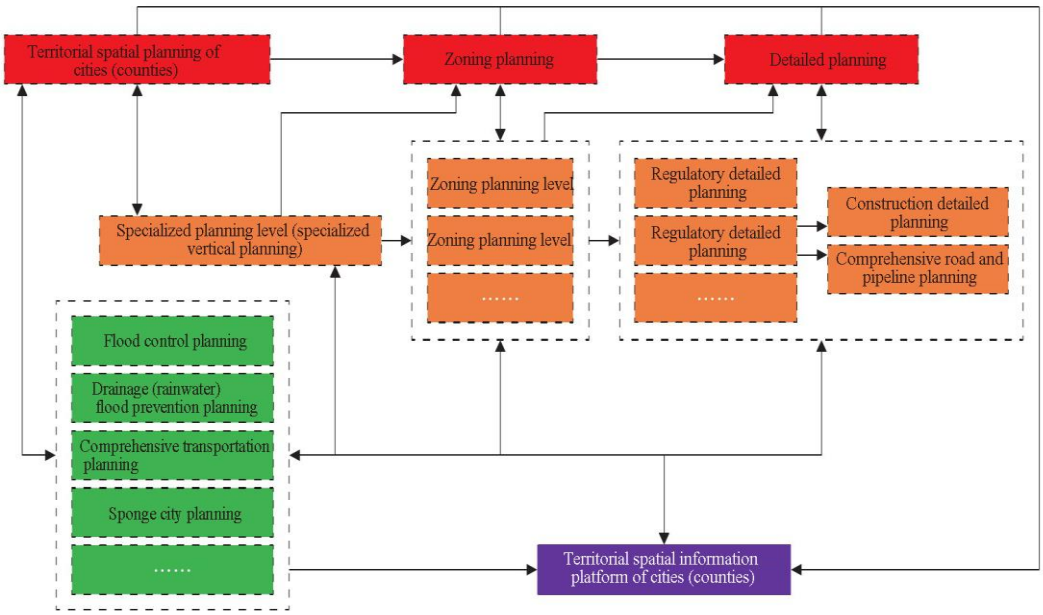

Fig. 1 Vertical planning compilation system in Zhengzhou

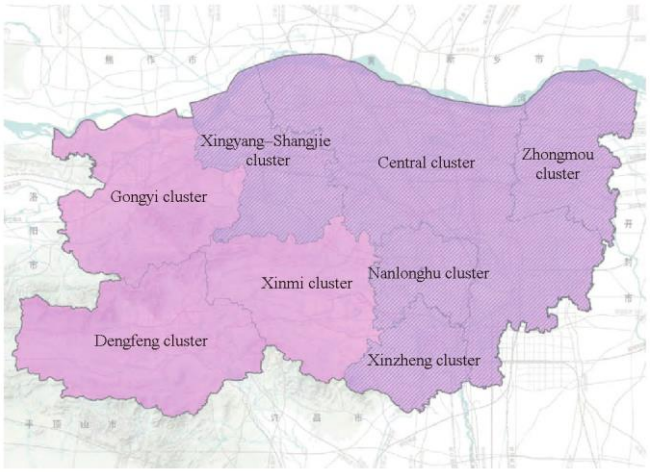

Fig. 2 Scope of Zhengzhou's specialized vertical planning

Zoning planning focuses on undertaking the requirements of specialized planning, guiding the subsequent planning stages, and clarifying the watershed and vertical conditions of the area. It delineates baseline elevations for vertical control units, determines control elevations for intersections of secondary roads and higher-grade roads, strengthens control requirements of significant infrastructure within the area, estimates earthwork quantities, and proposes vertical control strategies and earthwork allocation recommendations.

3.3 Detailed planning level

1) Regulatory detailed planning. Vertical planning is incorporated into the compilation of regulatory detailed planning for units and blocks. It focuses on implementing the requirements of higher-level plans, guiding the implementation of planning in the next stage, determining control elevations for intersections of roads of minor arterial levels and above, clarifying key control elevations for important resources within the planning scope, and proposing earthwork control requirements.

