WATER RESILIENT MOSAIC

Envisioning a co-evolutionary transformation of territories-in-between in the Beijing-Tianjin-Hebei metropolitan region

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Water resilient mosaic.
Envisioning a co-evolutionary transformation of territories-in-between in the BTH metropolitan region

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Fig. 01. A 12-meter deep flood occurred in Zhuozhou, Hebei province (Weibo, 2023)

Motivation

The unprecedented summer rainfall in 2023, the largest in 140 years in the Beijing-Tianjin-Hebei (BTH) region, highlighted the insufficient preparedness of Chinese metropolitan areas in dealing with unforeseen and extreme weather events. This event, which took many by surprise, serves as a stark reminder of the urgent need to enhance the resilience of urban and societal systems in the face of escalating climatic challenges.

We find ourselves in an era where the frequency of unpredictable incidents is increasing, yet our urban infrastructures and societal frameworks continue to demonstrate a lack of readiness to address these evolving threats. The summer rainfall in the BTH region in 2023 serves as a poignant example of the consequences of this unpreparedness.

The aftermath of this extreme weather event has been significant, impacting over five million people and necessitating the urgent evacuation of more than 1.8 million individuals. Tragically, there have been 62 fatalities and 34 people reported missing. The economic ramifications are severe, with direct economic losses totaling ¥958.11 billion in Hebei province alone. The city of Beijing also faced considerable challenges, affecting nearly 1.29 million people, and assessments of property damages are ongoing.

The situation is further complicated by reports of serious environmental justice violations during this tragedy. Economically vulnerable rural residents, unable to contend with the government's assertive flood control policies, have been disproportionately affected—a plight often overlooked in mainstream reporting. As an urbanist with a Chinese background, I am deeply concerned about these developments and recognize the imperative for an in-depth study of this phenomenon.

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ABSTRACT

The Beijing-Tianjin-Hebei (BTH) Metropolitan Region faces significant challenges, including drought, severe precipitation, floods, subsidence, societal disparities, air pollution, and an aging population. Fragmented spatial and institutional frameworks hinder effective responses, perpetuating vulnerabilities. This study focuses on enhancing water resilience with an emphasis on environmental justice in vulnerable areas between major cities. The proposed low-density development approach aims to balance economic productivity with ecological sensitivity, creating a decentralized, self-reliant, and resilient region.

The strategy integrates ecosystem-based adaptation, integrated water resources management, and water-sensitive village reorganization. A shift from a profit-centric model to one prioritizing water risk reduction in vulnerable areas is crucial for achieving environmental justice. The research employs pattern languages and the dynamic adaptive pathway method to organize potential measures, integrating future objectives, intervention patterns, and scenarios to feasibly implement actions by 2060.

Ultimately, the research envisions self-resilient units contributing crucial ecosystem services to urban centers and receiving support through knowledge exchange and economic assistance. This transformation will turn these units from sacrificial entities into integral components of sustainable development in the BTH region. Validated by both quantitative and qualitative assessments, this shift is anticipated to strengthen the water resilience of individual units and enhance the overall resilience of the metropolitan area.

INTRODUCTION

INTRODUCTION

| The Beijing-Tianjin-Hebei (BTH) Metropolitan Region

| Escalating social-environmental challenges

THE BEIJING-TIANJIN-HEBEI (BTH) METROPOLITAN REGION

The Beijing-Tianjin-Hebei (BTH) metropolitan region, commonly known as Jing-Jin-Ji, represents a highly dynamic and influential urban conglomerate within China. Integrating the national capital, Beijing, the major port city of Tianjin, and the surrounding Hebei Province, this extensive megalopolis serves as a cohesive economic, cultural, and administrative center. Covering an area of approximately 216,000 square kilometers, this strategic megalopolis reflects China's rapid urbanization and ambitious regional development initiatives.

The region's significance extends beyond its economic strength to encompass its role as the political and cultural nucleus of the nation. Beijing, with its historic landmarks such as the Forbidden City and the Great Wall, contributes to the area's cultural richness. Tianjin, a prominent international port, functions as a crucial trade and commerce gateway. Hebei Province complements these urban centers with its varied landscapes and industrial contributions, further augmenting the overall economic vitality of the region.

The BTH metropolitan region has been a focal point for the Chinese government's initiatives addressing urbanization challenges, including traffic congestion, environmental pollution, and uneven economic development.

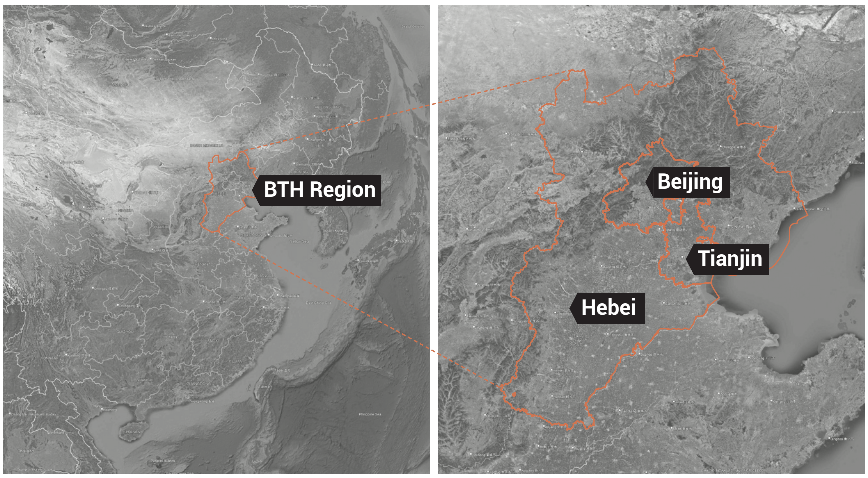


Fig. 02. Research area

ESCALATING SOCIAL-ENVIRONMENTAL CHALLENGES

The region is currently facing a range of intricate social and environmental challenges that necessitate prompt attention and innovative solutions. This densely populated area, home to over 110 million people, is confronted with diverse issues that pose significant threats to both its residents and sustainable development.

Recurring floods, droughts, and extreme heat events are intensified by factors such as climate change, urbanization, and unsustainable water management practices. These have disrupted the delicate balance between water supply and demand, increasing the risk of natural disasters and compromising the region's resilience.

A critical concern in the BTH metropolitan region is land subsidence, a gradual sinking of the land surface. This issue is exacerbated by rapid urbanization and excessive groundwater extraction, jeopardizing infrastructure stability and increasing the vulnerability of densely populated urban areas.

Persistent air pollution remains a prevalent and urgent issue, impacting public health and overall quality of life. Factors such as industrial activities, vehicular emissions, and coal-fired power plants contribute to elevated levels of particulate matter and harmful pollutants, posing serious health risks to the population.

The BTH region displays evident polarized development, characterized by a stark contrast between urban and rural areas. While urban centers experience rapid economic growth and infrastructural development, rural areas face challenges such as limited access to resources and opportunities, leading to a socio-economic imbalance that necessitates comprehensive and inclusive policy interventions.

Furthermore, the BTH metropolitan region is grappling with the social challenge of an aging population. With increasing life expectancy and declining birth rates, the region must adapt its social infrastructure to address the needs of an aging demographic, encompassing issues related to healthcare, social services, and overall well-being.

Fig. 03. Flood with Typhoon Doksuri, 2023

"Due to the impact of Typhoon Doksuri, extreme heavy rainfall occurred in areas including Beijing, Tianjin, and Hebei, surpassing the intensity of three previous extreme rain events in the history of North China. This phenomenon is historically unprecedented." (Caijing, 2023)

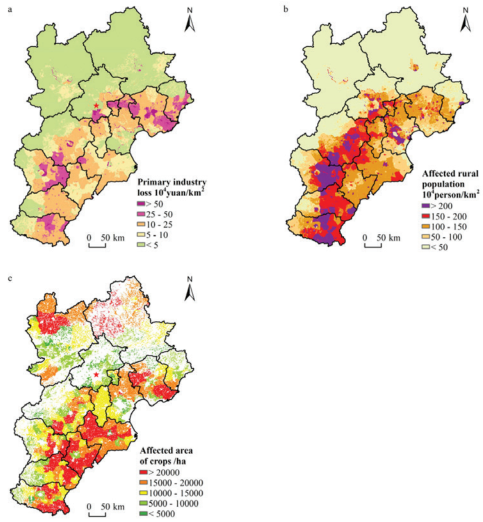


Fig. 04. Drought risk spatial distribution of primary industry loss (a), affected rural population (b), and affected cultivated area (c) (Li et al., 2022).

"Northern China has borne the brunt of the extreme heat. In June, Beijing logged 13.2 days with temperatures of at least 35C, the highest number of super hot days for the month since records began in 1961, with the mercury rising to at least 40C on a few days." (Reuters, 2023)

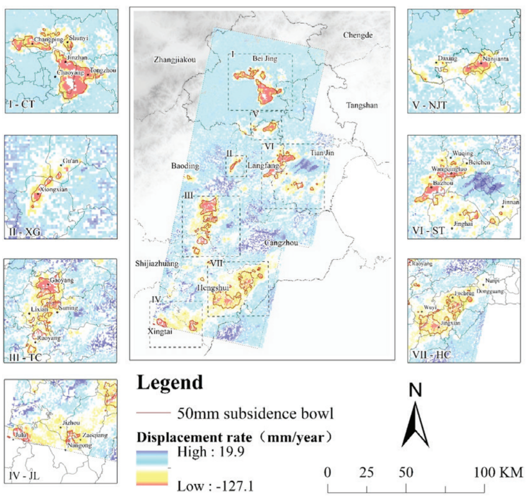


Fig. 05. Average displacement rates in the Jingjinji region from 2012 to 2019.

The red lines denote the boundaries of the 50mm subsidence bowls, and the black dotted rectangles denote the typical subsidence areas displayed in panels I-VII (Han et al., 2023).

Fig. 06. Air quality at Beijing Railway Station from December 17-22 (left to right) (Xinhua, 2016).

“Authorities in the northern Hebei province have arrested at least 12 people from three local companies for falsifying environmental data, which helped keep their reported air pollution in check.” (Ye, 2021)

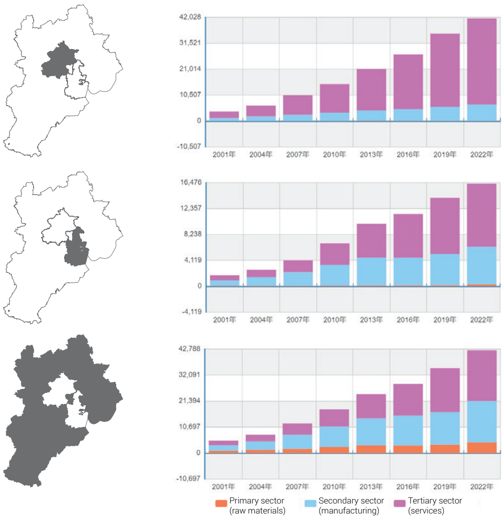
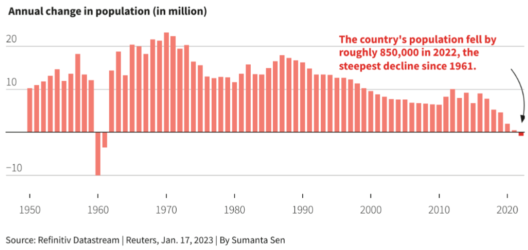


Fig. 07. GDP per sector of BTH region (Data: National Bureau of Statistics of China)

“The per capita GDP of Hebei Province in 2022 was only 29.9 percent of that of Beijing and 47.9 percent of that of Tianjin. In terms of education, healthcare, and other livelihood resources, Beijing significantly surpasses Tianjin and Hebei. ” (Fu, 2023)

Fig. 08. Aging population

“The country’s National Bureau of Statistics reported a drop of roughly 850,000 people for a population of 1.41175 billion in 2022, marking the first decline since 1961, the last year of China’s Great Famine.” (Zhang & Master, 2023)



POSITIONING

POSITIONING

| Problematization

| Theoretical framework

| Conceptual framework

PROBLEMATIZATION

Problem context

The BTH Metropolitan Region is facing multifaceted challenges that demand careful consideration. From the perspective of climate change, the region grapples with the repercussions of global environmental shifts, including rising temperatures, altered precipitation patterns, and an increased frequency of extreme weather events. These changes not only threaten the region's ecological balance but also impact the livelihoods and well-being of its inhabitants.

Simultaneously, the region faces challenges stemming from extensive growth and rapid urbanization. The unprecedented pace of development has led to issues such as environmental degradation, air and water pollution, and strained resources. The demand for infrastructure and urban expansion has created a complex interplay between economic progress and ecological sustainability. Balancing the needs of a burgeoning population with the imperative to preserve the environment presents a delicate and pressing challenge for policymakers and stakeholders in the BTH Metropolitan Region.

Problem statement

The BTH Metropolitan Region is known for its historical patterns of drought, along with increasing severe precipitation and flood events. Additionally, the region faces persistent challenges such as subsidence, societal disparities related to development, air pollution, and an aging population. The inherent spatial and institutional fragmentation within the region hinders its ability to effectively address these emerging socio-environmental challenges. Consequently, this situation leads to biophysical and social vulnerabilities that are expected to persist in the foreseeable future.

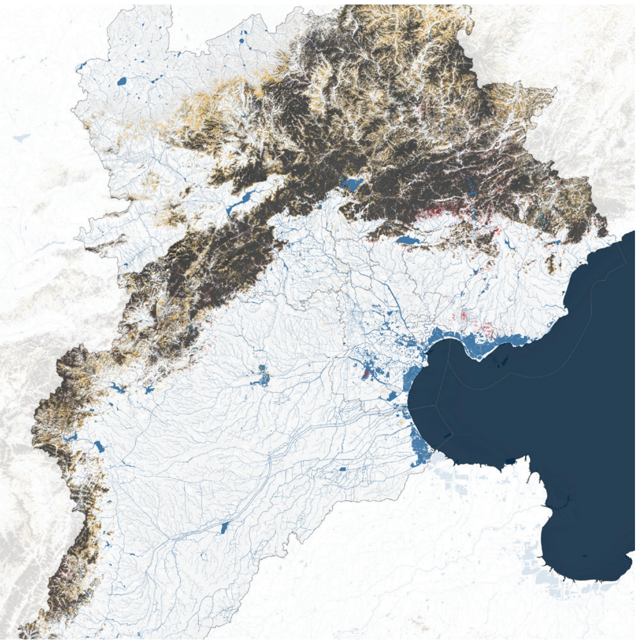


Fig. 09. Forest & Shrub change 1985-2022 (Data: OSM, Yang & Huang (2021))

- *Persistent*
- *Increasement*
- *Decreasement*
- *Waterbody*
- *Waterway*
- *Administrative boundary*

0 10 200 km

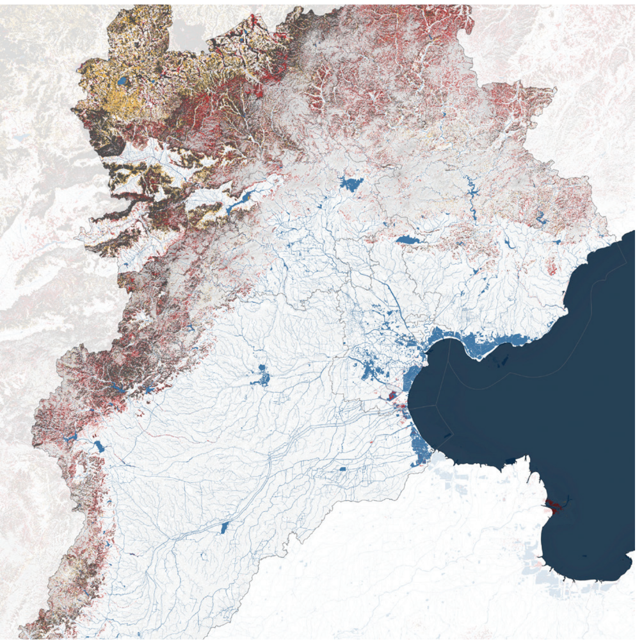


Fig. 10. Grassland change 1985-2022 (Data: OSM, Yang & Huang (2021))

- *Persistent*
- *Increasement*
- *Decreasement*
- *Waterbody*
- *Waterway*
- *Administrative boundary*

0 10 200 km

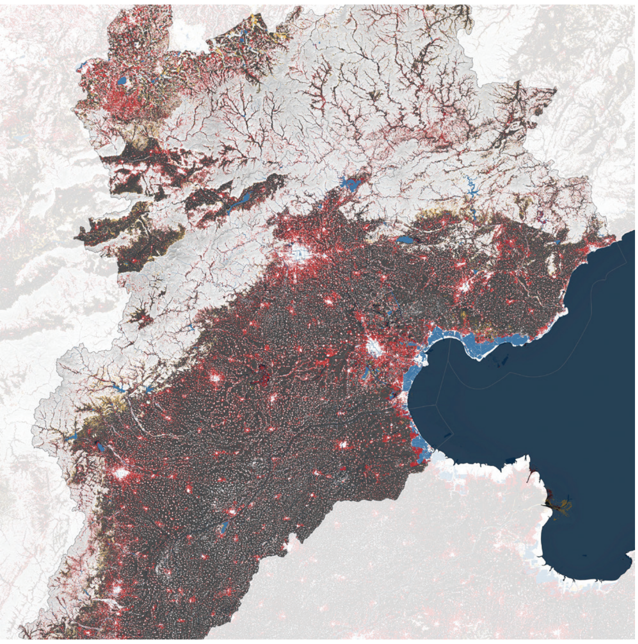


Fig. 11. Cropland change 1985-2022 (Data: OSM, Yang & Huang (2021))

- *Persistent*
- *Increasement*
- *Decreasement*
- *Waterbody*
- *Waterway*
- *Administrative boundary*

0 10 200 km

Landscape fragmentation | ecosystem degradation

The permeable surfaces, including forests, grasslands, and croplands, have undergone a reduction in size and increased fragmentation as a consequence of rapid urbanization since the 1980s. The degradation of these vital ecosystems has negatively impacted water-related ecosystem services, such as water purification and regulation, flood and erosion control, and groundwater recharge. The heightened landscape fragmentation, particularly evident in the Huabei Plain, characterized by significant urban centers and extensive agricultural practices, increases the region's susceptibility to extreme weather events.

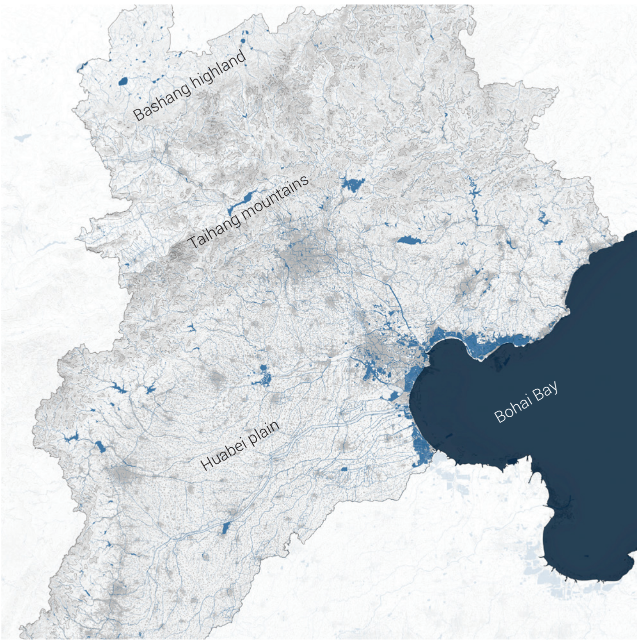


Fig. 12. The hydrological system of the BTH region (Data: ASTER Global Digital Elevation Model, GHS built-up surface, OSM)

Built-up surface
Waterbody
Waterway
Contour line 200/600m

0 10 200 km

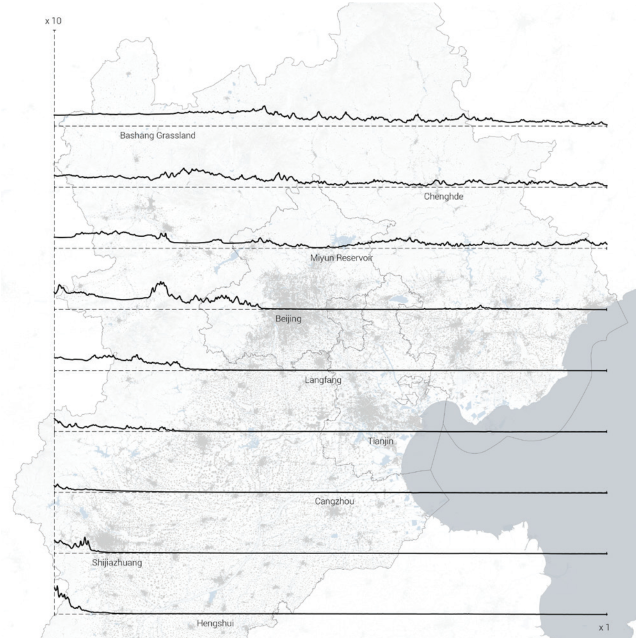


Fig. 13. The topography of the Hai River basin (Data: ASTER Global Digital Elevation Model, GHS built-up surface, OSM)

0 10 200 km

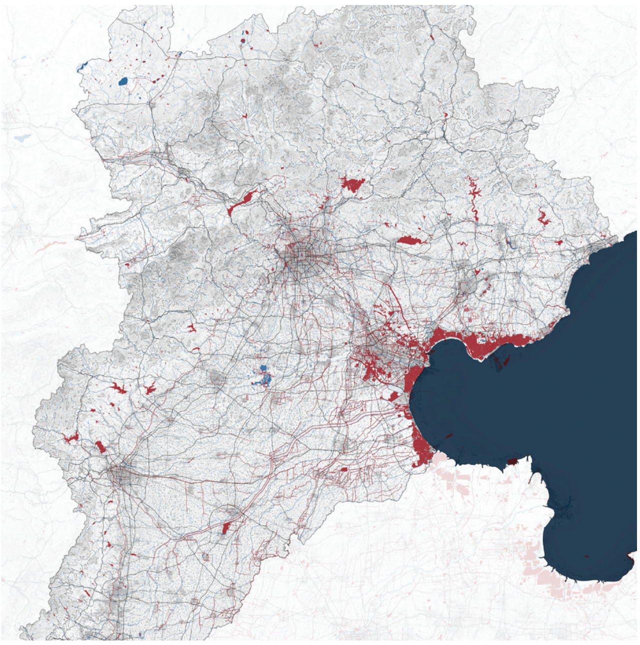


Fig. 14. The altered and fragment hydrological system of the BTH region (Data: ASTER Global Digital Elevation Model, GHS built-up surface, OSM)

Engineered waterbody (canal, reservior, salt pond, etc.)
Built-up surface
Waterbody
Transportation network
Waterway
Contour line 200/600m

0 10 200 km

Hydrological fragmentation | water hazard exposure

The hydrological system in the BTH metropolitan region has undergone substantial modifications as a result of engineered water management initiatives and transportation infrastructure. Reservoirs, while effective in mitigating flood events by retaining water, can contribute to increased flow rates in channelized waterways, thereby heightening the risk of downstream flooding, particularly during instances of extreme precipitation that surpass the system's capacity. In economically disadvantaged areas, particularly villages in Hebei province, elevated water hazard exposure is experienced by residents due to inadequate investment in water management systems. This heightened risk is in contrast to residents residing in major cities such as Beijing and Tianjin. Moreover, in times of drought, a significant proportion of the population in these areas is engaged in agricultural activities, thereby intensifying the challenge.

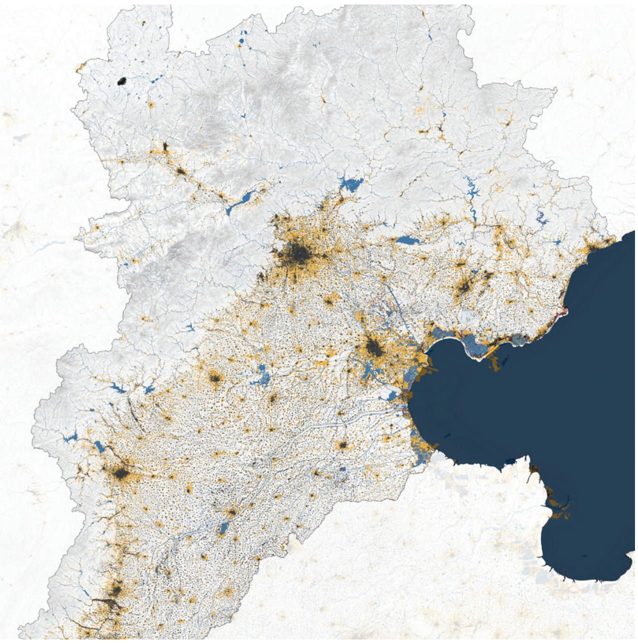


Fig. 15. Expansion of built-up areas since 1985 (Data: OSM, Yang & Huang (2021))

Persistent
Increasement
Decreasement
Waterbody
Waterway
Administrative boundary

0 10 200 km

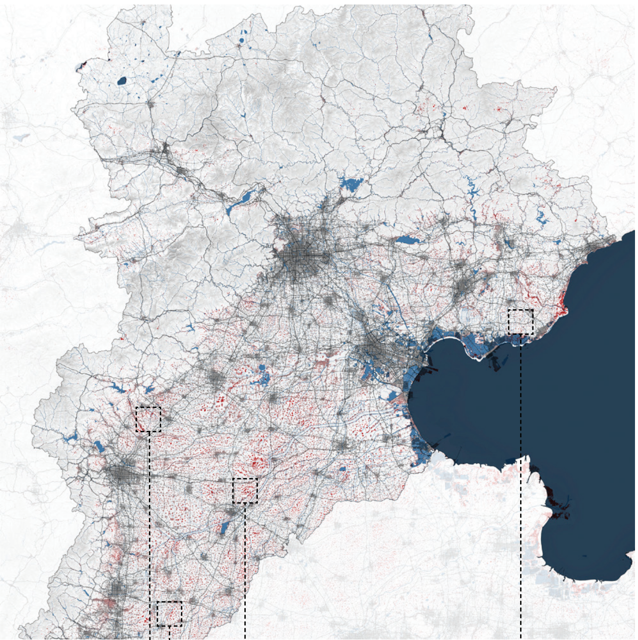


Fig. 16 Disconnected and fragment morphology (Data: ASTER Global Digital Elevation Model, GHS built-up surface, OSM)

Well-connected area
Poorly-connected area
Built-up surface
Waterbody
Transportation network
Waterway

0 10 200 km




Morphological fragmentation | social segregation

The process of rapid urbanization since the 1980s has not only led to landscape but also morphological fragmentation with disorderly and homogeneous development. Numerous villages have emerged and growed between cities and towns, but a significant portion of them lack proper transportation infrastructure, thereby intensifying developmental imbalances within the metropolitan region. The development paradigm influenced by land finance contributes to heightened segregation between these distant villages and large cities, consequently giving rise to notable economic disparities, educational gaps, and unequal access to essential resources such as healthcare, education, and job opportunities.

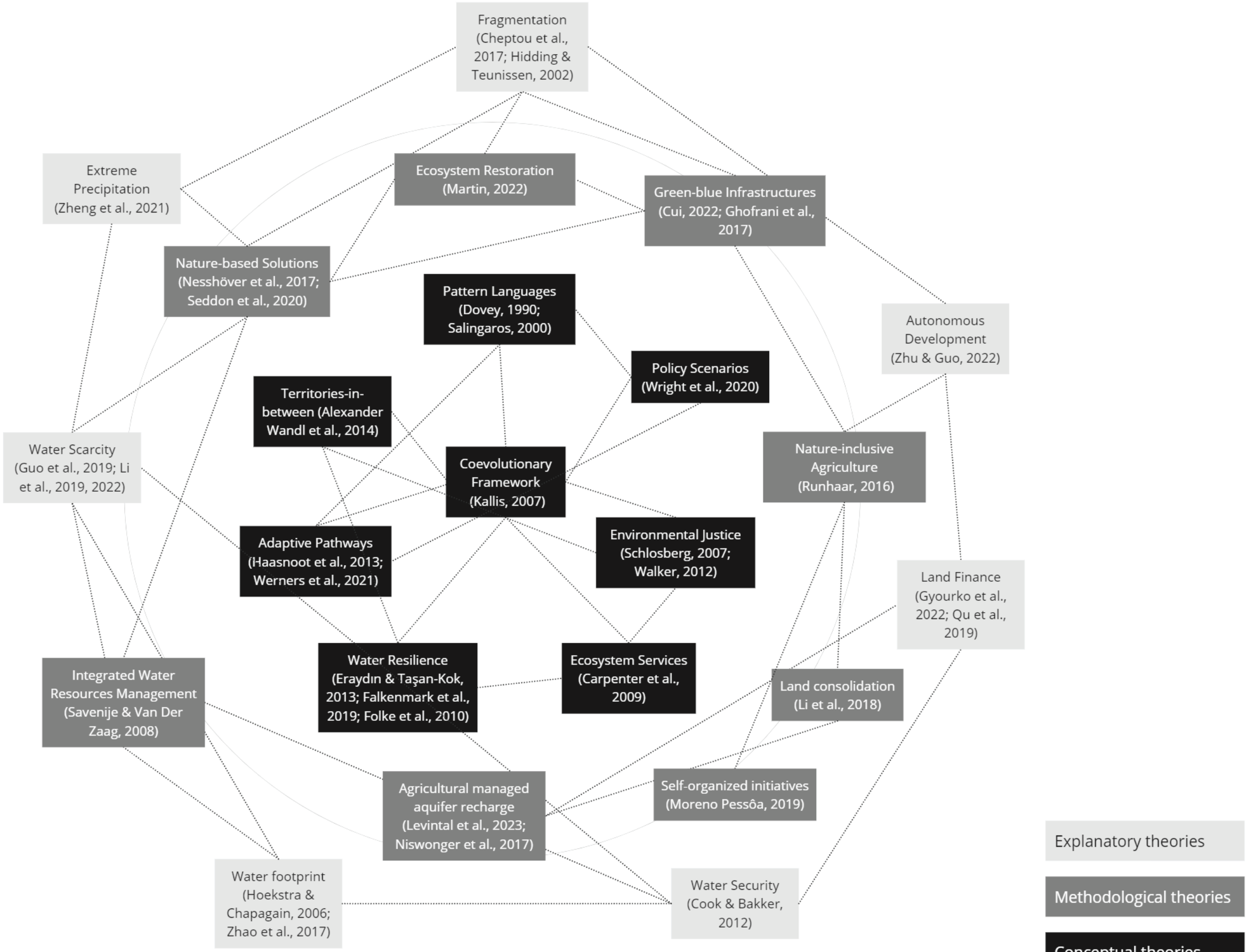


Fig. 17. Theoretical framework

THEORETICAL FRAMEWORK

The establishment of a theoretical framework serves as a systematic approach for organizing pertinent research and theories aimed at enhancing the understanding of the BTH region. Additionally, it facilitates the exploration of potential methodologies to address the region's issues and, crucially, contributes to the development of a comprehensive conceptual framework guiding the implementation of the thesis plan.

Explanatory theories are valuable tools for comprehending the phenomenon outlined in the problem statement. They provide theoretical underpinnings to elucidate the landscape, hydrological, and morphological fragmentation observed in the BTH region, paving the way for potential methodological theories for further investigation.

Methodological theories delineate viable approaches to address the identified issues through cutting-edge solutions, spanning both conceptual and practical realms. Additionally, they aid in restructuring the three potential intervention domains within the conceptual framework.

Lastly, the adoption of conceptual theories contributes to the development of a cohesive conceptual and methodological framework, guiding every step of the research process, from analysis and planning principles to policy recommendations, design implementation, and eventual assessment.

Explanatory theories

Fragmentation (Cheptou et al., 2017; Hidding & Teunissen, 2002)
Water Security (Cook & Bakker, 2012)
Land Finance (Gyourko et al., 2022; Qu et al., 2019)
Autonomous Development (Zhu & Guo, 2022)
Water Scarcity (Guo et al., 2019; Li et al., 2019, 2022)
Extreme Precipitation (Zheng et al., 2021)
Water footprint (Hoekstra & Chapagain, 2006; Zhao et al., 2017)

Methodological theories

Nature-based Solutions (Nesshöver et al., 2017; Seddon et al., 2020)
Green-blue Infrastructures (Cui, 2022; Ghofrani et al., 2017)
Ecosystem Restoration (Martin, 2022)
Integrated Water Resources Management (Savenije & Van Der Zaag, 2008)
Nature-inclusive Agriculture (Runhaar, 2016)
Agricultural managed aquifer recharge (Levintal et al., 2023; Niswonger et al., 2017)
Self-organized initiatives (Moreno Pessôa, 2019)
Land consolidation (Li et al., 2018)

Conceptual theories

Coevolutionary Framework (Kallis, 2007)
Territories-in-between (Alexander Wandl et al., 2014)
Policy Scenarios (Wright et al., 2020)
Adaptive Pathways (Haasnoot et al., 2013; Werners et al., 2021)
Pattern Languages (Dovey, 1990; Salingaros, 2000)
Ecosystem Services (Carpenter et al., 2009)
Water Resilience (Eraydın & Taşan-Kok, 2013; Falkenmark et al., 2019; Folke et al., 2010)
Environmental Justice (Schlosberg, 2007; Walker, 2012)

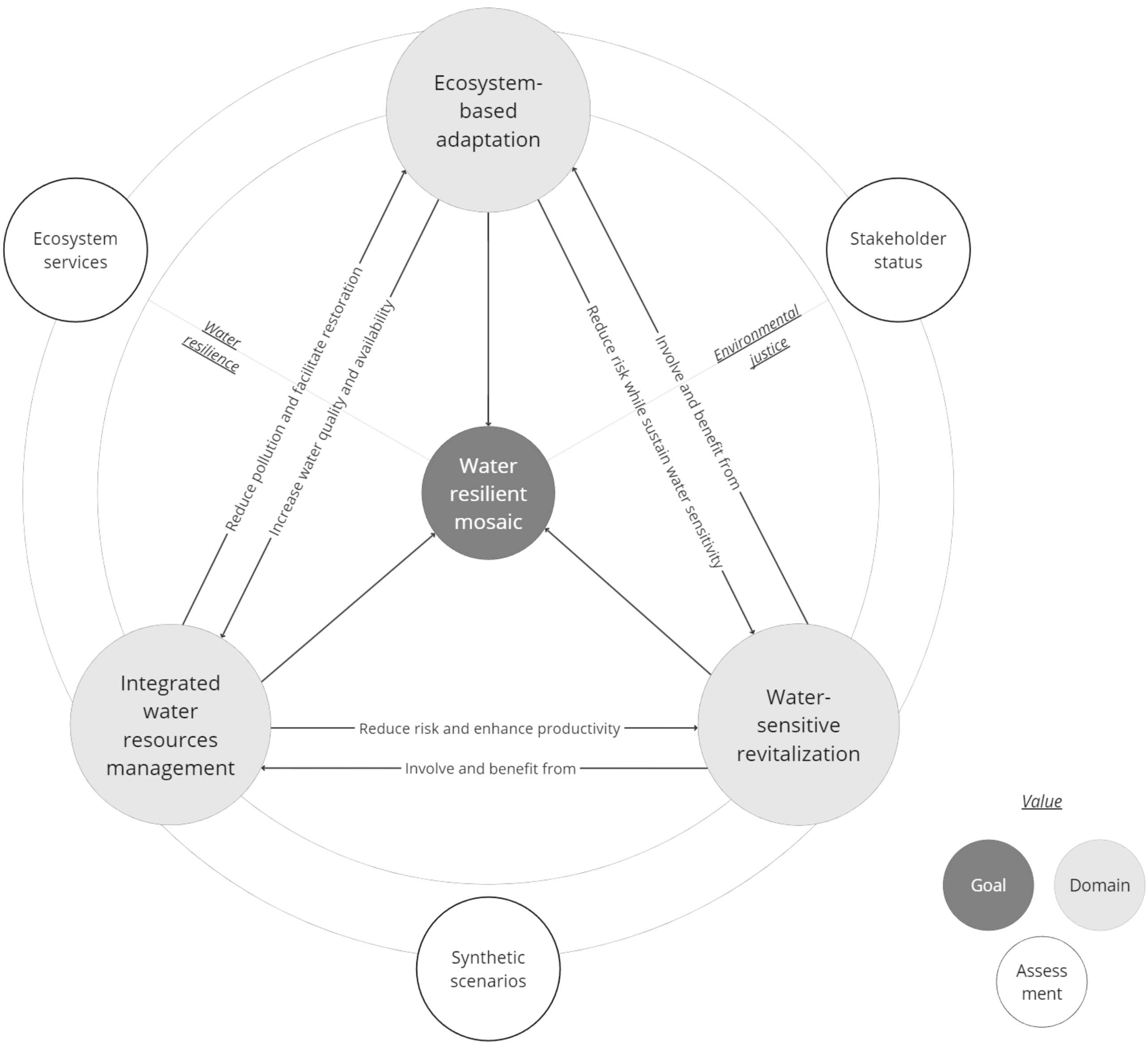


Fig. 18. Conceptual framework

CONCEPTUAL FRAMEWORK

The conceptual framework aims to clarify the central theme of this thesis by integrating insights from the problem domain and the primary research question. This conceptualization presents a personal interpretation of the problem statement, informed by pertinent theoretical literature outlined in the theoretical framework.

The primary goal of this research is to enhance the water resilience of the BHT region against increasing flood and drought occurrences while ensuring environmental justice by prioritizing the most vulnerable areas—not just major cities but also the territories in between. The foundation lies in a low-density spatial arrangement designed to foster local economic productivity and maintain water sensitivity. This decentralized mosaic, integrating built and natural environments, is envisioned as a self-reliant and resilient system that not only enhances its own resilience but also contributes to the overall resilience of the metropolitan region.

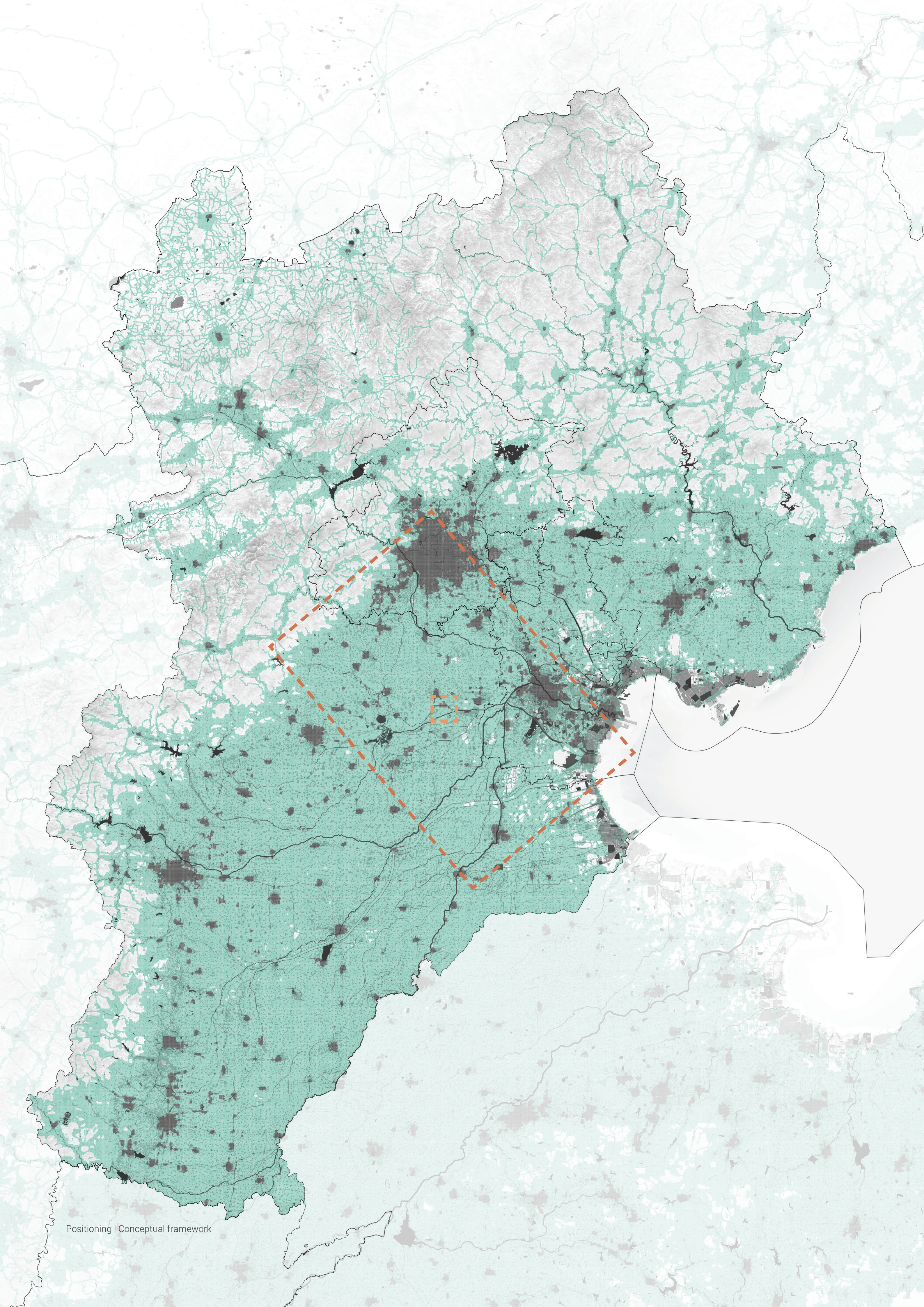
This will involve enhancing water resilience through a coevolutionary framework that incorporates three key domains:

(1) Ecosystem-based adaptation, primarily focused on the restoration and improvement of ecosystem services.

(2)Integrated water resources management, aiming to promote a more interconnected and coordinated hydrological system to mitigate water hazard exposure in vulnerable regions.

(3) Water-sensitive revitalization, strategically consolidating rural land in the TiB to create basic units aimed at improving water resilience, accessibility, and local identity. Scaling up these resilient units is intended to enhance the overall resilience of the metropolitan region.

Achieving environmental justice requires a shift from the current profit-driven paradigm to a new approach focused on reducing water risks and adapting to the needs of the most vulnerable regions.



