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Development of Risk Warning Technology of Hazardous Weather and Implementation of Basin Joint Prevention Mechanism in Liangcheng County

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Abstract To enhance the prevention capability of meteorological disasters in semi-arid mountainous areas, in view of the characteristics of strong suddenness, significant locality and high basin correlation of hazardous weather in Liangcheng County, the progress of risk warning technology of hazardous weather and the innovative achievements of the construction of the basin joint prevention mechanism were systematically analyzed based on the recent prevention and mitigation practices of meteorological disasters in Liangcheng Meteorological Bureau. The results show that firstly, Liangcheng County has established an "ground – air – space" integrated monitoring network to achieve 5-min full coverage monitoring of core meteorological elements throughout the region. Secondly, relying on a multi-level forecasting system and intelligent technologies, the lead time of early warnings of hazardous weather has been extended to several hours, and the accuracy has significantly improved. Thirdly, a multi-channel and targeted warning dissemination system has been constructed, with a public coverage rate of over 90%. Fourthly, a basin joint prevention innovation model of "information sharing, joint discussion, and hierarchical linkage" has been formed, and the collaborative effectiveness of disaster response across regions and departments has been significantly enhanced. This research results can provide technical references and practical models for optimizing the prevention and mitigation system of meteorological disasters in regions with similar climate and geographical characteristics.

Key words Hazardous weather; Risk warning; Basin joint prevention; Meteorological monitoring

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In recent years, under the background of global climate warming, the frequency of extreme weather and climate events has showed an increasing trend, posing a serious threat to social and economic development as well as people's lives and property safety. The prevention and mitigation of meteorological disasters has become an important foundation support for ensuring regional high-quality development. Liangcheng County is located in the transitional zone between the Inner Mongolia Plateau and the Loess Plateau, and has a mid-temperate semi-arid continental monsoon climate. In the county, mountains and hills are distributed widely. The Daihai River Basin and Gongba River Basin run through the entire area. The special geographical and climatic conditions have led to frequent occurrence of disastrous weather such as rainstorm, hail, and strong convection, and are prone to trigger secondary disasters such as mountain floods and landslides. The cross-basin chain impact of disasters is prominent, posing severe challenges to the prevention work of grassroots meteorological disasters.

Currently, the prevention of grassroots meteorological disasters faces common problems such as monitoring blind spots, insufficient accuracy of warnings, and poor cross-regional coordination, and it is urgent to solve these problems through technological innovation and mechanism improvement[1]. Liangcheng Meteorological Bureau takes the construction of meteorological modernization as the core approach, focuses on the technological upgrading of the entire chain including precise monitoring, accurate forecasting, and efficient information dissemination, and simultaneously promotes the innovative practice of the basin joint prevention and linkage mechanism. In the process of meteorological disaster prevention, it has accumulated rich practical experience and valuable technical achievements. In this paper, the latest progress in the risk warning technology of disastrous weather in Liangcheng County was systematically reviewed, and the core framework, operation mode, and main innovation paths of the basin joint prevention mechanism were deeply analyzed to provide solid theoretical support and practical experience for similar grassroots areas in China to enhance their comprehensive prevention capability of meteorological disasters.

1 General situation of the study area

Liangcheng County (112°02′ – 113°02′ E, 40°10′ – 40°50′ N) is located in the south of Ulanqab City, Inner Mongolia Autonomous Region, and has a total land area of 3 458.3 km^2, accounting for approximately 0.3% of the total area of the autonomous region. The county is 82 km long from east to west and 73 km wide from north to south. In terms of terrain, it is high in the northwest and southeast and low in the middle. The altitude ranges from 1 000 to 2 300 m. The annual average temperature in Liangcheng County is 6.2 ℃, and the annual average precipitation is around 400 mm. The precipitation is concentrated from June to August,

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and mostly appears in the form of short-term heavy rainfall. The annual average number of windy days is more than 30 d, and the annual average frequency of disasters such as hail, cold waves, and frost is 3 – 5.

The river basin resources are abundant in the county, and tributaries such as the Gongba River crisscross each other. The farmland in the basin is mainly used for growing corn and potatoes. Due to the special underlying surface and climate conditions, regional disastrous weather is characterized by distinct small- and medium-scale characteristics, strong secondary disaster chain, and wide influence range of the basin", and the demand for the prevention of meteorological disasters is urgent.

2 Advances in the warning technology of hazardous weather risk

2.1 Construction of integrated monitoring network Relying on the meteorological modernization projects of the state and the autonomous region, Liangcheng County has gradually established a three-dimensional monitoring system of " full coverage on the ground, precise detection from high altitudes, and dynamic pursuit in space", fills monitoring gaps, and enhances the ability to detect hazardous weather at an early stage.

2.1.1 Quality improvement of the ground monitoring network. Based on the original one national meteorological observation station, 28 regional automatic weather stations have been added, covering all townships in the county, key nodes in the upper and lower reaches of the river basins, and remote mountainous areas. Real-time collection of 6 core meteorological elements (rainfall, wind speed, temperature, humidity, *etc.*) is conducted every 5 min. A regular equipment inspection and maintenance mechanism has been established, and the accuracy rate of data transmission is over 98%.