2) Construction detailed planning. In line with the construction detailed planning of specific plots, this level emphasizes vertical design content, focusing on the micro-level and its feasibility, guiding the engineering design in the next stage. It organizes vertical impact factors and flood prevention and drainage engineering facility control requirements based on the vertical content of the regulatory detailed planning. This level also strengthens the connection between the planning plot and surrounding areas, implementing control elevations for internal and external access roads, determining the control elevations for outdoor ground levels of buildings within the plot, specifying the vertical control elevations for municipal facilities, underground space entrances, and exits within the plot, determining drainage network elevations, implementing sponge city construction requirements, and finalizing earthwork balance plans.

3) Comprehensive road and pipeline planning. This level guides the detailed design and construction of municipal roads and pipelines, closely aligning with the vertical content of relevant regulatory detailed planning. It refines and optimizes road alignment, slope, and key control elevations, determines the layout and elevations of municipal pipelines, and implements the sponge city concept to ensure consistent major control elevations and effective regional drainage.

4 Exploration and practice in Zhengzhou

4.1 Implementation of a layered control concept

Traditional vertical planning typically focuses on vertical design for specific meso-level or micro-level construction projects. Building on the foundation of traditional vertical planning, the *Guidelines* emphasize a progressive, hierarchical approach to vertical control, moving from macro to micro, large to small, and top to bottom. This approach ensures that each planning level highlights its specific priorities and strengths, enhancing systemic coherence and consistency.

At the macro level, through specialized vertical planning compilation, the overall urban framework is analyzed, and city characteristics on a large scale are captured. For example, the city's topographical data can be used to generate a digital elevation model (DEM) of the real land, and ArcGIS software is utilized to assess and analyze the terrain, fully considering the unique topographical features of each region and thus adopting corresponding planning strategies.

Zhengzhou spans secondary and tertiary geomorphic terraces, featuring a composite landscape of mountains, hills, plateaus, and plains. The general topography slopes from high elevations in the southwest to lower elevations in the northeast, forming a distinct stepped descent (Fig. 3–Fig. 4). The southwest distant suburban clusters are characterized by concentrated low mountains and hills with high altitudes, steep slopes, and rainfall runoff that easily converges in the urban area. Planning in these areas should maintain good overall vertical alignment, mitigate road slopes, and scientifically arrange drainage pathways to reduce the impact of flood discharge downstream. The central hills and terraces are primarily located at the front of the mid-low mountains, characterized by a landscape of intersecting gullies and fragmented terrain. Planning in these areas should emphasize the coordination of land elevation to minimize risk points. Drainage channels are supposed to be scientifically arranged to manage upstream water inflow and facilitate the effective discharge of floodwaters. The eastern plains, formed by the Yellow River's alluvium, are flat and low-lying, with significant flood risks. Planning here should leverage earthwork from underground space development to reshape the terrain according to the construction sequence, creating a "turtle-back" vertical structure. Moreover, drainage and flood

control measures and emergency management strategies should be taken to address flooding issues comprehensively.

