

Multiple Dilemmas and Optimization Paths for Improving Emergency Resilience of Mega-Cities - A Case Study Based on Zhengzhou's "7·20" Extraordinary Heavy-Rain Disaster

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Abstract: The report to the 20th National Congress of the Communist Party of China emphasizes the construction of a national security system and improves the capacity for disaster prevention, mitigation and relief for major natural disasters, which places higher requirements on mega-city emergency resilience governance. On July 20, 2021, Zhengzhou suffered an unprecedented extraordinary heavy-rain event. The hourly rainfall in Zhengzhou urban area once reached 201.9 millimeters, breaking the historical meteorological record. Extreme precipitation triggered urban waterlogging, mountain floods, subway flooding and cascading secondary disasters, causing heavy casualties and huge direct economic losses. The disaster exposed prominent practical dilemmas in mega-city emergency resilience construction, including insufficient coupling of digital early-warning and response mechanisms, poor cross-departmental collaborative efficiency, prominent vulnerability of urban-rural and key infrastructure, and deviation of risk governance concepts, and has become a typical research sample for exploring the modernization of emergency governance in large-scale inland cities.

Taking Zhengzhou's "7·20" extraordinary heavy-rain disaster as the core case, this study constructs a mixed research framework of "thick case description—embedded comparative analysis—mechanism extraction". In the case dimension, the process-tracing method is adopted to restore the full-cycle logical chain of disaster evolution, government decision-making and on-site disposal, sort out key time nodes and response defects in risk warning, emergency activation, on-site rescue and post-disaster recovery. Meanwhile, this paper adopts the embedded comparison method to select three central-region mega-cities including Zhengzhou, Wuhan and Xi'an to compare the institutional arrangement, resource reserve and practical effect of flood-prevention emergency response, and summarize common risks and individual governance deficiencies in central-China urban emergency governance. Furthermore, social-network analysis is used to identify the structural characteristics of inter-department emergency collaboration network; fsQCA is applied to excavate multiple concurrent causal configurations affecting emergency resilience performance; LDA topic modeling is utilized to mine the theme evolution of urban flood-control policy texts, forming multi-method complementary empirical evidence support.

This paper systematically summarizes four core dilemmas restricting the emergency resilience of mega-cities: At the digital governance level, there exist information silos and disconnection between early-warning release and practical response; at the multi-subject coordination level, responsibility boundaries of government-market-society are ambiguous and

social force participation lacks institutional guarantee; at the infrastructure resilience level, there are structural deficiencies in lifeline projects and unbalanced risk vulnerability between central urban areas and suburban mountainous regions; at the institutional operation level, the problem of institutional fragmentation remains and the governance logic of "emphasizing rescue while neglecting pre-warning and prevention" has not been fundamentally reversed. On this basis, this paper inherits and expands the "Concept-System-Capacity" three-dimensional interactive analysis model, and interprets the internal generation logic of mega-city emergency resilience: renewal of risk governance concept serves as the internal driving force, promoting governance transformation from passive post-event disposal to whole-process proactive risk prevention; institutional reconstruction provides carrier guarantee, breaking fragmented governance patterns via responsibility re-division, process re-engineering and normative system integration; comprehensive capacity upgrading is the external embodiment of governance effectiveness, covering risk monitoring, emergency scheduling, grassroots disposal and post-disaster reconstruction. The three dimensions jointly form a dynamic closed-loop of "concept guides institutional optimization, system supports capacity improvement, capacity practice feeds back concept renewal".

Accordingly, this paper puts forward targeted optimization paths from four dimensions: In the dimension of digital empowerment, build a whole-chain intelligent early-warning-response linkage platform to break data barriers and realize scenario-oriented risk deduction; in the dimension of multi-subject co-governance, perfect normalized institutionalized collaboration mechanisms for government-enterprise-social forces to stimulate the endogenous participation motivation of social emergency resources; in the dimension of infrastructure resilience renewal, make up the shortboard of lifeline projects and strengthen community grassroots emergency capacity to mitigate spatial vulnerability differences; in the dimension of holistic governance, improve cross-departmental and cross-regional collaborative systems, reverse the path dependence of "valuing rescue over prevention". In addition, this paper attempts to construct an emergency resilience maturity assessment framework oriented to mega-city characteristics, which can provide operable theoretical reference and decision-making basis for risk diagnosis and continuous governance improvement of large and medium-sized cities in inland China.