Positioning | Conceptual framework

Project framing

The BTH Metropolitan Region is renowned for its historical patterns of drought, coupled with increasing occurrences of severe precipitation and flood events. Additionally, the region grapples with persistent challenges such as subsidence, societal disparities related to development, air pollution, and an aging population. The inherent spatial and institutional fragmentation within the region hinders its ability to effectively address these emerging socio-environmental challenges. Consequently, this situation leads to biophysical and social vulnerabilities that are expected to persist in the foreseeable future.

The primary aim of this research is to enhance the water resilience of the BHT region against escalating flood and drought occurrences while ensuring environmental justice by prioritizing the most vulnerable areas—not just big cities, but also the territories in between. This forms the foundation for a low-density spatial arrangement that will proactively foster local economic productivity while upholding ecological sensitivity. This decentralized mosaic integrating built and non-built environments is envisioned as a self-reliant and resilient system that not only enhances its own resilience but also contributes to the overall resilience of the metropolitan region.

This will involve enhancing water resilience through a coevolutionary framework that incorporates three key domains: ecosystem-based adaptation, integrated water resources management, and water-sensitive village reorganization. Achieving environmental justice requires a shift away from the existing land-finance-driven paradigm, which prioritizes profitability, towards a new approach centered on reducing climate risks in the most vulnerable regions.

To achieve this goal, it is imperative to implement spatial interventions at various scales and policies that encourage multidisciplinary collaboration across provinces. The efficacy of these interventions in addressing seasonal imbalances in water availability will be considered, along with the long-term adaptive pathways responding to different climate scenarios. Additionally, assessing the impact of these interventions is crucial. Such evaluations serve not only to validate the efficacy of the proposal but also as a persuasive tool to encourage stakeholder involvement and collaboration toward a shared vision. Both the potential economic losses from climate-related risks and the non-economic losses should be considered, potentially through an assessment of ecosystem services.

Fig. 19. Territories-in-between | macro

Synthesis of population density, road and railway network, and land cover, adopting the approach proposed by Alexander Wandl et al. (2014) to define the territories-in-between in the BTH region.

Data: GPWv4, OSM, Yang & Huang (2021)

Local zoom-in | micro
Tributary zoom-in | meso
TiB
Urban
Waterbody
Waterway
Administrative boundary

0 50 100 km

METHODOLOGY

METHODOLOGY

| Research questions

| Research framework

| Methodological framework

RESEARCH QUESTIONS

Overall research question

How can a paradigm shift towards **water resilience** in the development of **territories-in-between** help alleviate the **spatial and temporal disequilibrium of water resources** in the Beijing-Tianjin-Hebei (BTH) region, while simultaneously sustaining **environmental justice** for its inhabitants?

Sub research question

Analytical research questions:
AQ.1 How do the current and historical policies shape the landscape and urban morphology in the BTH region?
AQ.2 Who are the major stakeholders involved in the urbanization process, and what is their relationship?
AQ.3 What is the seasonal hydrological pattern in the BTH region? Which areas are most vulnerable when facing flood and drought events?
AQ.4 Where lie the opportunities to re-balance the spatial and temporal disequilibrium of water resources in the BTH region?
AQ.5 What potential scenarios might the region encounter in the next fifty years in response to social-environmental challenges related to fluctuations in water resources and consumption?

Design and planning research questions:
DQ.1 What are the principles that assist in reorganizing the territories-in-between as a network, integrating local economic productivity with ecological sensitivity?
DQ.2 What potential design solutions can help these principles, and in which scale and domain?
DQ.3 What are the positive and negative impacts of these design approaches, and how do they correlate with each other?
DQ.4 How to establish a framework to guide future design implementations, taking into account such uncertainties?
DQ.5 How will the implementations unfold over time to alter the territory at various scales under different scenarios?

Evaluation research questions:
EQ.1 What are the relevant categories in ecosystem services (ES) assessment for water resilience and environmental justice?
EQ.2 How does the territorial alteration through the project impact the performance of relevant ES compared to the current status?
EQ.3 How will the implementation alter the interests, power dynamics, and relationships among stakeholders involved in the development of the territories-in-between?
EQ.4 How will the implementations transform the local spatial configuration in a convincing manner under synthetic scenarios?

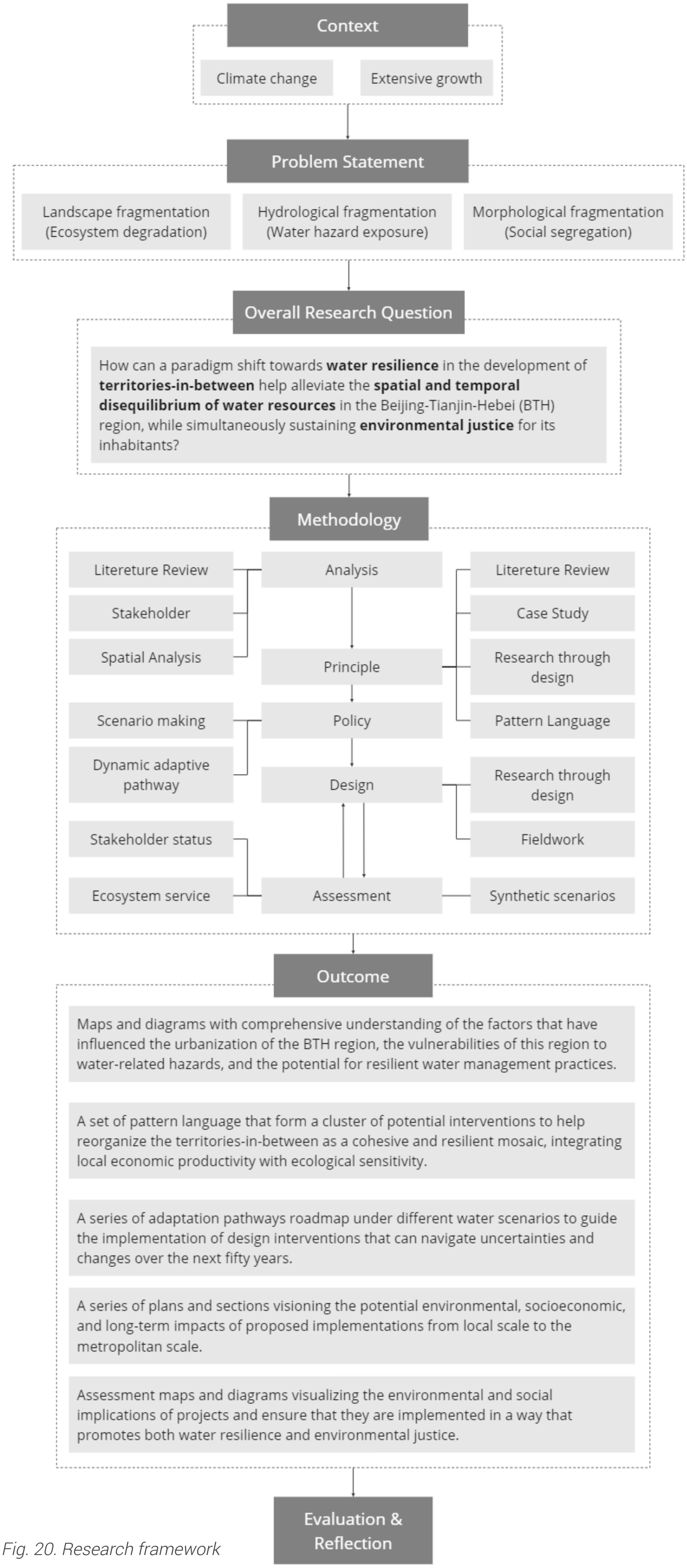


Fig. 20. Research framework

RESEARCH FRAMEWORK

Research aims

1. To reflect on the current unsustainable development paradigm in the region.
2. To ensure environmental justice by prioritizing the most vulnerable areas in the region.
3. To enhance the resilience of the BHT region against escalating flood and drought occurrences.
4. To assess and visualize the impact of the proposal for validation.

Research outcome

1. Maps and diagrams with comprehensive understanding of the factors that have influenced the urbanization and form of the BTH region, the vulnerabilities of this region to water-related hazards, and the potential for resilient water management practices. (AQ.1, AQ.2, AQ.3, AQ.4, AQ.5)

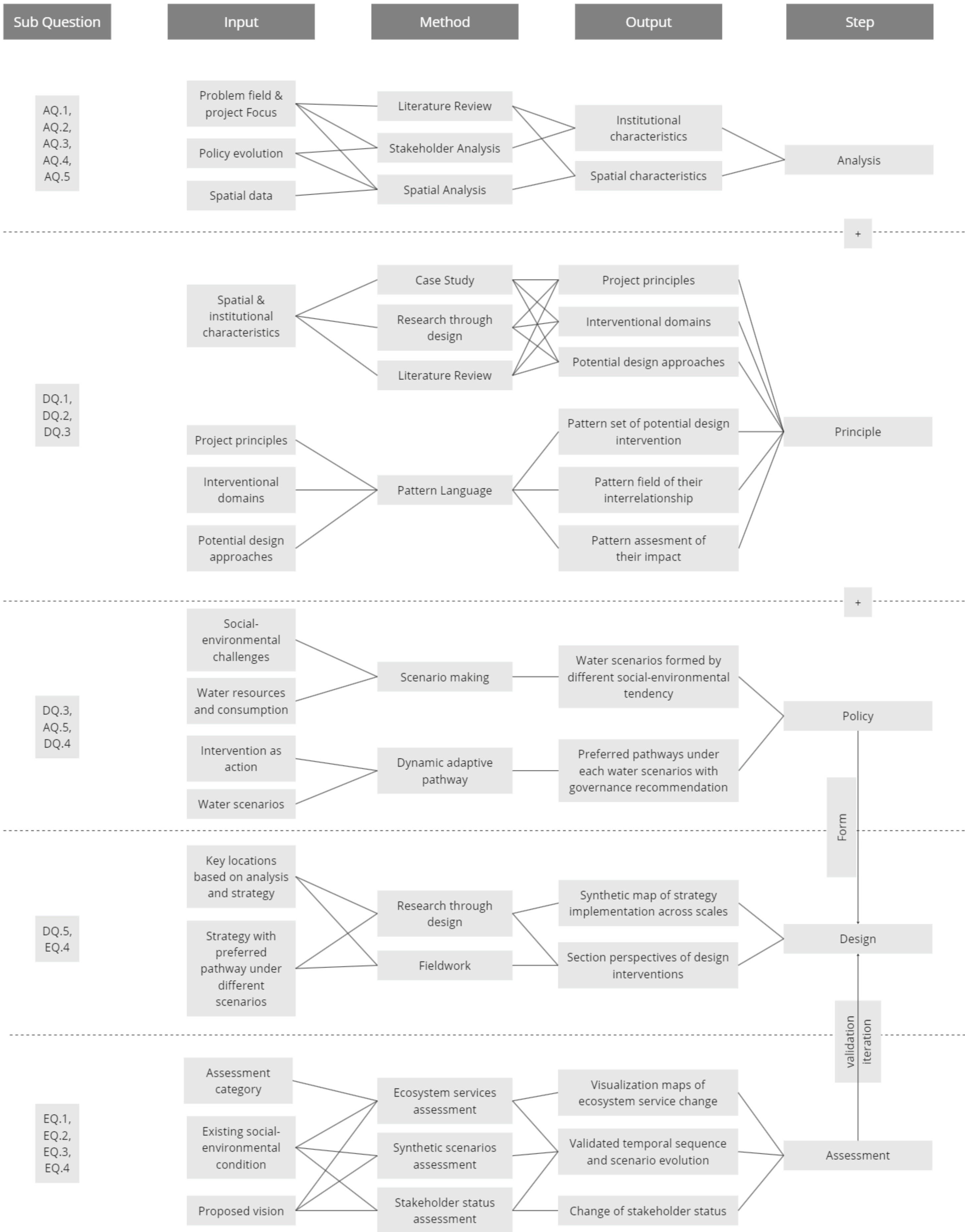
2. A set of pattern language that form a cluster of potential interventions to help reorganize the territories-in-between as a cohesive and resilient mosaic, integrating local economic productivity with ecological sensitivity. (DQ.1, DQ.2, DQ.3)

3. A series of adaptation pathways roadmap under different water scenarios to guide the implementation of design interventions that can navigate uncertainties and changes over the next fifty years. (DQ.3, AQ.5, DQ.4)

4. A series of plans and sections visioning the potential environmental, socioeconomic, and long-term impacts of proposed implementations from local scale to the metropolitan scale. (DQ.5, EQ.4)

5. Assessment maps visualizing the environmental and social implications of projects and ensure that they are implemented in a way that promotes both water resilience and environmental justice. (EQ.1, EQ.2, EQ.3, EQ.4)

METHODOLOGICAL FRAMEWORK



Scale	Outcome
Conceptual, regional, tributary, local	Maps and diagrams with comprehensive understanding of the factors that have influenced the urbanization and form of the BTH region, the vulnerabilities of this region to water-related hazards, and the potential for resilient water management practices.
Conceptual, regional, tributary	A set of pattern language that form a cluster of potential interventions to help reorganize the territories-in-between as a cohesive and resilient mosaic, integrating local economic productivity with ecological sensitivity.
Conceptual	A series of adaptation pathways roadmap under different water scenarios to guide the implementation of design interventions that can navigate uncertainties and changes over the next fifty years.
Regional, tributary, local	A series of plans and sections visioning the potential environmental, socioeconomic, and long-term impacts of proposed implementations from local scale to the metropolitan scale.
Conceptual, regional, tributary, local	Assessment maps visualizing the environmental and social implications of projects and ensure that they are implemented in a way that promotes both water resilience and environmental justice.

Fig. 21. Methodological framework

Literature Review

An essential and methodical examination of the prevailing academic literature related to a particular subject or research query. This analysis serves to establish a theoretical framework that situates and rationalizes the argument and proposal in the research, while also pinpointing areas requiring further development. The primary areas of concentration encompass ecosystem-based adaptation, integrated water resources management, village morphology and revitalization, and ecosystem services assessment.

Stakeholder Analysis

An analytical instrument employed to discern and comprehend the interests, requirements, and impact of diverse individuals or groups participating in the development of the territories-in-between. The onion diagram methodology devised by Alexander and Robertson (2004) unveils insights into the sector, level of engagement, and relationship of stakeholders.

Spatial Analysis

A Geographic Information System (GIS) approach to analyze spatial patterns, relationships, and trends resulting from policy evolution in the BTH region. The objective is to ascertain the vulnerabilities of the region to water-related hazards and to identify potential strategies for resilient water management practices.

Case Study

A qualitative research method concentrates on project scopes, seeking to comprehensively understand ongoing hypotheses and practices. The objective is to gain insights into potential design approaches that facilitate the reorganization of the territories-in-between into a cohesive and resilient mosaic.

Research through design

A methodology that employs design processes and outcomes to evaluate different combinations and resultant spatial configurations put forth by the project's guiding principles, anticipated future scenarios, and adaptive pathways.

Pattern Language

An approach for systematically categorizing prospective spatial tools, establishing a toolkit with well-defined solution hypotheses, theoretical foundations, and the anticipated outcomes of implementing such solutions (Salingaros, 2000). The pattern language will additionally serve as a shared communication medium for designers and researchers, fostering collaboration among individuals with diverse academic backgrounds.

Scenario making

A strategic planning and foresight method to construct narratives outlining potential alternative futures. This approach aids in the identification of potential disruptions and challenges, facilitating the development of strategies to address the uncertainties and complexities associated with water availability and demand in the region (Wright et al., 2020).

Dynamic adaptive pathway

A planning framework designed to facilitate flexible adjustments over time in response to evolving circumstances (Haasnoot et al., 2013). This is achieved through the integration of design actions, consideration of future scenarios, and the formulation of adaptive plans for implementation. Additionally, the framework offers decision-makers the capability to systematically monitor progress and make adjustments in accordance with altering conditions or newly acquired information.

Fieldwork

A process of capturing tangible sensory experiences through photography at the designated site of the proposed design, aiming to enhance comprehension of the actual conditions and validate the design proposition.

Ecosystem services assessment

A process aimed at discerning, quantifying, and appraising the advantages offered by ecosystems upon human society (Carpenter et al., 2009; Grizzetti et al., 2016). Specifically, the investigation centers on evaluating the water resilience and environmental justice aspects pertaining to the pre- and post-design implementation conditions at the designated site. Utilizing assessment tools like InVEST constitutes an integral component of this analytical approach.


P1
September
October
November
December
Jan
Project Framing
Motivation
Problem Statement
Research Questions
Research Framework
Research and Analysis
Litereture Review
Spatial Analysis
Stakeholder Analysis
Field Study
Strategy and Design
Case Study
Patterns of Intervention
Strategy of Implementation
Design Exploration
Assesment and Reflection
Assessment of proposal
Reflection and Iteration
Report and representation
Report Preparation
Presentation Preparation

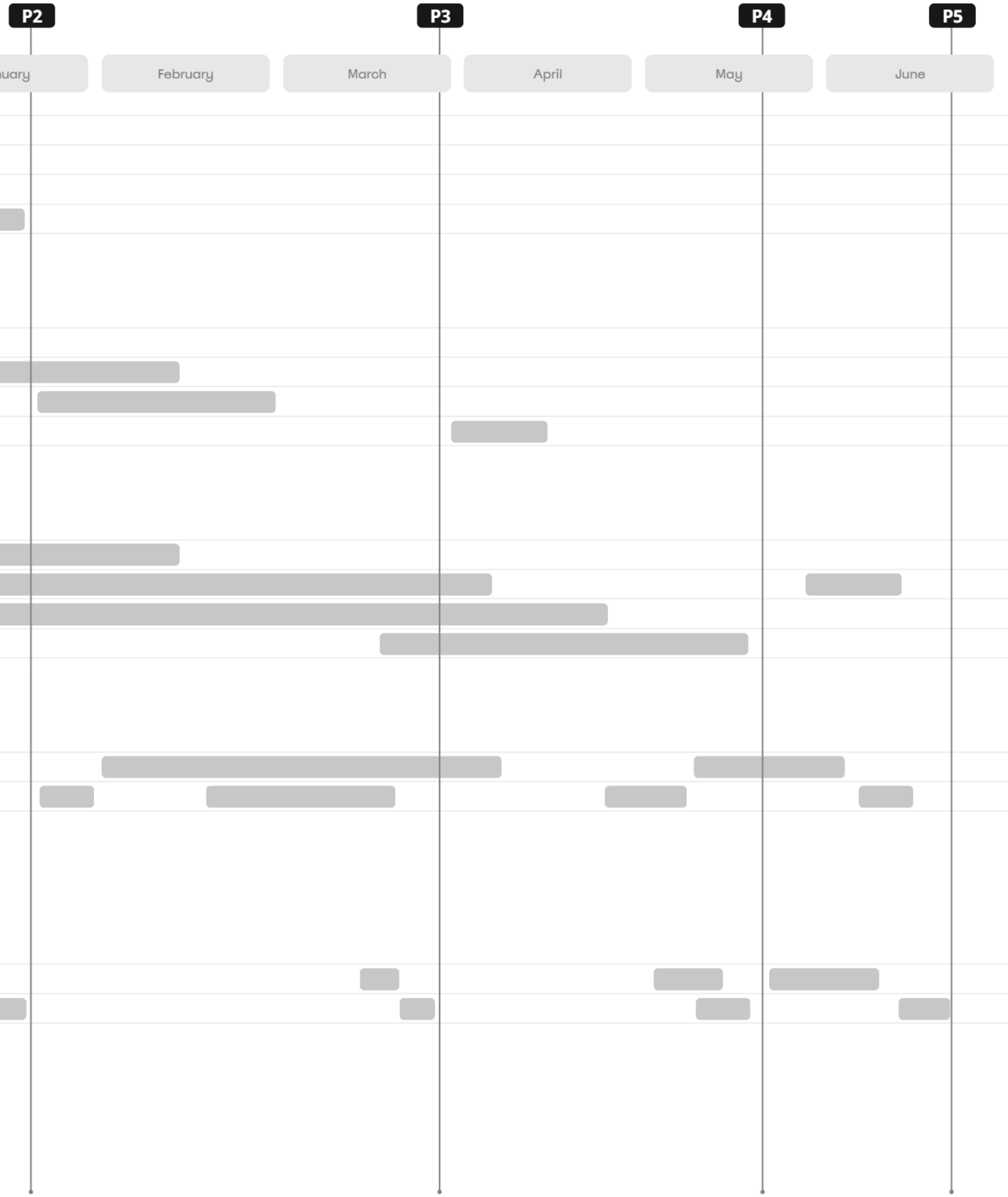


Fig. 22. Research timeline

ANALYSIS

ANALYSIS

| Water resource and consumption

| Water conflicts

| Profit-driven development paradigm

WATER RESOURCE AND CONSUMPTION

Water cycle in the Haihe basin

The Haihe Basin, located in northern China, is a significant geographical region with a complex water cycle that plays a crucial role in sustaining natural ecosystems and human activities. This hydrological system involves key geographical features, including the Taihang Mountains, Haihe Plain, and Bohai Bay.

The Taihang Mountains act as a natural barrier, influencing precipitation patterns within the Haihe Basin. When moist air masses from the south encounter these mountains, orographic lifting occurs, leading to increased condensation and precipitation on the windward side. This process affects the distribution of water resources in the basin.

Beijing, positioned at the northern edge of the Haihe Basin, serves as both a consumer and contributor to the water cycle. Urbanization and industrialization in Beijing have altered local hydrological dynamics, impacting water demand, land use, and impervious surface expansion, influencing surface water runoff and groundwater recharge.

Hebei, the province surrounding Beijing, plays a critical role due to its diverse landscapes. These include plains, mountains, and the Bohai Sea coast, influencing the movement of surface and groundwater throughout the Haihe Basin. Agricultural activities, urban development, and ecological conservation in Hebei contribute to the overall balance of the water cycle.

Tianjin, a major coastal city at the mouth of the Haihe River, is linked to the water cycle as a convergence point for various water sources. The city's port facilities and industrial activities impact local water quality, contributing to the dynamics of the Haihe Basin's hydrological system.

Bohai Bay, the terminal point of the Haihe River, marks the culmination of the water cycle in the basin. Interactions between river discharge, tidal movements, and marine processes in Bohai Bay influence nutrient cycling, sediment transport, and the overall health of coastal ecosystems.

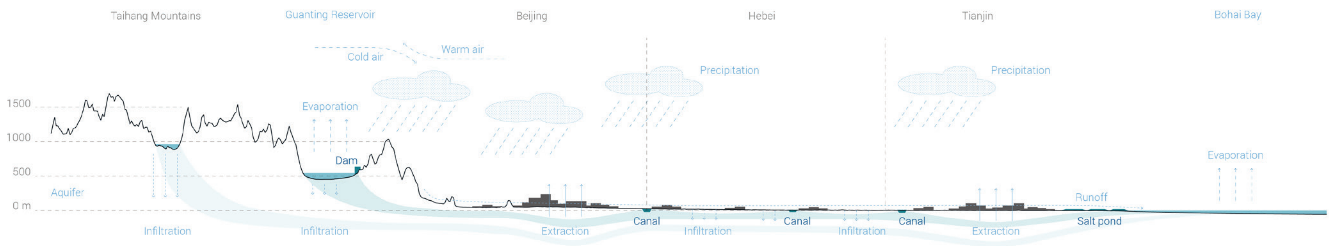


Fig. 23. Water cycle in the Haihe basin

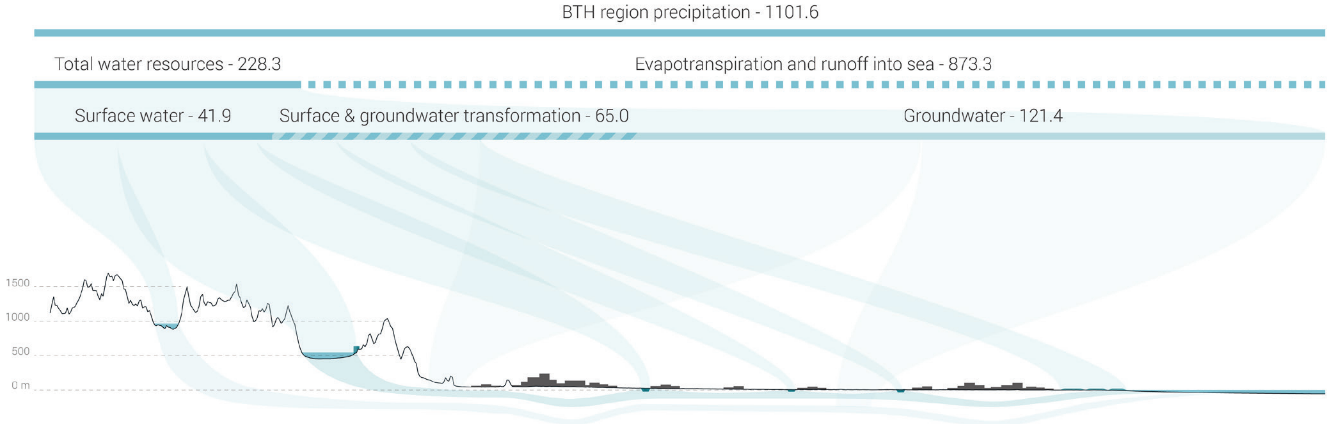


Fig. 24. Natural water resource of the BTH region, 2022 (Data: China Water Resources Bulletins, unit: 10^8 m3)

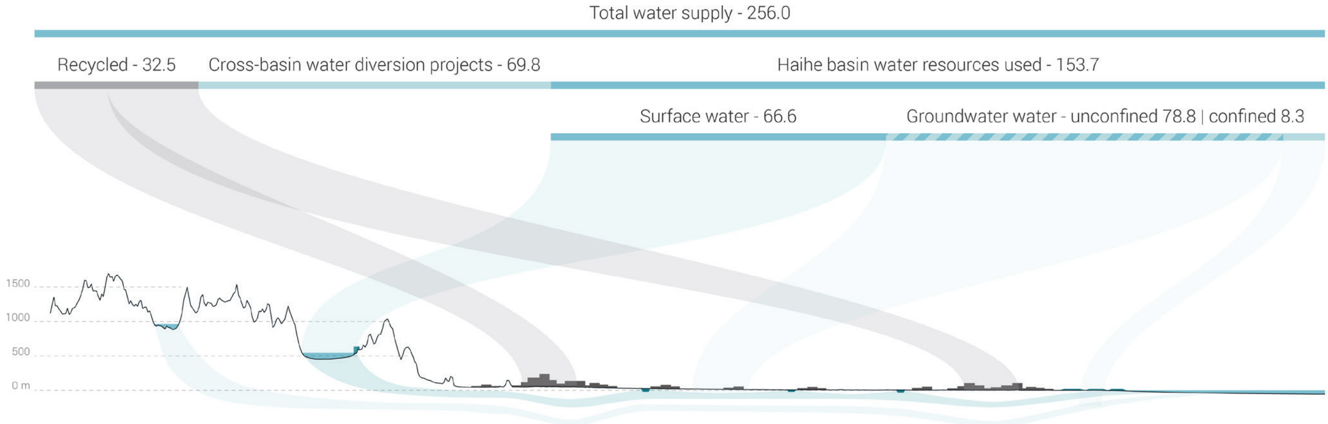


Fig. 25. Water supply of the BTH region, 2022 (Data: China Water Resources Bulletins, unit: 10^8 m3)

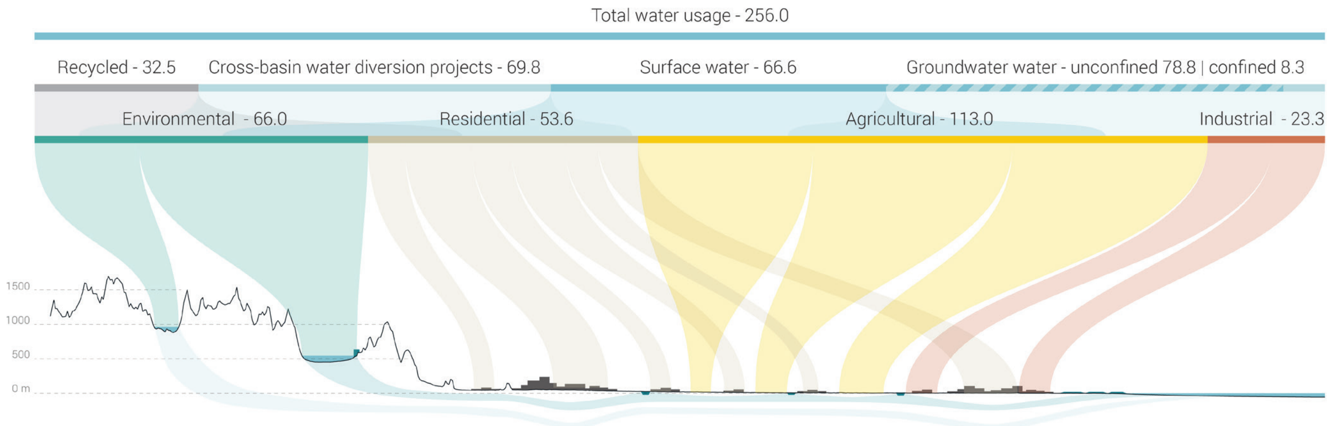


Fig. 26. Water consumption of the BTH region, 2022 (Data: China Water Resources Bulletins, unit: 10^8 m3)

The water resources, supply, and consumption in the BTH region

Natural water resource - Although the region does not suffer from precipitation deficiency, a significant challenge lies in the uneven distribution of this essential resource. Despite sufficient rainfall, a notable portion is lost to evapotranspiration processes and ultimately flows into the Bohai Bay. This highlights the necessity for a comprehensive understanding of the hydrological cycle and effective water management strategies to optimize the utilization and conservation of this valuable resource. An important facet of the water dynamics in the BTH region is the limited availability of surface water, constituting less than 20% of the total water resource. The majority infiltrates into the soil, replenishing the groundwater reservoirs. The reliance on groundwater underscores its pivotal role in maintaining the region's water supply.

Water supply - As of 2022, approximately 60% of the water supply in the Haihe Basin region originates from internal sources. Groundwater extraction constitutes a significant portion, making up around 57% of the total water supply, with a notable volume of 8.3 x 10^8 m3 extracted from confined aquifers. However, this dependence on groundwater extraction contributes to the challenge of land subsidence, posing a substantial threat to the region's environmental stability.

Moreover, only 12.7% of the water supply is sourced from recycled water, indicating a potential area for improvement in sustainable water management practices. In response to the increasing demand for water resources, over 27% of the total water supply is redirected from other water basins through large-scale water diversion projects. The South-to-North Water Diversion Project, in particular, stands out as a prominent example of such initiatives, playing a pivotal role in addressing the water requirements of the BTH region.

Water consumption - As of 2022, the water usage distribution in the region displays notable patterns that reflect varied demands on this essential resource. The primary sector in terms of water consumption is residential usage, constituting a significant 43% of the total. Notably, environmental restoration and maintenance constitute the second-highest share at 25.8%, indicating an increasing awareness of the significance of ecological preservation. Agricultural activities, pivotal to the region's economy, represent 22% of water usage, underscoring the vital role of water in sustaining agricultural productivity. In contrast, industrial purposes constitute the smallest share, utilizing only 9% of the total water supply.

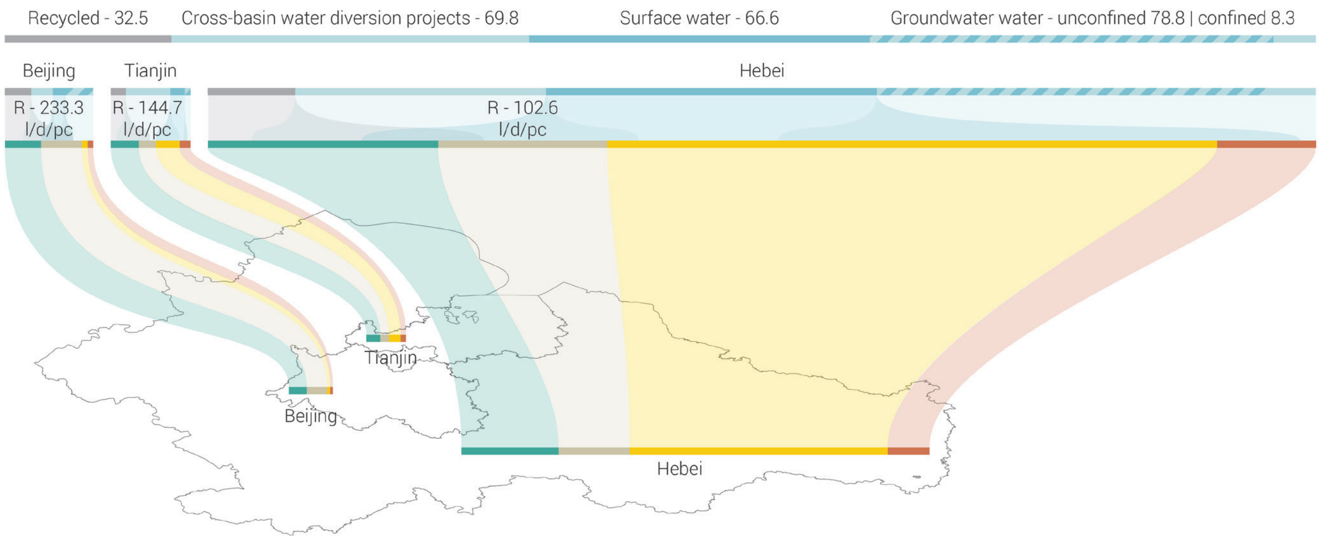


Fig. 27. Spatial distribution of water consumption, 2022 (Data: China Water Resources Bulletins, unit: 10^8 m3)

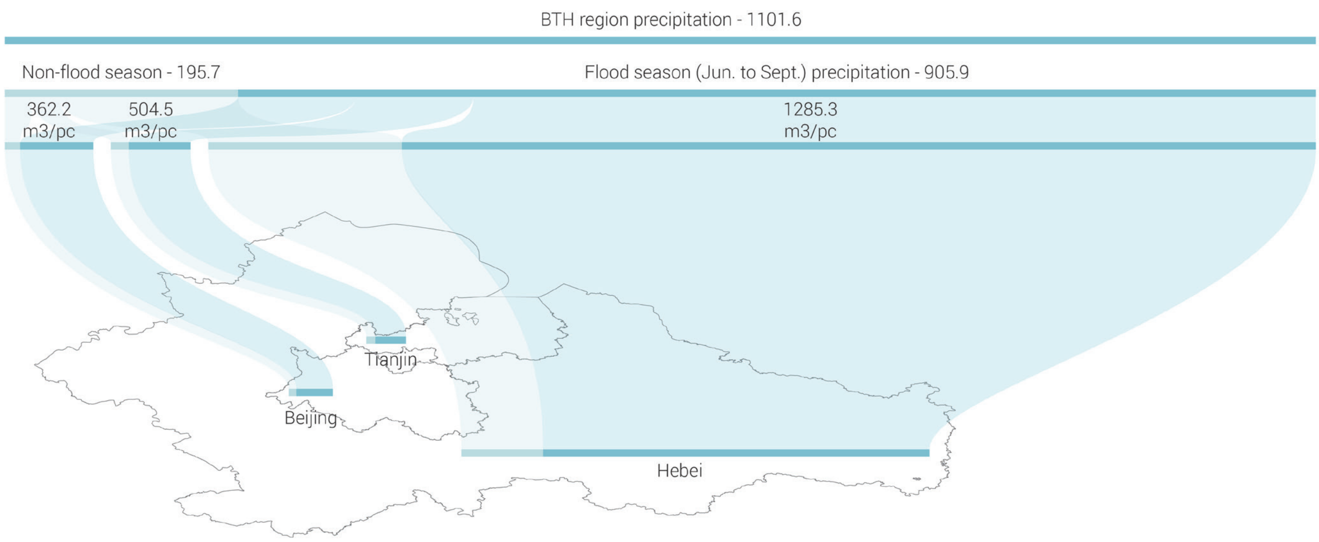


Fig. 28. Temporal distribution of water resource (Data: China Water Resources Bulletins, unit: 10^8 m3)

The spatial and temporal distribution

Spatial distribution of water consumption - Spatial heterogeneity in water consumption is primarily influenced by significant variations in provincial sizes, leading to differentiated utilization patterns based on factors like population density, economic activities, and geographical features.

Hebei province stands out as a major contributor, accounting for 71% of total water consumption in the BTH region. This dominance is evident in the allocation of the majority of water resources for residential purposes. Additionally, Hebei plays a substantial role in environmental preservation and agricultural activities, shaping its unique water consumption dynamics.

In contrast, Beijing, though smaller in size, holds influence by contributing 15.6% to the overall water consumption. The capital city's water demand is characterized by a notable emphasis on agriculture and environmental considerations, reflecting a delicate balance between urban development and ecosystem preservation.

Tianjin, while representing a smaller share of the total water consumption, plays a pivotal role in the regional water landscape. The province focuses its water resources mainly on agricultural and environmental pursuits too, highlighting the strategic significance of water management in sustaining both economic and ecological functions.

Temporal distribution of water resource - The BTH region displays notable spatial variations attributed to differences in provincial size. Despite these variances, the region experiences dynamic fluctuations in available water resources, primarily sourced from precipitation, throughout the year.

Annually, a substantial concentration of precipitation occurs from June to September, constituting the flood season in the BTH region. In 2022, 82.2% of the total precipitation for the entire BTH region transpired during this period, highlighting the seasonal nature of water availability. In terms of each provinces, Hebei recorded 82.5% of its precipitation during the flood season, closely followed by Beijing at 82.7%, and Tianjin at 77.7%.

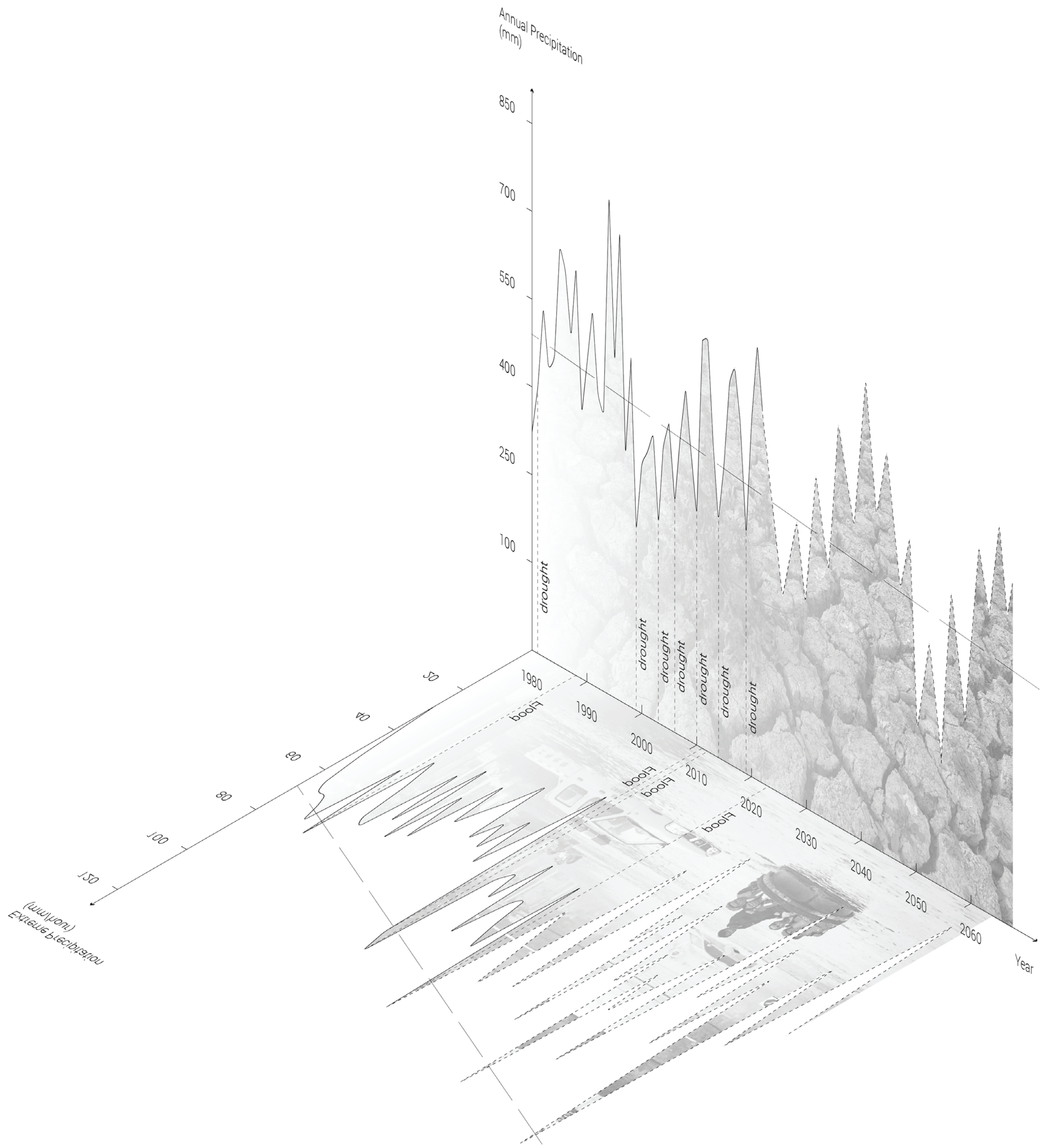


Fig. 29. Flood-drought duality (Data:Annual Report of Beijing Meteorological Bureau)

While this region has historically been renowned for its arid conditions, in recent years, the escalating instances of extreme rainfall events have inflicted significant devastation upon the built environment.

WATER CONFLICTS

Between drought and flooding

In this expansive region, primary water conflicts manifest as water scarcity and flooding, seemingly contradictory challenges converging in the BTH landscape. The predominant water conflicts in this area pose a complex challenge, intertwining climatic patterns, urban development, and socioeconomic factors.

During the flood season, characterized by intense precipitation over a short period, the inadequacy of infiltration exacerbates the flooding scenario. Urbanization and development, leading to extensive impervious surfaces, aggravate the runoff from the Huabei plain, directing it towards the Bohai Bay. Concurrently, during critical irrigation periods from March to May and October to November, when precipitation is limited, provinces such as Hebei, heavily dependent on agriculture, grapple with historical struggles related to drought, imposing hardships on farmers.