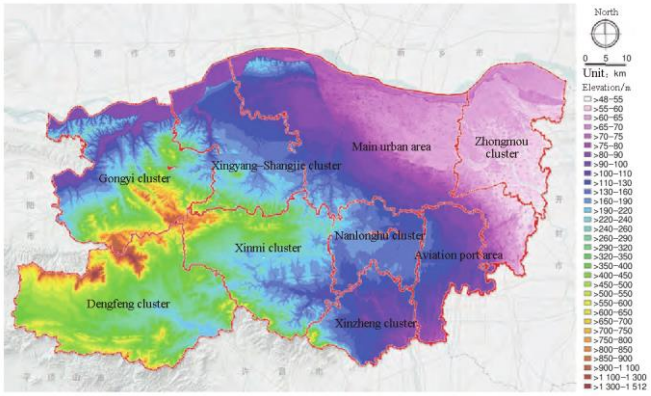

Fig. 3 Elevation analysis of Zhengzhou's territory

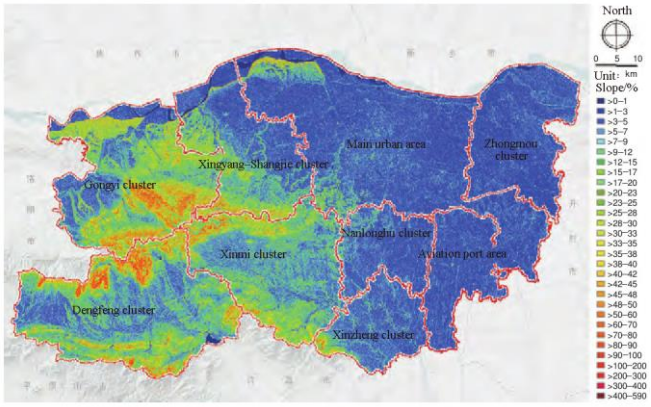

Fig. 4 Slope analysis of Zhengzhou's territory

At the meso level, endeavors should be made to sort out regional characteristics and planning priorities, ensure coordination and consistency with the overall planning scheme, and refine the control requirements of specialized planning. For instance, the Zhengzhou South Station area, located in the southern part of the central urban area, primarily consists of plains with terrain that gradually declines from southwest to northeast. This area features intersecting rivers and railways, with dispersed existing construction land, and it is an important leading area poised for the integration of station and city, with the planned South high-speed rail station as its core. Vertical planning here integrates topographical and water system features, road networks, and rail transit conditions, employing a hump-shaped drainage method to incrementally disperse and intercept runoff, thereby reducing flood risks. Additionally, it considers the operational needs of the Zhengzhou South Station transport hub and combines an underground space development plan, optimizing site elevations and minimizing earthwork transport, securing key urban safety points like railways and platforms, thus avoiding impacts on critical infrastructure (Fig. 5).

At the micro level, vertical planning aligns with Zhengzhou's existing planning management system, emphasizing practical project implementation. During the regulatory detailed planning phase, qualitative and quantitative methods are employed to implement higher-level planning requirements, specifying vertical control indicators to provide definite direction and guidance for subsequent planning execution. In the construction detailed planning phase, vertical design is further emphasized, coordinating with adjacent land, roads, and municipal pipelines to avoid connectivity issues and ensure the successful progression of the project. In the comprehensive road and pipeline planning phase, specific elevations, slopes, and other critical aspects of roads and gravity-flow pipelines are clarified to guide construction drawing design, providing essential references for subsequent construction processes.

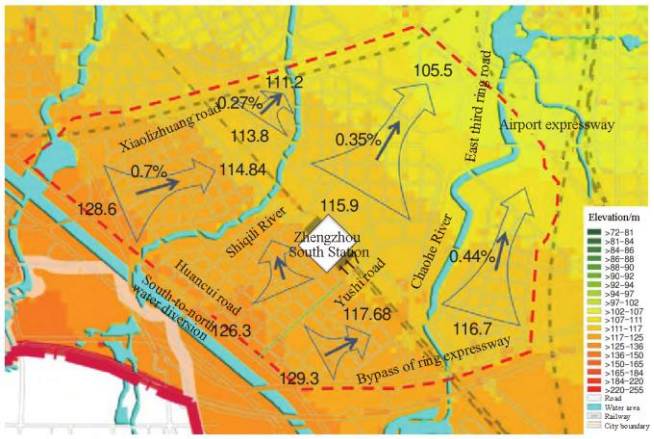

Fig. 5 Analysis of regional elevation, water system, and infrastructure

4.2 Coordination of spatial-temporal elements

In alignment with the vertical control needs of different functional entities within territorial spatial planning, the *Guidelines* adopt a comprehensive approach to control, incorporating spatial and temporal elements throughout the entire process. Based on the five categories of land space protection and development planning divisions identified in territorial spatial planning, the municipal territory is categorized into four spatial forms (Fig. 6–Fig. 7), tailored to meet the vertical development needs of different regions.