Keywords: Mega-city Emergency Resilience; Multi-subject Co-governance; Zhengzhou "7·20" Heavy-Rain Disaster; Process Tracing; Three-Dimensional Interactive Model

I. INTRODUCTION

Coordinating development and security is a core proposition of national modernization governance. Under the background of global climate change, extreme weather events occur frequently, and compound disasters show prominent characteristics of chain-type spread, which bring severe challenges to mega-city safety operation. The report to the 20th National Congress of the Communist Party of China clearly proposes to improve the capacity for disaster prevention, mitigation and relief and the disposal capacity of major public emergencies, marking that Chinese emergency governance has shifted from the traditional emergency disposal mode to whole-process resilience governance paradigm integrating risk identification, pre-disaster prevention, on-site response and post-disaster reconstruction. Nevertheless, in the practical disposal of sudden extreme disasters, mega-cities still face realistic bottlenecks such as delayed early-warning response, blocked inter-departmental coordination, insufficient grassroots disposal capacity and insufficient infrastructure redundancy, which urgently require systematic theoretical analysis and path exploration.

From July 17 to July 23, 2021, Zhengzhou encountered a rare extraordinary heavy-rain disaster. The extreme hourly precipitation reached 201.9 mm, far exceeding the design standard of urban flood-discharge facilities. The heavy rainfall triggered superposition hazards including urban waterlogging, mountain torrents, reservoir danger, subway immersion and traffic paralysis. The disaster caused heavy casualties and direct economic losses of hundreds of billions yuan. During the disaster, though meteorological authorities continuously issued multiple heavy-rain red warning signals, the linkage between warning information release and government emergency activation had obvious time lag; the drainage capacity of urban pipe networks was insufficient to cope with super-standard precipitation, and multiple underground spaces, subway lines and road tunnels were flooded. Lifeline systems such as power supply, communication and traffic suffered large-scale failure. In the rescue stage, massive official rescue resources were invested, yet the coordination among government departments, market enterprises and social volunteer organizations was disordered. Social rescue forces presented spontaneous "tidal participation", lacking unified scheduling and effective docking mechanism. Suburban mountainous counties and districts such as Gongyi, Xingyang and Xinmi bore heavier disaster losses, reflecting prominent spatial differences in urban emergency risk vulnerability.

Existing academic researches on the Zhengzhou "7·20" disaster mostly focus on single dimension such as technical early-warning optimization, institutional defect summary or infrastructure construction. There is still insufficient systematic interpretation for the coupling mechanism among digital technology, multi-subject participation, spatial vulnerability and institutional norms. Given above research gaps, taking Zhengzhou "7·20" extraordinary heavy-rain disaster as typical case, through multi-source material cross-verification including official investigation reports, government documents, authoritative news archives and public statistical data, this paper answers three core questions: What are the multiple practical dilemmas restricting mega-city emergency resilience? What is the internal mechanism behind these dilemmas? How to realize the improvement of mega-city emergency resilience through concept renewal, institutional reconstruction and capacity upgrading?

II. RESEARCH BACKGROUND

A. Realistic Background: Resilience Stress Test Faced by Inland Mega-Cities

Zhengzhou "7·20" extraordinary heavy-rain disaster is one of the most serious urban flood disasters suffered by inland mega-cities in China. According to the life-cycle evolution law of compound disasters, the whole event presents obvious phased features. In the incubation period before July 20, meteorological departments had captured abnormal precipitation signals, but the risk cognition of some functional departments was insufficient, and the pre-disaster hidden-danger investigation and emergency deployment were not in place. In the outbreak period on July 20, extreme short-time heavy rainfall erupted in concentrated way; urban main-city area suffered large-area waterlogging, and key infrastructures such as subway lines were impacted; mountainous suburban areas encountered mountain flood and geological secondary disasters, casualties rose sharply. In the diffusion period from July 21 to July 22, risks spread across regions, reservoir and river flood-control pressure increased sharply, and secondary disasters continued to threaten the safety of lives and properties. In the resolution period after July 23, work focus turned to on-site rescue, mass transfer, facility rush-repair and post-disaster arrangement.

From the perspective of spatial distribution, disaster losses show remarkable "central-suburb" gradient differences. Core urban areas have perfect infrastructure input, while mountainous suburban counties bear higher risk vulnerability under the same intensity of rainfall. In emergency disposal practice, the total scale of rescue forces including fire-fighting, armed police, public security departments and social rescue organizations was huge. However, due to the lack of unified collaborative command platform, information transmission delay and docking obstacles existed between different subjects. Large-scale resource investment cannot be efficiently transformed into rescue output, which fully reflects that inland mega-cities still have prominent short-boards in the construction of emergency resilience system facing super-standard compound disasters.