Furthermore, the impact of these water-related events varies across the region, affecting residents differently based on geographical and socio-economic factors. Vulnerability is heightened in remote and economically disadvantaged villages where the local government often lacks risk awareness and fails to invest adequately in water management projects. In such areas, floods pose a severe threat due to inadequate infrastructure, while during droughts, farmers become the most vulnerable demographic. The government's prioritization of water usage for domestic purposes exposes agriculture to risk, with even a brief period of water scarcity potentially having devastating consequences for farmers whose livelihoods rely on consistent water availability.

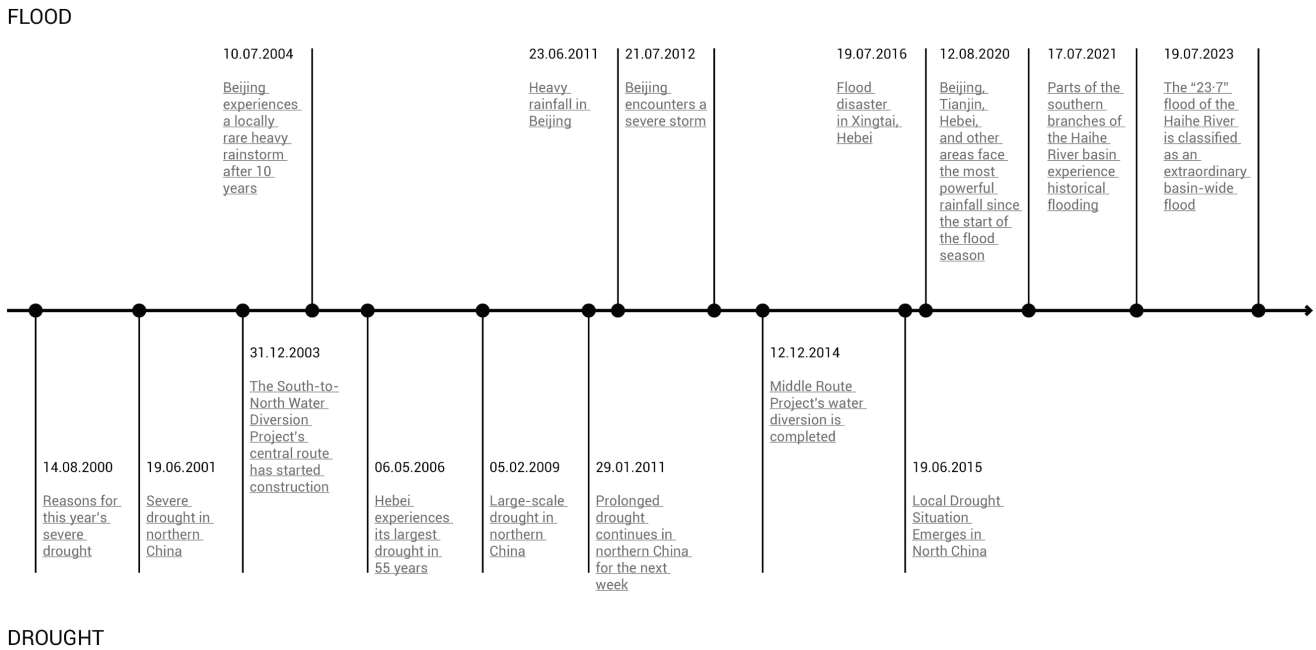
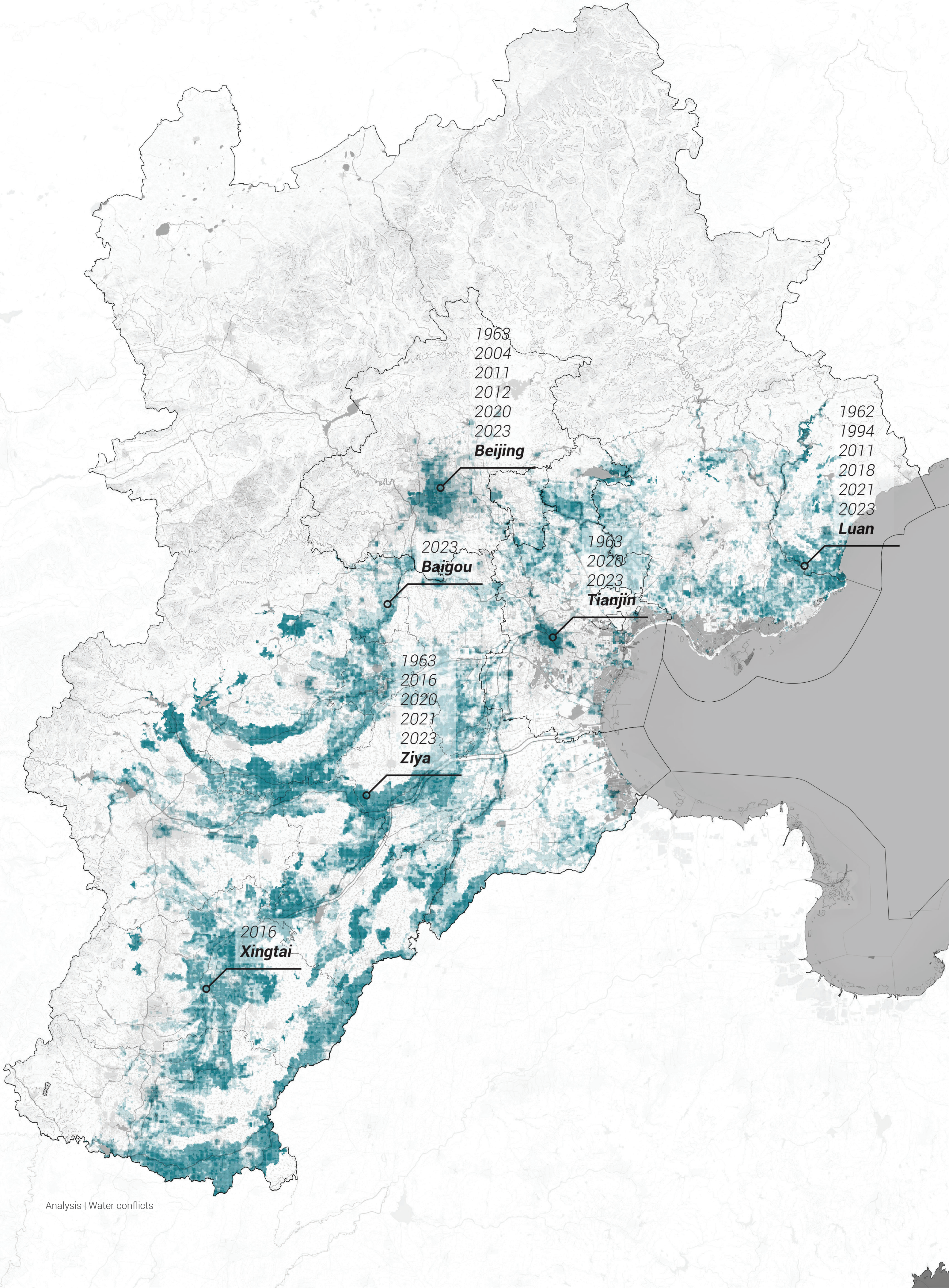


Fig. 30. Historical flood and drought events in the Haihe basin



1963
2004
2011
2012
2020
2023
Beijing
1962
1994
2011
2018
2021
2023
Luan
2023
Baigou
1963
2020
2023
Tianjin
1963
2016
2020
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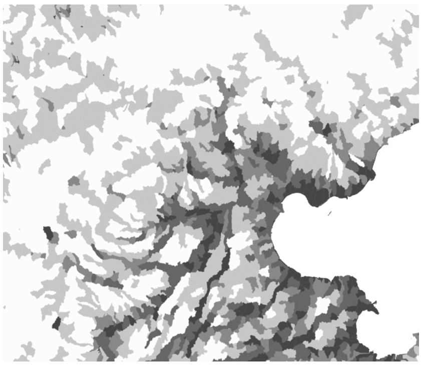
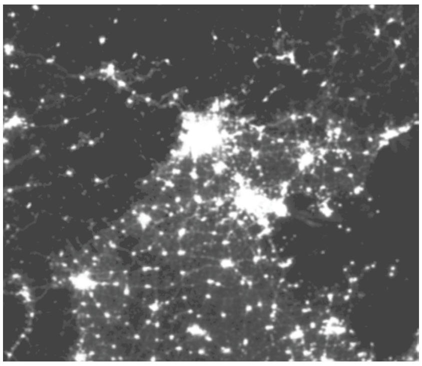
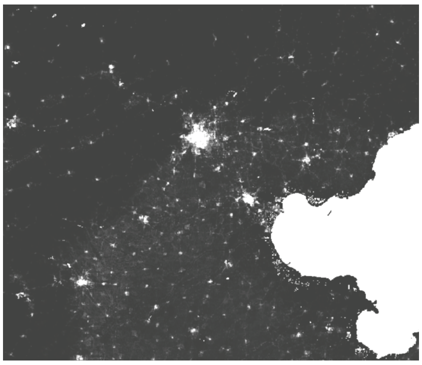
2023
Ziya
2016
Xingtai



Inundation Potential GIEMS-D15



DMSP Nighttime Lights



Population Density GPWv4

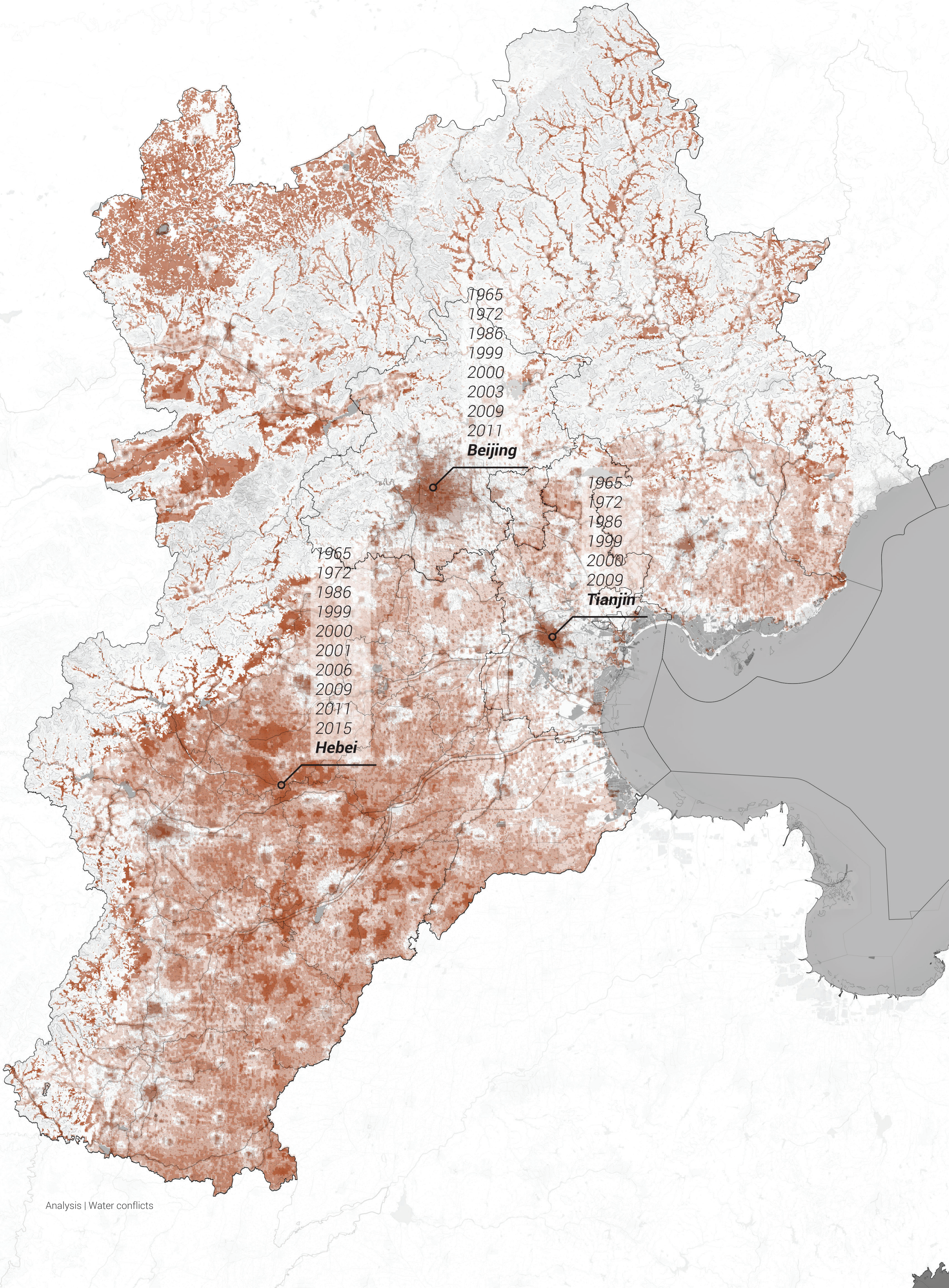
Fig. 31. Flood risk

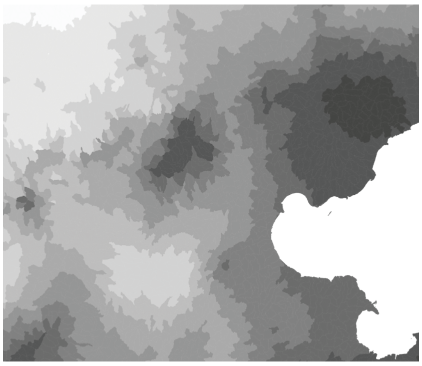
Synthesis of inundation potential, development inequality (utilizing night-time light data as a proxy), and population density to provide an initial understanding of flood risk in the BTH region.

Data: GIEMS-D15, DMSP Nighttime Lights, GPWv4

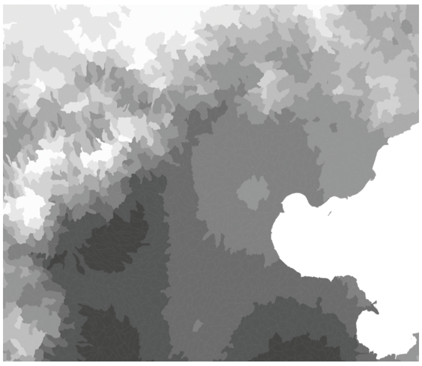
1963 Recorded event
Lower risk
Higher risk
Built-up area
Waterbody
Waterway
Administrative boundary

0 50 100 km

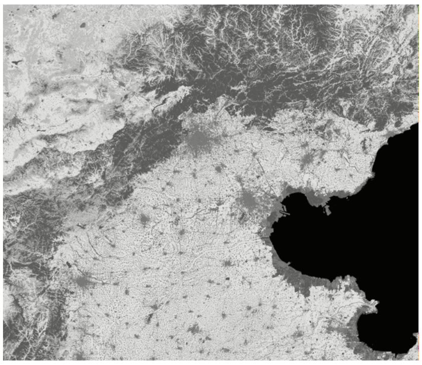

1965
1972
1986
1999
2000
2003
2009
2011
Beijing
1965
1972
1986
1999
2000
2009
Tianjin
1965
1972
1986
1999
2000
2001
2006
2009
2011
2015
Hebei



Annual Precipitation WorldClim



Evapotranspiration Global-AET



CLCD Land Cover Jie Yang et al.

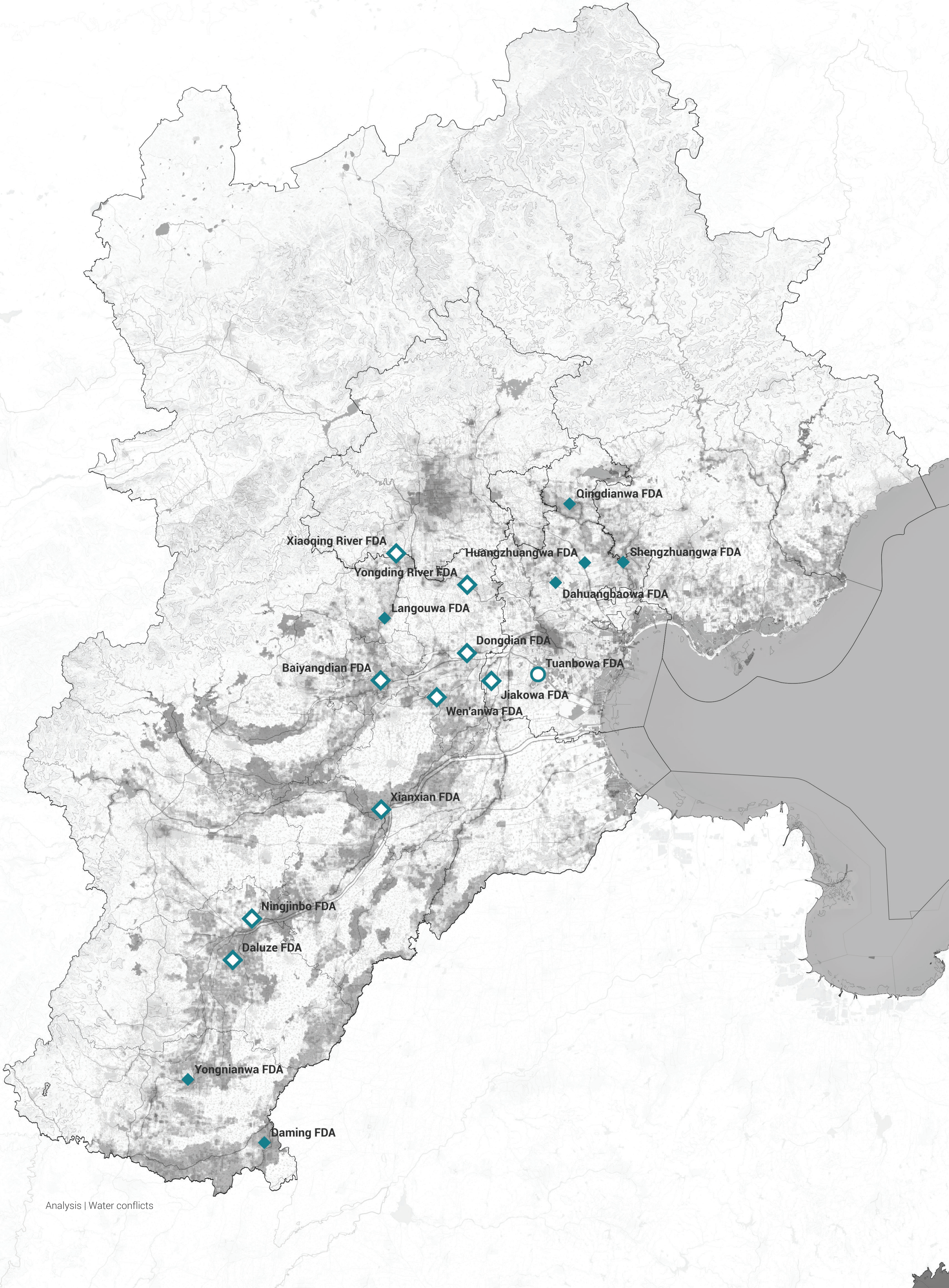
Fig. 32. Drought risk

Synthesis of annual precipitation, evapotranspiration, population density, and average water consumption per landcover type to provide an initial understanding of water scarcity in the BTH region.

Data: WorldClim, Global-AET, GPWv4, Yang & Huang (2021).

1965 Recorded event
Lower risk
Higher risk
Built-up area
Waterbody
Waterway
Administrative boundary

0 50 100 km



Analysis | Water conflicts

Flood Detention Areas (FDAs)

In China, Flood detention areas are an important component of the main river flood control system, working together with reservoirs, embankments, and river channels to prevent and control floods. By utilizing embankments and river channels to release floodwater and using reservoirs to detain floodwater, if flood control measures are still insufficient, flood detention areas are then activated in a timely manner. This helps to store excess floodwater, reduce peak flow, and minimize overall flood disaster losses to the greatest extent possible. According to the position and role of flood storage and detention areas in the flood control system, factors such as utilization probability, dispatching authority, and geographical location, the flood storage and detention areas are classified into three categories:

Important Flood Detention Areas: These are areas and facilities of great importance involving inter-provincial flood safety and protection. They have a high probability of utilization and are dispatched by the State Council, the National Flood Control and Drought Relief Headquarters, or the basin flood control and drought relief headquarters. The embankments or levees are reinforced or separated according to flood control planning requirements, and necessary facilities for flood retention and release are constructed. Priority is given to the relocation of local residents, or the focus is on the construction of safety facilities in safety zones (enclosed villages or protected embankment areas) to ensure the normal life of the population and avoid frequent, large-scale population movements.

General Flood Detention Areas: These are areas protecting specific localities and are dispatched by the basin flood control and drought relief headquarters or provincial flood control command institutions. The emphasis is on reinforcing embankments or levees, with the construction of fixed flood inlet and outlet gates when necessary. The main focus is on the evacuation of personnel, and the construction of safety facilities is centered on evacuation routes and bridges.

Reserved Flood Detention Areas: These are areas with a lower probability of utilization, but are temporarily not subject to cancellation. In principle, no further construction of flood storage and detention areas is undertaken.

Fig. 33. Flood Detention Areas at macro scale

Data: National Development and Reform Commission, People's Republic of China, 2009

Important FDA
General FDA
Reserved FDA
Lower risk
Higher risk
Built-up area
Waterbody
Waterway
Administrative boundary

0 50 100 km

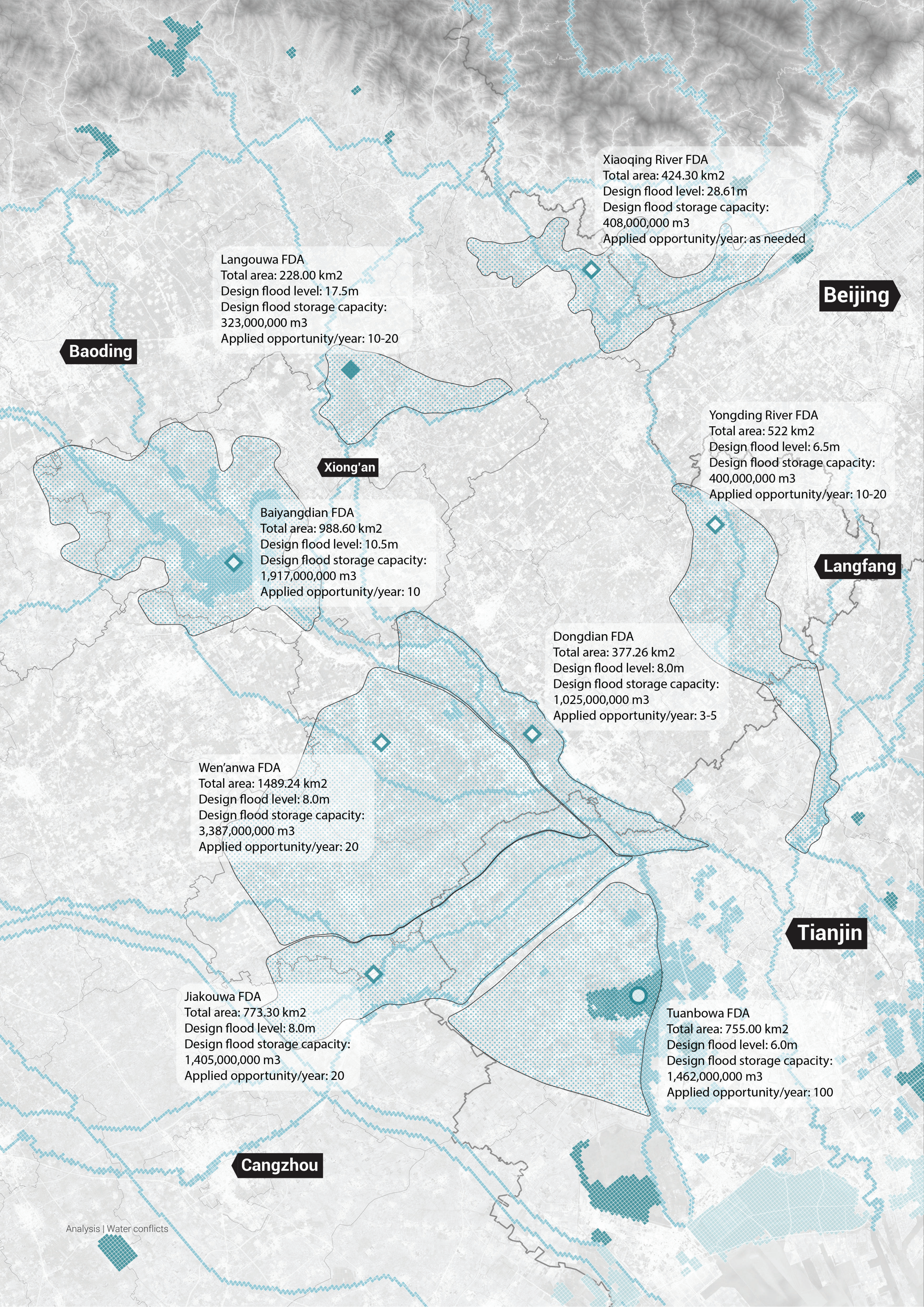
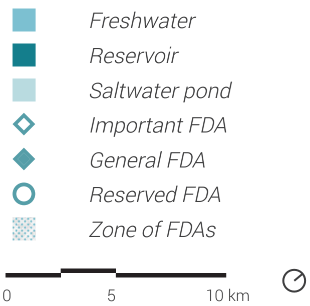
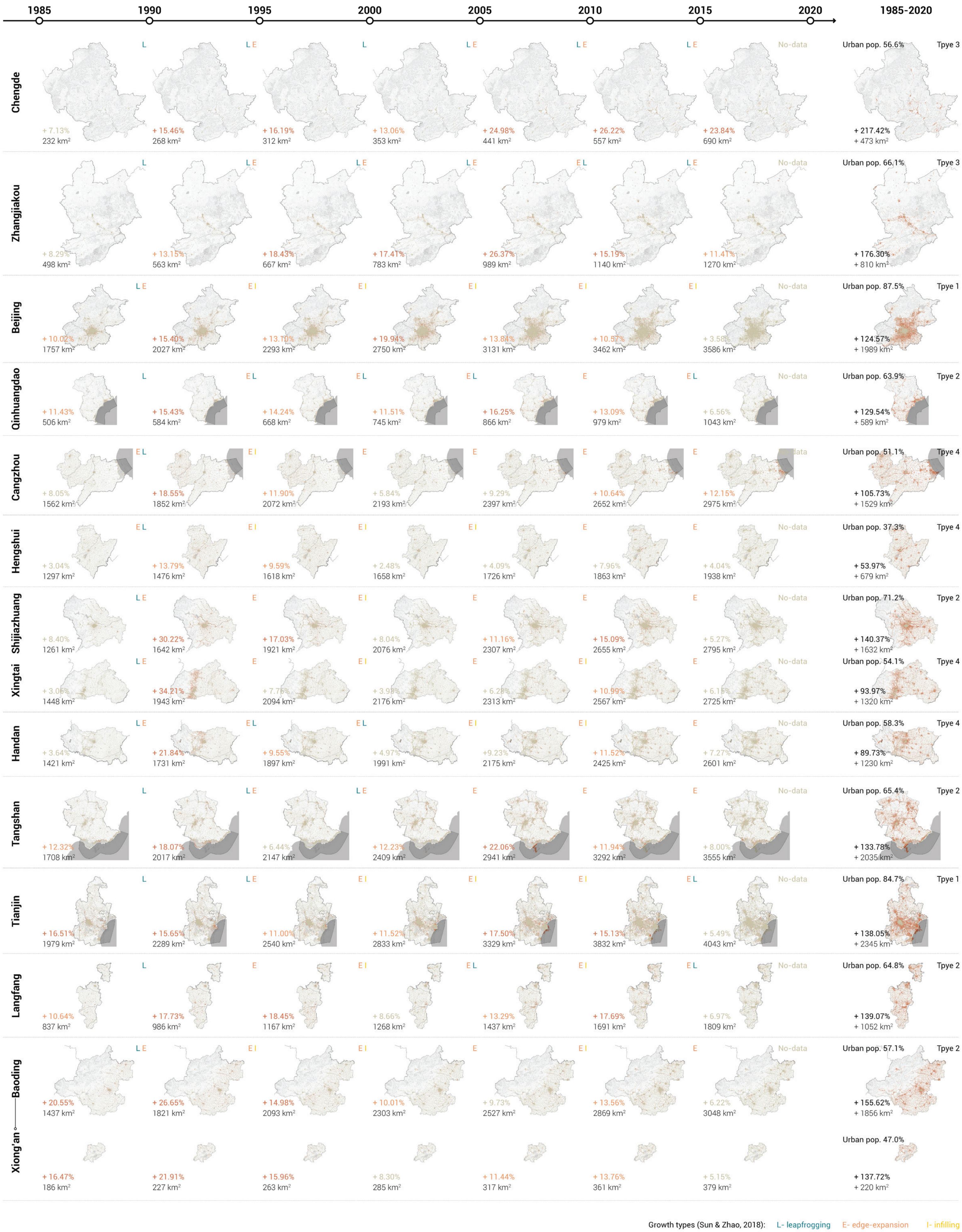

Xiaoqing River FDA
Total area: 424.30 km2
Design flood level: 28.61m
Design flood storage capacity:
408,000,000 m3
Applied opportunity/year: as needed
Beijing
Langouwa FDA
Total area: 228.00 km2
Design flood level: 17.5m
Design flood storage capacity:
323,000,000 m3
Applied opportunity/year: 10-20
Baoding
Xiong'an
Yongding River FDA
Total area: 522 km2
Design flood level: 6.5m
Design flood storage capacity:
400,000,000 m3
Applied opportunity/year: 10-20
Baiyangdian FDA
Total area: 988.60 km2
Design flood level: 10.5m
Design flood storage capacity:
1,917,000,000 m3
Applied opportunity/year: 10
Langfang
Dongdian FDA
Total area: 377.26 km2
Design flood level: 8.0m
Design flood storage capacity:
1,025,000,000 m3
Applied opportunity/year: 3-5
Wen'anwa FDA
Total area: 1489.24 km2
Design flood level: 8.0m
Design flood storage capacity:
3,387,000,000 m3
Applied opportunity/year: 20
Tianjin
Jiakouwa FDA
Total area: 773.30 km2
Design flood level: 8.0m
Design flood storage capacity:
1,405,000,000 m3
Applied opportunity/year: 20
Tuanbowa FDA
Total area: 755.00 km2
Design flood level: 6.0m
Design flood storage capacity:
1,462,000,000 m3
Applied opportunity/year: 100
Cangzhou

Fig. 34. Flood Detention Areas at meso scale

By utilizing embankments and river channels to release floodwater and using reservoirs to detain floodwater, if flood control measures are still insufficient, flood detention areas are then activated in a timely manner. This helps to store excess floodwater, reduce peak flow, and minimize overall flood disaster losses to the greatest extent possible.

Data: OSM, National Development and Reform Commission, People's Republic of China, 2009




1985 1990 1995 2000 2005 2010 2015 2020 1985-2020
Chengde
L | L E | L | L E | L E | L E | No-data
+ 7.13% 232 km^2 | + 15.46% 268 km^2 | + 16.19% 312 km^2 | + 13.06% 353 km^2 | + 24.98% 441 km^2 | + 26.22% 557 km^2 | + 23.84% 690 km^2
Urban pop. 56.6% Tpye 3 + 217.42% + 473 km^2
Zhangjiakou
L | L E | L E | L E | E L | L E | No-data
+ 8.29% 498 km^2 | + 13.15% 563 km^2 | + 18.43% 667 km^2 | + 17.41% 783 km^2 | + 26.37% 989 km^2 | + 15.19% 1140 km^2 | + 11.41% 1270 km^2
Urban pop. 66.1% Tpye 3 + 176.30% + 810 km^2
Beijing
L E | E I | E I | E I | E I | E I | No-data
+ 10.02% 1757 km^2 | + 15.40% 2027 km^2 | + 13.10% 2293 km^2 | + 19.94% 2750 km^2 | + 13.84% 3131 km^2 | + 10.57% 3462 km^2 | + 3.58% 3586 km^2
Urban pop. 87.5% Tpye 1 + 124.57% + 1989 km^2
Qinhuangdao
L | E L | E L | E L | E | E L | No-data
+ 11.43% 506 km^2 | + 15.43% 584 km^2 | + 14.24% 668 km^2 | + 11.51% 745 km^2 | + 16.25% 866 km^2 | + 13.09% 979 km^2 | + 6.56% 1043 km^2
Urban pop. 63.9% Tpye 2 + 129.54% + 589 km^2
Cangzhou
E L | E I | E | E | E | E | E
+ 8.05% 1562 km^2 | + 18.55% 1852 km^2 | + 11.90% 2072 km^2 | + 5.84% 2193 km^2 | + 9.29% 2397 km^2 | + 10.64% 2652 km^2 | + 12.15% 2975 km^2
Urban pop. 51.1% Tpye 4 + 105.73% + 1529 km^2
Hengshui
E L | E I | E I | E I | E | E | No-data
+ 3.04% 1297 km^2 | + 13.79% 1476 km^2 | + 9.59% 1618 km^2 | + 2.48% 1658 km^2 | + 4.09% 1726 km^2 | + 7.96% 1863 km^2 | + 4.04% 1938 km^2
Urban pop. 37.3% Tpye 4 + 53.97% + 679 km^2
Shijiazhuang
L E | E | E I | E | E | E | No-data
+ 8.40% 1261 km^2 | + 30.22% 1642 km^2 | + 17.03% 1921 km^2 | + 8.04% 2076 km^2 | + 11.16% 2307 km^2 | + 15.09% 2655 km^2 | + 5.27% 2795 km^2
Urban pop. 71.2% Tpye 2 + 140.37% + 1632 km^2
Xingtai
L E | E | E I | E | E I | E | No-data
+ 3.06% 1448 km^2 | + 34.21% 1943 km^2 | + 7.76% 2094 km^2 | + 3.93% 2176 km^2 | + 6.28% 2313 km^2 | + 10.99% 2567 km^2 | + 6.15% 2725 km^2
Urban pop. 54.1% Tpye 4 + 93.97% + 1320 km^2
Handan
L E | E L | E L | E I | E I | E | No-data
+ 3.64% 1421 km^2 | + 21.84% 1731 km^2 | + 9.55% 1897 km^2 | + 4.97% 1991 km^2 | +9.23% 2175 km^2 | + 11.52% 2425 km^2 | + 7.27% 2601 km^2
Urban pop. 58.3% Tpye 4 + 89.73% + 1230 km^2
Tangshan
L | L E | L E | E | E | E | No-data
+ 12.32% 1708 km^2 | + 18.07% 2017 km^2 | + 6.44% 2147 km^2 | + 12.23% 2409 km^2 | + 22.06% 2941 km^2 | + 11.94% 3292 km^2 | + 8.00% 3555 km^2
Urban pop. 65.4% Tpye 2 + 133.78% + 2035 km^2
Tianjin
L | L E | E I | E I | E I | E L | No-data
+ 16.51% 1979 km^2 | + 15.65% 2289 km^2 | + 11.00% 2540 km^2 | + 11.52% 2833 km^2 | + 17.50% 3329 km^2 | + 15.13% 3832 km^2 | + 5.49% 4043 km^2
Urban pop. 84.7% Tpye 1 + 138.05% + 2345 km^2
Langfang
L | E | E I | E L | E I | E L | No-data
+ 10.64% 837 km^2 | + 17.73% 986 km^2 | + 18.45% 1167 km^2 | + 8.66% 1268 km^2 | + 13.29% 1437 km^2 | + 17.69% 1691 km^2 | + 6.97% 1809 km^2
Urban pop. 64.8% Tpye 2 + 139.07% + 1052 km^2
Baoding
L E | E I | E I | E | E I | E | No-data
+ 20.55% 1437 km^2 | + 26.65% 1821 km^2 | + 14.98% 2093 km^2 | + 10.01% 2303 km^2 | + 9.73% 2527 km^2 | + 13.56% 2869 km^2 | + 6.22% 3048 km^2
Urban pop. 57.1% Tpye 2 + 155.62% + 1856 km^2
Xiong'an
+ 16.47% 186 km^2 | + 21.91% 227 km^2 | + 15.96% 263 km^2 | + 8.30% 285 km^2 | + 11.44% 317 km^2 | + 13.76% 361 km^2 | + 5.15% 379 km^2
Urban pop. 47.0% + 137.72% + 220 km^2
Growth types (Sun & Zhao, 2018): L- leapfrogging E- edge-expansion I- infilling

Urbanization process in the BTH region

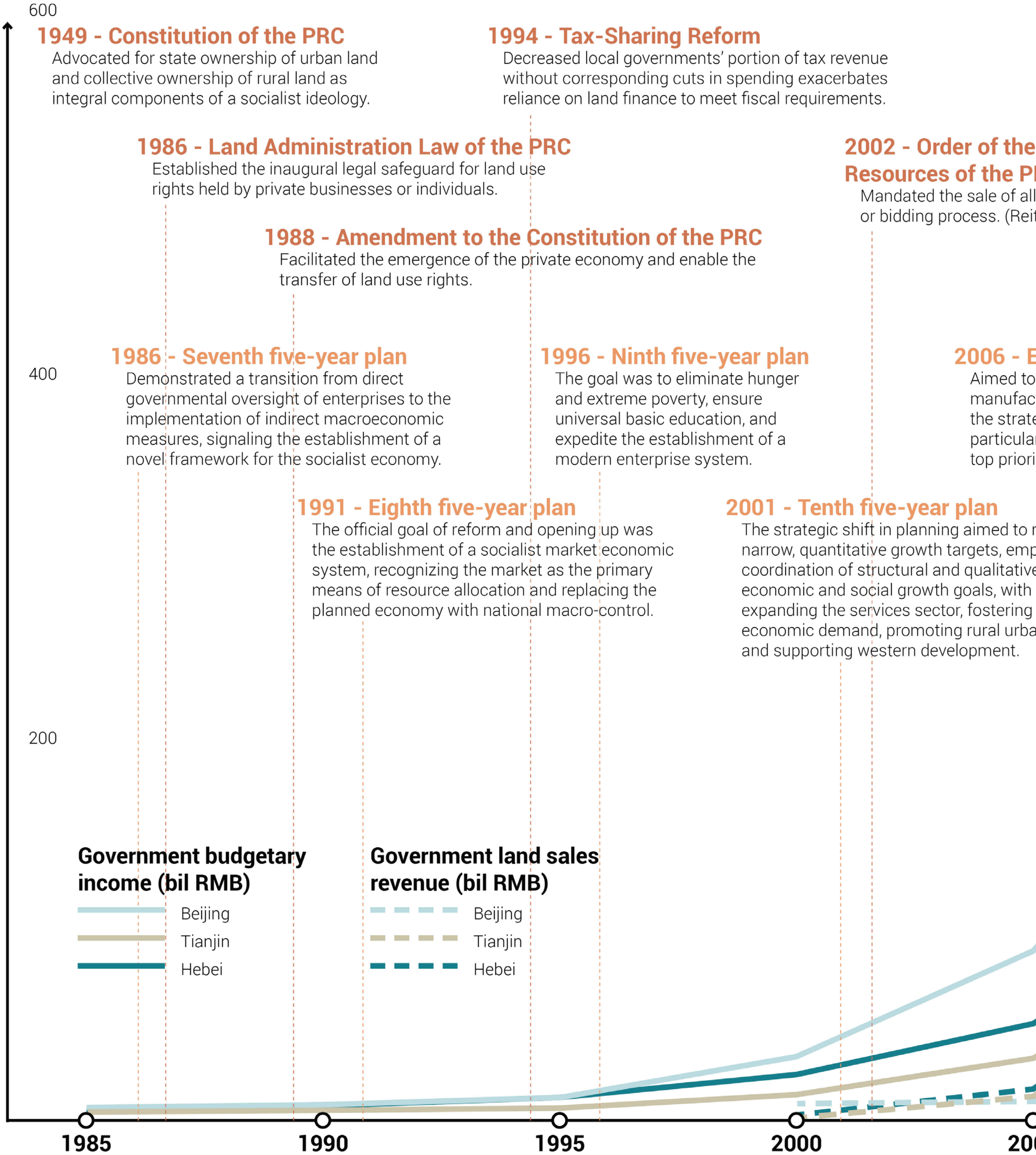
It's crucial to grasp the urbanization process within the sub-region to gain insight into the current development model in the BTH region.

By analyzing the proportions and rates of urbanization in each sub-region over the past 35 years, as well as their growth types, this set of analytical figures reveals uneven development among various areas in the BTH region. Major cities (types 1 & 2), such as Beijing, Tianjin, and Shijiazhuang, entered a phase of slow expansion around 2020 after a period of rapid growth. Cities in the northern highland and mountainous areas (type 3) are still steadily expanding. Regions with lower levels of urbanization (type 4), like Hengshui and Xingtai, have also shifted into a phase of slow expansion, despite ample land resources available for urbanization in these areas.

This indicates that the current paradigm in the plains of the BTH region has become stagnant, making it challenging to promote urbanization in underdeveloped areas. Without changes, these underdeveloped areas will become the most vulnerable to drought and flood events in the BTH region, although they still possess the greatest potential to achieve self-resilience and support the entire region in achieving water resilience.