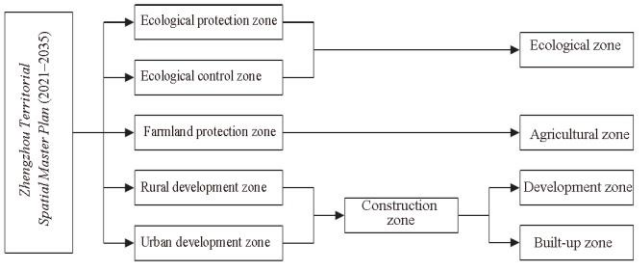

Fig. 6 Classification approach for vertical spaces in Zhengzhou

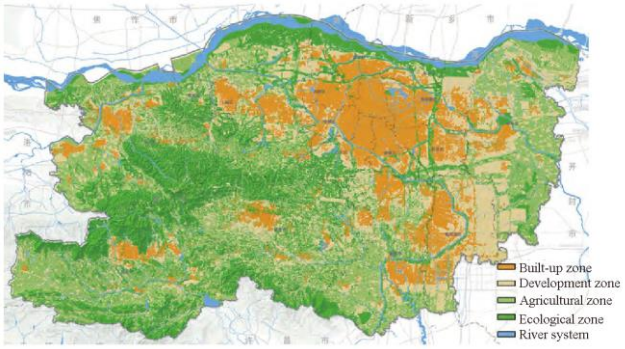

Fig. 7 Classification of vertical spaces in Zhengzhou

Ecological zones are composed of ecological protection zones and ecological control zones. Given their sensitive and fragile ecological functions, vertical planning here focuses on ecological protection, strictly limiting development activities except for necessary human activities. Agricultural zones primarily encompass farmland protection zones. As such, the vertical planning here mainly maintains the current terrain, emphasizing the consolidation and enhancement of food production capacity and promoting high-standard farmland development. Construction zones merge rural and urban development zones, which are core to population agglomeration and urban-rural development. Vertical planning here focuses on maximizing land potential to meet diverse urban-rural construction needs. Additionally, based on the delineated urban construction zones of Zhengzhou, they are further subdivided into development zones and built-up zones according to satellite remote sensing raster data that assess the maturity of their development and construction, with more precise vertical control requirements proposed depending on their distinct characteristics. The vertical control requirements for different types of spaces are as follows:

1) Ecological zones. Vertical planning in ecological zones emphasizes the prevention of mountain destruction, while maintaining natural ponds, water systems, and low-lying green spaces for water retention, aiming to maximize the protection of existing ecological elements.

2) Agricultural zones. The focus of agricultural zones is on preserving the existing terrain, with appropriate vertical adjustments made to meet agricultural production needs, ensuring the integrity and stability of farmland. This also supports the construction of high-standard farmland and strengthens flood retention capabilities through temporary flood storage areas.

3) Development zones. Vertical constraints in development zones are identified based on terrain and development needs. On the premise of flood prevention and drainage safety, the optimization of vertical conditions is achieved by balancing earthwork to avoid excessive filling, deep excavation, and disorderly soil disposal. A "turtle-back" vertical structure is created in low-lying areas to locally disperse floodwater discharge. Additionally, composite spaces are utilized to enhance urban functionality and improve cityscape.

4) Built-up zones. Vertical control focuses on maintaining the current topography in non-flood-prone areas, protecting critical resources during urban renewal, and avoiding lowland formation. In flood-prone areas, projects such as urban renewal and water system management are used to optimize vertical design, reducing rainwater runoff. For areas lacking conditions for optimal transformation, the risk of waterlogging should be reduced through subsequent engineering measures.

4.3 Enhancement of planning coordination

The *Guidelines* emphasize the synergy between various plans, closely integrating territorial spatial planning with flood control planning, drainage (rainwater) and flood prevention planning, comprehensive transportation planning, and other relevant plans. Comprehensive consideration is given to aspects including disaster prevention and mitigation, site utilization, drainage demands, landscape environment, sponge city construction, and planning management to ensure coordinated feedback. Besides, a multi-factor evaluation method is employed to scrutinize various factors and requirements affecting vertical planning, ensuring that all planning aspects complement and coordinate with vertical planning (Tab. 1).