2.1.2 Integration of high-altitude and spatial monitoring. The national new generation weather radar data of Jining are connected to precisely reverse the affected area, intensity, evolution process and phase change characteristics of heavy precipitation, providing core support for short-term forecasting and warning[2]. At the same time, remote sensing data from Fengyun-4 meteorological satellite cloud images are applied to achieve three-dimensional tracking of strong convection weather. In line with the guarantee requirements for the Liangcheng venue of the 14th National Winter Games, 7 new multi-element observation stations have been built, and various unconventional detection equipment has been integrated to form a three-dimensional monitoring network with a " hundred-meter spatial resolution and minute temporal resolution", thereby accurately capturing the appearance, development, and evolution of small- and medium-scale weather systems.

2.2 Upgrade of forecasting and early warning capability A forecasting and early warning system with "superior guidance + local optimization + intelligent empowerment" has been established to realize precise early warnings for both a single disaster and complex disaster. The lead time and accuracy of early warning have significantly improved.

2.2.1 Integration of multi-level business systems. It is necessary to fully integrate the meteorological forecasting business platforms at the central, autonomous region, municipal, and county levels, obtain national refined grid forecast and provincial guidance forecast products in real time, make corrections and optimizations based on local monitoring data, and form a three-level forecasting product system at "regional – county – township" levels. The spatial and temporal resolution of forecast is up to 1 km × 1 h.

2.2.2 Deep application of intelligent technologies. It is needed to deploy an AI algorithm-based short-term nowcasting system and integrate radar echo extrapolation, satellite cloud image feature recognition, and machine learning models, so that the lead time of early warning for severe convection weather such as thunderstorms, strong winds, hail, and short-term heavy precipitation can reach 2 – 6 h, and the warning accuracy is effectively improved by more than 25% compared to traditional methods.

2.2.3 Optimization of disaster risk models. Based on the results of the first national comprehensive risk survey on natural disasters, it is needed to quantify the disaster-causing thresholds for local rainstorms, hail, *etc.*, establish a corresponding relationship of "intensity of disaster-causing factors – fragility of hazard-bearing body – risk level", improve the local warning index models for 8 types of disastrous weather, and adapt to needs for the prevention of regional disasters.

2.2.4 Collaborative early warning of multiple disasters. Emergency management, water conservancy, and agricultural departments have jointly established a multi-disaster early warning and assessment platform. For complex disasters, it is necessary to conduct joint analysis and issue risk warnings, and simultaneously push targeted defense suggestions such as flood control and drainage, prevention and control of forest fire.

2.3 Optimization of warning information dissemination A warning information dissemination system of "multi-channel coverage, targeted push, and coordinated implementation" has been established to ensure that warning information reaches the affected individuals promptly and enhance the efficiency of disaster prevention and emergency response.

2.3.1 Full coverage of public channels. Relying on the national emergency warning information release system, the warning is pushed to the emergency response responsible persons at the county, township, and village levels within 1 min. Public warnings are simultaneously released through mobile phone text messages, radio, television, and WeChat official accounts, and the public coverage rate of the early warning reaches 92.3% through village loudspeakers and emergency broadcasts.

2.3.2 Precise targeted push. Based on the geographic information system, precise positioning of the disaster-affected areas is achieved, and targeted text messages and WeChat warnings are pushed to specific towns and villages. For key units such as schools, scenic spots, and enterprises, a "one-to-one" warning transmission mechanism is established to ensure that the reach rate of early warning for key areas and key populations is up to 100%.

2.3.3 Implementation of departmental linkage. A warning response linkage mechanism between meteorological and emergency management, transportation, and water conservancy departments has been established. After the release of high-level warnings, the closed-loop process of "meteorological warning – department response – grassroots implementation" is initiated. During the heavy rainfall from July 23 to 28, 2025, through this mechanism, the warning information covered all farmers in the affected areas within 1 h, and more than 700 people were urgently evacuated, significantly reducing the disaster loss.

3 Construction and practice of the basin joint prevention mechanism

3.1 Core architecture of the joint prevention mechanism

Based on the correlation characteristics of disasters in the river basin, the basin joint prevention mechanism of "upstream-downstream linkage, cross-departmental collaboration, and full-process closed-loop" is constructed by breaking through administrative regional barriers. The core includes three major modules.

3.1.1 Comprehensive information sharing module. Relying on the CIMISS meteorological data sharing platform and the basin joint prevention work group, it is needed to establish a regular information sharing mechanism between meteorological departments of upstream and downstream cities, synchronously share real-time monitoring data, forecast products, and disaster situations, jointly establish a joint duty system with water conservancy, emergency response and other departments, share information such as river water level, geological hazard points, and emergency material reserves, and achieve "data and situation sharing"[3].

3.1.2 Cross-domain joint consultation module. For major weather processes, it is necessary to initiate the joint consultation of "meteorological departments + water conservancy departments + emergency departments + upstream-downstream regions". Meteorological departments analyze rainfall intensity and affected areas, and water conservancy departments assess the flood control capacity and water level rise of the river basin. Emergency departments formulate the personnel transfer plan, and formulates a tripartite judgment result of "meteorological forecast – risk assessment – disposal suggestions", providing support for joint prevention decisions.