Fig. 35. Urbanization process of 13 cities in the region

Data: CLCD Land Cover, Yang & Huang (2021)


600
400
200
1949 - Constitution of the PRC
Advocated for state ownership of urban land and collective ownership of rural land as integral components of a socialist ideology.
1994 - Tax-Sharing Reform
Decreased local governments' portion of tax revenue without corresponding cuts in spending exacerbates reliance on land finance to meet fiscal requirements.
1986 - Land Administration Law of the PRC
Established the inaugural legal safeguard for land use rights held by private businesses or individuals.
2002 - Order of the
Resources of the P
Mandated the sale of all
or bidding process. (Rei
1988 - Amendment to the Constitution of the PRC
Facilitated the emergence of the private economy and enable the transfer of land use rights.
1986 - Seventh five-year plan
Demonstrated a transition from direct governmental oversight of enterprises to the implementation of indirect macroeconomic measures, signaling the establishment of a novel framework for the socialist economy.
1996 - Ninth five-year plan
The goal was to eliminate hunger and extreme poverty, ensure universal basic education, and expedite the establishment of a modern enterprise system.
2006 - E
Aimed to
manufac
the strate
particula
top priori
1991 - Eighth five-year plan
The official goal of reform and opening up was the establishment of a socialist market economic system, recognizing the market as the primary means of resource allocation and replacing the planned economy with national macro-control.
2001 - Tenth five-year plan
The strategic shift in planning aimed to r
narrow, quantitative growth targets, emp
coordination of structural and qualitative
economic and social growth goals, with
expanding the services sector, fostering
economic demand, promoting rural urba
and supporting western development.
Government budgetary income (bil RMB)
Beijing
Tianjin
Hebei
Government land sales revenue (bil RMB)
Beijing
Tianjin
Hebei
1985
1990
1995
2000
200

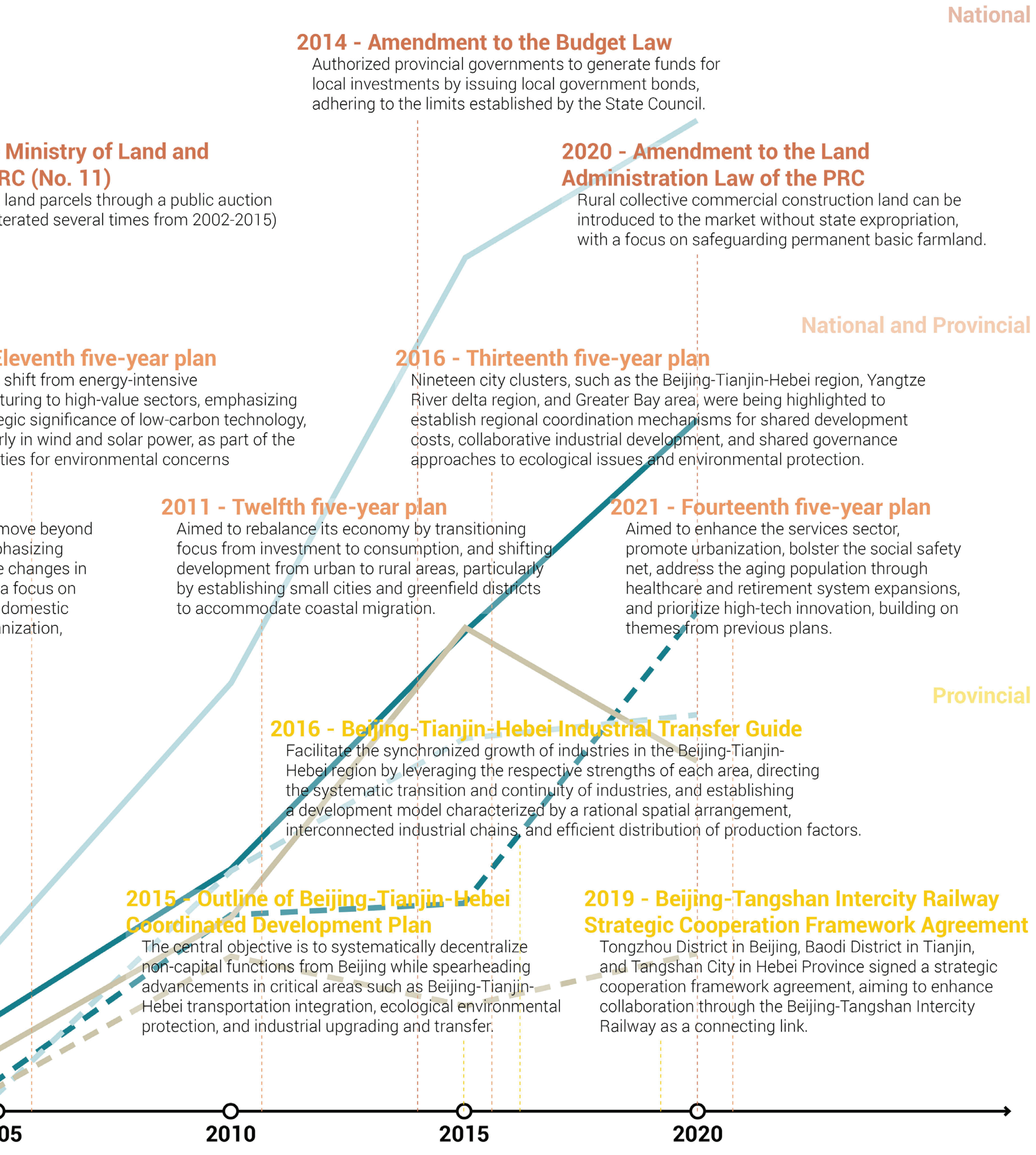
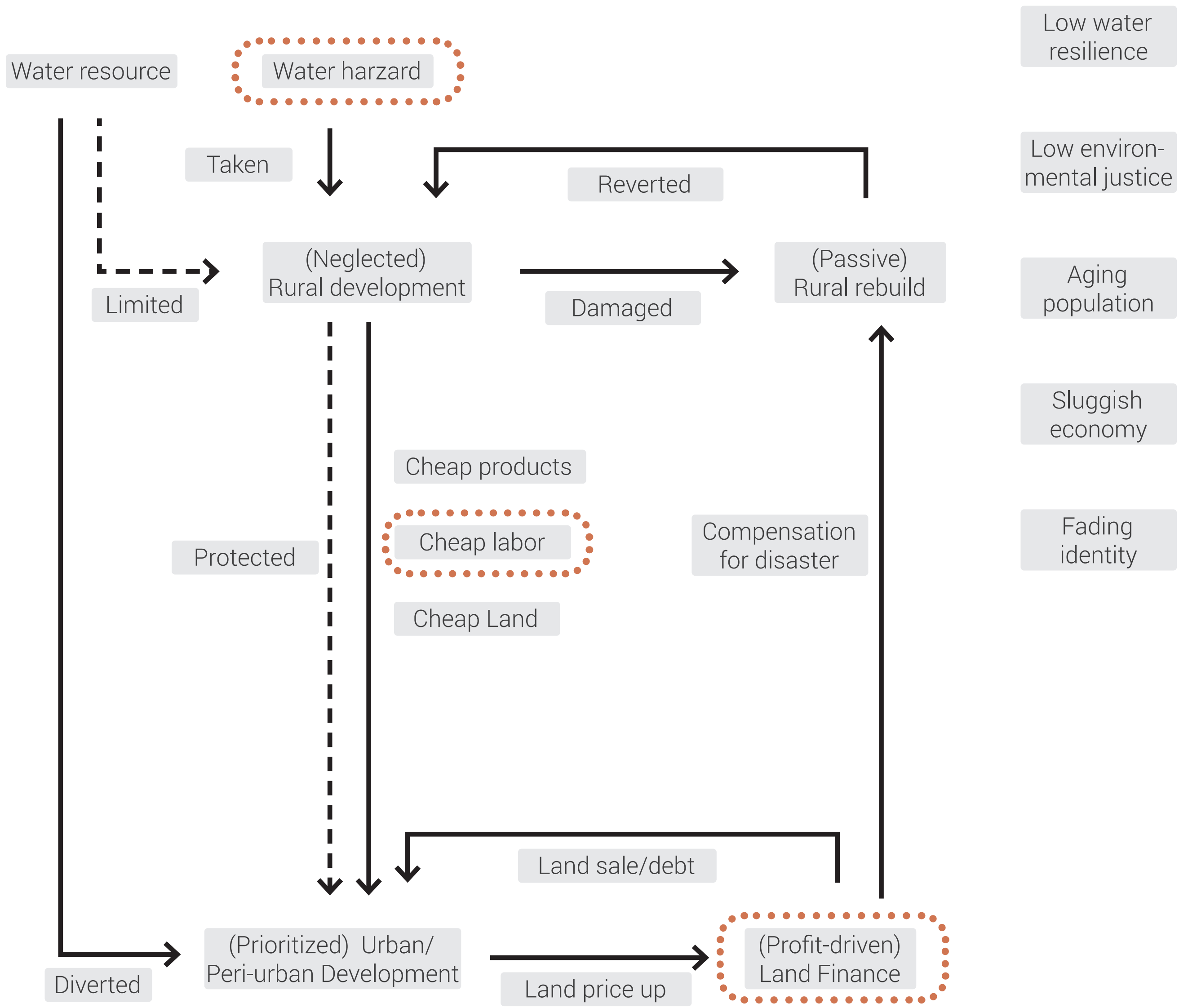


Fig. 36. Major law & policy evolution which shaped the urbanization of the BTH region

Data: Gyourko et al. (2022)


Water resource
Water harzard
Low water resilience
Taken
Reverted
Low environ-mental justice
Limited
(Neglected) Rural development
Damaged
(Passive) Rural rebuild
Aging population
Sluggish economy
Cheap products
Protected
Cheap labor
Compensation for disaster
Fading identity
Cheap Land
Land sale/debt
Diverted
(Prioritized) Urban/ Peri-urban Development
Land price up
(Profit-driven) Land Finance

PROFIT-DRIVEN DEVELOPMENT PARADIGM

Through the analysis above, it's evident that one of the primary reasons for water hazard vulnerability in rural China is the existing development model. The core of this paradigm is land finance. According to the Chinese constitution, rural land is collectively owned, while urban land is owned by the government. Therefore, the government can profit by selling rural land resources at low prices to developers, generating substantial income from land sales, or by using land resources as collateral for loans to finance infrastructure investment. These investments attract labor from surrounding areas to work in these newly developed areas and settle there, thereby driving up land prices nearby and reinforcing the cycle of land finance to infrastructure development. This model inevitably prioritizes urban and peri-urban development over rural development, as only when people move from rural to urban areas and engage in higher-paying jobs relative to agriculture can they afford the high housing prices (which are the premiums obtained by the government through the transfer of land resources). The low-profit agricultural model further encourages young people in rural areas to migrate to cities for work, supplying a steady stream of labor to these newly developed areas.

This prioritization of urban and peri-urban development has led to significant disparities in development levels between urban and rural areas. On one hand, urban areas have more robust infrastructure to cope with droughts or floods, while on the other hand, they sacrifice low-development rural areas (such as designating flood detention areas) to further mitigate the adverse effects of water hazards on urban areas. Furthermore, government compensation for rural areas post-disaster is short-sighted. According to local villagers, the government provides sufficient compensation for agricultural and property losses post-disaster, but this is all. Most villagers rebuild their homes in the same location in the same way after receiving compensation, continuing their previous way of life. It's foreseeable that they will face the next flood or drought, and with increasing extreme weather events, the damage they suffer may become even greater.

This paradigm is based on rural areas surrounding cities continuously providing low-cost agricultural products, cheap labor, and cheap land resources. In the current state where housing prices are already unaffordable and rural labor is scarce, this paradigm is clearly unsustainable. Meanwhile, the water hazard risk borne by rural areas far outweighs the available water resources allocated to them, the majority of which are controlled by dams and channels in upstream areas and diverted to users in urban areas.

This unsustainable profit-driven development paradigm has resulted in low water resilience, low environmental justice, an aging population, a sluggish economy, and a fading identity in these low-development rural areas.

Fig. 37. Profit-driven development paradigm

MEASURE

MEASURE

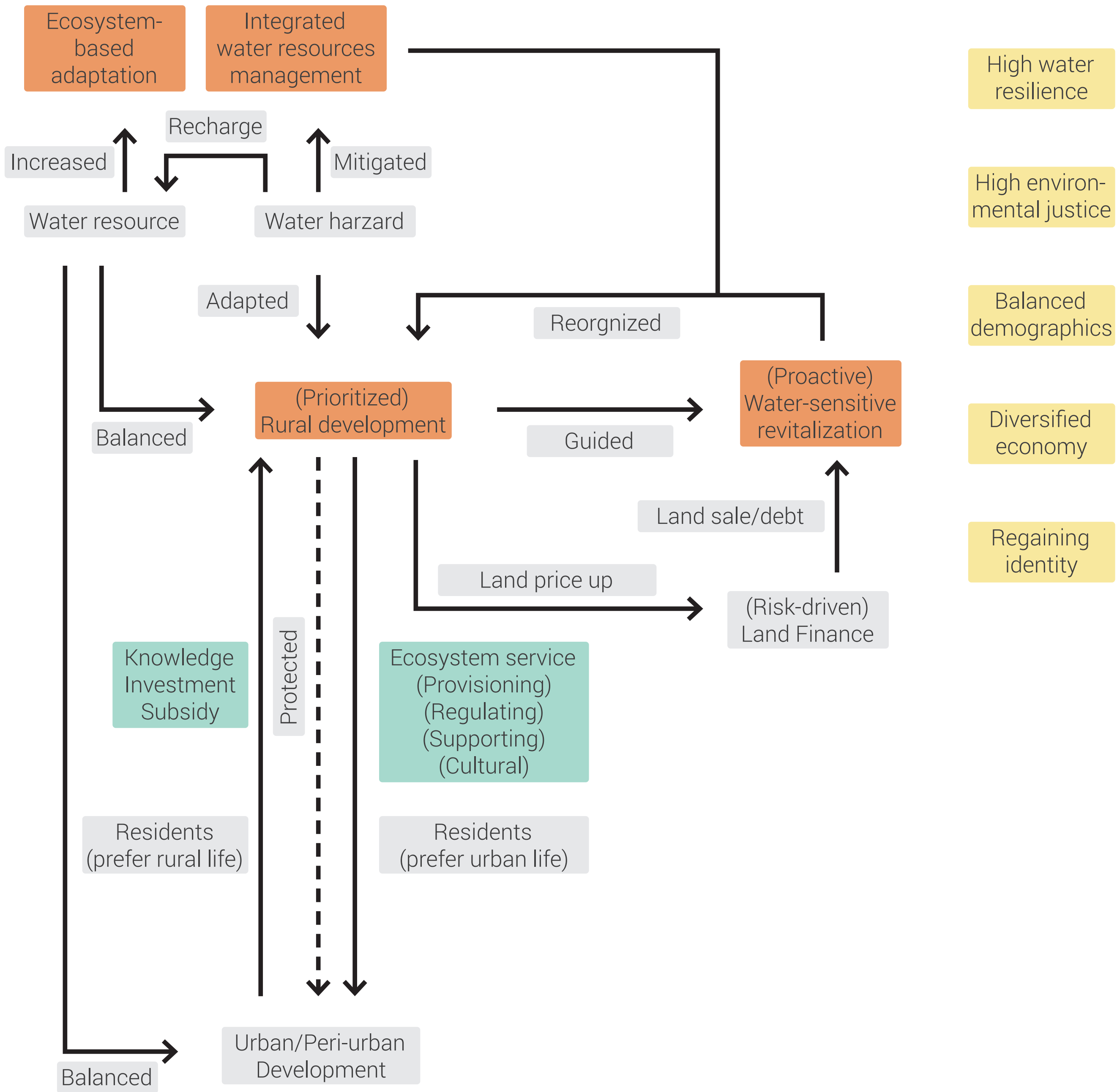
| Risk management-driven development paradigm

| Pattern languages

| Actions and measures

| Pattern assessment

| Spatial anchoring



Measure | Risk management-driven development paradigm

RISK MANAGEMENT-DRIVEN DEVELOPMENT PARADIGM

Although the existing profit-driven development paradigm is collapsing, the new paradigm must still partially build upon the old foundation. This research proposes that land finance can continue to be a potent tool for facilitating a new risk reduction model in rural regions, provided it shifts from being profit-driven to being risk management-driven. This shift will allow rural areas with low development levels and high water risk to take center stage in development.

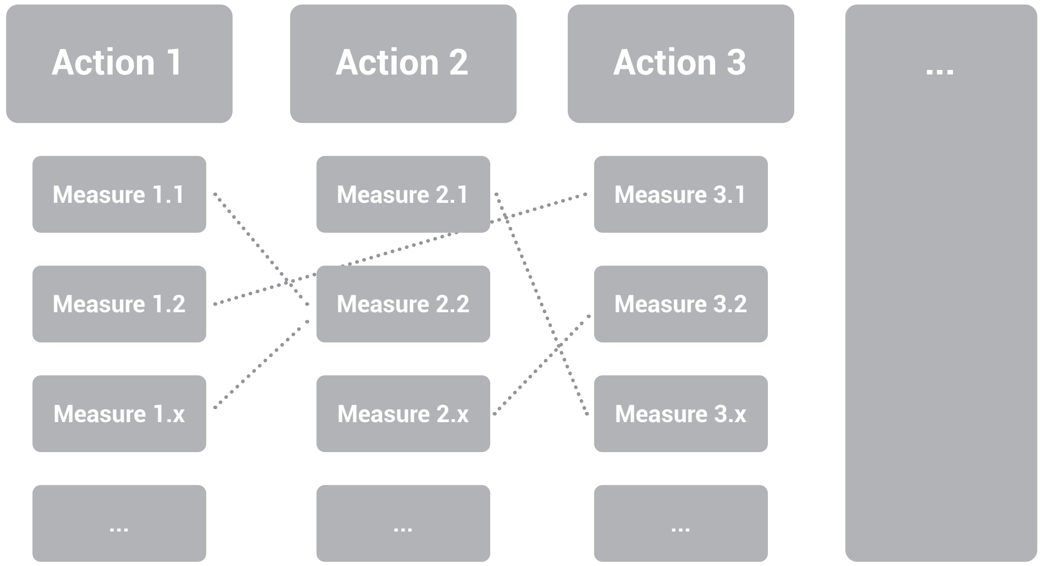
Rural areas have historically been overlooked by investors, who perceive them as having less economic value compared to urban and peri-urban areas. However, this perspective is highly profit-driven. Without rural areas providing primary production, acting as the first line of defense against water hazards impacting cities, supplying river water sources and major underground water supplies, and offering urban residents opportunities for outdoor recreation such as fishing, cities would not have achieved their current level of development. Rural regions have consistently provided these vital ecosystem services, as well as labor and land resources. However, these non-economic values have been taken for granted, without equivalent resource feedback to rural areas. This has resulted in towns and villages in the BTH region, apart from major cities, experiencing little improvement or even decline during China's rapid economic development over the past 50 years.

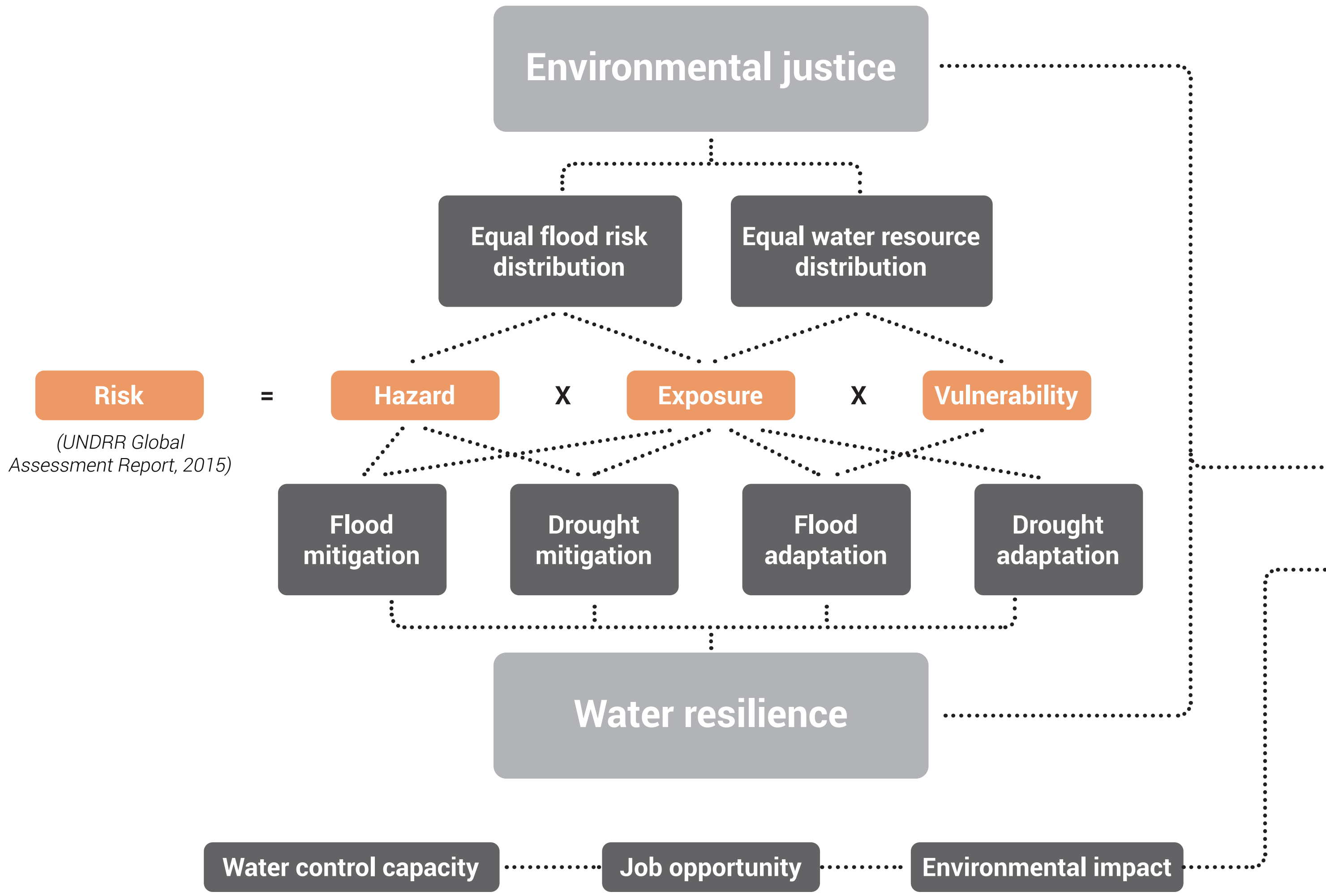
However, solely exploiting rural regions as resources in a one-sided manner is unsustainable, as evidenced by current circumstances. Urban and peri-urban regions, as beneficiaries, need to acknowledge these non-economic values and help guide rural regions to develop and grow through knowledge, investment, and subsidies. This will enable rural regions to sustain and amplify these values, continuing to support the entire region. Only through this approach can the cities and rural areas in the BTH region overcome their inherent boundaries and oppositional positions and jointly develop through a new risk management-driven development paradigm.

More specifically, this research proposes intervening through three domains to facilitate the new paradigm. Through ecosystem-based adaptation and integrated water resources management, current water infrastructure will be effectively utilized and integrated with new nature-based solutions into a hybrid water management system. This system is capable of mitigating escalating water hazards and, more importantly, utilizing floods as opportunities to recharge available water resources during the wet season to ensure water availability in the dry season. Additionally, water-sensitive revitalization will replace previous short-sighted, passive rebuilding strategies to proactively guide rural development towards water resilience and environmental justice. Residents will be encouraged to freely move between urban and rural life based on personal preference, with a more open policy towards the marketization of rural land use rights, encouraging new knowledge and businesses to move to rural regions as well.

The ultimate goal is for this risk management-driven development paradigm to transform rural regions into dynamic mosaics with high levels of water resilience and environmental justice, balanced demographics, diversified economies, and gradually regain a new identity.

Fig. 38. Risk management-driven development paradigm


Action 1
Action 2
Action 3
...
Measure 1.1
Measure 1.2
Measure 1.x
...
Measure 2.1
Measure 2.2
Measure 2.x
...
Measure 3.1
Measure 3.2
Measure 3.x
...


Environmental justice
Equal flood risk distribution
Equal water resource distribution
Risk
=
Hazard
X
Exposure
X
Vulnerability
(UNDRR Global Assessment Report, 2015)
Flood mitigation
Drought mitigation
Flood adaptation
Drought adaptation
Water resilience
Water control capacity
Job opportunity
Environmental impact

PATTERN LANGUAGES

To organize potential measures facilitating a new risk-driven development paradigm, this research adopts the method of pattern languages. This approach systematically categorizes prospective spatial tools and establishes a toolkit with well-defined solution hypotheses, theoretical foundations, and anticipated outcomes for implementing these solutions (Salingaros, 2000).

Various potential measures are classified into several main actions. For each measure, its characteristics are described by attributes with uniform standards, including hypotheses, theoretical backup, target effects, costs, side effects, practical implications, synergies, conflicts, expiration date, and stakeholders.

Among these, the target effect has two main focuses: water resilience and environmental justice. Water resilience primarily assesses a measure's ability to mitigate and adapt to water hazards, while environmental justice evaluates a measure's contributions to equal flood risk distribution and equal water resource distribution. The costs of each measure include the initial cost of implementation and the ongoing cost to maintain the intervention's effect. Side effects focus on assessing a measure's positive or negative impacts on water control capacity, job opportunities, and the environment.

All the attributes not only help to quickly clarify the operation, potential impacts, and trade-offs of each measure but also play an important role in filtering and making decisions in the later exploration of dynamic adaptive pathways.

Pattern languages | attributes

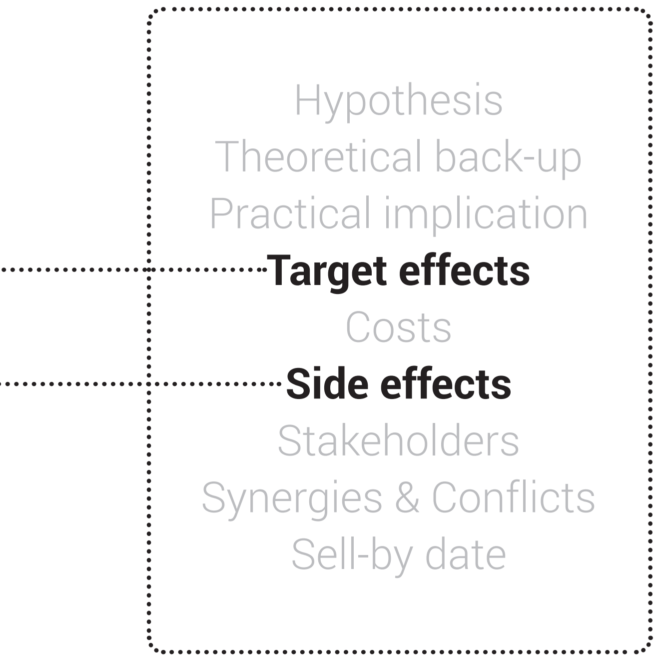


Fig. 39. Pattern languages - stracutre

A1 Waterway restoration

- E10 Elimination of riverbank protection
- E11 Stream bed re-naturalization
- E12 Restoration of seasonal streams
- E13 Removal of dams and barriers

A2 Floodplain restoration

- E1 Meadows and pastures
- E2 Buffer strips and hedges
- E3 Green cover
- E5 Forest riparian buffers
- E8 Basins and ponds
- E9 Wetland restoration

A3 Water source protection

- E4 Agri-managed aquifer recharge
- E6 Afforestation in headwater areas
- E7 Afforestation of reservoir catchments

A4 Efficient water use

- I3 Precision irrigation
- I10 Use of adapted crops and varieties

A5 Hybrid infrastructure system

- I2 Channel as distributor
- I4 Decentralized water storage
- I7 Dike as flood-proof road network
- I8 Reuse of sediment

A6 Non-conventional water resources

- I1 Sustainable desalination
- I5 Greywater Recycling
- I6 Agro-industrial wastewater reuse
- I9 Rainwater harvesting

A7 Water sensitive land consolidation

- W1 Village relocation
- W2 Farmland consolidation
- W7 Economy diversification
- W8 Climate-proofing structure

A8 Water-resilient communities

- W3 Water resilience knowledge hub
- W4 Increasing public risk awareness
- W5 Establishment of early warning systems
- W6 Monitoring and evaluation

ACTIONS AND MEASURES

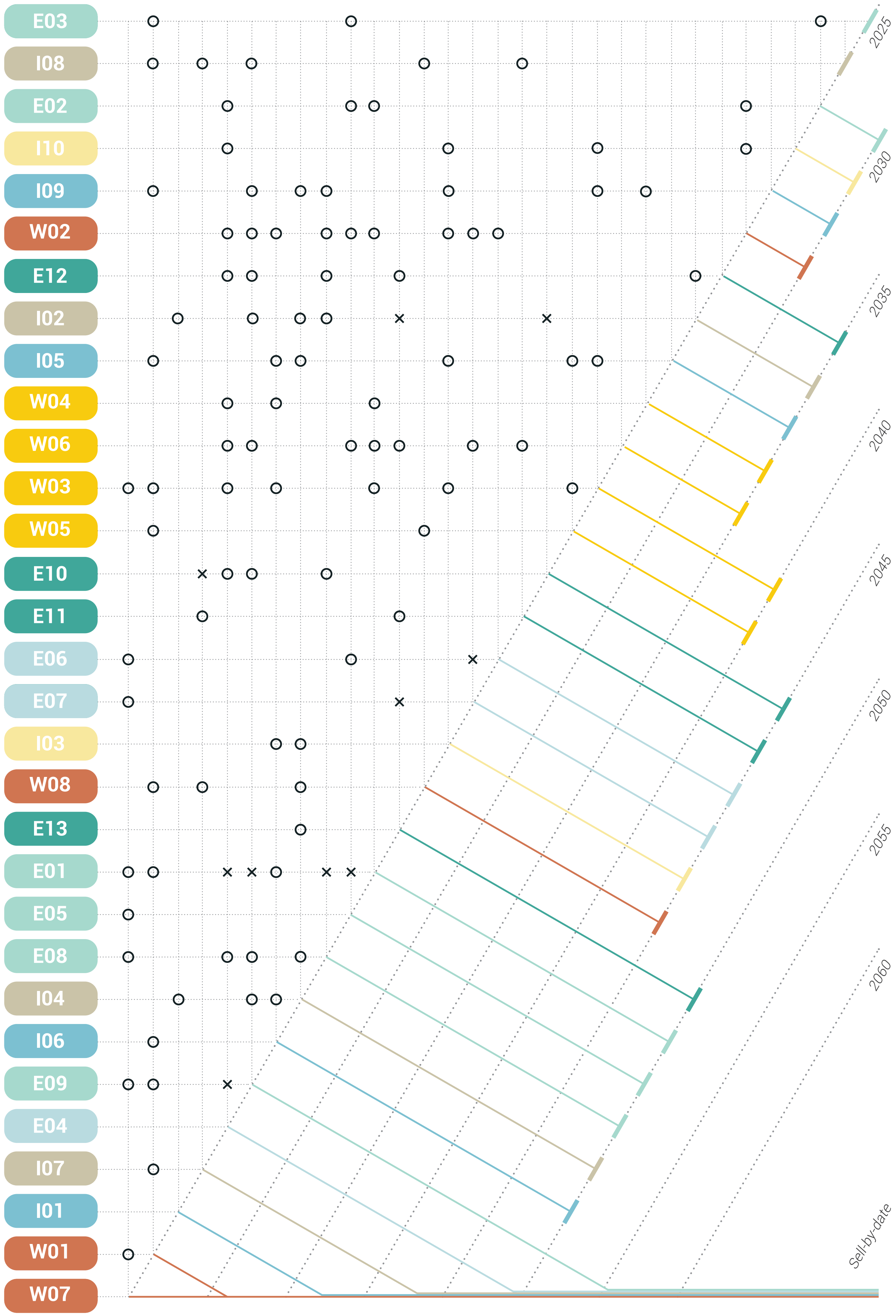
There are a total of 8 actions to categorize 31 measures.

Among them, A1 (waterway restoration), A2 (floodplain restoration), and A3 (water source protection) are proposed from the perspective of ecosystem-based adaptation. These actions focus on restoring the area's water balance and achieving a more even distribution of available water resources and potential water risks over time and space.

In contrast, A4 (efficient water use), A5 (hybrid infrastructure system), and A6 (non-conventional water resources) are based on integrated water resources management. These actions emphasize the comprehensive and effective utilization of existing grey infrastructure and its synergies with newly introduced green and blue infrastructure.

Meanwhile, A7 (water-sensitive land consolidation) and A8 (water-resilient communities) originate from the domain of water-sensitive reorganization. These actions focus on rationalizing land use to reduce flood risks and striving to build cohesive communities capable of securing water resilience in the area. They involve promoting knowledge dissemination, status monitoring, and disaster early warning for newly introduced interventions.

Fig. 40. Actions and measures - overview



Measure | Pattern assessment

PATTERN ASSESSMENT

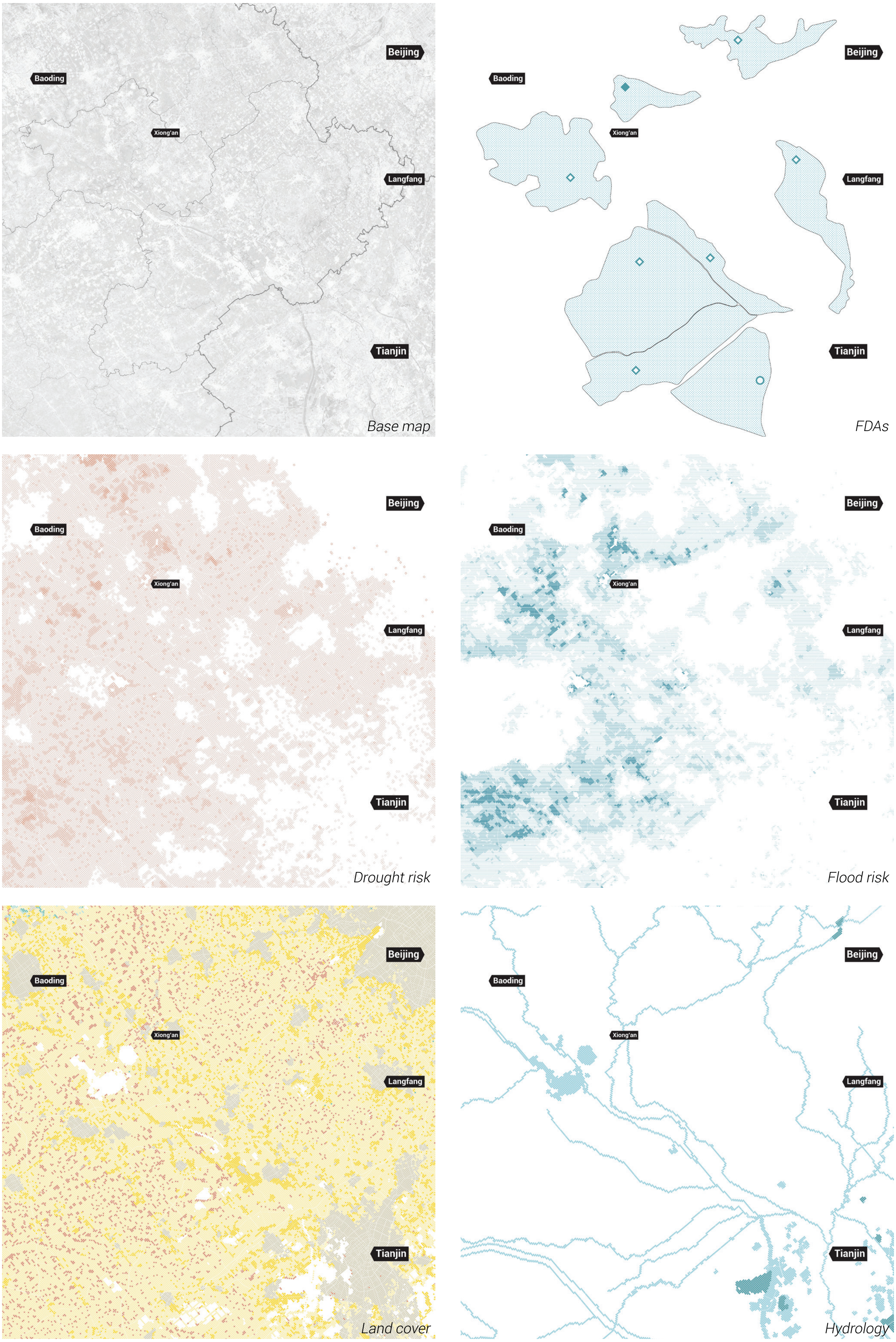
Based on the attributes of each pattern, pattern fields are created to evaluate each pattern and provide a means of visual communication for decision makers.

The diagram shows the synergies and conflicts between each pattern, as well as their implementation deadlines (Sell-by-date), based on the resources and effort required for each pattern's implementation.

(See the appendix for more information on each pattern.)

Fig. 41. Pattern assessment field

X00 *Patterns*
O *Synergies*
× *Conflicts*
—┃ *Sell-by-date*



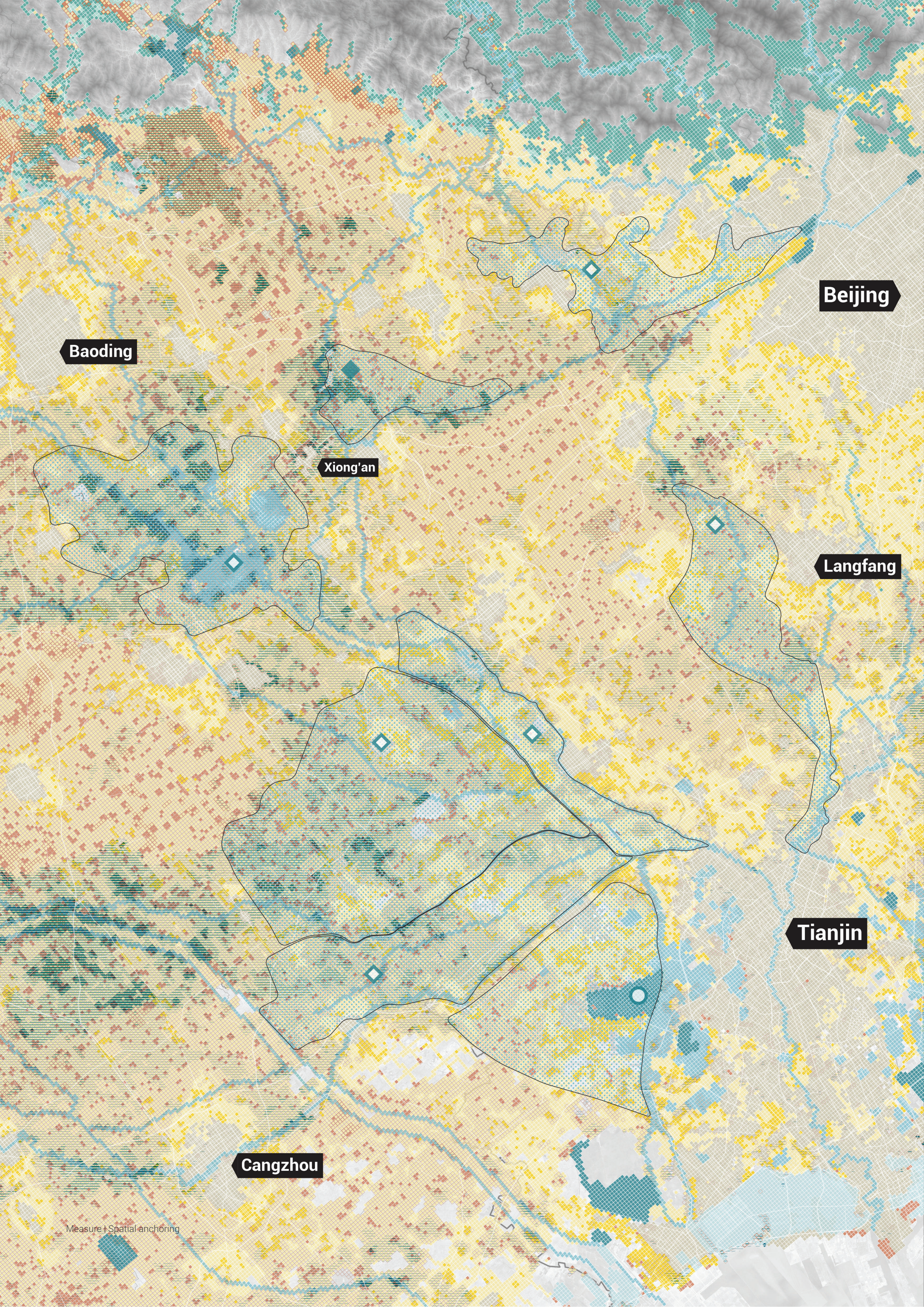
Measure | Spatial anchoring

SPATIAL ANCHORING

While the method of pattern languages provides a clear and abstract understanding of the possible measures available for the paradigm shift, it runs the risk of merely becoming another 'general toolbox,' similar to many other clusters of interventions proposed by urbanists. To avoid this, a spatial anchoring process is introduced, which links local land types, drought and flood risks, and the hydrological system to the potential measures.