Taking the drainage (rainwater) and flood prevention planning for an example, based on the *Comprehensive Plan for Drainage (Rainwater) and Flood Prevention in Zhengzhou* (2021–2035) and its delineated drainage and flood control zones (Fig. 8), vertical planning adopts principles of coordinated watershed drainage and localized discharge. Strategies such as high-level discharge during peak flows and low-level discharge during low flows are implemented, leveraging natural terrain and river flows to delineate vertical zones, providing specific planning objectives for subsequent vertical control.

Fig. 8 Drainage and flood prevention zoning in main urban area of Zhengzhou

Source: Based on *Comprehensive Plan for Drainage* (*Rainwater*) *and Flood Prevention in Zhengzhou* (2021–2035).

Tab. 1 Coordination requirements of related plans for vertical planning compilation

Categories	Main coordination requirements
Territorial spatial planning	Adhere to the overall goals,spatial layout, binding indicators, and major policies determined by territorial spatial planning; implement corresponding special planning and rigid control requirements in vertical planning, and clarify major project arrangements
Flood control planning	Comply with flood control standards and safety requirements; strictly protect watershed flood control facilities, maintain natural ecological rivers, and ensure flood control safety in the planning area; utilize blue-green spaces for combined storage and drainage, reduce urban flood risk, and ease downstream flood discharge pressure; define vertical zoning based on watershed boundaries and use hydraulic elements such as river flood control standards and water levels as the basis for vertical assessment and baseline elevation
Drainage (rainwater) and flood prevention planning	Formulate vertical planning strategies based on drainage patterns; define vertical zoning based on drainage and flood prevention strategies, and evaluate vertical conditions; ensure the overall slope towards the rainwater outlet; incorporate vertical control requirements from storage space management, focusing on regions recommended for vertical optimization; integrate discharge channel design with the regional drainage and flood prevention system, meeting corresponding requirements
Urban renewal planning	Optimize regional vertical structures through urban organic renewal and manage original depressions to form low-lying systems via comprehensive river and lake water system governance, enhancing urban flood safety resilience
Resilient city planning	Identify critical elements for urban resilience and safety, designing vertical optimization to mitigate flood risks
Comprehensive transportation planning	Establish road network structure and main road framework as a basis for vertical planning, focusing on vertical planning for major transportation facilities to enhance safety resilience; coordinate with the overall layout of rail transit, ensuring that the vertical planning of rail transit station land is integrated with the surrounding vertical planning to ensure flood prevention and drainage safety
Specialized underground space planning	Base underground space vertical planning strategies on the designed floodwater levels of river bodies; design underground space entrance elevations and barrier elevations to meet flood control requirements, enhancing urban disaster prevention and mitigation capabilities
Sponge city planning	Direct block and road runoff into surrounding green systems and urban water systems, maximizing the function of low-impact development facilities; strengthen the rainwater retention function of blue-green spaces, ensuring the construction of low-lying systems; protect existing green spaces and water bodies, gradually converting low-lying areas; ensure new green spaces are designed with low-lying construction to increase storage space for extreme precipitation events
General urban design	Continue the spatial structure and stylistic features established by general urban design, enhancing the quality of external urban spaces and forms; implement vertical construction requirements for low-lying systems, creating low-lying systems based on different terrain patterns
Ecological landscape and green space system planning	Develop protection strategies according to region and type, maintaining ecological patterns in the planning area, and shaping rich urban landscapes
Disaster prevention and mitigation planning	Fully implement the resilient city concept, improve disaster prevention and mitigation facilities, strengthen lifeline system security, and enhance the city's ability to systematically respond to disaster risks
Emergency transportation planning	Strengthen vertical planning for flood emergency channels, focusing on areas with high and medium risk to ensure favorable emergency channel conditions under different precipitation scenarios, ensuring emergency rescue safety
Historical and cultural city protection planning	Meet historical and cultural protection requirements by primarily maintaining the status quo without increasing flood risks
Phased construction plan	Reasonably arrange project construction sequences to avoid redundant investments and engineering waste
Other related plans	Additional analysis elements and depth can be added based on specific project needst