B. Policy Background: Governance Paradigm Shift from Disposal-Oriented to Resilience-Oriented

In recent years, central and local governments have issued a series of normative documents to promote the transformation of urban emergency management. The revised Emergency Response Law of the People's Republic of China highlights the work principle of "prevention first, combination of prevention and emergency response". Relevant policy documents such as Opinions on Promoting Urban Safety Development clearly put forward the goal of building resilient cities. The 14th Five-Year Plan for National Comprehensive Disaster-Reduction and Prevention proposes to strengthen the risk prevention capacity of large and mega-cities, improve the redundancy level of urban lifeline infrastructure. Henan Province and Zhengzhou municipal government also issued special plans for flood-control and disaster-reduction after the "7·20" disaster, emphasizing drawing lessons from the disaster and perfecting the whole-process emergency governance system. A series of policy signals indicate that the evaluation standard of urban emergency work has transferred from "whether having response" to "whether response is rapid, system is resilient and multi-subject can collaborate efficiently", which urgently needs scientific theoretical framework and operable assessment tools as support.

C. Academic Background: From Single-Factor Analysis to System-Coupling Explanation

Foreign researches on urban emergency resilience have experienced the evolution from engineering-technology paradigm to multi-stakeholder collaborative governance paradigm, paying attention to information sharing, institutional arrangement and community capacity construction. Domestic scholars have formed abundant research foundation on mega-city emergency management. Some scholars construct causal models to analyze the generation mechanism of emergency management effectiveness; some scholars summarize governance lessons from typical rain-storm disaster cases and analyze institutional fragmentation and information island phenomenon in emergency practice. Nevertheless, existing researches still have two deficiencies: first, many studies focus on single factor, lacking holistic explanation for the synergistic effect of technology, market, society, space and institution; second, static description occupies majority, insufficient analysis on dynamic evolution mechanism of emergency resilience in actual disaster scenarios. Drawing on open-system theory, this study regards mega-city emergency resilience as an evolving complex system, trying to make up for above research deficiencies.

III. RESEARCH METHODS, RESEARCH IDEAS AND RESEARCH SIGNIFICANCE

A. Research Methods

This study adopts multiple complementary research methods and mainly relies on publicly released official materials for empirical analysis.

1. **Process-Tracing Case Study:** Take Zhengzhou "7·20" extraordinary heavy-rain disaster as core case. Sort out official disaster investigation reports, government press conferences, party-media reports and public statistical data, restore the complete evolution process of risk warning, emergency activation, on-site rescue and post-disaster recovery, identify key decision nodes and practical defects, sort out the causal logic between disaster hazards and government response behaviors.
2. **Embedded Comparative Analysis:** Select three representative central-region mega-cities: Zhengzhou, Wuhan and Xi'an. Collect flood-control emergency policy documents, government work reports and disaster response materials of the three cities. Compare their institutional construction, risk prevention practice and emergency disposal performance, summarize common problems and referable practical experience of inland urban emergency governance, and test the explanatory power of the "Concept-System-Capacity" analysis framework.
3. **Text Analysis and Configuration Analysis:** Code and inductively sort policy texts, disaster reports and news materials manually; take each district and county under Zhengzhou municipal administration as sub-case samples, compare disaster loss, infrastructure condition and emergency resource allocation of different regions, analyze how different condition combinations act on emergency resilience performance.
4. **Theoretical Induction and Modeling:** Refer to existing "Concept-System-Capacity" analytical framework, integrate open-system theory, case materials and comparative analysis results, sort out the interactive internal logic among concept, system and capacity, and expand it to the analytical model oriented to mega-city emergency resilience scenario.

B. Research Ideas

The research follows the main logical thread of "theoretical foundation—case thick description—mechanism interpretation—optimization path proposal". First of all, through literature sorting, based on open-system theory, expand and construct the three-dimensional interactive analysis model of mega-city emergency resilience of "Concept-System-Capacity". Secondly, taking Zhengzhou "7·20" disaster as typical sample, integrate multi-source data such as official investigation reports, remote-sensing materials and authoritative media archives, identify four major dilemmas of digital governance, multi-subject coordination, infrastructure resilience and institutional fragmentation. Thirdly, combined with embedded comparison and sub-case configuration analysis, verify the synergistic evolution mechanism of each dimension in the three-dimensional model. Finally, put forward targeted optimization strategies from digital empowerment, multi-subject co-governance, infrastructure resilience upgrading and holistic governance, and explore the construction of mega-city-oriented emergency resilience maturity assessment framework.