Fig. 42. Spatial anchoring - layers

Data: OSM, GIEMS-D15, DMSP Nighttime Lights, GPWv4, WorldClim, Global-AET, Yang & Huang (2021), National Development and Reform Commission, People's Republic of China (2009)



Measure | Spatial anchoring

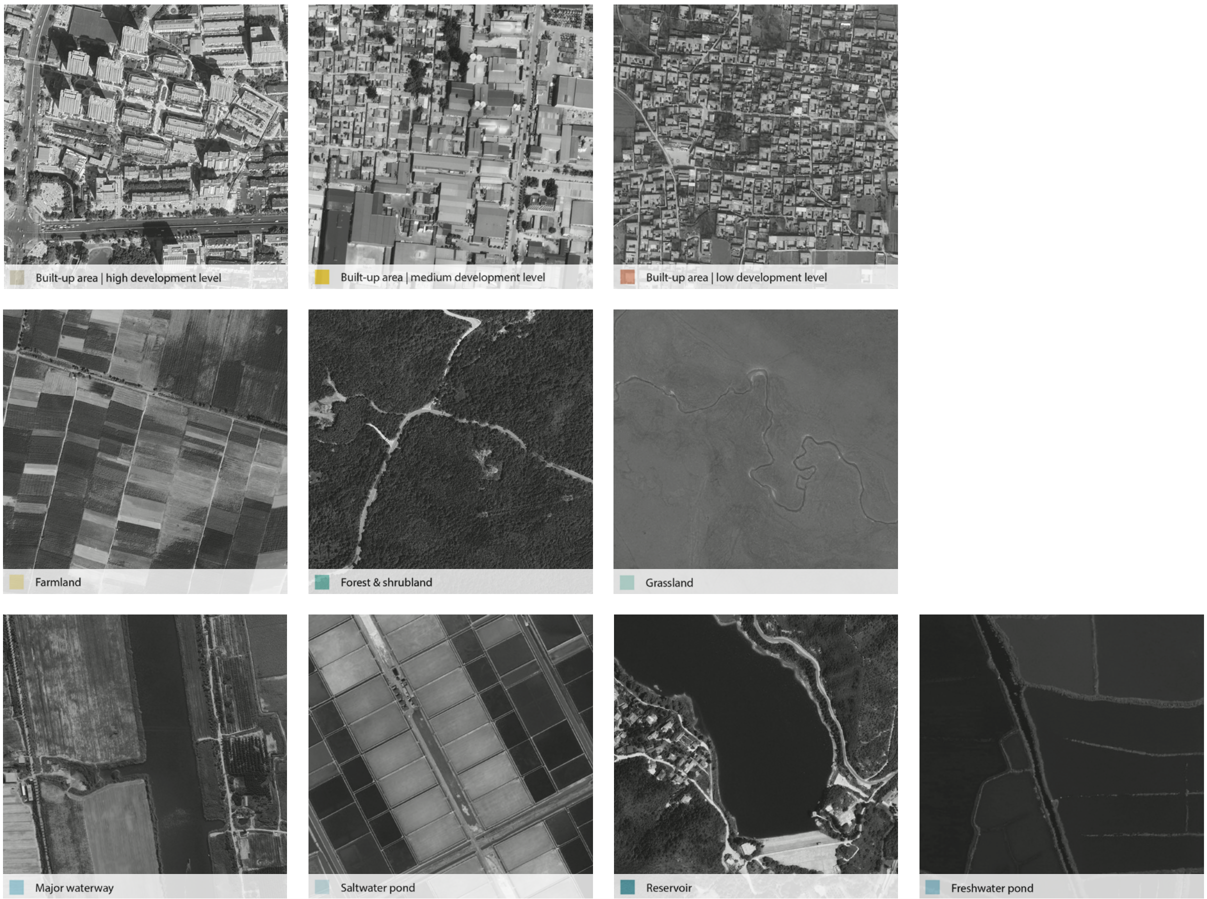
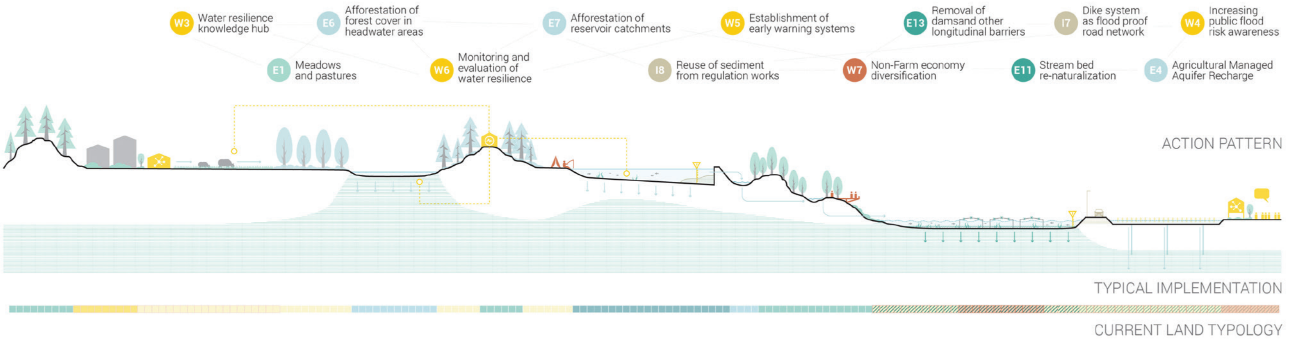


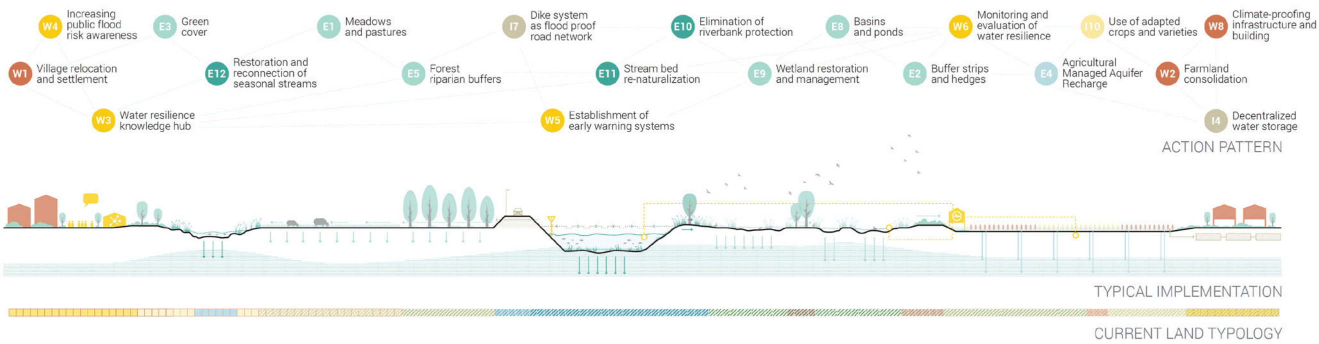
Fig. 43. Spatial anchoring - index map | meso

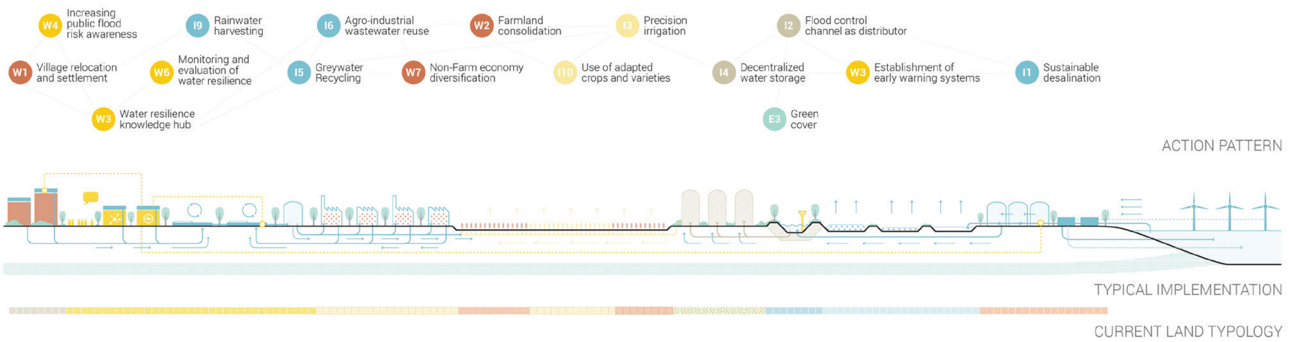
Data: OSM, GIEMS-D15, DMSP Nighttime Lights, GPWv4, WorldClim, Global-AET, Yang & Huang (2021), National Development and Reform Commission, People's Republic of China (2009)

Important FDA
General FDA
Reserved FDA
Zone of FDA
Built-up area | high development level
Built-up area | medium development level
Built-up area | low development level
Farmland
Forest & shrubland
Grassland
Major waterway
Saltwater pond
Reservoir
Freshwater pond
Highway
Railway
Flood risk | high
Flood risk | medium
Flood risk | low
Drought risk | high
Drought risk | medium
Drought risk | low

0 5 10 km


W3 Water resilience knowledge hub
E6 Afforestation of forest cover in headwater areas
E7 Afforestation of reservoir catchments
W5 Establishment of early warning systems
E13 Removal of damsand other longitudinal barriers
I7 Dike system as flood proof road network
W4 Increasing public flood risk awareness
E1 Meadows and pastures
W6 Monitoring and evaluation of water resilience
I8 Reuse of sediment from regulation works
W7 Non-Farm economy diversification
E11 Stream bed re-naturalization
E4 Agricultural Managed Aquifer Recharge
ACTION PATTERN
TYPICAL IMPLEMENTATION
CURRENT LAND TYPOLOGY


W4 Increasing public flood risk awareness
E3 Green cover
E1 Meadows and pastures
I7 Dike system as flood proof road network
E10 Elimination of riverbank protection
E8 Basins and ponds
W6 Monitoring and evaluation of water resilience
I10 Use of adapted crops and varieties
W8 Climate-proofing infrastructure and building
W1 Village relocation and settlement
E12 Restoration and reconnection of seasonal streams
E5 Forest riparian buffers
E11 Stream bed re-naturalization
E9 Wetland restoration and management
E2 Buffer strips and hedges
E4 Agricultural Managed Aquifer Recharge
W2 Farmland consolidation
W3 Water resilience knowledge hub
W5 Establishment of early warning systems
I4 Decentralized water storage
ACTION PATTERN
TYPICAL IMPLEMENTATION
CURRENT LAND TYPOLOGY


W4 Increasing public flood risk awareness
I9 Rainwater harvesting
I6 Agro-industrial wastewater reuse
W2 Farmland consolidation
I3 Precision irrigation
I2 Flood control channel as distributor
W1 Village relocation and settlement
W6 Monitoring and evaluation of water resilience
I5 Greywater Recycling
W7 Non-Farm economy diversification
I10 Use of adapted crops and varieties
I4 Decentralized water storage
W3 Establishment of early warning systems
I1 Sustainable desalination
W3 Water resilience knowledge hub
E3 Green cover
ACTION PATTERN
TYPICAL IMPLEMENTATION
CURRENT LAND TYPOLOGY

On the meso scale, land types are categorized into ten basic types, each associated with drought and flood risks. This logic is applied to three schematic sections, representing typical conditions of the upstream, midstream, and downstream areas in the BTH region. In each section, these land types and possible measures are matched one-to-one, visually demonstrating the spatial implications and interrelationships of the proposed patterns.

Fig. 44. Spatial anchoring - schematic section | upstream

Fig. 45. Spatial anchoring - schematic section | midstream

Fig. 46. Spatial anchoring - schematic section | downstream

Built-up area | high development level
Built-up area | medium development level
Built-up area | low development level
Farmland
Forest & shrubland
Grassland
Major waterway
Saltwater pond
Reservoir
Freshwater pond
Flood risk | high
Flood risk | medium
Flood risk | low
Drought risk | high
Drought risk | medium
Drought risk | low

STRATEGY

STRATEGY

| Dynamic adaptive pathway

| Scenario making

| Prefered pathway

Objectives:
1. Overall target
2. Definition of 'success'
3. Phase target

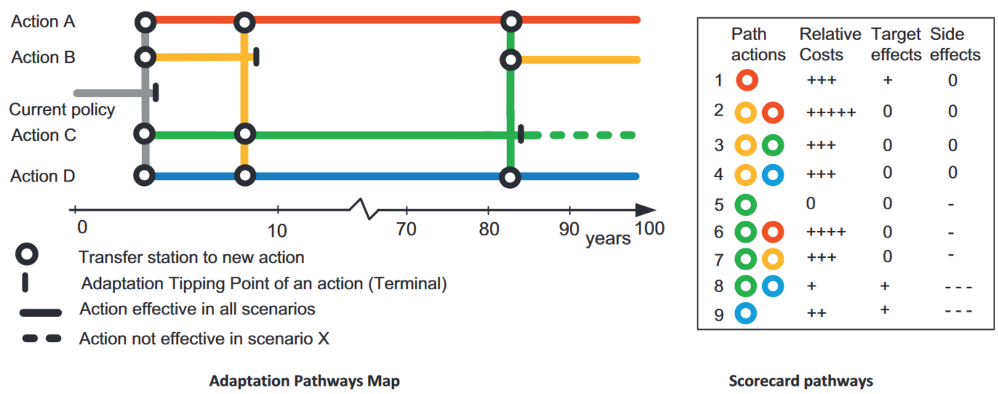
Patterns:
1. Action
2. Relative cost
3. Target effect
4. Side effect
5. Sell-by date

Scenarios:
1. Socio-economic condition
2. Climate change speed
3. Risk composition

→ Dynamic adaptive policy pathways

Input **Method**

↓



(Diagram by Haasnoot et al., 2013)

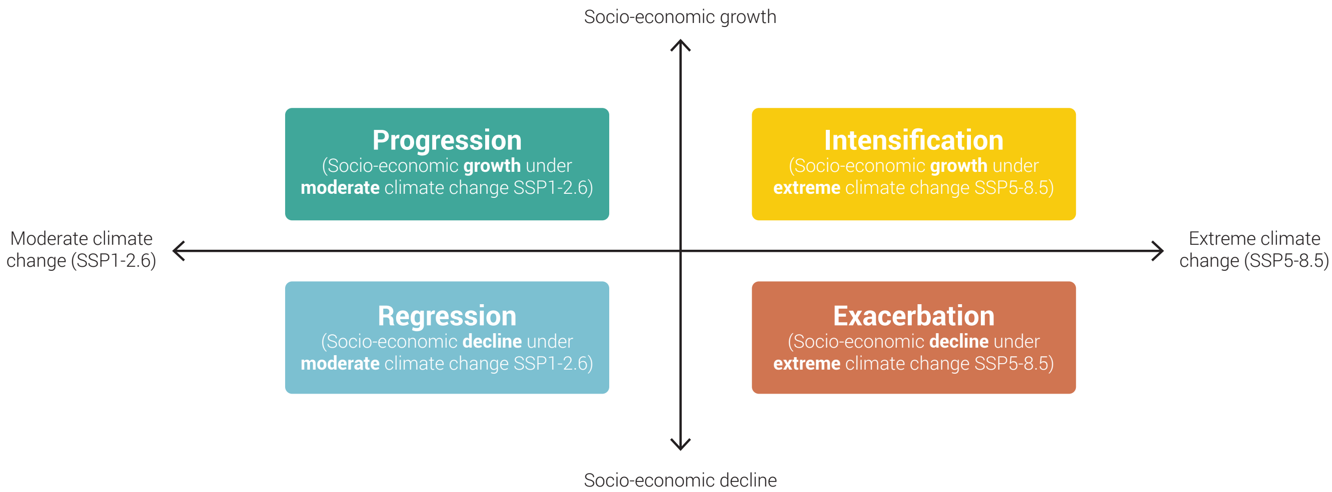
Output

DYNAMIC ADAPTIVE PATHWAY

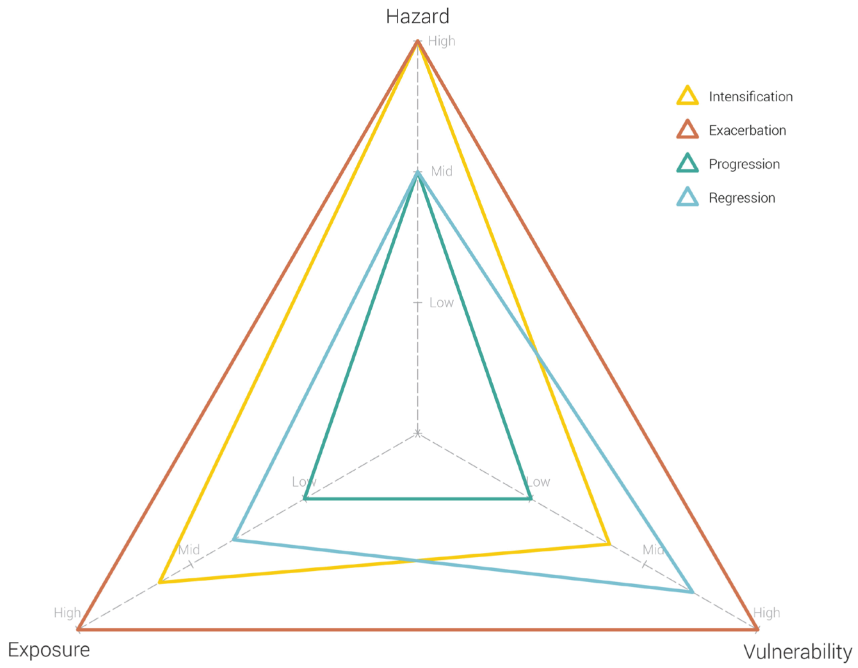
The Dynamic Adaptive Policy Pathway is a framework developed by Deltares and TU Delft to evaluate the robustness and adaptiveness of policies under conditions of deep uncertainty . It integrates concepts from adaptive planning and adaptive pathways with the aim of providing guidance for designing a resilient and flexible plan comprising a series of actions (Haasnoot et al., 2013). These actions encompass both immediate and potential future measures to be implemented over time.

Initially, 'actions' referred solely to policy interventions. However, in this research, the scope of this method has expanded to include the incorporation of 31 spatial and institutional interventions mentioned earlier. Furthermore, the feasibility of implementing these actions in a reasonable sequence by 2060 is explored. Additionally, potential pathways will be validated under four future scenarios that are challenging to predict but plausible, thereby enhancing the feasibility of this proposal amidst the dual uncertainties of future environmental and social conditions.

Fig. 47. Dynamic adaptive pathway - structrue and targets



Socio-economic growth
Progression
(Socio-economic **growth** under **moderate** climate change SSP1-2.6)
Intensification
(Socio-economic **growth** under **extreme** climate change SSP5-8.5)
Moderate climate change (SSP1-2.6)
Extreme climate change (SSP5-8.5)
Regression
(Socio-economic **decline** under **moderate** climate change SSP1-2.6)
Exacerbation
(Socio-economic **decline** under **extreme** climate change SSP5-8.5)
Socio-economic decline



Hazard
High
Mid
Low
Intensification
Exacerbation
Progression
Regression
Exposure
Vulnerability

SCENARIO MAKING

Four scenarios are proposed to address socio-environmental uncertainties in the region, rather than aiming to predict its future trajectory. These scenarios serve to embrace uncertainty and evaluate the preferred course of action under each circumstance.

	Intensification	Exacerbation	Progression	Regression	Ref.
Mean temperature (deg C)	+2.3	+2.3	+1.5	+1.5	(Calvin et al., 2023)
Days with TX above 35ºC	+9.2	+9.2	+6.0	+6.0	(Calvin et al., 2023)
Frost days	-25.7	-25.7	-12.5	-12.5	(Calvin et al., 2023)
Total precipitation during flood season (6-9)	+7.1%	+7.1%	+6.6%	+6.6%	(Calvin et al., 2023)
Total precipitation during non-flood season	+7.3%	+7.3%	+7.8%	+7.8%	(Calvin et al., 2023)
Maximum 1-day precipitation during flood season	+21.1%	+21.1%	+17.8%	+17.8%	(Calvin et al., 2023)
Population of BTH region (million people)	-9	-26	-9	-26	(Zhang et al., 2023)
GDP	+225%	+94%	+225%	+94%	(Jiang et al., 2018)
GDP growth rate	+2% per year	+0% per year	+2% per year	+0% per year	(Jiang et al., 2018)
Builtup area	7%	5%	7%	5%	(Fan, 2022)
Nature and recreation	40%	38%	40%	38%	(Fan, 2022)
Agriculture	53%	57%	53%	57%	(Fan, 2022)

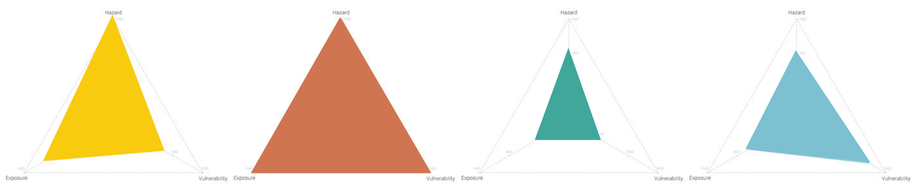
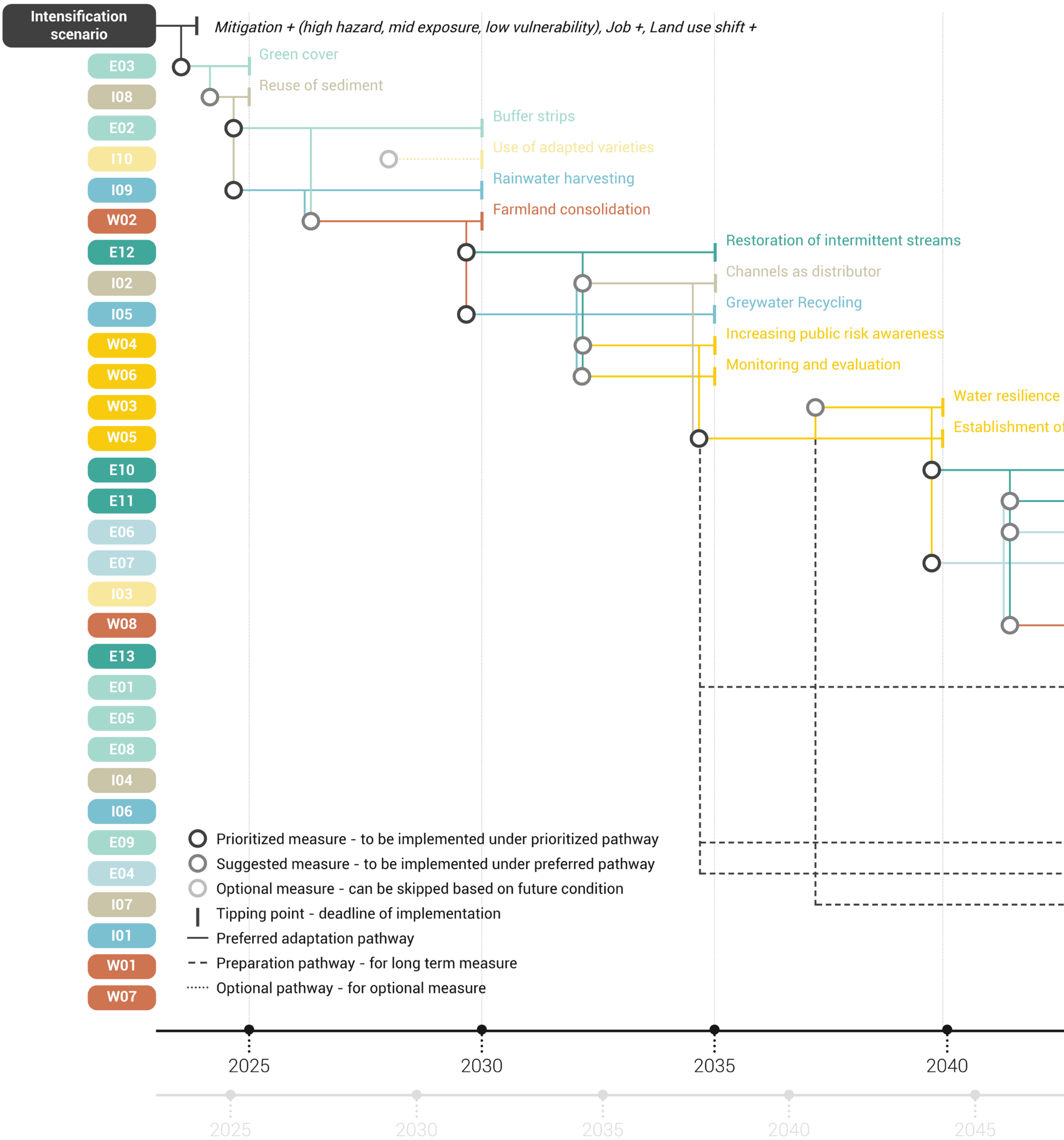


Fig. 48. Scenario making



Intensification scenario
Mitigation + (high hazard, mid exposure, low vulnerability), Job +, Land use shift +
E03
I08
E02
I10
I09
W02
E12
I02
I05
W04
W06
W03
W05
E10
E11
E06
E07
I03
W08
E13
E01
E05
E08
I04
I06
E09
E04
I07
I01
W01
W07
Green cover
Reuse of sediment
Buffer strips
Use of adapted varieties
Rainwater harvesting
Farmland consolidation
Restoration of intermittent streams
Channels as distributor
Greywater Recycling
Increasing public risk awareness
Monitoring and evaluation
Water resilience
Establishment o
Prioritized measure - to be implemented under prioritized pathway
Suggested measure - to be implemented under preferred pathway
Optional measure - can be skipped based on future condition
Tipping point - deadline of implementation
Preferred adaptation pathway
Preparation pathway - for long term measure
Optional pathway - for optional measure
2025
2030
2035
2040
2025
2030
2035
2040
2045

Intensification scenario

This scenario entails socio-economic growth amidst extreme climate change conditions (SSP5-8.5 level). Urbanization will continue to expand alongside socio-economic advancement in intermediate territories. Climate hazards such as droughts and floods will escalate, reaching a medium level of exposure, yet overall vulnerability will remain moderately low due to the compensatory effects of socio-economic growth. Mitigation efforts will be prioritized, with cost not being a significant constraint. Land use shifts will occur more frequently, and job-creating actions will be favored.

# Measure	Target effects (0,+,++,+++) water resilience				Target effects (0,+,++,+++) environmental justice		Costs (0,+,++,+++)		Side effects(---,--,-,0,+,++,+++)		
	Flood mitigation	Drought mitigation	Flood adaptation	Drought adaptation	Equal flood risk distribution	Equal water resource distribution	Initiate	Maintain	Water control capacity	Job opportunity	Environmental impact
now-2030											
Prioritized pathway	2	2	3	0	3	3	2	1	2	1	3
Preferred pathway	3	2	3	1	4	5	3	3	2	5	6
2030-2045											
Prioritized pathway	6	7	5	4	7	8	7	5	-1	4	8
Preferred pathway	8	10	17	15	15	16	17	17	3	12	17
2045-2060											
Prioritized pathway	11	11	11	5	13	11	15	10	5	8	6
Preferred pathway	13	16	11	5	16	17	22	13	5	10	8
By 2060	Flood mitigation	Drought mitigation	Flood adaptation	Drought adaptation	Equal flood risk distribution	Equal water resource distribution	Initiate	Maintain	Water control capacity	Job opportunity	Environmental impact
Prioritized pathway	19	20	19	9	23	22	24	16	6	13	17
Preferred pathway	24	28	31	21	35	38	42	33	10	27	31

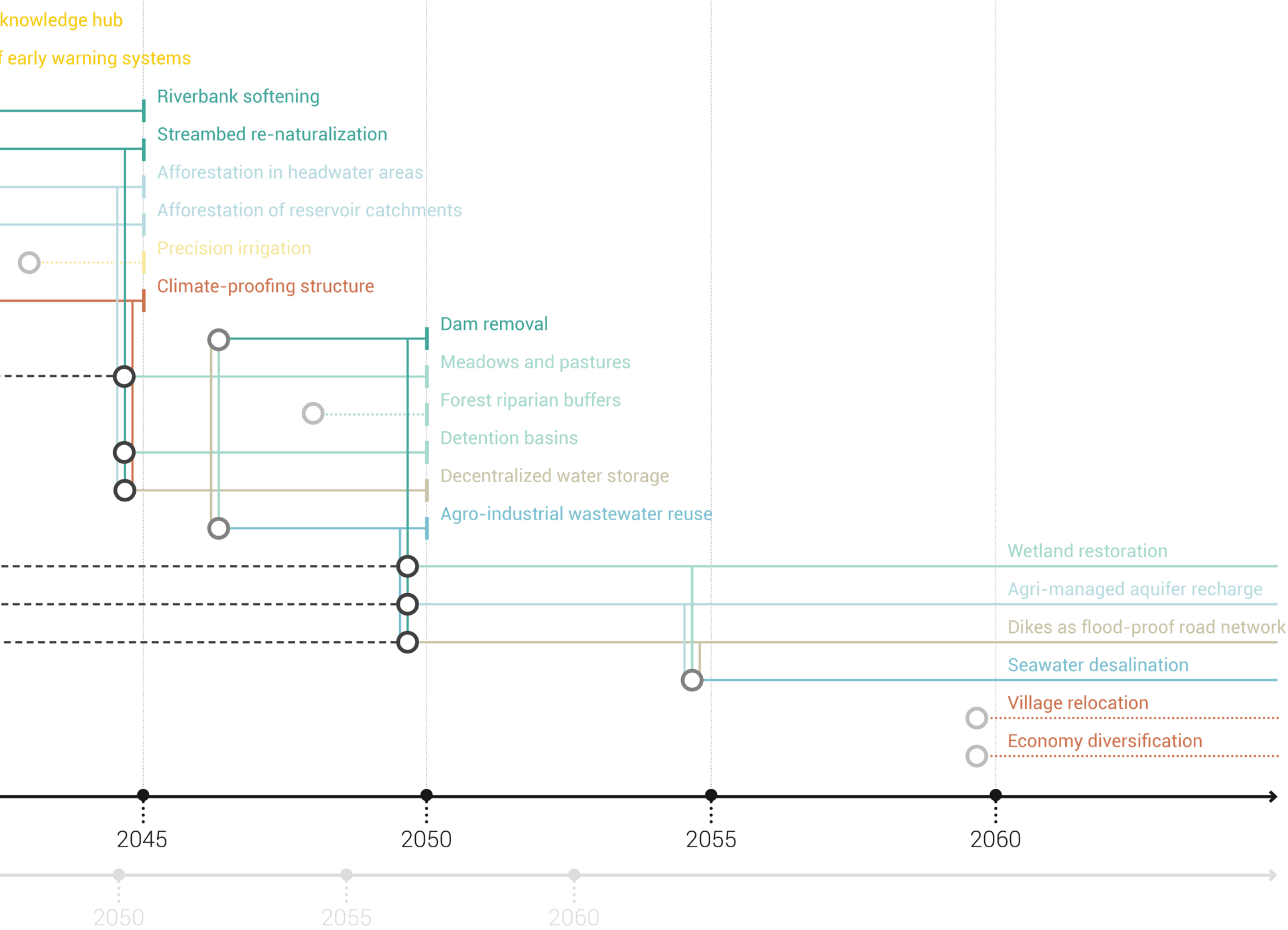
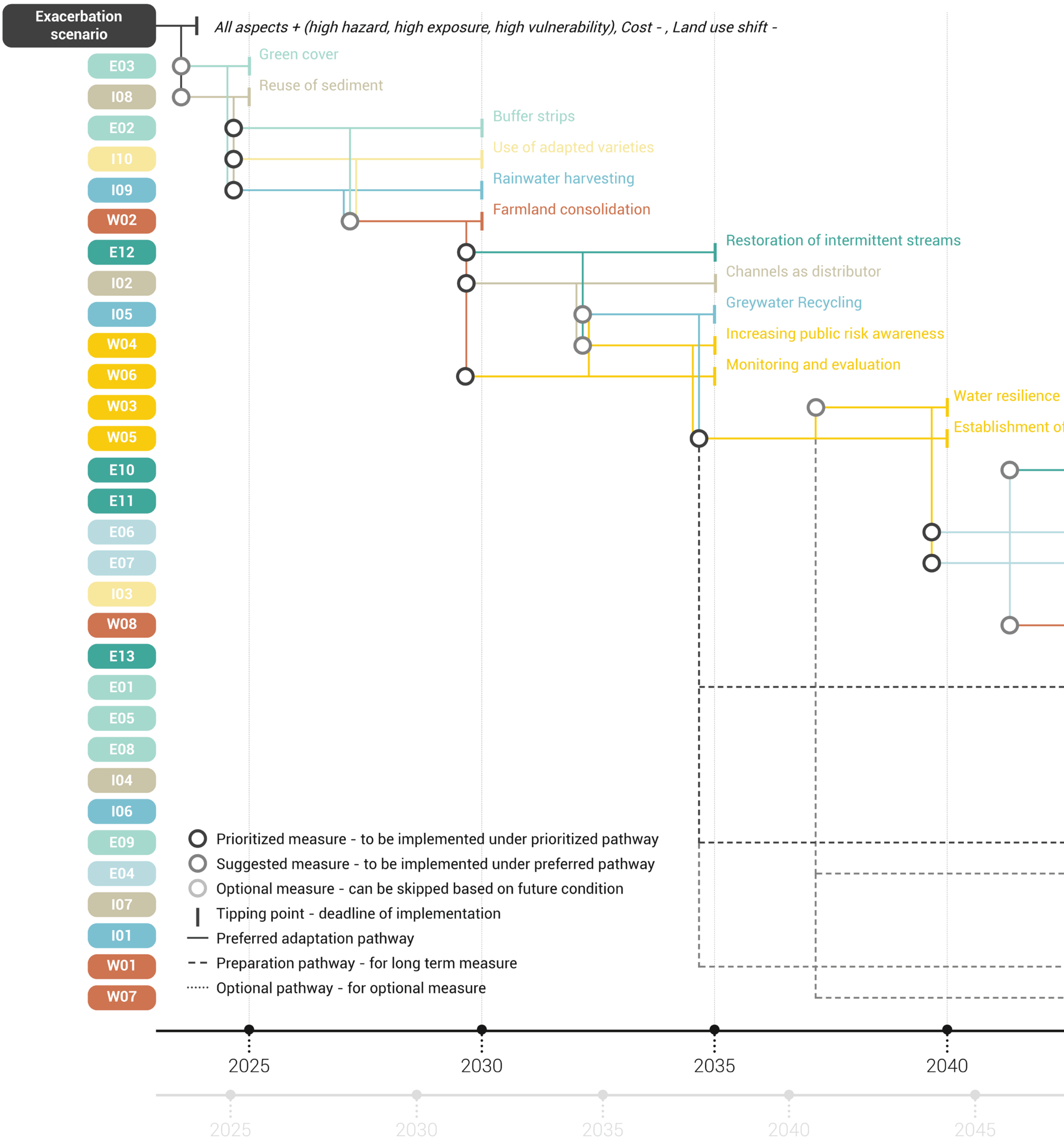


Fig. 49. Prefered pathway - intensification


Exacerbation scenario
All aspects + (high hazard, high exposure, high vulnerability), Cost - , Land use shift -
E03
I08
E02
I10
I09
W02
E12
I02
I05
W04
W06
W03
W05
E10
E11
E06
E07
I03
W08
E13
E01
E05
E08
I04
I06
E09
E04
I07
I01
W01
W07
Green cover
Reuse of sediment
Buffer strips
Use of adapted varieties
Rainwater harvesting
Farmland consolidation
Restoration of intermittent streams
Channels as distributor
Greywater Recycling
Increasing public risk awareness
Monitoring and evaluation
Water resilience
Establishment o
Prioritized measure - to be implemented under prioritized pathway
Suggested measure - to be implemented under preferred pathway
Optional measure - can be skipped based on future condition
Tipping point - deadline of implementation
Preferred adaptation pathway
Preparation pathway - for long term measure
Optional pathway - for optional measure
2025
2030
2035
2040
2025
2030
2035
2040
2045

Exacerbation scenario

In this scenario, socio-economic decline is expected under extreme climate change conditions (SSP5-8.5 level). Urbanization will peak and slightly contract due to population decreases in intermediate territories. Exposure to climate hazards will be high, resulting in the region's overall vulnerability reaching its peak among all scenarios. Cost-effective actions will be prioritized, although cost limitations will be significant. Land use shifts will be less common.

#	Measure	Target effects (0,+,++,+++)						Costs (0,+,++,+++)		Side effects(---,--,-,0,+,++,+++)		
		water resilience		environmental justice								
		Flood mitigation	Drought mitigation	Flood adaptation	Drought adaptation	Equal flood risk distribution	Equal water resource distribution	Initiate	Maintain	Water control capacity	Job opportunity	Environmental impact
	now-2030											
	Prioritized pathway	1	2	3	2	3	3	2	2	2	2	1
	Preferred pathway	3	2	4	3	5	5	4	4	2	6	6
	2030-2045											
	Prioritized pathway	5	5	10	8	11	9	8	9	3	6	9
	Preferred pathway	7	9	17	15	16	15	15	17	4	12	14
	2045-2060											
	Prioritized pathway	7	8	6	5	8	8	9	6	2	6	6
	Preferred pathway	12	11	17	9	20	15	21	14	0	11	13
	By 2060	Flood mitigation	Drought mitigation	Flood adaptation	Drought adaptation	Equal flood risk distribution	Equal water resource distribution	Initiate	Maintain	Water control capacity	Job opportunity	Environmental impact
	Prioritized pathway	13	15	19	15	22	20	19	17	7	14	16
	Preferred pathway	22	22	38	27	41	35	40	35	6	29	33

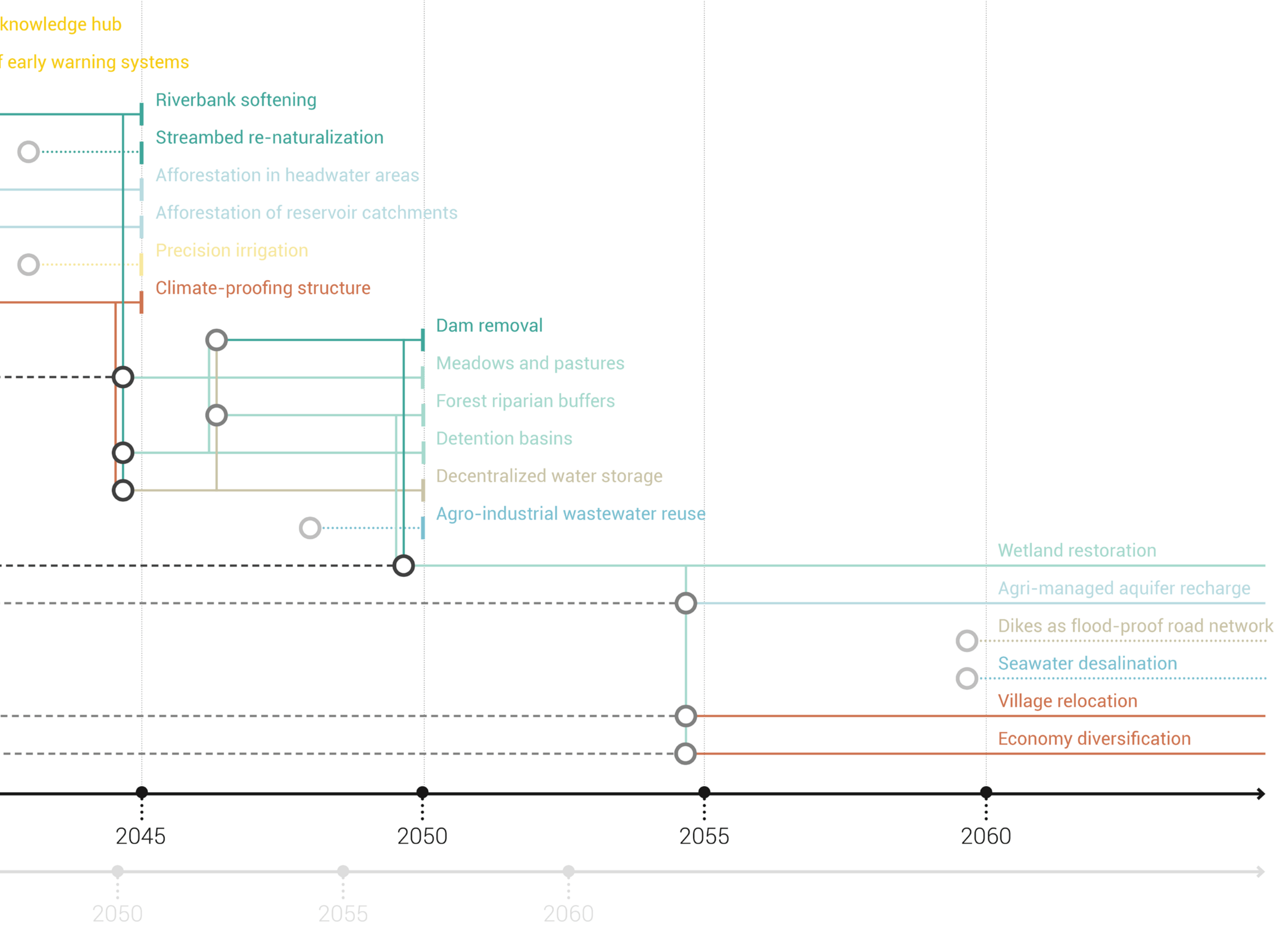
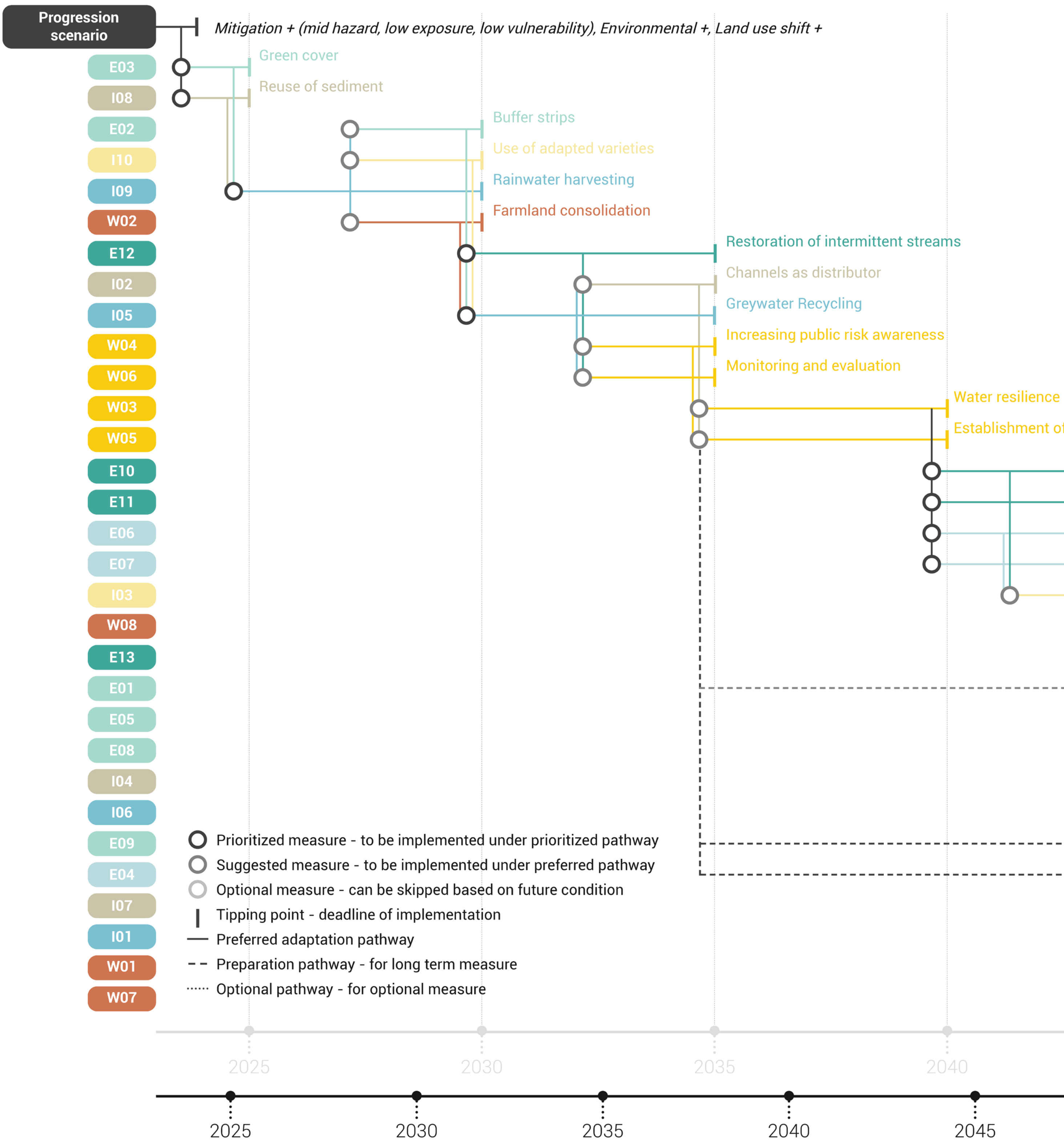


Fig. 50. Prefered pathway - exacerbation



Progression scenario
Mitigation + (mid hazard, low exposure, low vulnerability), Environmental +, Land use shift +
E03
I08
E02
I10
I09
W02
E12
I02
I05
W04
W06
W03
W05
E10
E11
E06
E07
I03
W08
E13
E01
E05
E08
I04
I06
E09
E04
I07
I01
W01
W07
Green cover
Reuse of sediment
Buffer strips
Use of adapted varieties
Rainwater harvesting
Farmland consolidation
Restoration of intermittent streams
Channels as distributor
Greywater Recycling
Increasing public risk awareness
Monitoring and evaluation
Water resilience
Establishment of
Prioritized measure - to be implemented under prioritized pathway
Suggested measure - to be implemented under preferred pathway
Optional measure - can be skipped based on future condition
Tipping point - deadline of implementation
Preferred adaptation pathway
Preparation pathway - for long term measure
Optional pathway - for optional measure
2025
2030
2035
2040
2025
2030
2035
2040
2045

Progression scenario

Under moderate climate change conditions (SSP1-2.6 level), this scenario anticipates continued socio-economic growth, leading to urbanization expansion in intermediate territories. Climate hazards will remain at a moderate level, resulting in decreased exposure and vulnerability compared to other scenarios. Mitigation-focused actions will be favored, with cost not posing a major constraint. Land use shifts will be more prevalent, and actions with positive environmental impacts will be prioritized.