According to flood control standards established by the drainage (rainwater) and flood prevention planning and the precipitation data and the calculation method of rainstorm intensity in Zhengzhou, the central cluster should be capable of coping with a 100-year precipitation event (up to 253.5 mm/24 h). Referring to the *Technical specification for Construction and Application of Mathematical Model of Urban Flooding Prevention and Control System* (T/CECS 647-2019) and a coupling model between river channels and land surfaces constructed by the InfoWorks ICM software, a two-dimensional surface diffuse flow model under extreme precipitation conditions can be obtained to simulate the risk of surface water accumulation (Fig. 9) combined with the precipitation model constructed based on the mathematical analysis of precipitation data. Comparing surface water accumulation conditions at different time helps evaluate the vertical drainage capacity in different areas, providing a critical evaluation basis and data support for vertical planning.

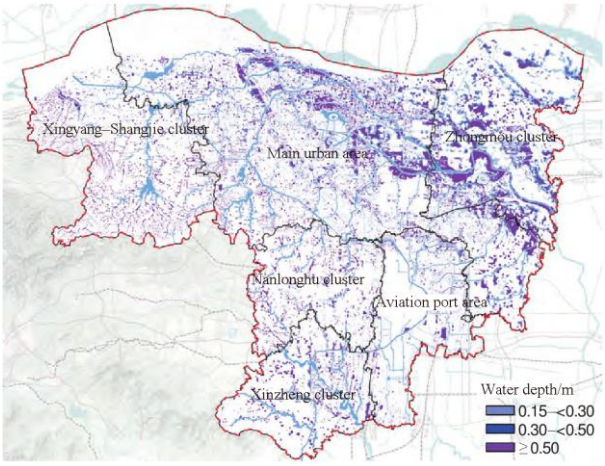

Fig. 9 Simulation of surface water accumulation risk in Zhengzhou's central and suburban clusters under a 100-year precipitation event

4.4 Maintenance of safety baselines

To strengthen urban resilience and safety, the *Guidelines* reference the *Code for Vertical Planning on Urban and Rural Development Land* (CJJ 83-2016), categorizing construction land into high zones, mid-zones, and low zones. The *Guidelines* also establish vertical evaluation standards, propose corresponding vertical planning strategies, and set baseline control elevations.

1) Vertical evaluation standards

Vertical high zones refer to areas with regional vertical planning above the "planned maximum flood level + safety freeboard" of the corresponding drainage channel design. These areas have favorable vertical conditions, supporting surface runoff during precipitation and efficient drainage with good pipes and canal conditions.

Vertical mid-zones refer to areas with regional vertical planning between the "planned maximum flood level + safety freeboard" and "planned flood discharge level + safety freeboard" of the corresponding drainage channel design. These areas can rely on gravity drainage during short precipitation events but may face drainage limitations during flood periods due to the backwater effect.

Vertical low zones refer to areas below the "planned flood discharge level + safety freeboard" of the corresponding drainage channel design. These areas have poor drainage conditions, relying heavily on pump stations for drainage and facing significant drainage pressure.

The vertical evaluation standards are illustrated in Fig. 10. The safety freeboard depends on the level of structure and the type of embankment materials, typically ranging from 0.4 m to 1.0 m [1].

2) Vertical planning strategies

In vertical high zones, the focus should be placed on maintaining the current elevation system combined with other construction planning to address internal risks. When carrying out local construction projects, attention should be paid to coordination with surrounding areas to avoid creating new low-lying points and mitigate downstream impacts.

In vertical mid-zones, the construction sequence is taken into account according to the development situation, and a scientific approach to allocating excavation and filling is adopted, optimizing the vertical layout according to local conditions. Measures such as guiding and optimizing drainage directions through runoff channels are implemented to effectively manage upstream inflows and reduce downstream discharge pressure.