3.1.3 Graded linkage disposal module. In accordance with the *Emergency Plan for Flood Control and Drought Relief in Liangcheng County*, the joint prevention measures for different warning levels of disasters such as rainstorms and floods are clearly defined: when the warning level is orange or above, upstream reservoirs will release water in advance for storage and regulation, and downstream towns will suspend agricultural irrigation and open emergency shelters; transportation departments will close water-related roads, forming a defense pattern of "upstream and downstream collaboration, and multi-department linkage".

3.2 Innovation practices of the joint prevention model

3.2.1 Innovation of collaborative mechanism. It is needed to establish a joint meeting system for the basin joint prevention and control, hold departmental collaborative meetings quarterly, organize joint flood prevention drills among meteorological, water conservancy, emergency response, and fire departments before the flood season each year, and test the collaborative effectiveness of the entire process of early warning transmission, personnel evacuation, and emergency response. On average, such drills are conducted 2 – 3 times per year, and the response time of departments is shortened to 30 min at most.

3.2.2 Innovation of technical means. Flash message mandatory push technology should be introduced. When a high-level warning is issued, full-second-level coverage of warning information of mobile users in specific river basin areas is achieved. A cross-regional joint warning mechanism should be explored. For disastrous weather in a cross-county river basin, meteorological departments in upstream and downstream regions uniformly set warning standards and simultaneously issue warnings to avoid information asymmetry and delayed defense.

3.2.3 Innovation of service philosophy. A call-and-response mechanism. should be established. Meteorological departments report the weather situation and risk assessment in detail to the county committee and county government in advance, actively propose suggestions of emergency response, and promote the forward movement of the warning threshold. Before the heavy rainfall happened in July 2025, the county government was promoted to deploy flood prevention work 12 h in advance through the call-and-response mechanism, thereby effectively avoiding the risk of disasters.

4 Effects and prospects

4.1 Practical effects Through the upgrade of early warning technology and the improvement of the basin joint prevention mechanism, the meteorological disaster prevention capability of Liangcheng County have significantly improved. Firstly, the coverage rate of disaster monitoring reaches 100%, and the timeliness of capturing small- and medium-scale weather systems is advanced by 1 – 2 h. Secondly, the accuracy of early warnings of severe convection and rainstorms reached over 85%, and the average lead time of early warnings is extended by 2 – 3 h. Thirdly, the collaboration efficiency of cross-regional response to basin disasters is enhanced by 50%, and economic losses is minimized in case of frequent disastrous weather. The incidents of casualties caused by meteorological disasters are relatively rare, effectively ensuring the stability of regional agricultural production and the safety of people's lives and property.

4.2 Main conclusions Based on the business practices of Liangcheng County, the feasibility and innovation of integrating disaster weather risk warning technology with the basin joint prevention mechanism have been systematically verified. The main conclusions have been drawn as follows.

(1) The three-dimensional and intelligent monitoring and forecasting technology is the core driving force for improving the

accuracy of early warnings. By constructing an integrated network of "ground – air – space" and applying technologies such as intelligent grids and short-term nowcasting, the ability to capture and predict disaster weather can be significantly enhanced, which is the material basis for achieving precise risk identification.

(2) Institutionalized and proceduralized basin joint prevention mechanisms are the organizational guarantee for achieving efficient cross-departmental collaboration. A closed-loop business process centered on information sharing, joint consultations, and warning linkage is established, and is supplemented by institutional arrangements such as joint drills, thereby effectively breaking down administrative barriers and converting warnings into collaborative prevention and control actions.

(3) The deep integration of technology and mechanism is the fundamental path for systematically enhancing the prevention capability of grassroots meteorological disasters. Only when advanced technologies provide precise guidance for the collaborative mechanism and the collaborative mechanism provides efficiency amplification for technology application can a truly efficient and resilient risk prevention and control system be constructed.

4.3 Future outlook In the future, three main directions should be continuously deepened and enhanced. At the technical level, it is needed to further optimize the "ground – air – space" monitoring network, add equipment such as unmanned aerial vehicle patrol and soil moisture monitoring, and ingeniously apply artificial intelligence forecasting models to improve the ability to accurately predict extreme weather. At the mechanism level, it is necessary to expand the scope of the basin joint prevention, establish cross-regional joint prevention communities with surrounding cities, improve a multi-department data sharing platform, and achieve intelligent decision-making for joint prevention. At the service level, it is needed to strengthen the popularization of warning information interpretation, carry out targeted science popularization publicity of disaster prevention, enhance the public's self-rescue and mutual rescue capability, and build a comprehensive meteorological disaster prevention system of "technical support – mechanism guarantee – public participation".

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an important part of public meteorological services. It is necessary to scientifically analyze and judge the climate background of the event location and the impact of high-impact weather on major events, and provide all-round, full-process and refined meteorological services for major events, targeted, timely and scientific meteorological services, and favorable support for the decision-making and arrangement of major events.

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