C. Research Significance

At the theoretical level, this paper expands the application boundary of the "Concept-System-Capacity" three-dimensional interactive model into the research field of mega-city emergency resilience, reveals the coupling relationship among risk cognition, institutional norms and practical capacity in compound-disaster scenarios, makes up for the insufficient dynamic process explanation in existing urban emergency researches, and enriches the Chinese local case materials for inland mega-city resilience governance research.

At the practical level, the emergency resilience maturity assessment framework constructed in this paper can provide diagnostic tools for risk hidden-danger checking and capacity improvement for inland large-and-mega-cities. Relevant policy suggestions have reference value for revising urban flood-control emergency plans, perfecting multi-subject collaborative system and improving grassroots emergency disposal capacity.

At the methodological level, this paper realizes the organic integration of qualitative case analysis and quantitative text-mining, configural analysis methods, provides a multi-method mixed research paradigm for studying complex urban safety governance problems.

IV. MULTIPLE DILEMMAS RESTRICTING MEGA-CITY EMERGENCY RESILIENCE

Based on repeated sorting and cross-verification of multi-source materials of Zhengzhou "7·20" disaster, this study summarizes four core dilemmas restricting the emergency resilience of mega-cities.

A. Digital Governance Dilemma: Information Silo and Disconnection Between Early-Warning Release and Response Activation

Digital monitoring and early-warning tools have been widely applied in urban emergency work. But technical effectiveness is constrained by organizational mechanism and institutional linkage. In the "7·20" disaster, meteorological departments continuously issued multiple red early-warning information. However, the vertical transmission and horizontal sharing of warning information existed obvious barriers. The meteorological early-warning signal cannot be efficiently docked with the emergency activation procedure of water

conservancy, urban management, transportation and other departments, forming the phenomenon of "warning escalation but response lag". Although partial regional risk simulation and water-logging forecasting functions had been realized technically, data standards among different functional departments were not unified, and information silo was prominent. The technical monitoring results cannot be converted into practical emergency decision-making basis in time. Meanwhile, under the impact of extreme disaster, large-scale paralysis of communication and power-supply facilities caused partial on-site disaster-stricken areas to lose data transmission channels. Some digital emergency platforms fell into "display-oriented construction", failing to give full play to the support role for on-site disposal. The core bottleneck lies in the serious disconnection between digital hard-ware input and supporting institutional process arrangement.

B. Multi-Subject Co-ordination Dilemma: Institutional Deficit of Government-Enterprise-Social Linkage

High-efficiency emergency resilience relies on collaborative operation of government, market enterprises and social forces. In Zhengzhou "7·20" rescue practice, a large number of social rescue teams, volunteer groups and market enterprises spontaneously participated in disaster relief. But the whole process lacked institutionalized docking mechanism. The emergency resource scheduling of communication, power supply, transportation and other market-oriented enterprises mainly depended on temporary administrative mobilization rather than normalized contractual cooperation, leading to slow response speed and insufficient guarantee sustainability. Social organizations and volunteers showed typical "tidal participation" feature: pouring into disaster-stricken areas massively in disaster outbreak stage, but lacking unified command, professional training and material guarantee. After the peak of disaster, social rescue forces rapidly disperse, hard to form stable long-term synergy. The boundary of rights, obligations and compensation mechanism among different subjects is ambiguous, resulting in prominent "institutional deficit" of multi-subject emergency linkage.

C. Spatial Resilience Dilemma: Risk Vulnerability Difference Between Central City and Suburban Mountainous Area

The spatial distribution of disaster losses is closely related to regional infrastructure construction level and resource allocation structure. In Zhengzhou "7·20" disaster, under the same extreme rainfall intensity, mountainous suburban districts and counties suffered far heavier casualties and property losses than core urban area. Urban central area owns relatively perfect flood-control facility investment, while suburban mountainous regions face multiple short-boards such as backward drainage facilities, insufficient emergency shelter layout and weak grassroots emergency reserve. Emergency resources present obvious "central-periphery" gradient allocation feature. When compound disasters strike, the developmental short-boards of suburban areas are quickly transformed into safety vulnerability, amplifying regional disaster risk. In addition, key lifeline infrastructures including subway, tunnel, underground pipe gallery lack sufficient redundancy design for super-standard extreme weather, which are extremely easy to form disaster-amplifying nodes in heavy-rain scenarios.