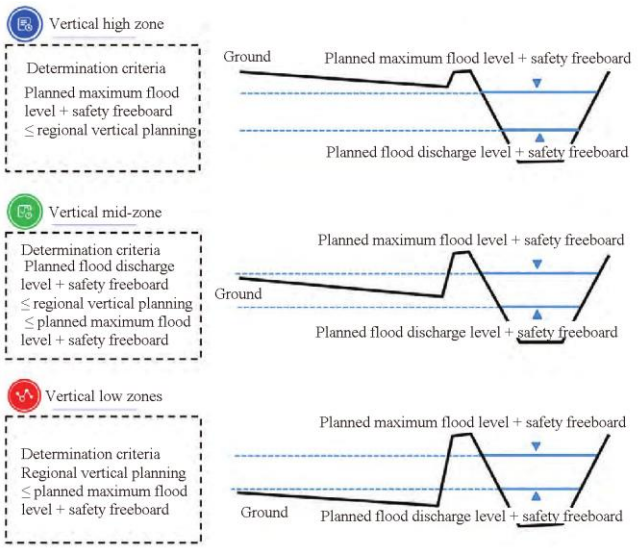

Fig. 10 Standards for vertical assessment in Zhengzhou

In vertical low zones, priority is given to achieving vertical design optimization through development, aiming to minimize the catchment area in low-lying regions. For areas where modifications are challenging, temporary retention spaces are established to manage drainage pressure during extreme weather events, while highlighting key risks at the same time. Land-use planning and engineering construction incorporate thorough risk assessments, relying primarily on engineering measures for drainage, and enhancing emergency management to ensure rapid response in critical situations.

3) Baseline control elevations

The *Guidelines* establish rigid control by delineating baseline elevation standards for each region. The vertical design of new projects must comply with the baseline elevation requirements specific to their area to minimize flood risks caused by inappropriate vertical planning, while also carefully considering the balance of earthworks.

For vertical high zones, the baseline control elevation standard aligns with the assessment criteria, defined as the "planned maximum flood level + safety freeboard" of the corresponding drainage channel design, ensuring effective

drainage during extreme weather conditions and preventing flooding. In vertical mid-zones, the baseline control elevation standard corresponds to the "planned flood discharge level + safety freeboard" of the corresponding drainage channel design, allowing the drainage system to function normally under regular precipitation, thereby reducing flood risks. To optimize drainage conditions and enhance flood prevention safety, the baseline elevation control standard for vertical low zones is set to the same level as that for vertical mid-zones, defined as the "planned flood discharge level + safety freeboard" under the designed discharge conditions of the corresponding river.

4) Important resource management

For critical municipal infrastructure such as transportation hubs and lifeline projects, the *Guidelines* emphasize the importance of evaluating the vertical conditions of these areas to assess flood risk, and corresponding vertical planning strategies are then proposed to mitigate these risks. For planned critical resources with specified locations, the baseline control elevation requirements are determined based on the elevation of surrounding roads.

4.5 Implementation of planning management

The *Guidelines* ensure the effective implementation and management of vertical planning through the establishment of a rigid-flexible index control system (Fig. 11). The rigid control requirements include baseline control elevations for regions and critical resources, serving as fundamental standards for vertical planning. These requirements help safeguard urban flood prevention and drainage safety, reducing waterlogging risks and providing clear and specific references for planning management. Flexible guidelines, such as those for earthwork management and landscape shaping, offer a degree of adaptability in vertical planning to accommodate future urban development changes.

The *Guidelines* mandate the integration of vertical planning data from all levels into a comprehensive vertical planning platform database, which is incorporated into a "one map" supervision information system for the implementation of territorial spatial planning (Fig. 12). Active collaboration with relevant departments, such as the Zhengzhou Big Data Administration and the Zhengzhou Urban and Rural Construction Bureau, ensures that updates and optimizations to vertical planning at various levels are promptly reflected on the platform. This enables real-time monitoring of the latest urban vertical data, enhancing the efficiency and accuracy of planning management and providing crucial information support for future construction and maintenance.

5 Conclusions

Urban vertical planning is still in its exploratory phase, with Zhengzhou being one of the first cities in China to issue guidelines for vertical planning compilation. In response to urban flood prevention and control needs, Zhengzhou has established a vertical planning compilation system, clarifying the requirements and methods for vertical planning at various levels. This exploration addresses the comprehensive management of urban vertical planning, from design and management to construction, enhancing the urban resilience and bearing capacity and further advancing Zhengzhou's territorial spatial planning system.