#	Measure	Target effects (0,+,++,+++)						Costs (0,+,++,+++)		Side effects(---,--,-,0,+,++,+++)		
		water resilience				environmental justice						
		Flood mitigation	Drought mitigation	Flood adaptation	Drought adaptation	Equal flood risk distribution	Equal water resource distribution	Initiate	Maintain	Water control capacity	Job opportunity	Environmental impact
	now-2030											
	Prioritized pathway	2	2	1	0	2	3	1	2	1	3	4
	Preferred pathway	3	2	4	3	5	5	4	4	2	6	6
	2030-2045											
	Prioritized pathway	8	10	3	1	7	10	10	3	-2	4	14
	Preferred pathway	8	10	15	16	15	17	17	17	2	12	19
	2045-2060											
	Prioritized pathway	9	8	6	2	10	10	10	5	-2	3	10
	Preferred pathway	12	14	11	5	16	16	18	10	1	8	16
	By 2060	Flood mitigation	Drought mitigation	Flood adaptation	Drought adaptation	Equal flood risk distribution	Equal water resource distribution	Initiate	Maintain	Water control capacity	Job opportunity	Environmental impact
	Prioritized pathway	19	20	10	3	19	23	21	10	-3	10	28
	Preferred pathway	23	26	30	24	36	38	39	31	5	26	41

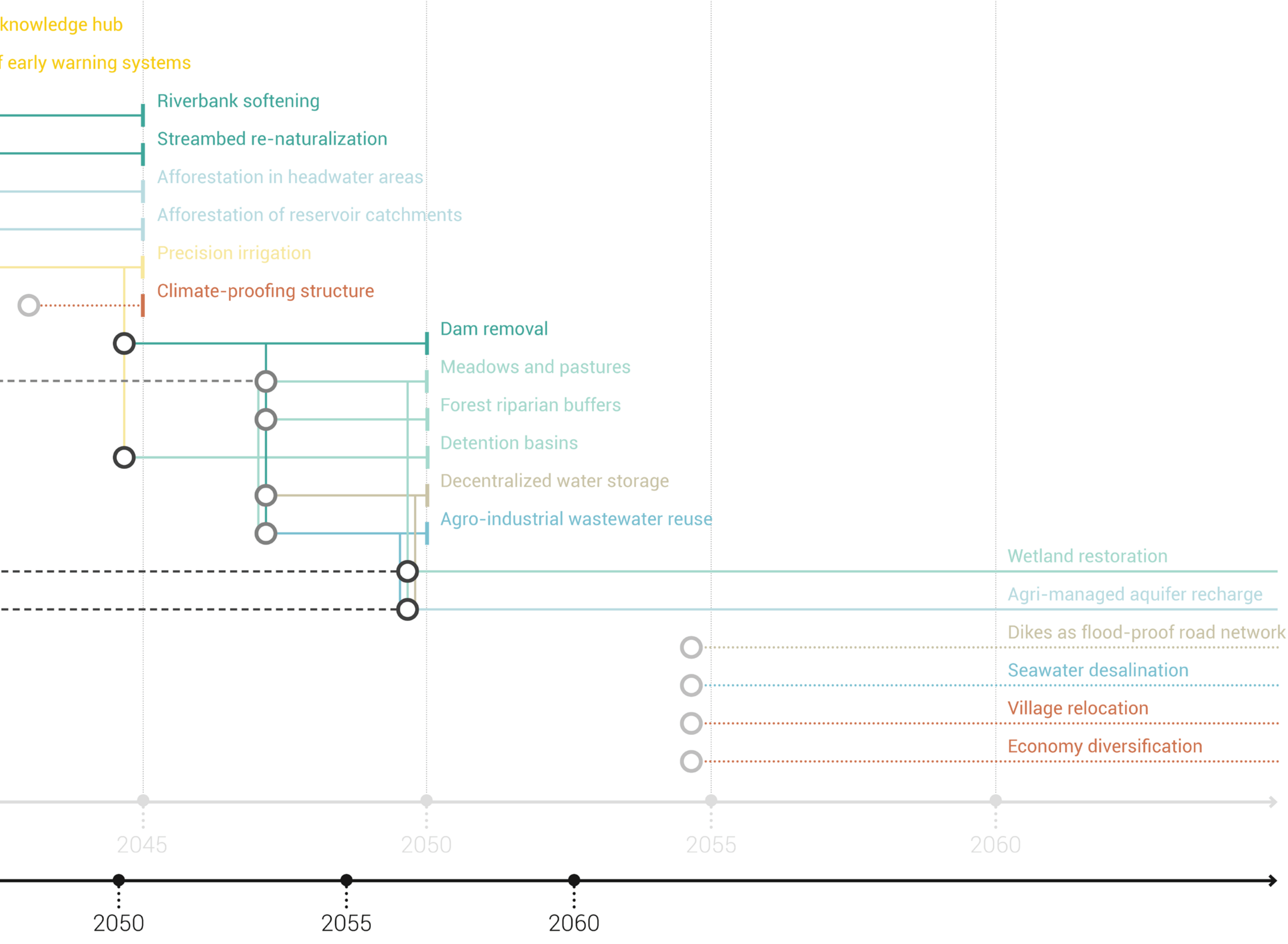


Fig. 51. Prefered pathway - progression


Regression scenario
Adaptation + (mid hazard, low exposure, high vulnerability), Cost - , Land use shift -
E03
I08
E02
I10
I09
W02
E12
I02
I05
W04
W06
W03
W05
E10
E11
E06
E07
I03
W08
E13
E01
E05
E08
I04
I06
E09
E04
I07
I01
W01
W07
Green cover
Reuse of sediment
Buffer strips
Use of adapted varieties
Rainwater harvesting
Farmland consolidation
Restoration of intermittent streams
Channels as distributor
Greywater Recycling
Increasing public risk awareness
Monitoring and evaluation
Water resilience
Establishment o
Prioritized measure - to be implemented under prioritized pathway
Suggested measure - to be implemented under preferred pathway
Optional measure - can be skipped based on future condition
Tipping point - deadline of implementation
Preferred adaptation pathway
Preparation pathway - for long term measure
Optional pathway - for optional measure
2025
2030
2035
2040
2025
2030
2035
2040
2045

Regression scenario

This scenario envisions socio-economic decline amidst moderate climate change conditions (SSP1-2.6 level). Urbanization will peak and slightly decline due to population decreases in intermediate territories. Exposure to climate hazards will be moderate-low, yet the overall vulnerability of the region will remain medium-high due to stalled socio-economic growth. Adaptation-focused actions will be favored, although cost constraints will be significant. Land use shifts will be less frequent.

#	Measure	Target effects (0,+,++,+++)						Costs (0,+,++,+++)		Side effects(---,--,-,0,+,++,+++)		
		water resilience				environmental justice						
		Flood mitigation	Drought mitigation	Flood adaptation	Drought adaptation	Equal flood risk distribution	Equal water resource distribution	Initiate	Maintain	Water control capacity	Job opportunity	Environmental impact
	now-2030											
	Prioritized pathway	1	2	3	2	3	3	2	2	2	2	1
	Preferred pathway	3	2	4	3	5	5	4	4	2	6	6
	2030-2045											
	Prioritized pathway	2	2	9	9	7	7	4	7	2	4	3
	Preferred pathway	4	6	15	18	11	14	13	16	5	11	11
	2045-2060											
	Prioritized pathway	3	4	8	7	7	5	8	6	2	5	5
	Preferred pathway	10	8	15	9	18	12	18	12	-1	11	13
	By 2060	Flood mitigation	Drought mitigation	Flood adaptation	Drought adaptation	Equal flood risk distribution	Equal water resource distribution	Initiate	Maintain	Water control capacity	Job opportunity	Environmental impact
	Prioritized pathway	6	8	20	18	17	15	14	15	6	11	9
	Preferred pathway	17	16	34	30	34	31	35	32	6	28	30

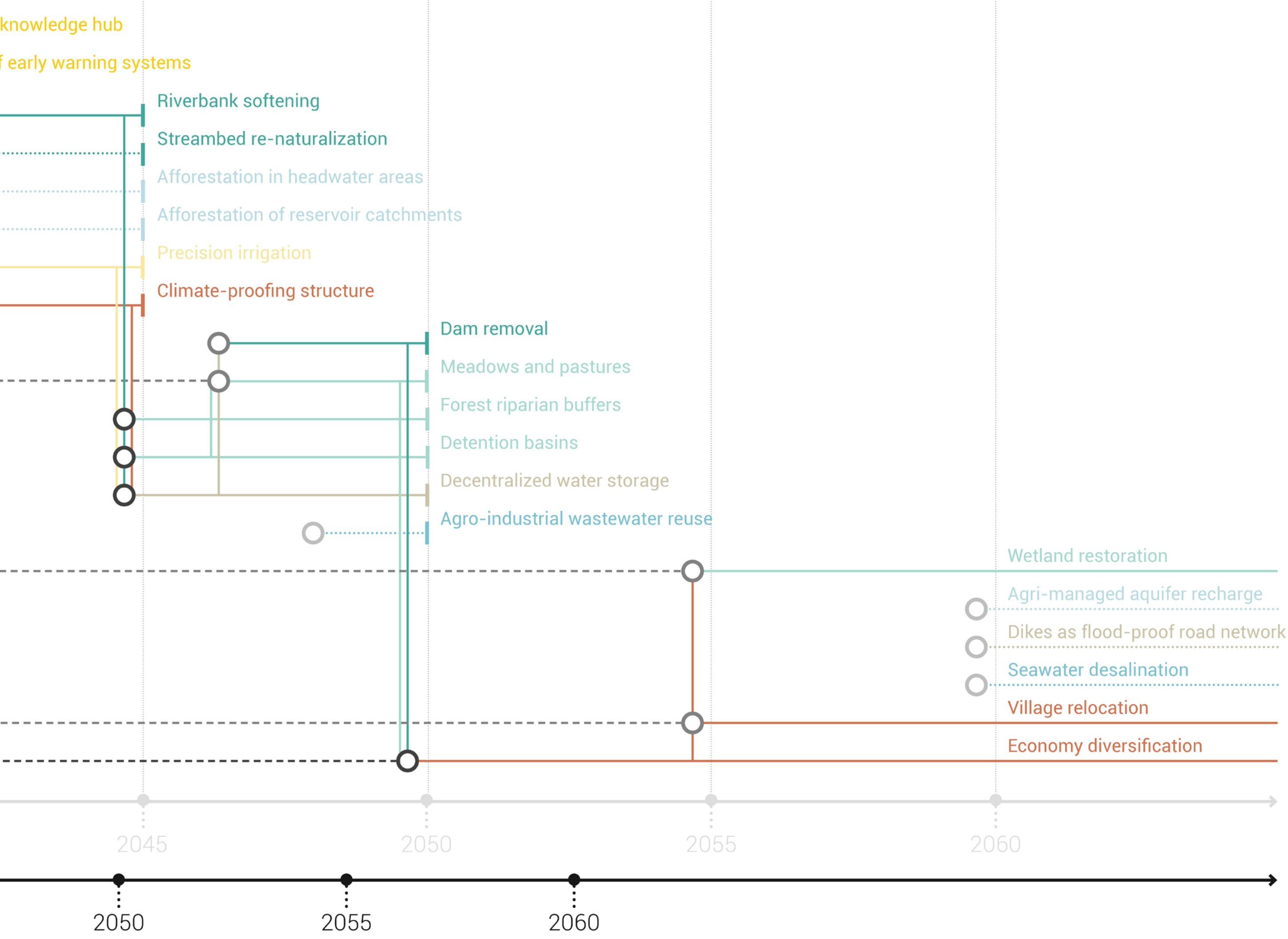


Fig. 52. Prefered pathway - regression

DESIGN

DESIGN

| Fieldwork

| Micro | local adaptation

| Meso | tributary reorganization

| Macro | territory transformation

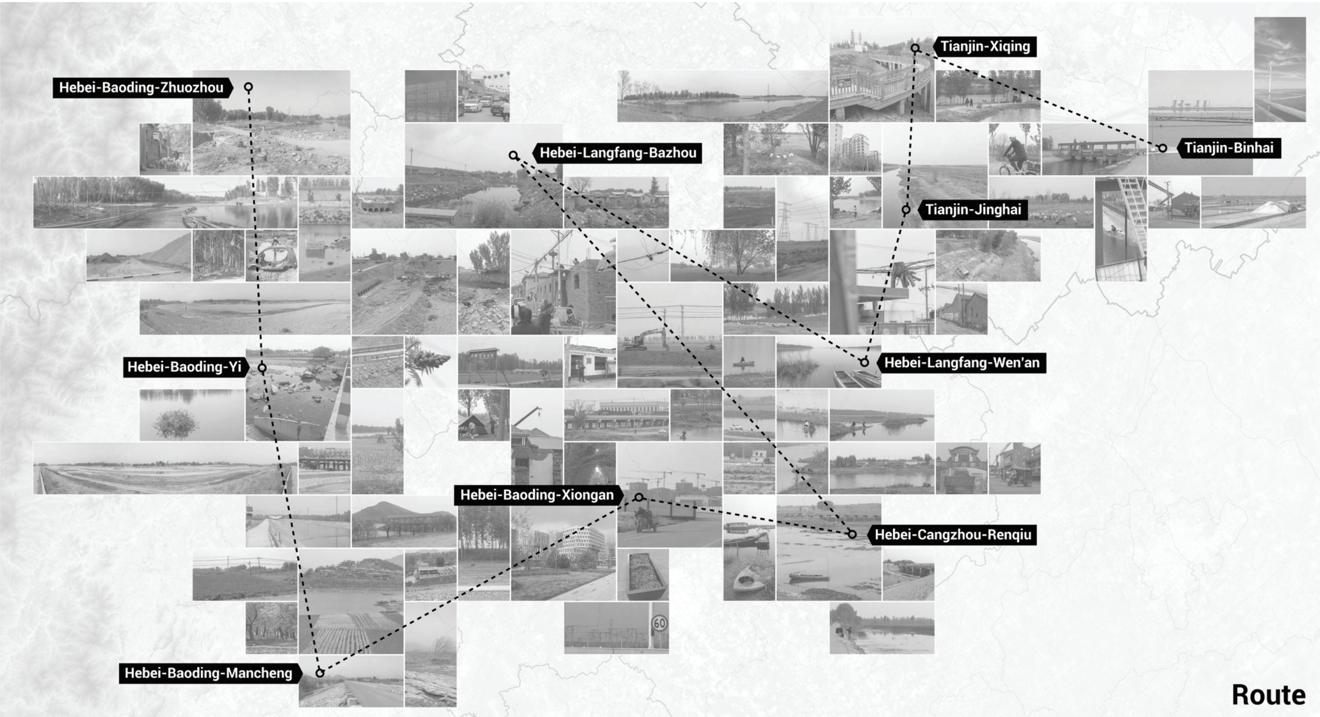


Fig. 53. Fieldwork - route

The excursion initiated at the mouth of the Hai River in Tianjin and proceeded through Bazhou, which sustained significant damage in the preceding year's flood and functioned as a primary Flood Detention Area activated during the calamity. Subsequently, the journey traversed through the Xiong'an New Area, proceeding to the mountainous terrain surrounding the Longmen Reservoir. The expedition concluded in Zhuozhou, which encountered a 12-meter flood last year aimed at safeguarding Beijing and downstream municipalities including Xiong'an and Tianjin.

FIELDWORK

Prior to commencing the design exploration, a field trip was conducted to corroborate previous findings through empirical observation and to gather creative inspiration.

A plethora of visual documentation, including photographs and videos, was amassed to depict the authentic ambiance of the local topography, communal dynamics, and residents' engagements. Dialogues with inhabitants facilitated a nuanced understanding, encompassing their daily routines, experiential narratives pertaining to droughts and floods, as well as their aspirations and needs. Major findings include:

Validation

1. Lack of awareness and over-optimism: People tend to believe they live in a safe area, even if it was hit by a flood last year. They tend to believe it won't happen again in the near future.
2. Insufficient pasture availability: Most fields produce staple food, and forage relies on imports.
3. Top-down projects like Xiongan didn't end well: Residents are mainly previous local villagers instead of new immigrants, and companies don't have enough motivation to move in.
4. Cities and villages represent different worlds: There is a huge gap between the rich and poor.
5. Inefficient irrigation systems: Surface irrigation is more common than sprinkler or drip irrigation.
6. Flood detention areas (FDAs) are actively used.
7. Air quality in the city is improving, while extensive bare land in rural areas is leading to flying dust issues.

Inspiration

1. People love fishing (recreational).
2. Conflict between farmland preservation (red line policy) and labor shortages.
3. Government compensation schemes are not sustainable: While generous compensation was given to farmers for rebuilding and agricultural losses, they are encouraged to rebuild their lives exactly the same as before, with no options or policies to encourage people to move away from high-risk areas.
4. Disparity between agricultural and industrial income: Most fields produce staple food, leaving farmers with very little profit margin. Many farmers lease their land instead of farming it themselves.
5. Consolidation needs to be accompanied by education and opportunities; otherwise, people lack the motivation to move from risk or change the way they live. There is a knowledge gap for farmers to try other work as well.
6. Emphasis remains heavily on grey infrastructure: Rivers are dammed and interconnected by pipelines. Most of the rebuild projects along the river are still dams with designated capacities for flood flow and traditional dikes.
7. Transportation networks require improvement: Many low-capacity roads and bridges are congested by heavy trucks, as there is a lack of medium-grade roads connecting towns and villages.
8. Numerous timber processing plants result in high water consumption and pollution.


60

Fig. 54. Fieldwork - impression

A plethora of visual documentation, including photographs and videos, was amassed to depict the authentic ambiance of the local topography, communal dynamics, and residents' daily life.

Impression

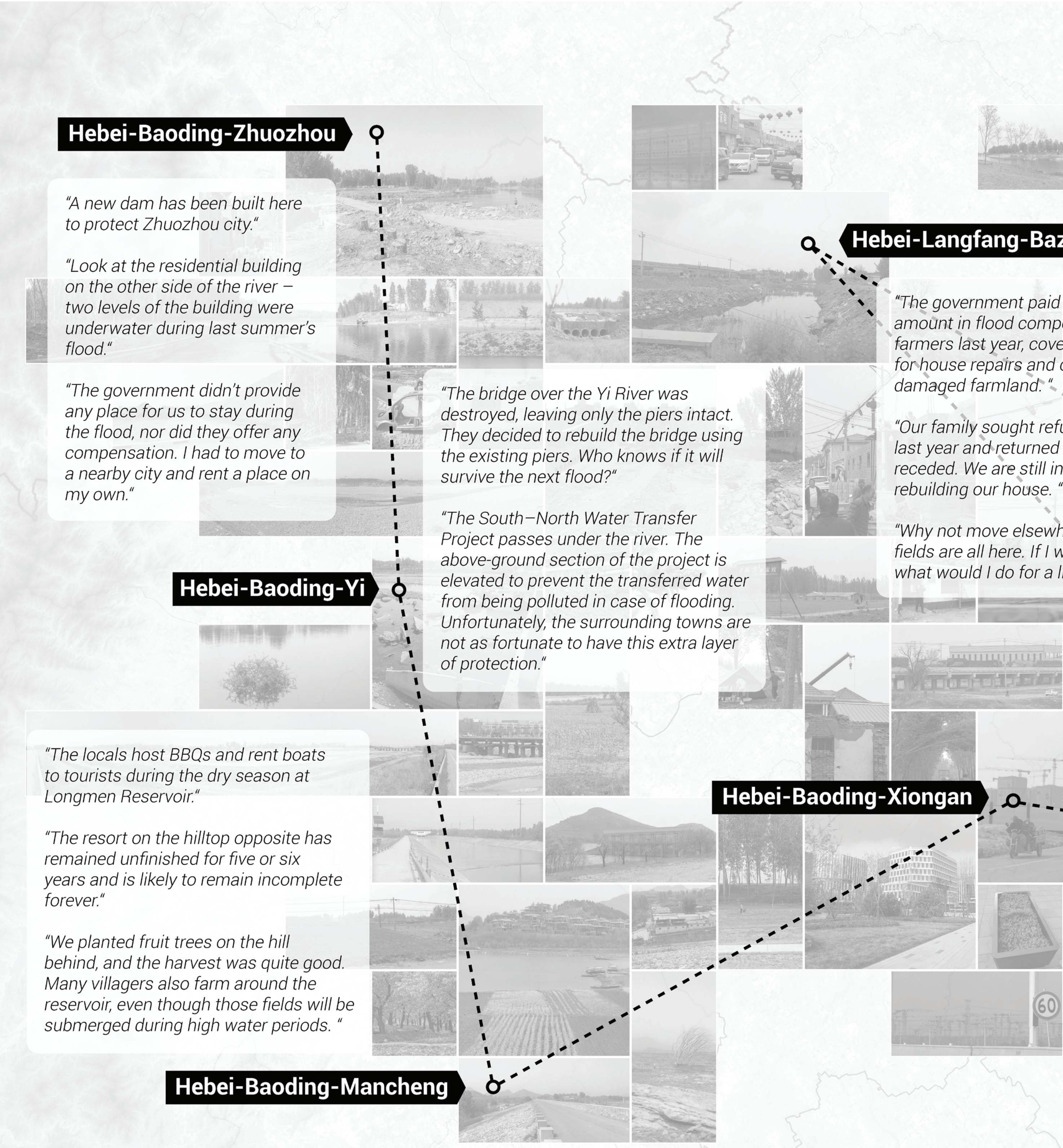
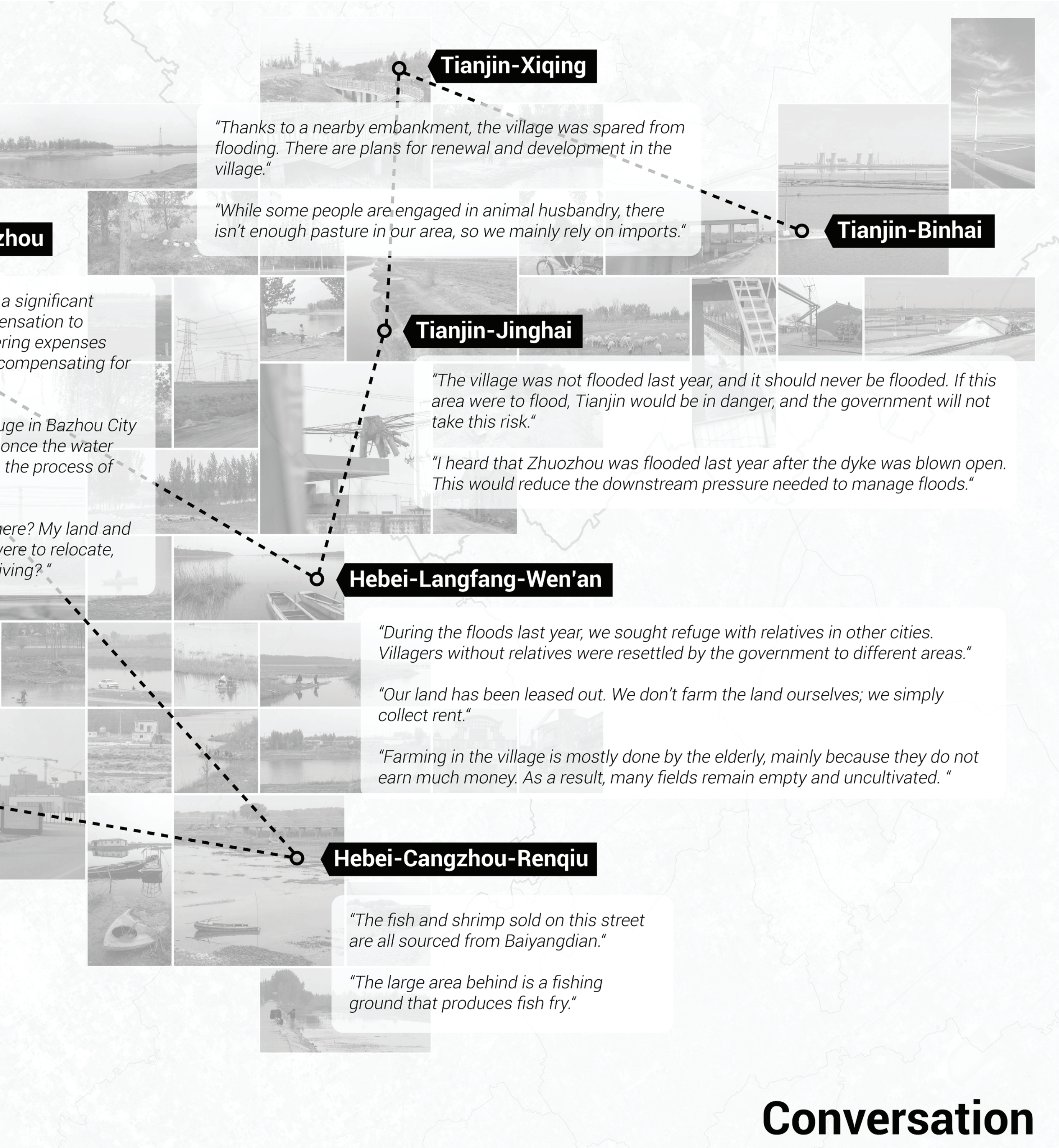

Hebei-Baoding-Zhuozhou
"A new dam has been built here to protect Zhuozhou city."
"Look at the residential building on the other side of the river – two levels of the building were underwater during last summer's flood."
"The government didn't provide any place for us to stay during the flood, nor did they offer any compensation. I had to move to a nearby city and rent a place on my own."
Hebei-Langfang-Baz
"The government paid amount in flood comp farmers last year, cove for house repairs and damaged farmland."
"Our family sought refu last year and returned receded. We are still in rebuilding our house."
"Why not move elsewh fields are all here. If I w what would I do for a l
"The bridge over the Yi River was destroyed, leaving only the piers intact. They decided to rebuild the bridge using the existing piers. Who knows if it will survive the next flood?"
"The South–North Water Transfer Project passes under the river. The above-ground section of the project is elevated to prevent the transferred water from being polluted in case of flooding. Unfortunately, the surrounding towns are not as fortunate to have this extra layer of protection."
Hebei-Baoding-Yi
"The locals host BBQs and rent boats to tourists during the dry season at Longmen Reservoir."
"The resort on the hilltop opposite has remained unfinished for five or six years and is likely to remain incomplete forever."
"We planted fruit trees on the hill behind, and the harvest was quite good. Many villagers also farm around the reservoir, even though those fields will be submerged during high water periods."
Hebei-Baoding-Xiongan
Hebei-Baoding-Mancheng
60

Fig. 55. Fieldwork - conversation

Dialogues with inhabitants facilitated a nuanced comprehension, encompassing their quotidian routines, experiential narratives pertaining to droughts and floods, as well as their aspirations and requisites.



Conversation


Bazhou
Laodi
Zhongting River
Xiawuge
Koutou
Suqiao
Daqing River
Xinzhen
Zhaowang New River

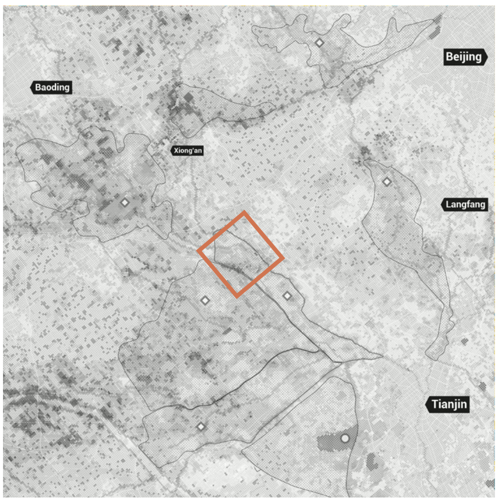
MICRO | LOCAL ADAPTATION

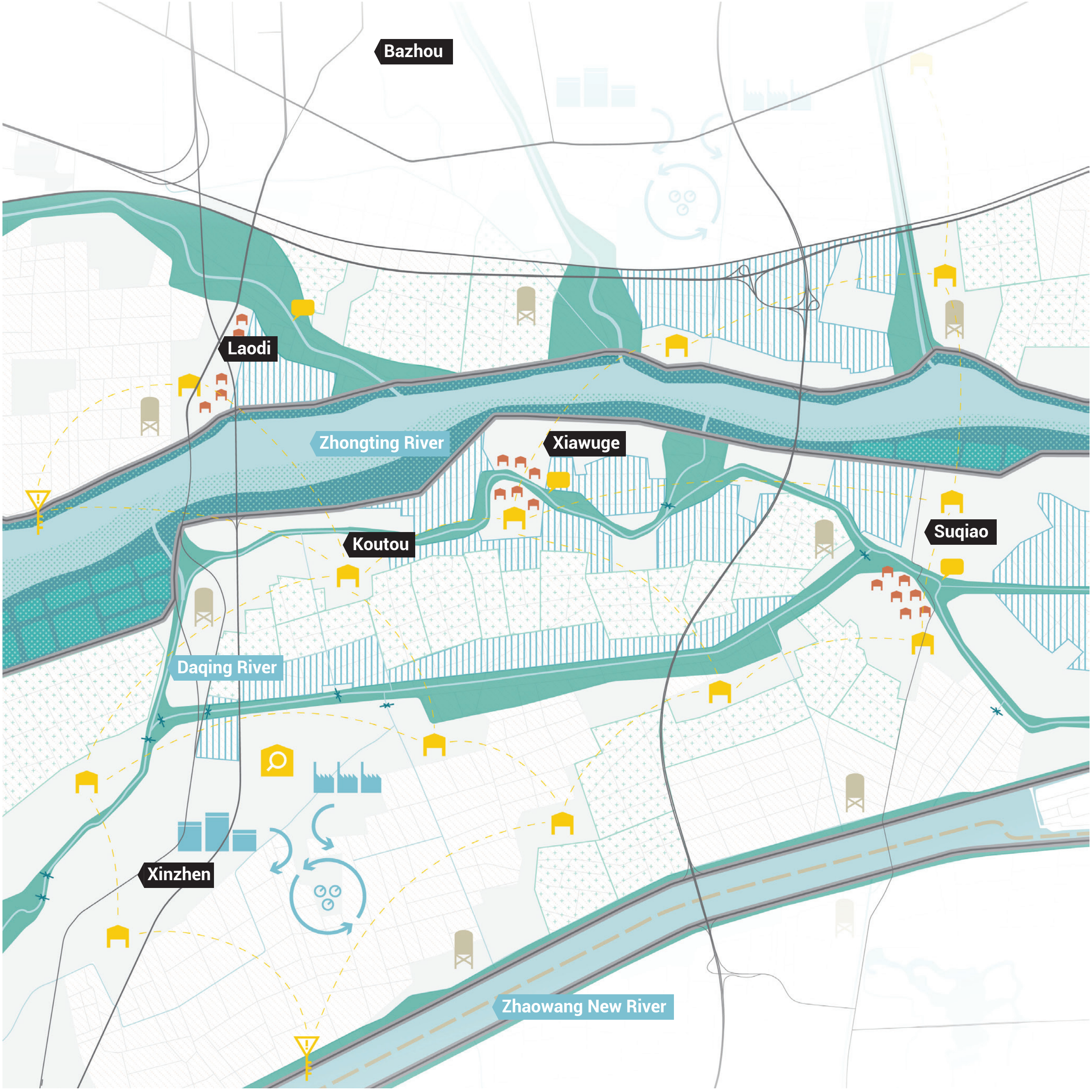
The micro-scale zoom-in has been conducted in the Dongdian Flood Detention Area, which comprises a typical agglomeration of developing villages and towns proximate to Bazhou city. This region experienced complete inundation during the previous year's flood season, with an average water depth exceeding 2 meters. A considerable number of residents were evacuated to shelters within Bazhou. The Zhaowang New River, situated in the southern sector of the area, functions as a recently constructed flood discharge channel spanning over 500 meters in width. Remnants of former farmland topography are discernible on the riverbed during periods of low precipitation. In the event that the influx of floodwater surpasses the capacity of this discharge channel, surplus water will be redirected into the Dongdian FDA situated northward of the discharge channel. This measure is implemented to mitigate the risk of uncontrolled levee breaches downstream. Owing to regulatory measures enacted at upstream dams and the utilization of the Zhaowang New River as the primary flood discharge conduit, other tributaries within the region have gradually transitioned into seasonal watercourses. However, these tributaries face significant obstruction due to the accumulation of domestic waste from local residents, rendering them nearly ineffective in water discharge during periods of heavy precipitation. Furthermore, unregulated urban expansion along the banks of these rivers has resulted in pronounced degradation of vegetation, exacerbating visible erosion throughout the area.

Fig. 56. Micro scale zoom-in location | Dongdian FDA

Built-up area | low development level
Built-up area | medium development level
Built-up area | high development level
Dike
Forest
Road
Waterway

0 600 1200 m





Bazhou
Laodi
Zhongting River
Xiawuge
Koutou
Suqiao
Daqing River
Xinzhen
Zhaowang New River

Intensification scenario

This scenario entails socio-economic growth amidst severe climate change conditions. With the ongoing economic expansion, the populations of small villages are anticipated to remain stable or potentially increase. Given this context, the feasibility and cost-effectiveness of large-scale village relocation are questionable. Nevertheless, the heightened frequency of floods due to extreme climate change underscores the necessity for effective flood management strategies.

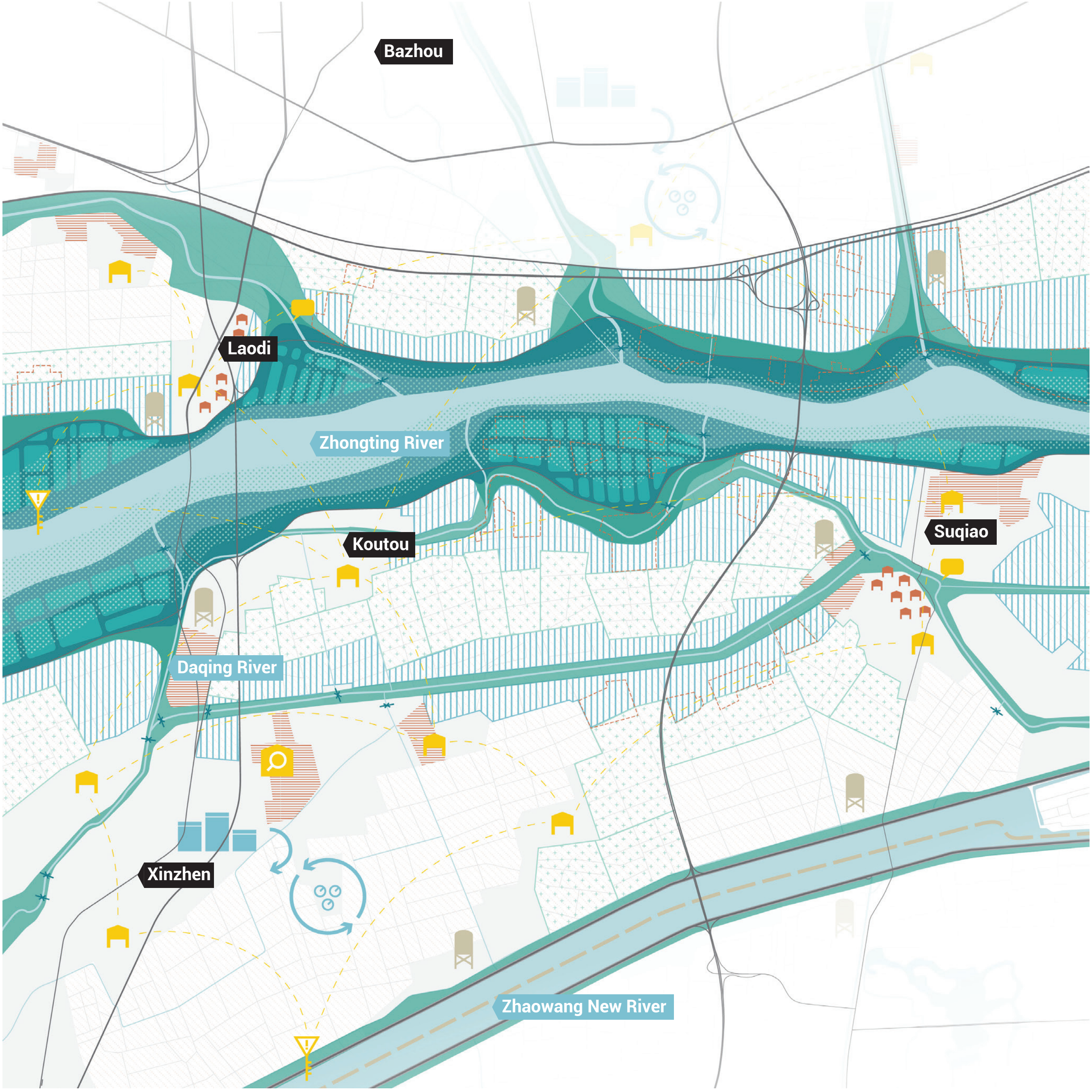
A notable aspect of this scenario is the implementation of a new dike system along the widened Zhongting River, aimed at maximizing flood mitigation and adaptation capabilities. By expanding the Zhongting River, the burden of flood control on the southern Zhaowang New River is alleviated, thereby safeguarding the Dongdian flood detention area from inundation. Moreover, the widened river will incorporate detention ponds repurposed from agricultural land, facilitating water storage and regulating the water balance during periods of heavy rainfall. Additionally, the presence of wetlands along the river serves as a natural buffer zone, absorbing flood impact and reducing pressure on the dike structure.

Efforts will be made to manage excess floodwater efficiently, diverting it into agricultural managed aquifer recharge fields and surrounding pastures. This approach ensures gradual seepage of water into the ground, contributing to sustainable water management practices in the region.