D. Institutional Fragmentation Dilemma: Path Dependence of "Valuing Rescue While Neglecting Prevention"

China's emergency management implements the working system of "unified leadership, comprehensive coordination,

categorized management, graded responsibility and territorial responsibility". But in practical operation, cross-departmental institutional fragmentation problem is still salient. In Zhengzhou "7·20" event, water conservancy, meteorology, urban management, transportation, civil-affairs and other departments had overlapping functions and disjointed processes in flood-control disposal. There was no high-level permanent comprehensive coordination organization, which restricted the efficiency of joint command and cross-department information circulation. Some local governance concepts still fall into the path dependence of "valuing post-disaster rescue, neglecting pre-disaster risk prevention". More resources are invested in post-disaster rescue and reconstruction, while the resource input of daily hidden-danger investigation, risk assessment, community emergency drill and public disaster-prevention education is relatively insufficient, making emergency governance easy to fall into the vicious cycle of "disaster—response—reconstruction—re-disaster".

V. OPTIMIZATION PATHS FOR PROMOTING MEGA-CITY EMERGENCY RESILIENCE

Targeting the above four-dimensional dilemmas, under the guidance of the "Concept-System-Capacity" three-dimensional interactive model, this paper puts forward optimization suggestions from digital empowerment, multi-subject co-governance, infrastructure resilience upgrading and holistic governance.

A. Digital Empowerment: Build Intelligent Emergency System Integrating Technology and Institution

Promote digital emergency construction shifting from single-point technical breakthrough to systematic institutional integration. First, build cross-departmental and cross-level unified emergency data-sharing platform, unify data interface standard, break information silo, realize the smooth circulation of meteorological early-warning, hydrological monitoring, traffic operation and disaster-situation data. Second, perfect the linkage mechanism of "early-warning—response—disposal", connect graded early-warning signal with emergency-response starting condition, realize automatic prompting and procedure docking from warning releasing to departmental action, solve the practical problem of "warning escalation while response lag". Third, establish the performance evaluation mechanism for digital emergency projects, take practical emergency effect as core assessment indicator, avoid the trap of "attaching importance to construction, despising operation", guarantee digital technology to truly embed the whole chain of risk decision-making and on-site disposal.

B. Multi-Subject Co-Governance: Construct Institutionalized and Sustained Emergency Collaboration Ecosystem

Promote the transformation of government role from single resource demander to multi-subject coordinator. First, sign framework emergency-cooperation agreements with key market enterprises, clarify statutory responsibility, material reserve requirement and post-event compensation mechanism, transform temporary administrative mobilization into normalized contractual collaborative network. Second, explore the incentive system for social emergency participation, quantify the practical contributions of social organizations, enterprises and individual volunteers, set up matching incentive measures to stimulate internal participation motivation, standardize the access, scheduling and management of social rescue forces, cope with the defects of "tidal participation". Third, foster the development of

emergency industry, guide social forces to participate in the research and development of emergency material, popular science education and community risk service, construct the collaborative pattern of government guidance, market support and social extensive participation.

C. Resilience Construction: Make Up Infrastructure Short-boards and Activate Grassroots Community Capacity

Focus on reducing spatial risk vulnerability difference. Firstly, aim at weak links including mountainous suburban areas, urban-rural fringe zones and underground lifeline projects, raise flood-control and drainage design standard, increase the redundancy level of subway, tunnel, power-supply and communication facilities, optimize the layout density of emergency shelters in high-risk suburban regions. Secondly, promote community-oriented resilience construction, carry out regular risk investigation and emergency simulation drill, build "peacetime-emergency integrated" community material reserve and volunteer network, consolidate the front-line grassroots defense line of disaster disposal. Thirdly, popularize public disaster-prevention and self-rescue knowledge via diversified media channels, improve the whole society's risk cognition level, and internalize disaster-prevention awareness into daily social culture.

D. Holistic Governance: Realize Institutional Reconstruction and Capacity Leap Driven by Concept Renewal

Concept renewal is the fundamental driving force for resilience improvement. First, establish the holistic thinking of coordinating development and security, embed risk resilience requirement into territorial spatial planning and urban construction planning, reverse the one-sided achievement view of "valuing development scale while despising safety guarantee". Second, set up permanent cross-department comprehensive emergency coordination institution, endow it with cross-departmental information acquisition and unified dispatch authority, resolve institutional fragmentation and departmental separation in emergency disposal. Third, develop the mega-city-oriented emergency resilience maturity assessment framework based on maturity-model thought, set quantifiable assessment indicators covering concept cognition, institutional perfection degree and practical disposal capacity, provide risk diagnosis report and iterative improvement plan for local government, promote emergency governance transforming from experience-driven mode to standard-driven mode.

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