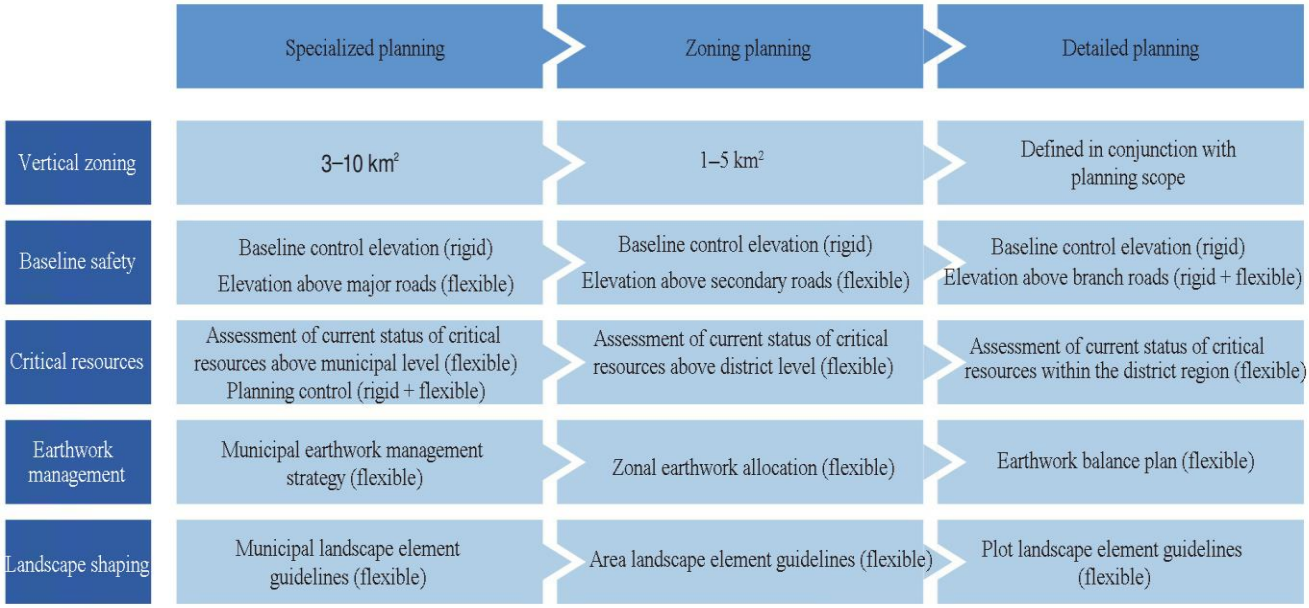

Fig. 11 Control system for vertical planning indicators

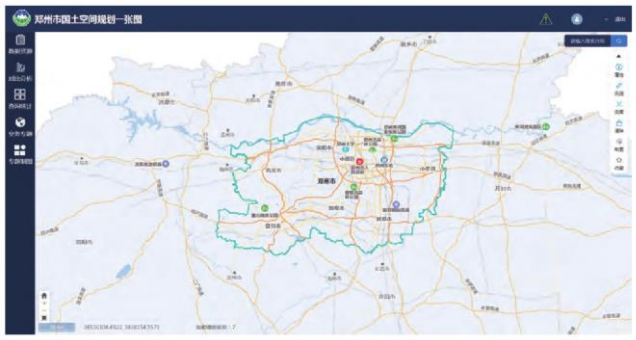

Fig. 12 "One map" supervision information system for implementation of Zhengzhou's territorial spatial planning

This paper provides a preliminary discussion on the compilation of vertical planning under new circumstances. As vertical planning progresses at various levels in Zhengzhou, future research should focus on two key areas: First, promoting the full integration of vertical planning with territorial spatial planning at all levels and fostering the self-improvement of the vertical planning system; second, conducting in-depth studies on vertical optimization in built-up areas and exploring deep integration with urban renewal and old city renovation projects to effectively address urban flooding issues in these areas.

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