Fig. 57. Micro scale | intensification | local adaptation plan

Wetland restoration
Detention basins
Farmland consolidation
Agri-managed aquifer recharge
Meadows and pastures
Decentralized water storage
Climate-proofing structure
Monitoring and evaluation
Water resilience knowledge hub
Monitoring and evaluation
Early warning system
Water recycling
Dam removal
Buffer strips
Reuse of sediment
Dike
Riverbank softening
Road
Waterway

0 600 1200 m


Bazhou
Laodi
Zhongting River
Koutou
Suqiao
Daqing River
Xinzhen
Zhaowang New River

Exacerbation scenario

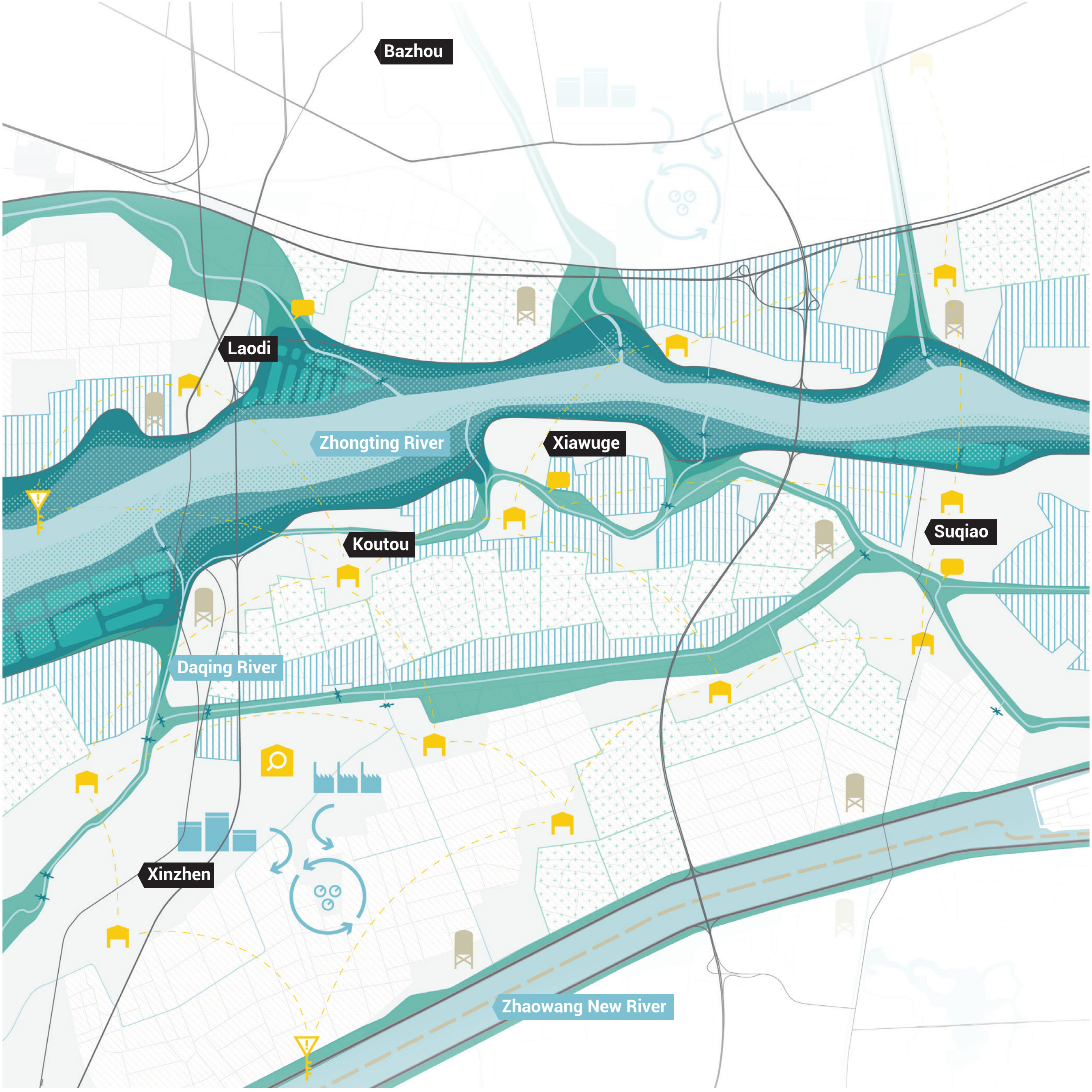
In the context of socio-economic decline exacerbated by extreme climate change conditions, small villages are anticipated to undergo depopulation and eventual abandonment due to economic stagnation. Consequently, village relocation emerges as a viable strategy. Government intervention is expected to facilitate post-disaster reconstruction efforts, encouraging and supporting residents to relocate either to nearby urban centers or to areas with lower flood risks within proximity.

Under such circumstances, the frequency of floods is likely to increase. However, the consolidation of dispersed small villages offers the opportunity to designate more high-risk land for flood mitigation purposes, such as detention basins, wetlands, and forests. Consequently, the necessity for expensive dike systems, particularly along the Zhongting River, may diminish. While the widened Zhongting River remains effective in reducing flood risks along the southern Zhaowang New River, the management approach differs from the intensification scenario. In this scenario, excess flood water is channeled into detention basins and river wetlands, where it is gradually released and absorbed into the ground. This process aids in water storage and balance regulation, with surplus water directed into agricultural managed aquifer recharge fields and surrounding pastures.

Fig. 58. Micro scale | exacerbation | local adaptation plan

Forest riparian buffers
Wetland restoration
Detention basins
Economy diversification
Farmland consolidation
Agri-managed aquifer recharge
Meadows and pastures
Village relocation
Decentralized water storage
Climate-proofing structure
Monitoring and evaluation
Water resilience knowledge hub
Monitoring and evaluation
Early warning system
Water recycling
Dam removal
Buffer strips
Reuse of sediment
Dike
Riverbank softening
Road
Waterway

0 600 1200 m


Bazhou
Laodi
Zhongting River
Xiawuge
Koutou
Suqiao
Daqing River
Xinzhen
Zhaowang New River

Progression scenario

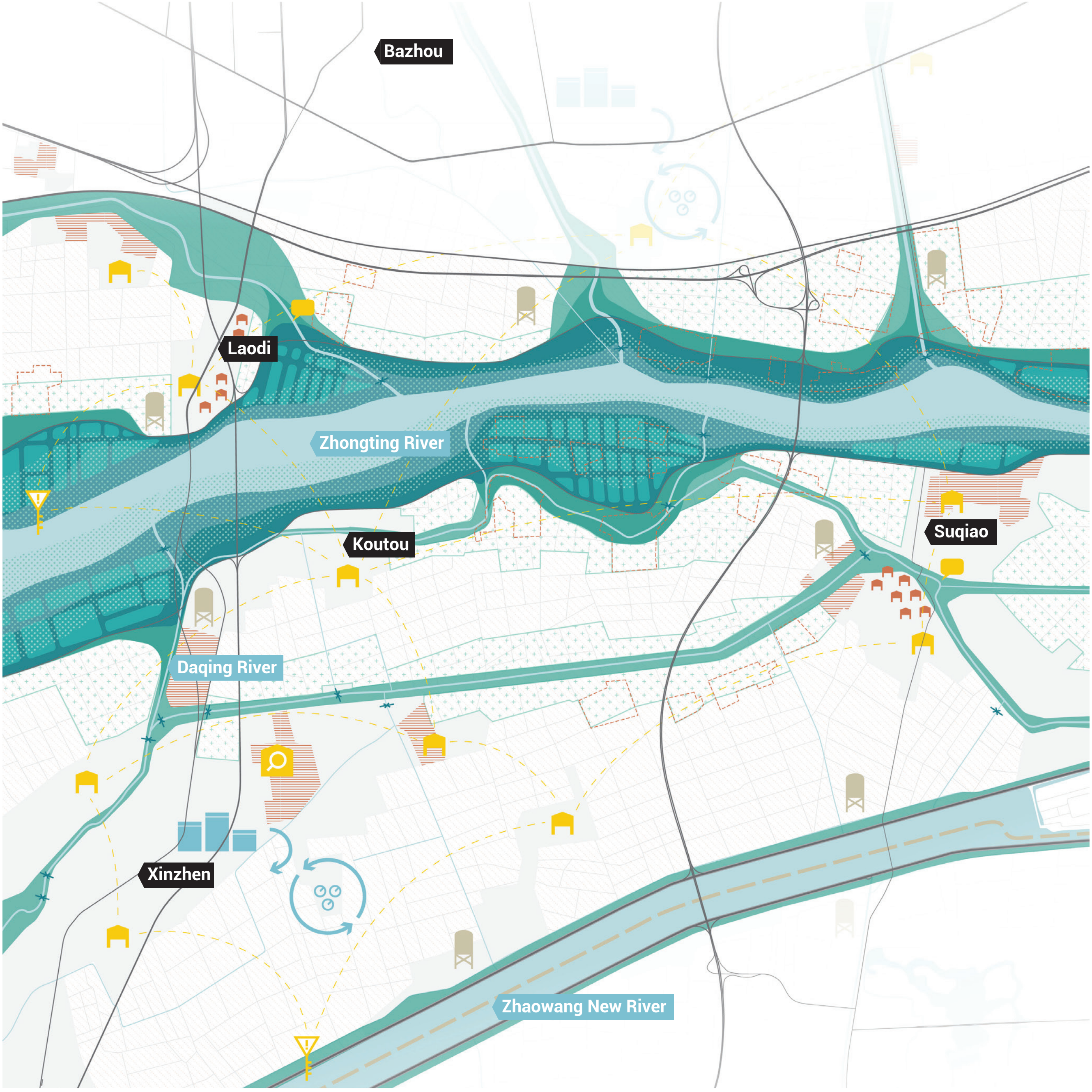
This scenario entails socio-economic growth amidst moderate climate change conditions. Comparable to the Intensification scenario, sustained economic development is anticipated to maintain or potentially expand the current population size of small villages. In this context, the feasibility and practicality of large-scale village relocation are questioned due to associated costs and logistical challenges. Moreover, the occurrence of floods is expected to decrease under these milder climate change conditions. Consequently, the implementation of a high-cost dike system along the Zhongting River may not be deemed imperative.

Instead, a more cost-effective and environmentally compatible approach could involve expanding the Zhongting River through measures akin to those proposed in the Exacerbation scenario, such as integrating detention basins, linear wetlands, and afforestation efforts. However, this approach would be implemented on a smaller scale and tailored to harmonize with the existing riverside villages. Furthermore, the restoration of the Daqing River, along with the removal of several dams obstructing water flow, is recommended to enhance flood resilience, recreational amenities, and mitigate environmental repercussions.

Fig. 59. Micro scale | progression | local adaptation plan

Forest riparian buffers
Wetland restoration
Detention basins
Economy diversification
Farmland consolidation
Agri-managed aquifer recharge
Meadows and pastures
Decentralized water storage
Monitoring and evaluation
Water resilience knowledge hub
Monitoring and evaluation
Early warning system
Water recycling
Dam removal
Buffer strips
Reuse of sediment
Dike
Riverbank softening
Road
Waterway

0 600 1200 m



Bazhou
Laodi
Zhongting River
Koutou
Suqiao
Daqing River
Xinzhen
Zhaowang New River

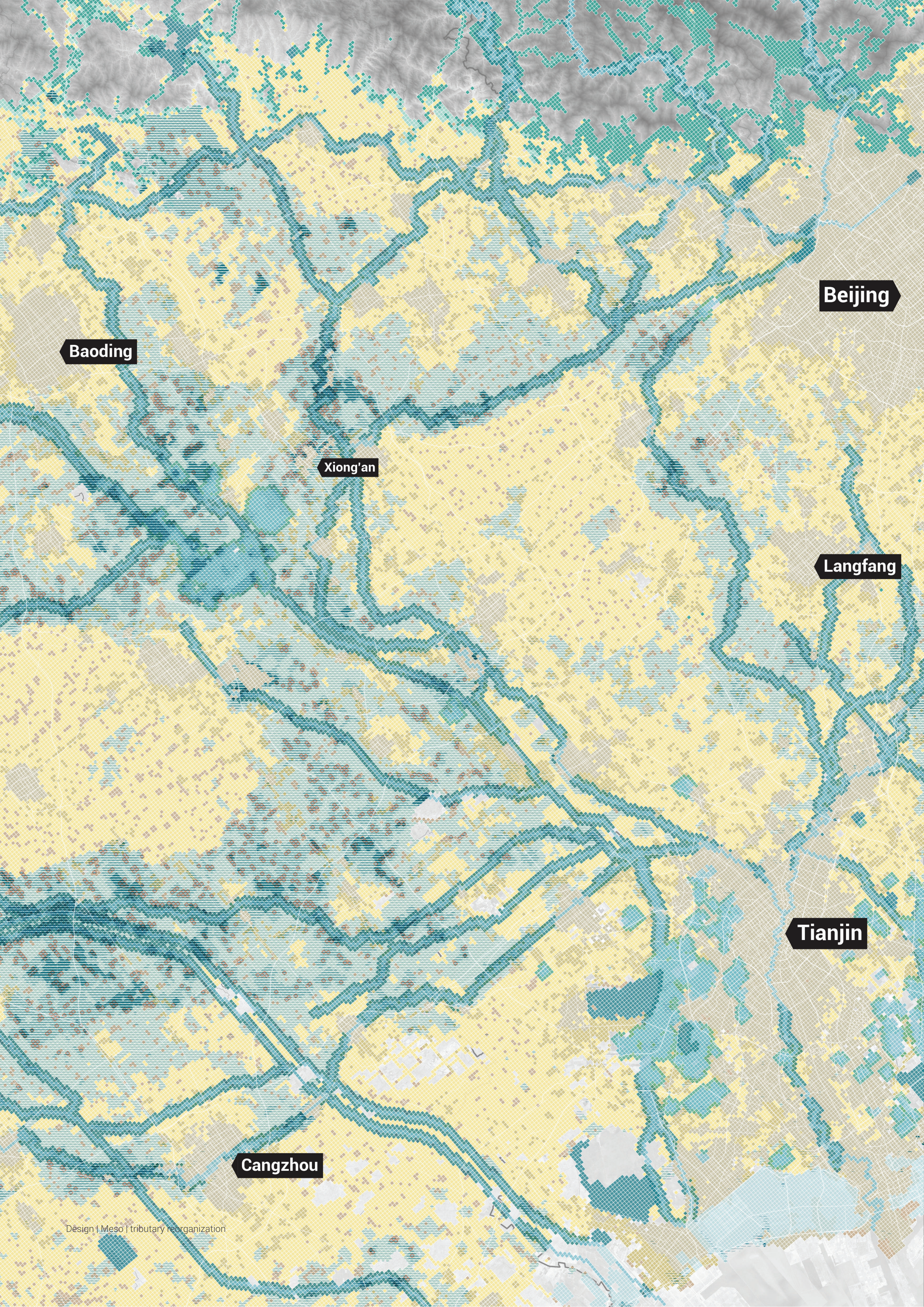
Regression scenario

This scenario is marked by socio-economic decline amid moderate climate change conditions. As with the Exacerbation scenario, against a backdrop of economic stagnation, existing small villages are likely to experience a reduction in population size, potentially leading to their transformation into hollow villages. In such circumstances, village relocation emerges as a feasible and pragmatic option. Concurrently, the relocation and consolidation of scattered small villages could facilitate the transfer of high-risk land to detention basins, wetlands, and forests for mitigating flood impacts. Given the mild nature of climate change, the implementation of a costly dike system along the Zhongting River may not be deemed necessary. Instead, a strategy akin to that proposed in the Exacerbation scenario, incorporating detention basins, linear wetlands, and forests, could be adopted to expand the Zhongting River. A portion of the government budget ought to be earmarked for incentivizing economic diversification in the region, aimed at reducing reliance on traditional agriculture and thereby mitigating the adverse effects of droughts or floods on the economy.

Fig. 60. Micro scale | regression | local adaptation plan

Forest riparian buffers
Wetland restoration
Detention basins
Economy diversification
Farmland consolidation
Meadows and pastures
Village relocation
Decentralized water storage
Monitoring and evaluation
Water resilience knowledge hub
Monitoring and evaluation
Early warning system
Water recycling
Dam removal
Buffer strips
Reuse of sediment
Dike
Riverbank softening
Road
Waterway

0 600 1200 m



Beijing
Baoding
Xiong'an
Langfang
Tianjin
Cangzhou
Design | Meso | tributary reorganization

MESO | TRIBUTARY REORGANIZATION

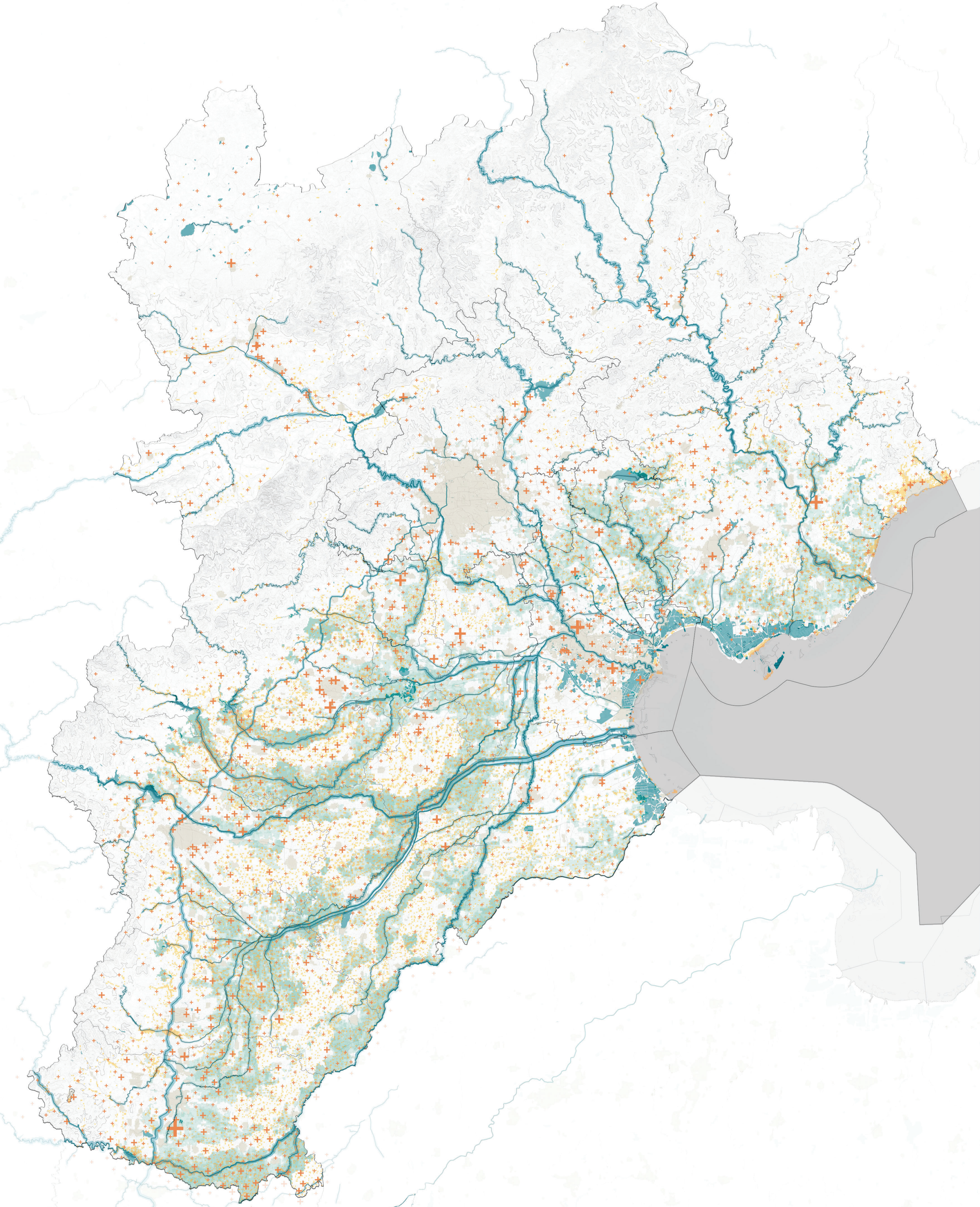
At the meso scale, this study examines potential tributary reorganization using the most plausible exacerbation scenario as a case study. Drawing from micro-scale testing, projections suggest that by 2060, the main rivers in the region will undergo modest widening, alongside efforts such as wetland restoration and riparian afforestation. These measures aim to enhance flood-carrying capacity and balance water resources between dry and wet seasons. Consequently, villages with limited development in high-risk zones may experience population decline. However, this presents an opportunity for their relocation to safer areas. Subsequently, land in flood-prone regions may become available, primarily allocated for pasture or agricultural measures with Managed Aquifer Recharge (Ag-MAR). This land use strategy serves dual purposes: providing seasonal grazing and agricultural areas during dry periods, and functioning as temporary reservoirs during rainy seasons. This approach aims to replenish groundwater and mitigate flood peaks, thereby safeguarding communities from flood-related damages.

In contrast to centralized Flood Detention Areas (FDAs), the proposed strategy advocates for decentralized flood retention and buffering. This involves utilizing patchy non-residential areas along the river within the Hai River Basin. The quantitative impact of this tributary reorganization will be assessed against the current FDA capacity in the assessment chapter to ascertain the viability of this proposal.

Fig. 61. Meso scale | exacerbation | tributary reorganization

Relocated built-up area
Built-up area
Farmland
Forest & shrubland
Grassland
Pasture & Ag-MAR farmland
Freshwater
Highway
Railway

0 5 10 km



Design | Macro | territory transformation

MACRO | TERRITORY TRANSFORMATION

As for the regional vision that integrates the four scenarios together, by 2060, tributaries of varying sizes within the Hai River Basin, the restored floodplains, coupled with a network fostering collective water knowledge sharing and water risk-sharing among towns and villages within the territories-in-between. Together, these components are poised to establish a decentralized water-resilient mosaic. Through the restoration of rivers' ecological service functions and the implementation of multifunctional land use, this territorial transformation aims to mitigate the limitations associated with the existing FDA-style water risk transfer mechanism, adopting a more environmentally equitable approach. Consequently, surrounding towns and villages are expected to achieve greater self-resilience. These numerous self-resilient units are envisaged to contribute to the regional mosaic, delivering crucial ecosystem services to urban centers. In return, they are anticipated to receive support from urban areas in terms of knowledge exchange and economic assistance. In this manner, they will transition from being sacrificial entities to becoming integral components in fostering sustainable development across the entire BTH region. Ultimately, this paradigm shift is anticipated not only to fortify the resilience of individual units but also to enhance the overall resilience of the metropolitan area.

Fig. 62. Macro scale | synthesis scenarios | territory transformation

Urban area
Water-resilient communities
Water sensitive land consolidation
Water source protection
Floodplain restoration
Waterway restoration
Waterway
Administrative boundary

0 50 100 km

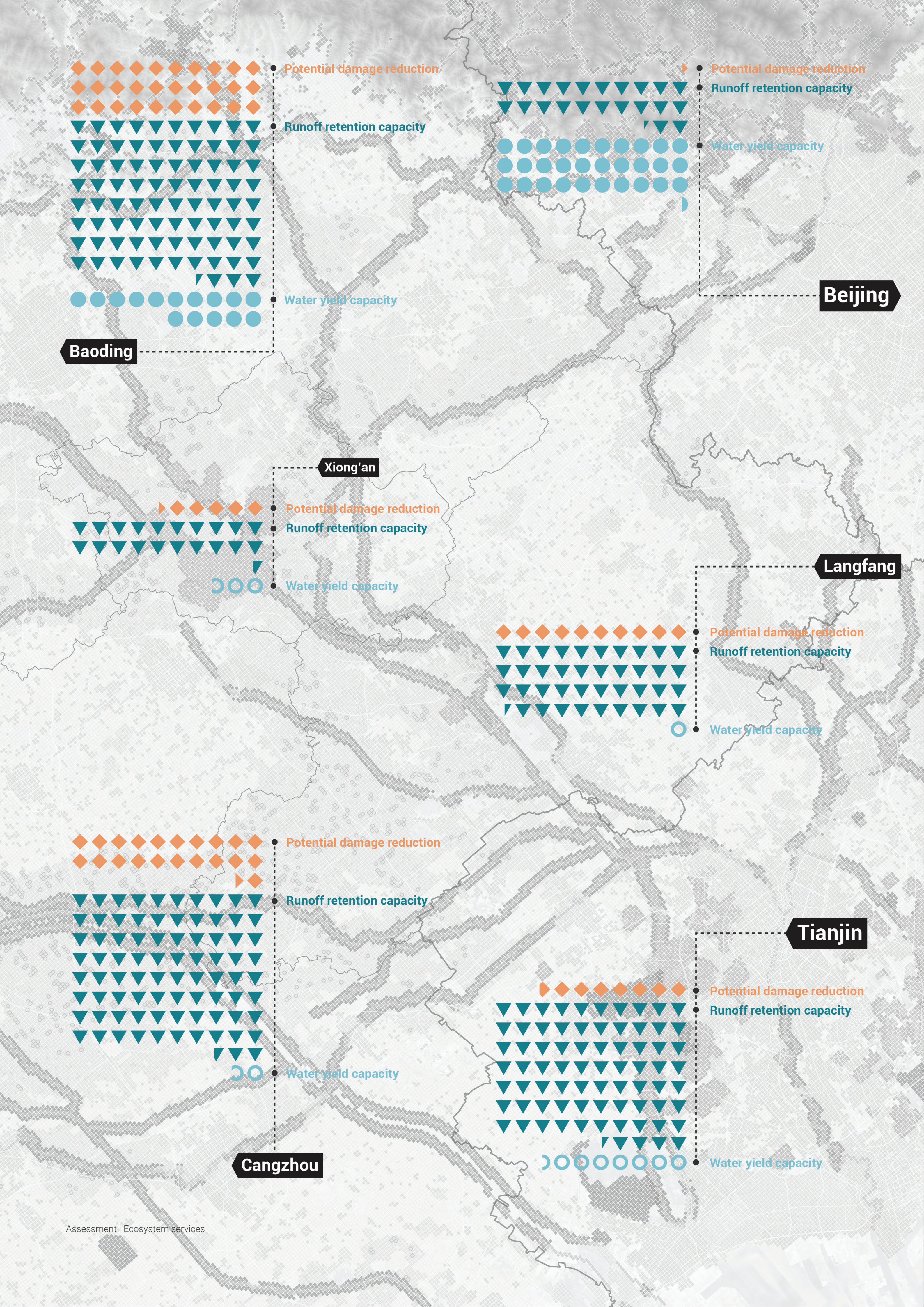
ASSESSMENT

ASSESSMENT

| Ecosystem services

| Stakeholder status

| Synthetic scenarios


Baoding
Potential damage reduction
Runoff retention capacity
Water yield capacity
Beijing
Potential damage reduction
Runoff retention capacity
Water yield capacity
Xiong'an
Potential damage reduction
Runoff retention capacity
Water yield capacity
Langfang
Potential damage reduction
Runoff retention capacity
Water yield capacity
Cangzhou
Potential damage reduction
Runoff retention capacity
Water yield capacity
Tianjin
Potential damage reduction
Runoff retention capacity
Water yield capacity

ECOSYSTEM SERVICES

To validate the actual contribution of the proposal to water resilience and environmental justice in the BTH region, InVEST is used as a practical tool to assess the changes in ecosystems provided by the territories-in-between before and after the implementation of the proposal. This assessment is conducted at a meso scale, simulating potential outcomes under the exacerbation scenario.

The simulation results indicate that within the meso scale research frame:

Potential Damage Reduction: Nearly 750 million m^2 of built-up area will be protected from flood damage due to water-sensitive land consolidation measures, particularly in the relatively underdeveloped areas of Baoding and Cangzhou. This demonstrates that the proposal helps improve the current imbalance in flood risk distribution.

Runoff Retention Capacity: Given a design storm with a rainfall depth of 150mm (similar to the 2023 rainfall event in the BTH region), runoff retention capacity increases across all areas, ranging from 200 million m^3 (Xiong'an) to 830 million m^3 (Baoding). This indicates that the proposal significantly enhances the territories-in-between's capacity to mitigate flood peaks and potentially replenish groundwater, thereby balancing seasonal water resource disparities and mitigating the impacts of drought and flood events.

Water Yield Capacity: Annual water yield capacity increases in Beijing and Baoding (by 320 million m^3 and 150 million m^3, respectively). However, other cities may see a total reduction of about 130 million m^3 due to increased evapotranspiration from non-agricultural green spaces such as wetlands, forests, and pastures. Despite this, the region's overall annual water yield is expected to increase with climate change. Combined with the enhanced runoff retention capacity, which leads to richer and more sustainable groundwater resources, the region's drought conditions should improve.

Fig. 63. Ecosystem service assessment via InVEST

Synthesis analysis through InVEST's module of annual water yield and urban flood risk mitigation. Various socio-environmental data including precipitation, evaporation, root restricting layer depth, plant available water content, land cover, soil hydrologic group, and biophysical parameters for different land cover types were used.

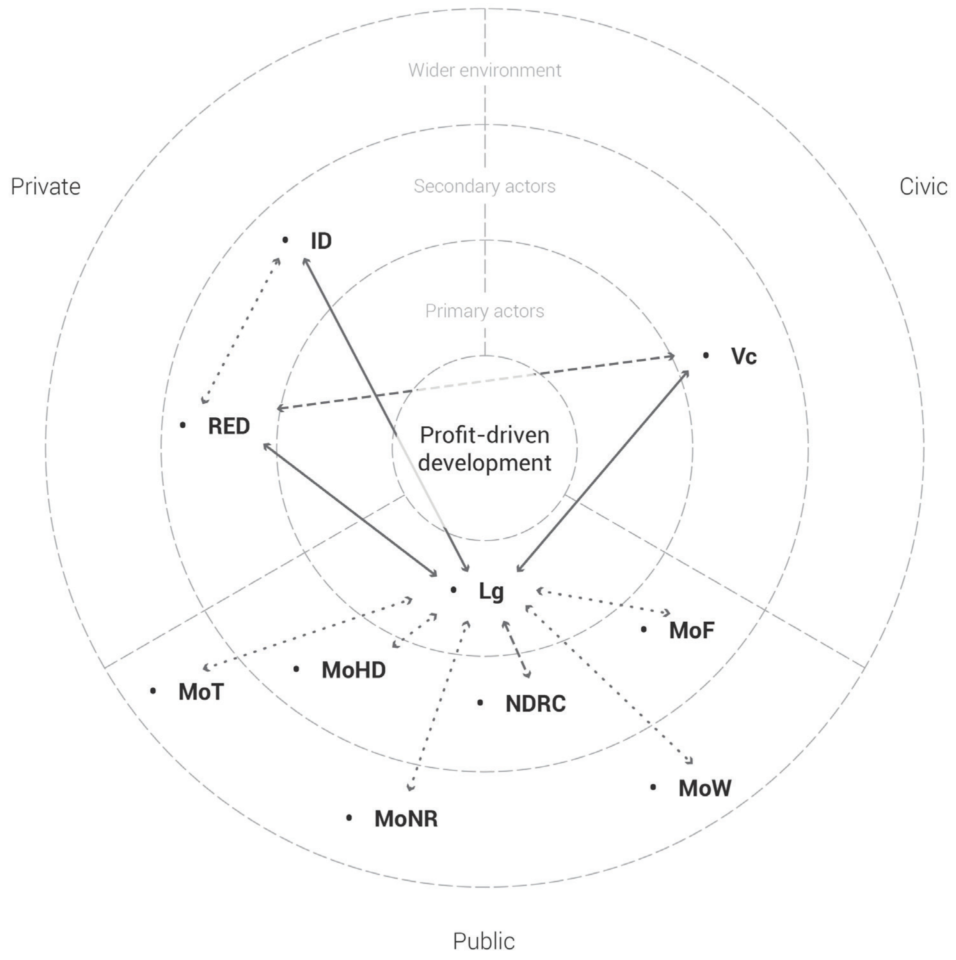
Data: OSM, WorldClim, Global-AET, Yang & Huang (2021), ISRIC Data Hub, USDA handbook, HiHydroSoil v2.0

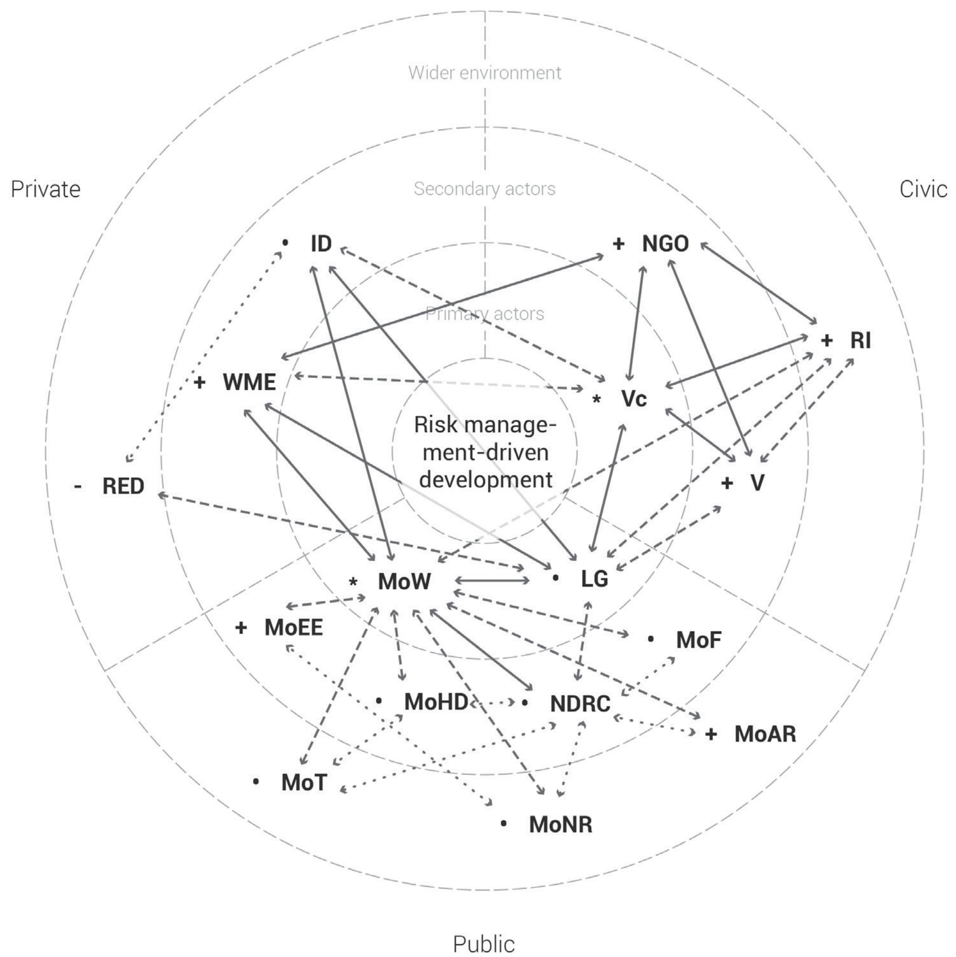
Potential damage reduction - builtup area (10 million m^2/each)

Runoff retention capacity increasement- 150 mm rainfall event (10 million m^3/each)

Water yield capacity change (+/- 10 million m^3/year/each)

0 5 10 km


Wider environment
Secondary actors
Primary actors
Private
Civic
Public
Profit-driven development
ID
RED
Vc
Lg
MoF
MoT
MoHD
NDRC
MoW
MoNR


Wider environment
Secondary actors
Primary actors
Private
Civic
Public
Risk management-driven development
ID
+ NGO
+ RI
+ WME
* Vc
- RED
+ V
* MoW
LG
+ MoEE
MoF
MoHD
NDRC
+ MoAR
MoT
MoNR

STAKEHOLDER STATUS

This pair of diagrams illustrates the possible changes in stakeholder status before and after the paradigm shift, in order to validate the institutional changes required to implement this proposal.

Current Stakeholder Status:
Lack of civic agents. The current diagram indicates that the primary civic agent involved is the Villagers' committee (Vc). This highlights a lack of diverse civic participation in the decision-making process.
Monopoly of private agents. There is a noticeable dominance of private agents, specifically real estate developers (RED) and infrastructure developers (ID). These stakeholders have a significant influence, leading to a profit-driven development focus.
Sectoral public agencies. Public agencies such as the Ministry of Finance (MoF), Ministry of Housing and Urban-Rural Development (MoHD), and others operate within their specific scopes with minimal collaboration. This sectoral focus results in isolated efforts rather than integrated development.

Proposed Stakeholder Status:
Introduce new civic agents. The proposed diagram shows the introduction of new civic agents including non-governmental organizations (NGOs), research institutes (RI), and more active involvement from villagers (V). This diversification aims to enhance engagement and integrate local practices and knowledge into development plans.
Balance the role of private agents. The significance of real estate developers is balanced by introducing water management entrepreneurs (WME). This shift aims to diversify the types of private agents involved, promoting water collection, recharge, and recycling initiatives. Additionally, there is an emphasis on facilitating consistent communication among local and regional stakeholders, fostering a more collaborative environment.
Integrated public agency network. The Ministry of Water Resources (MoWR) is positioned to lead the formation of a more integrated stakeholder network. This network encourages information exchange, collective decision-making, and co-monitoring among public agencies. The aim is to move from a profit-driven development focus to a risk management-driven development approach, as illustrated by the enhanced and more interconnected relationships between stakeholders.

Fig. 64. Stakeholder status - current

Fig. 65. Stakeholder status - proposed

MoF *Ministry of Finance*
NDRC *National Development and Reform Commission*
MoNR *Ministry of Natural Resources*
MoEE *Ministry of Ecology and Environment*
MoW *Ministry of Water Resources*
V *Villager*
Vc *Villagers' committee*
MoAR *Ministry of Agriculture and Rural Affairs*
MoT *Ministry of Transport*
MoHD *Ministry of Housing and Urban-Rural Development*
NGO *Non-governmental organisation*
RED *Real estate developer*
LG *Local government*
ID *Infrastructure developer*
RI *Research institute*
WME *Water management entrepreneur*

* *Enhanced participation*
- *Diminished participation*
+ *Introduced participation*
• *No change*
⟷ *Strong collaboration*
← → *Task-specific collaboration*
<-·-> *Indirect collaboration*

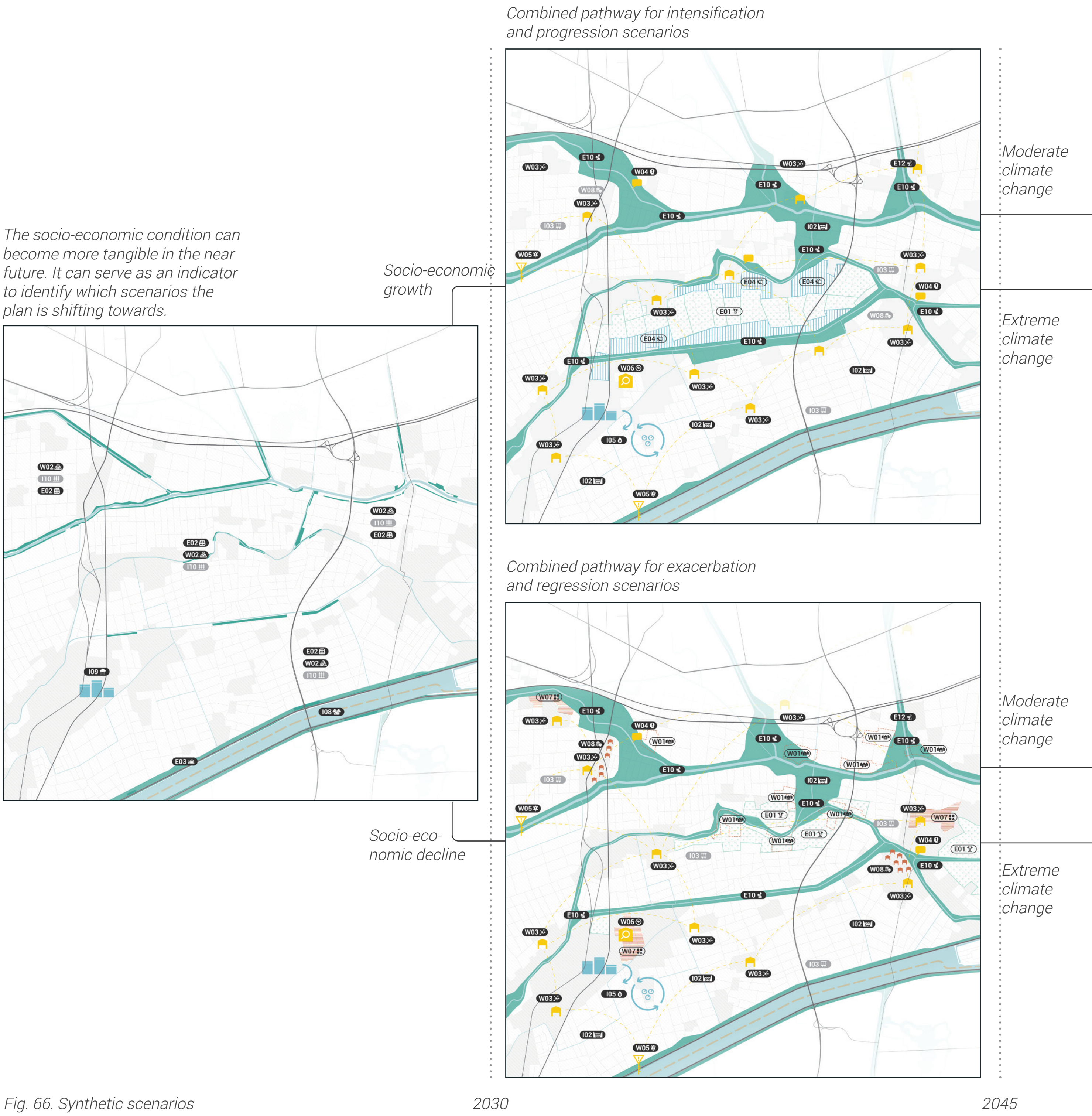


Fig. 66. Synthetic scenarios

X00 Prioritized & suggested measure

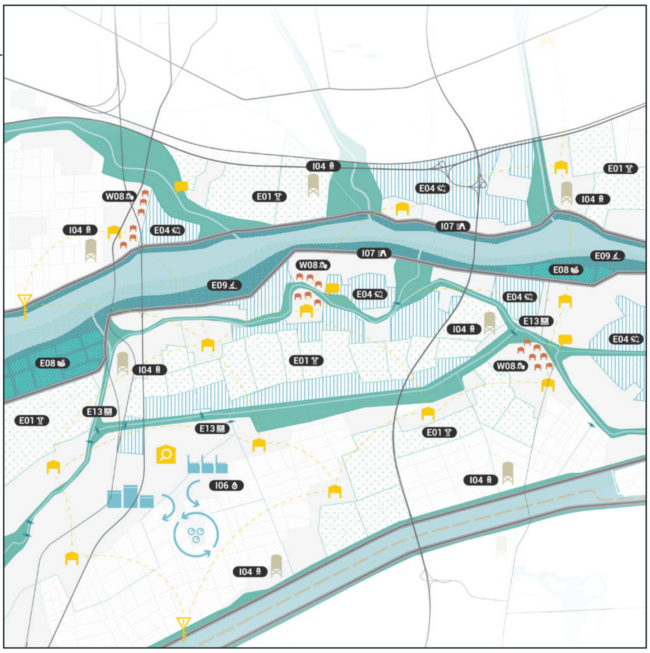
X00 Long-term masure preparation

X00 Optional measure

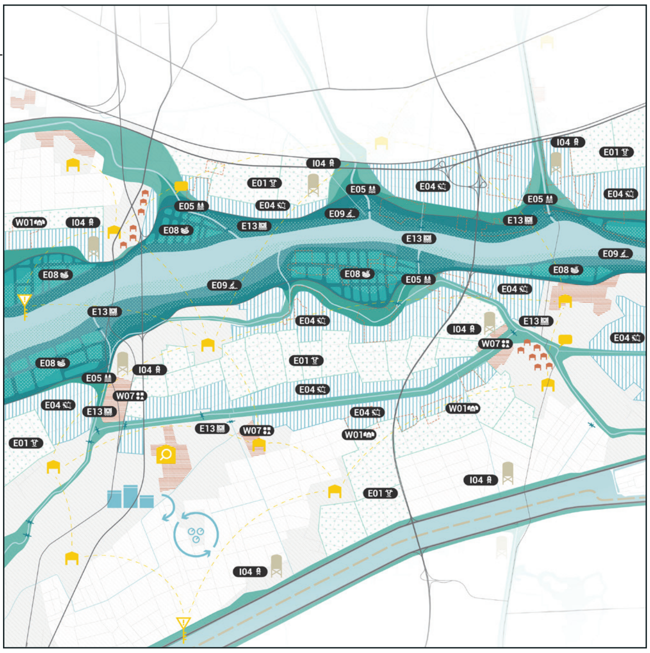
SYNTHETIC SCENARIOS

Synthetic scenarios are used to validate the proposed dynamic adaptation pathway in a visualized temporal sequence. At certain milestone points, the current socio-environmental conditions should be reevaluated to steer the strategic plan towards certain pre-considered scenarios. At the same time, this pathway should never be seen as a static blueprint. At each milestone, the pathway with potential measures should be re-examined and adjusted to facilitate a co-evolutionary transformation among local society, the environment, and stakeholders.

Intensification scenario

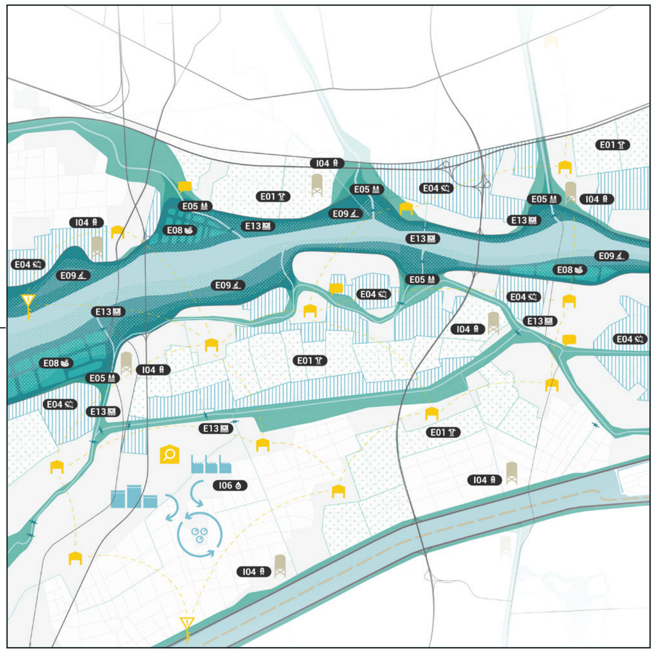


Exacerbation scenario

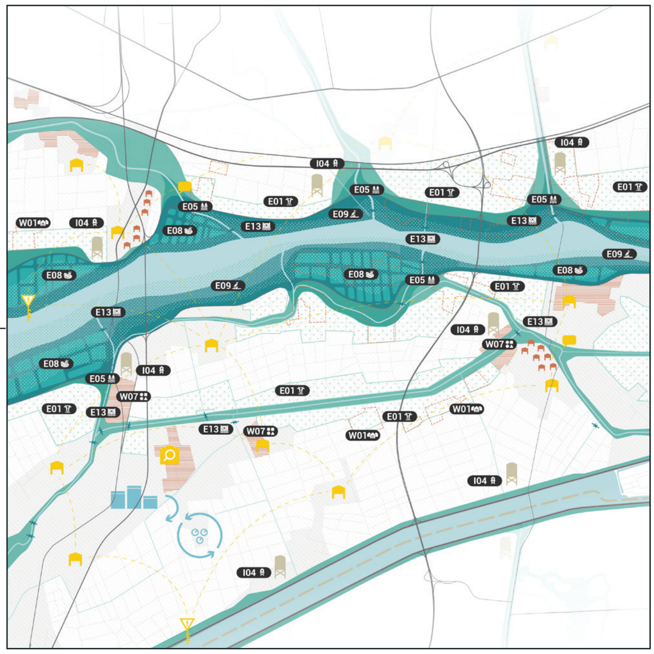


2060

Progression scenario



Regression scenario



2060+

CONCLUSION

This thesis focused on exploring the reasons behind the duality of long-standing droughts and escalating floods in the Beijing-Tianjin-Hebei (BTH) metropolitan region. The primary goal was to investigate how a paradigm shift towards water resilience in the development of intermediary territories can alleviate the spatial and temporal disequilibrium of water resources in the BTH region while sustaining environmental justice for its inhabitants.

The findings indicate that the most critical cause of this drought-flood duality is the current profit-driven development paradigm. This approach fragmentizes the regional landscape and hydrological system, undermining its capacity to retain water as a resource or to mitigate floods by slowing down peak flow. Exacerbated by climate change, such fragmentation cripples the environment's ability to balance water disequilibrium over time. Additionally, this profit-driven development leads to social segregation and unequal level of stakeholder's voices over water management. Consequently, large cities with economic significance are prioritized in water resource distribution and protected from flood events, at the expense of poorly developed villages and town, particularly on the areas in-between the metropolitan systems.

To improve water resilience and environmental justice in this region, this thesis recognised the hydrological sensitivity and proposed a risk management-driven development paradigm. This paradigm prioritizes rural development, mitigates water hazards, and leverages them as opportunities to recharge and increase the available water resources in the region. A set of measures was developed and organized using the method of pattern languages. Alongside four future scenarios based on possible socio-environmental trends, these patterns were integrated into the framework of dynamic adaptive pathways to formulate feasible implementation pathways in a temporal sequence. Through this design framework, plausible visions were revealed, ranging from local adaptation to tributary reorganization, and ultimately, a territorial transformation of the entire metropolitan region.

The results of this thesis validate that despite the complex socio-environmental conditions in the BTH region, the problematic duality of drought and flood could be addressed with a long-term adaptation plan that shifts from the current profit-driven paradigm to a risk management-driven development paradigm. The outdated and centralized water management approaches, notably the Flood Detention Areas (FDAs), can be replaced by more decentralized approaches proposed in this thesis, to enhance water resilience from the local to the regional scale. These decentralized approaches also empower local communities with stronger endogenous capacities and agency to negotiate with the government for more equitable water risk and resource distribution, thus sustaining a high level of environmental justice across the entire metropolitan region. However, achieving this requires consistent and transparent communication among stakeholders from civic, private, and public sectors. Collaborations among institutions across scopes, scales, and administrative boundaries are also vital for the successful long-term implementation of the plan.

Despite the insightful findings, this thesis had certain limitations due to the limited time scope. The assessment of each pattern's effects is based on the author's research rather than a collective review from local experts and involved stakeholders. Future research could further validate these findings through a more integrated discussion with a wider variety of participants. Additionally, there is a knowledge gap regarding FDAs as water management approaches in China, which warrants further exploration to understand their scale of implementation and socio-economic impacts.

In conclusion, this thesis envisions a co-evolutionary transformation in the often-neglected territories-in-between of the BTH region. As China continues to develop under uncertained socio-environmental conditions, a sustainable future can only be achieved with equitable risk and resource distribution, transforming poorly developed towns and villages from sacrificial entities into integral components of sustainable development across the entire BTH region.

REFLECTION

Last summer, a catastrophic torrential rain hit the BTH region, affecting over five million people and causing property losses exceeding 100 billion RMB. People were completely unprepared to face such a flood, partly because the region was historically known for its droughts, leading to a lack of awareness about flood prevention. Another reason was the rapid urbanization of the BTH region over the past 50 years, making it increasingly vulnerable to water hazards. I see this as a manageable socio-environmental challenge for urban planners, with great potential for improvement.

The research process has been much more convoluted than I initially expected. What started as a simple water resource issue has evolved, through preliminary research, to reveal intricate connections with the level of urban development, policy biases, and even the development paradigm of Chinese cities. These connections gradually shaped the project from mere water resource management to a comprehensive landscape, infrastructural, and social transformation of the mega-region. Additionally, the field trip after P3 broadened my perspective, validating some preliminary findings from data analysis while also providing many new insights. The ongoing plight of the local residents almost a year later is still heart-wrenching. However, witnessing their resilient efforts to rebuild their homes is equally inspiring and prompts me to consider how, as an urbanist, I can better assist them in reconstructing a homeland free from water hazards. These discoveries and inspirations have been integrated into the revised design exploration, showing greater respect for local villages and their way of life.

The core of this project is to explore a viable methodological framework to better address the socio-environmental uncertainty in this region while retaining scalability. To achieve this, I attempted to merge pattern language with dynamic adaptive policy pathways. The former provides a highly scalable framework for potential design interventions, while the latter explores how to implement these interventions in stages under various uncertain scenarios. Although I made adjustments and expansions to both original theoretical frameworks to achieve this goal, the resulting modified methodology has met expectations, preserving scalability and providing means to cope with future uncertainty.

Another advantage of this methodology framework is its adaptability beyond the local context. By localizing attributes such as target effects, practical implications, and stakeholders in each design pattern, existing patterns can be transferred to fit new locations. Furthermore, the framework maintains flexibility across temporal and spatial scales, making the adaptive pathway and scenario-making combination powerful tools for tackling future uncertainty. With regards to project scale changes, the framework exhibits considerable elasticity, requiring only adjustments to design patterns to better fit the project scale, which can be achieved through the search for new cases and theoretical backup. This flexibility is key to the transferability of this thesis project.

Of course, reaching this stage of the project would not have been possible without the guidance and feedback of two main mentors and several professors. Both my first and second mentors contributed in their unique ways, providing a valuable combination of guidance. Diego offered guidance to redirect my research framework and imparted extensive knowledge of adaptive planning and policy recommendations, all of which were new to me. Danielle provided critical feedback and practical instructions on analysis, data processing, and spatial assessment, which were essential for such a large-scale project. Other professors, including Luisa, Taneha, Alexandra, and Nikos, also generously offered insightful recommendations, collectively shaping the research into what it is today.

In terms of societal relevance, the research area confronts several societal challenges, such as an aging population and social segregation resulting from polarized urbanization processes. Additionally, due to insufficient preparedness and short-sighted development approaches, there have been reports of serious environmental justice violations during extreme weather events. My research addresses these societal issues by proposing a shift from the current profit-driven to a risk-driven development paradigm.

In terms of academic relevance, apart from the methodological framework optimized for scalability and uncertainty and the new risk management-driven development paradigm for the BTH metropolitan region mentioned earlier, the research on China's currentFlood Detention Areas (FDAs) has revealed many previously unexplored issues covered under rapid development. Methods like FDAs, which are too simplistic to simultaneously consider the safety of residents' lives and property, as well as the effectiveness of flood control, are still actively implemented in today's China, despite its status as the world's second-largest economy, which is surprising. Moreover, research on FDAs in China is notably lacking, with little scholarly discourse beyond government documents. This gap needs to be addressed, and this thesis is just the beginning.

In terms of ethical relevance, this research criticizes China's current profit-driven development paradigm and calls for more attention to be paid to people in the territories-in-between, who are often poor and vulnerable to escalating water hazards. Within a profit-driven narrative, these regions are often considered to have no development value and are merely seen as suppliers of nutrients for urban development. Such a narrative justifies water management approaches like FDAs, which are based on sacrificing less-developed regions to protect well-developed cities. By revealing this reality, the thesis proposes possible alternatives for a more equitable approach to tackling water issues in the region, aiming to address and prevent such unethical conditions in China.

China is a vast and complex country. The rapid development in large cities is impressive, but it was during field trips that I realized the struggles faced by residents in rural areas, repeatedly battling floods and rebuilding their homes. However, it's not just a battle against floods; besides geographical and environmental factors, there are also power struggles at play behind the scenes. I often felt powerless in the face of such complexity. How much can an individual, as an urbanist, contribute? There's no definitive answer when facing the uncertainty of both the environment and society in today's China. However, the stark reality of imbalanced development revealed during field trips convinced me of one thing – rural regions still hold immense potential for improvement in the near future if not now. The knowledge gap regarding proper integrated water management approaches remains significant, especially concerning the context of such massive complexity, and that's where a small urbanist can contribute, piece by piece.

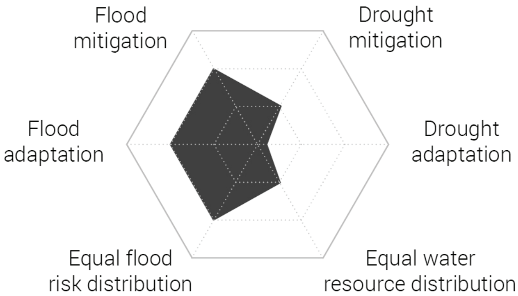
APPENDIXES

APPENDIXES

| Patterns

| Raw data for InVEST

E1
Meadows and pastures



- -	Cost - Initiate
- -	Cost - Maintain
	Side effects - Water control capacity
+ +	Side effects - Job opportunity
+	Side effects - Environmental impact

Hypothesis

Meadows and pastures, characterized by grass or non-woody plants, contribute to temporary flood storage, enhanced water retention, runoff reduction, and improved water quality through sediment trapping and nutrient assimilation.

Theoretical Backup

BIO Intelligence Service (2014) report that a study in Catalonia (Spain) found that run off was 1884 m3/ha for arable land compared to between 643 to 962m3/ha for grassland, i.e. reductions of between 49% and 66%. Soil water retention can be improved by increased organic matter content and improved soil structure (Kedziora et al., 2011).

Practical Implication

This measure is implemented prior to areas with medium to high flood risk, transferring livestock to safe structures during the flood season. It should be implemented in conjunction with riverbank softening, buffer strips, village relocation, and farmland consolidation. It can serve as a direction for economic diversification. Progress in transforming animal husbandry requires combining measures such as increasing public risk awareness and establishing a water resilience knowledge hub.

Belong to

A2 Floodplain restoration

Synergies

E2, I6, W1, W2, W3, W4, W6, W7

Conflicts

E5, E8, E9

Sell-by date

2050

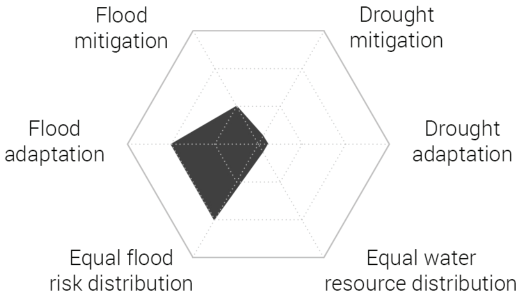
Stakeholders

Villager
Villagers' committee
Ministry of Agriculture and Rural Affairs
Ministry of Natural Resources
Ministry of Water Resources
Local government
Research institute
Water management entrepreneur

References

European Commission. Directorate General for the Environment., BIO Intelligence Service., & HydroLogic. (2014). Study on soil and water in a changing environment. Publications Office. https://data.europa.eu/doi/10.2779/20608
Kędziora, A., Zerihun Negussie, Y., Tenaw Asres, M., & Zalewski, M. (2011). Shaping of an agricultural landscape to increase water and nutrient retention. Ecohydrology & Hydrobiology, 11(3–4), 205–222. https://doi.org/10.2478/v10104-011-0048-x

E2
Buffer strips



- Cost - Initiate
  Cost - Maintain
+ Side effects - Water control capacity
  Side effects - Job opportunity
+ Side effects - Environmental impact

Hypothesis

Buffer strips, comprising natural vegetation at field margins, water courses, and transport infrastructures, facilitate water infiltration, slow surface flow, and mitigate agricultural run-off pollutants.

Theoretical Backup

Borin et al (2010) report on a study in Padova, Italy, in which a 6m wider buffer strip of trees and shrubs reduced runoff by 78% compared to no buffer strip, this was equivalent to a runoff depth of 231mm over 5 years.

Practical Implication

This measure is implemented as a priority in areas with medium to high flood risk. Consider implementing it in conjunction with meadows and pastures, green cover, forest riparian buffers, agri-managed aquifer recharge, and farmland consolidation.

Belong to

A2 Floodplain restoration

Synergies

E1, E3, E4, E5, W2

Conflicts

-

Sell-by date

2030

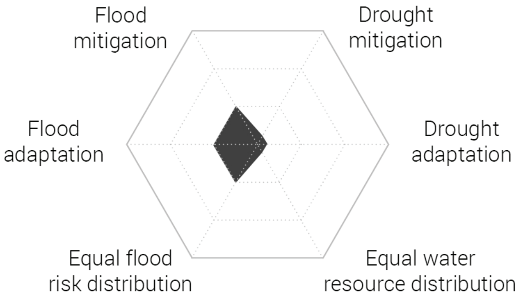
Stakeholders

Villager
Villagers' committee
Ministry of Agriculture and Rural Affairs
Ministry of Natural Resources
Local government

References

Borin, M., Passoni, M., Thiene, M., & Tempesta, T. (2010). Multiple functions of buffer strips in farming areas. European Journal of Agronomy, 32(1), 103–111. https://doi.org/10.1016/j.eja.2009.05.003

E3
Green cover



- Cost - Initiate

Cost - Maintain

Side effects - Water control capacity

Side effects - Job opportunity

+ + Side effects - Environmental impact

Hypothesis

Vegetative cover can help safeguard soil against erosion, improve soil structure, decrease dust accumulation, broaden crop diversity, and alleviate nutrient loss, particularly during the winter season.

Theoretical Backup

Green cover prevents the soil from remaining bare during winter, thus it reduces runoff. O'Connell et al (2007) showed that green cover can reduce surface runoff up to 80%.

Practical Implication

This measure primarily targets bare land and uncultivated farmland in villages and their surrounding areas. It is implemented in conjunction with considerations for buffer strips, forest riparian buffers, and village relocation.

Belong to

A2 Floodplain restoration

Synergies

E2, E5, W1

Conflicts

-

Sell-by date

2025

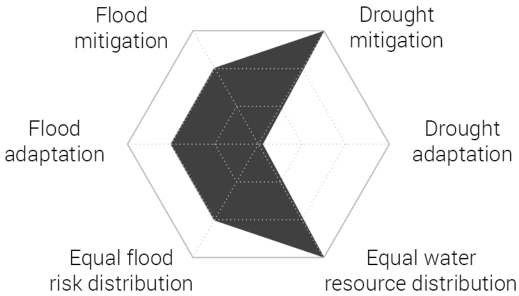
Stakeholders

Villager
Villagers' committee
Ministry of Water Resources
Ministry of Natural Resources
Ministry of Ecology and Environment
Water management entrepreneur

References

O'Connell, P. E., Ewen, J., O'Donnell, G., & Quinn, P. (2007). Is there a link between agricultural land-use management and flooding? Hydrology and Earth System Sciences, 11(1), 96–107. https://doi.org/10.5194/hess-11-96-2007

E4
Agri-managed aquifer recharge



- - - Cost - Initiate
- - Cost - Maintain
\+ Side effects - Water control capacity
\+ Side effects - Job opportunity
\+ + Side effects - Environmental impact

Hypothesis

Agricultural Managed Aquifer Recharge (AMAR) contributes to the restoration of groundwater infiltration, thereby enhancing water availability and quality. It serves as an infiltration pond during periods of flooding and as farmland during non-flooding seasons.

Theoretical Backup

Agricultural Managed Aquifer Recharge (Ag-MAR) represents a nascent method within the Managed Aquifer Recharge (MAR) framework, showing promise for extensive adoption. Also known as agricultural groundwater banking, on-farm recharge, or flood-flow capture, Ag-MAR seeks to redirect surplus surface water from periods of abundance (e.g., rainy season, snowmelt, reservoir releases) onto agricultural terrain, facilitating groundwater recharge (Levintal et al., 2023).

Practical Implication

This measure is prioritized for agricultural fields with high flood risk and heavy rainfall. It involves coordinated implementation with detention basins, riverbank softening, restoration of intermittent streams, use of adapted crops and varieties, and farmland consolidation. It requires motivating farmers to transition through increasing public risk awareness, while providing education on new skills through the Water Resilience Knowledge Hub.

Belong to

A3 Water source protection

Synergies

E2, E8, E10, E12, I10, W2, W3, W4, W6

Conflicts

E1, E9

Sell-by date

>2060

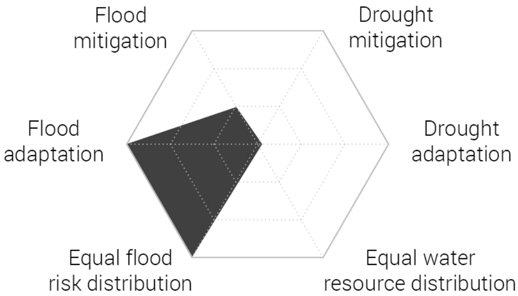
Stakeholders

Villager
Villagers' committee
Ministry of Water Resources
Ministry of Agriculture and Rural Affairs
Ministry of Water Resources
Ministry of Ecology and Environment
Ministry of Finance
National Development and Reform Commission
Ministry of Natural Resources
Local government
Research institute
Water management entrepreneur

References

Levintal, E., Kniffin, M. L., Ganot, Y., Marwaha, N., Murphy, N. P., & Dahlke, H. E. (2023). Agricultural managed aquifer recharge (Ag-MAR)—a method for sustainable groundwater management: A review. Critical Reviews in Environmental Science and Technology, 53(3), 291–314. https://doi.org/10.1080/10643389.2022.2050160

E5
Forest riparian buffers



- - Cost - Initiate
- Cost - Maintain
Side effects - Water control capacity
+ Side effects - Job opportunity
+ + + Side effects - Environmental impact

Hypothesis

Forest riparian buffers, located along water bodies in various environments play a crucial role in improving water quality by absorbing nutrients, enhancing infiltration, and reducing sediment runoff.

Theoretical Backup

Wider riparian buffer strips demonstrate diminishing returns on sediment reduction, plateauing at 50 m width; increasing from 15 to 100 m enhances sediment retention by around 30-36% (Sirabahenda et al., 2020).

Practical Implication

This measure is prioritized around high-traffic streams, adjusting buffer widths based on peak flow. It is implemented in conjunction with buffer strips, green cover, and farmland consolidation. In addition to natural forest areas, it can also include riverfront parks with recreational opportunities or nurseries. It can serve as one direction for economic diversification.

Belong to

A2 Floodplain restoration

Synergies

E2, E3, E6, W2, W6, W7

Conflicts

E1

Sell-by date

2050

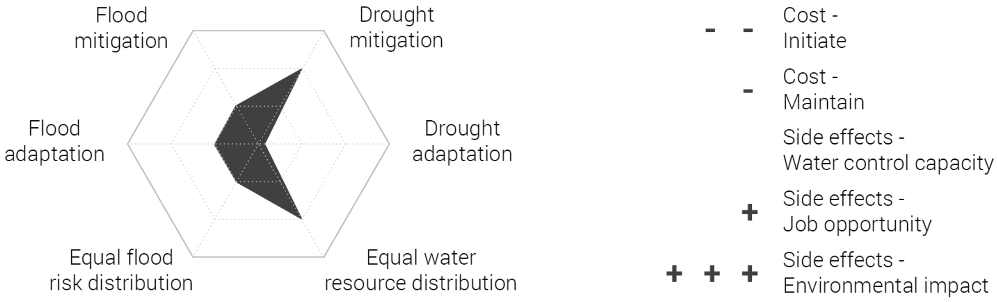
Stakeholders

Villager
Villagers' committee
Ministry of Ecology and Environment
Ministry of Agriculture and Rural Affairs
Ministry of Natural Resources
Ministry of Water Resources
Local government
Water management entrepreneur

References

Sirabahenda, Z., St-Hilaire, A., Courtenay, S. C., & Van Den Heuvel, M. R. (2020). Assessment of the effective width of riparian buffer strips to reduce suspended sediment in an agricultural landscape using ANFIS and SWAT models. CATENA, 195, 104762. https://doi.org/10.1016/j.catena.2020.104762

E6
Afforestation in headwater areas



Hypothesis

Headwaters, crucial for downstream ecosystems, play a vital role in hydrologic cycling, with forests in these areas beneficial for water quantity and quality, making them essential for cities relying on headwater forests for drinking water provisioning.

Theoretical Backup

Agricultural practices modifying headwaters and wetlands contribute to downstream eutrophication, coastal hypoxia, and reduced river system productivity, impacting aquatic and terrestrial ecosystems through altered nutrient runoff and stream-system length (Freeman et al., 2007).

Practical Implication

This measure is implemented in the source areas of major rivers, involving the consideration of Forest Riparian Buffers and Farmland Consolidation, and coordinating their implementation. In addition to natural forest areas, it can also encompass forest parks offering recreational opportunities. It can serve as one direction for economic diversification.

Belong to

A3 Water source protection

Synergies

E5, W2, W7

Conflicts

E7

Sell-by date

2045

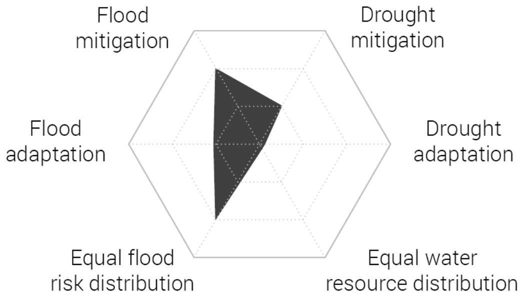
Stakeholders

Ministry of Ecology and Environment
Ministry of Natural Resources
Ministry of Water Resources
Local government
Water management entrepreneur

References

Freeman, M. C., Pringle, C. M., & Jackson, C. R. (2007). Hydrologic Connectivity and the Contribution of Stream Headwaters to Ecological Integrity at Regional Scales 1. JAWRA Journal of the American Water Resources Association, 43(1), 5–14. https://doi.org/10.1111/j.1752-1688.2007.00002.x

E7
Afforestation of reservoir catchments



- -	Cost - Initiate
-	Cost - Maintain
	Side effects - Water control capacity
+	Side effects - Job opportunity
+ +	Side effects - Environmental impact

Hypothesis

Reforesting reservoir catchments can improve water quality and prolong reservoir longevity by managing soil erosion.

Theoretical Backup

Afforestation generally decreases local water yield, with downstream impacts on water security and river ecosystems being minimal unless afforestation is extensive; in some cases, it may enhance groundwater recharge, reduce sediment, nutrients, and salt in rivers, and mitigate shallow landslides and local flash floods (Van Dijk & Keenan, 2007).

Practical Implication

This measure is deployed in mountainous regions for fresh water reservoirs. It is coordinated with farmland consolidation for implementation. Besides natural forest areas, it can also include forest parks that provide recreational opportunities. It can serve as one direction for economic diversification.

Belong to

A3 Water source protection

Synergies

W2, W6, W7

Conflicts

E6, E13

Sell-by date

2045

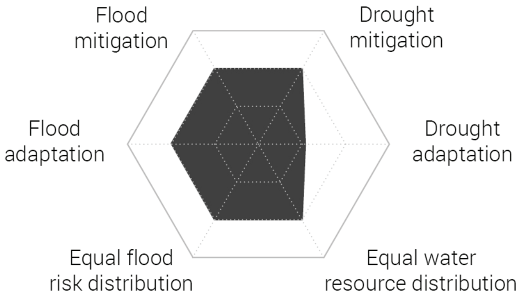
Stakeholders

Ministry of Ecology and Environment
Ministry of Water Resources
Ministry of Natural Resources
Local government
Water management entrepreneur

References

Van Dijk, A. I. J. M., & Keenan, R. J. (2007). Planted forests and water in perspective. Forest Ecology and Management, 251(1–2), 1–9. https://doi.org/10.1016/j.foreco.2007.06.010

E8
Detention basins



- - Cost - Initiate
- Cost - Maintain
Side effects - Water control capacity
+ Side effects - Job opportunity
+ + Side effects - Environmental impact

Hypothesis

Detention basins remain dry in dry weather, while ponds, such as retention ponds and flood storage reservoirs, retain water during dry conditions and are designed for increased capacity during rainfall.

Theoretical Backup

Physiographic inundation and flood routing models were employed to assess the impact of Tainan Scientific Base Industrial Park and Feng-Hua detention ponds, revealing their effectiveness in reducing inundated area and flood damage along Yen-Shui creek during 2-day floods for various return periods (Chen et al., 2007).

Practical Implication

This measure is prioritized for low-lying areas with high flood risk. It is implemented in conjunction with riverbank softening, restoration of intermittent streams, wetland restoration, agricultural managed aquifer recharge, and farmland consolidation. It has the potential to become part of wetland landscapes that provide recreational opportunities and can serve as one direction for economic diversification. It can facilitate ecological replenishment through channels as distributors. It can also serve as a form of decentralized water storage and rainwater harvesting.

Belong to

A2 Floodplain restoration

Synergies

E4, E9, E10, E12, I2, I4, I9, W2, W7

Conflicts

E1

Sell-by date

2050

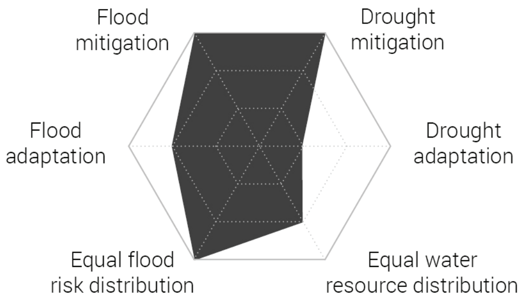
Stakeholders

Ministry of Ecology and Environment
Ministry of Water Resources
Ministry of Natural Resources
Villager
Villagers' committee
Ministry of Agriculture and Rural Affairs
Local government
Water management entrepreneur

References

Chen, C., Tsai, C., & Tsai, C. (2007). Reduction of discharge hydrograph and flood stage resulted from upstream detention ponds. Hydrological Processes, 21(25), 3492–3506. https://doi.org/10.1002/hyp.6546

E9
Wetland restoration



- - - Cost - Initiate
- - Cost - Maintain
Side effects - Water control capacity
+ + Side effects - Job opportunity
+ + + Side effects - Environmental impact

Hypothesis

Wetlands encompass diverse water areas, natural or man-made, offering water-related benefits and supporting biodiversity through restoration methods, including river widening and farmland transformation.

Theoretical Backup

The economic value of wetland soil in flood mitigation at Momoge Reserve was quantified at $5700 per hectare per year. This finding suggests that the flood mitigation contribution of wetland soils is comparable in significance to the overall flood mitigation benefits derived from various mitigating factors (Ming et al., 2007).

Practical Implication

This measure is prioritized in low-lying areas with high flood risk and heavy rainfall. It involves coordinated efforts such as riverbank softening, restoration of intermittent streams, detention basins, village relocation, and farmland consolidation. It has the potential to become a wetland landscape that provides recreational opportunities and serves as one direction for economic diversification. It can also be utilized for ecological replenishment through channels as distributors. Additionally, it can serve as a form of decentralized water storage and rainwater harvesting.

Belong to

A2 Floodplain restoration

Synergies

E8, E10, E12, I2, I4, I8, I9, W1, W2, W6, W7

Conflicts

E1, E4

Sell-by date

>2060

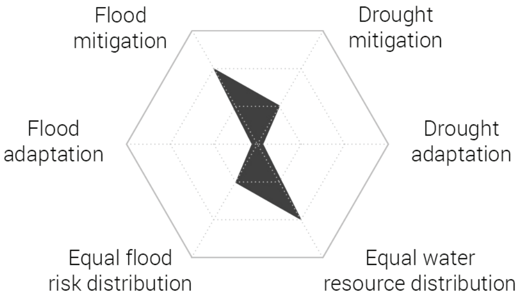
Stakeholders

Ministry of Ecology and Environment
Ministry of Water Resources
Ministry of Finance
National Development and Reform Commission
Ministry of Natural Resources
Villager
Villagers' committee
Ministry of Agriculture and Rural Affairs
Local government
Research institute
Water management entrepreneur

References

Ming, J., Xian-guo, L., Lin-shu, X., Li-juan, C., & Shouzheng, T. (2007). Flood mitigation benefit of wetland soil—A case study in Momoge National Nature Reserve in China. Ecological Economics, 61(2–3), 217–223. https://doi.org/10.1016/j.ecolecon.2006.10.019

E10
Riverbank softening



- -	Cost - Initiate
	Cost - Maintain
- -	Side effects - Water control capacity
	Side effects - Job opportunity
+ +	Side effects - Environmental impact

Hypothesis

Softening riverbanks enhances lateral connections, diversifies flows and habitats, mitigates floods, and is crucial for measures such as re-meandering, widening, and channel migration in impounded rivers with limited potential for restoration.

Theoretical Backup

The research unequivocally demonstrates enhanced ecosystem services through bioengineering interventions in contrast to conventionally stabilized riverbanks. Removal of riprap results in the extraction of nitrogen and phosphorous from the river load at rates up to 30 and 20 times higher, respectively. Further, slope lowering amplifies these values by up to 50 times. Reed beds exhibit a fourfold increase in carbon storage capacity, while willow-brush mattresses demonstrate a 30-fold increase (Symmank et al., 2020).

Practical Implication

This measure is strategically deployed in tributaries with lower flood risk rather than the high-risk main river channel. Consideration should be given to and integrated with agri-managed aquifer recharge fields, detention basins, and restored wetlands.

Belong to

A1 Waterway restoration

Synergies

E4, E8, E9

Conflicts

I2, I7

Sell-by date

2045

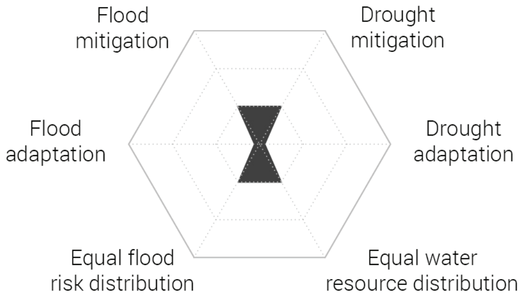
Stakeholders

Ministry of Ecology and Environment
Ministry of Water Resources
Ministry of Natural Resources
Local government
Water management entrepreneur

References

Symmank, L., Natho, S., Scholz, M., Schröder, U., Raupach, K., & Schulz-Zunkel, C. (2020). The impact of bioengineering techniques for riverbank protection on ecosystem services of riparian zones. Ecological Engineering, 158, 106040. https://doi.org/10.1016/j.ecoleng.2020.106040

E11
Streambed re-naturalization



- \- Cost - Initiate
Cost - Maintain
\- Side effects - Water control capacity
Side effects - Job opportunity
\+ + + Side effects - Environmental impact

Hypothesis

Re-naturalizing riverbeds entails the removal of artificial constructions and their replacement with vegetation, aiming to restore biodiversity, mitigate erosion, and improve infiltration and soil quality.

Theoretical Backup

The examination of the Wandle River, a tributary of the Thames flowing through densely urbanized regions in London, serves as a illustration of river restoration. In this instance, the implementation of natural solutions has enhanced flood and drought risk mitigation, stormwater retention, public access to the river, and the biodiversity of habitats linked to the river (Mazur, 2021).

Practical Implication

This measure is implemented starting from small floodways that are channelized and have perennial water flow, gradually extending to all rivers within the Haihe River basin that are not used for transportation. Consider implementing it in conjunction with dam removal and dike reinforcement, and utilize sediment from dredging and reservoir maintenance.

Belong to

A1 Waterway restoration

Synergies

E13, I7, I8, W6

Conflicts

\-

Sell-by date

2045

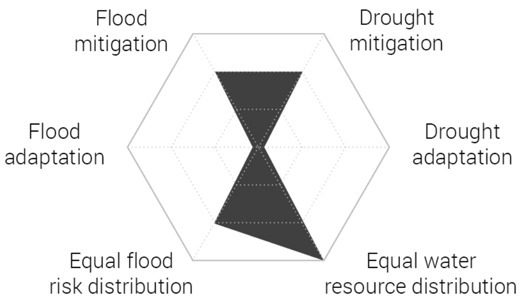
Stakeholders

Ministry of Ecology and Environment
Ministry of Water Resources
Ministry of Natural Resources
Local government
Water management entrepreneur

References

Mazur, K. (2021). River Re-naturalization—A Nature-based Solution for Climate Change in Urban Areas. IOP Conference Series: Materials Science and Engineering, 1203(2), 022044. https://doi.org/10.1088/1757-899X/1203/2/022044

E12
Restoration of intermittent streams



- Cost - Initiate
Cost - Maintain
Side effects - Water control capacity
Side effects - Job opportunity
+ + Side effects - Environmental impact

Hypothesis

Restoring intermittent streams enhances overall river function by improving water replenishment, connectivity, and retention, which are crucial for supporting diverse ecosystems and essential services like flood control and irrigation.

Theoretical Backup

The arid channel exhibits an increased ability to function as a receptacle for floodwaters and sediments, contributing to the regulation of erosion and mitigating natural hazards, including flooding (Koundouri et al., 2017).

Practical Implication

This measure is promoted and implemented from the main river channels to the tributaries, prioritizing the restoration of intermittent streams in high-risk areas. It should be carried out in coordination with dam removal, agricultural managed aquifer recharge fields, detention basins, and wetland restoration, and utilizing the channel as a distributor for ecological water replenishment.

Belong to

A1 Waterway restoration

Synergies

E4, E8, E9, E13, I2

Conflicts

-

Sell-by date

2035

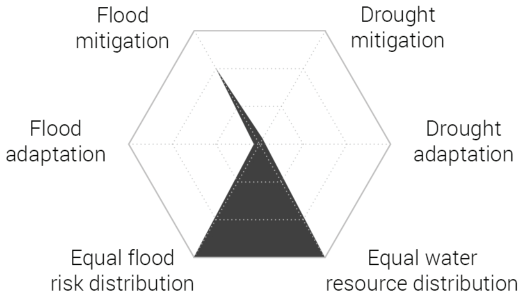
Stakeholders

Ministry of Ecology and Environment
Ministry of Water Resources
Ministry of Natural Resources
Villager
Villagers' committee
Water management entrepreneur

References

Koundouri, P., Boulton, A. J., Datry, T., & Souliotis, I. (2017). Ecosystem Services, Values, and Societal Perceptions of Intermittent Rivers and Ephemeral Streams. In Intermittent Rivers and Ephemeral Streams (pp. 455–476). Elsevier. https://doi.org/10.1016/B978-0-12-803835-2.00018-8

E13
Dam removal



- - Cost - Initiate

Cost - Maintain

- - - Side effects - Water control capacity

- Side effects - Job opportunity

+ + + Side effects - Environmental impact

Hypothesis

Removing dams and transversal barriers involves destroying obstacles in rivers, restoring the natural slope, and allowing the re-establishment of fluvial dynamics, sedimentary, and ecological continuity.

Theoretical Backup

Dam removal, driven by social and economic factors, is primarily environmentally justified due to the adverse effects of dams on river ecosystems, causing fundamental transformations such as changes in water and sediment flux, alterations to biogeochemical cycles, impact on water temperatures, and hindrance to biotic exchange (Poff & Hart, 2002).

Practical Implication

This measure starts by dismantling the dams that are passable in high-risk areas within the river, while simultaneously evaluating the necessity of reservoirs in mountainous areas and dismantling those with high maintenance and high risk, which significantly impact the ecological environment of the watershed negatively. Consider implementing streambed re-naturalization, the restoration of intermittent streams, and decentralized water storage in coordination.

Belong to

A1 Waterway restoration

Synergies

E11, E12, I4, W6

Conflicts

E7, I2

Sell-by date

2050

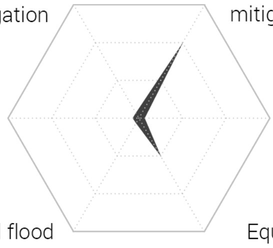
Stakeholders

Ministry of Water Resources
Ministry of Natural Resources
Ministry of Ecology and Environment
Local government
Infrastructure developer

References

Poff, N. L., & Hart, D. D. (2002). How Dams Vary and Why It Matters for the Emerging Science of Dam Removal. BioScience, 52(8), 659. https://doi.org/10.1641/0006-3568(2002)052[0659:HDVAWI]2.0.CO;2

I1
Seawater desalination



- - -	Cost - Initiate
- -	Cost - Maintain
+ +	Side effects - Water control capacity
+ +	Side effects - Job opportunity
- - -	Side effects - Environmental impact

Hypothesis

Desalination, a process to remove salt from water, can address water scarcity amid climate change, but its energy intensity and brine by-product require careful consideration, making renewable energy essential and alternative sustainable options preferable when possible.

Theoretical Backup

Formerly regarded as a resource-intensive and financially burdensome technology for freshwater generation, desalination has emerged as a viable alternative to address global freshwater demands. The desalination sector is anticipated to undergo substantial expansion in tandem with worldwide population growth and swift industrial development (Gude, 2016).

Practical Implication

This measure is deployed near coastal salt fields. It is implemented in conjunction with considerations for Channels as distributors and decentralized water storage.

Belong to

A6 Non-conventional water resources

Synergies

I2, I4, W6

Conflicts

-

Sell-by date

>2060

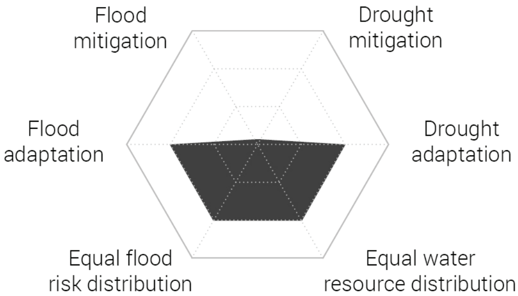
Stakeholders

Ministry of Water Resources
Ministry of Finance
National Development and Reform Commission
Ministry of Ecology and Environment
Local government
Research institute
Water management entrepreneur

References

Gude, V. G. (2016). Desalination and sustainability – An appraisal and current perspective. Water Research, 89, 87–106. https://doi.org/10.1016/j.watres.2015.11.012

I2
Channels as distributor



- Cost - Initiate
- Cost - Maintain
++ Side effects - Water control capacity
+ Side effects - Job opportunity
Side effects - Environmental impact

Hypothesis

Canals serve dual purposes, functioning as flood control channels and surface water distributors to redistribute water, balancing regional water resources during flood seasons.

Theoretical Backup

The predominant method of agricultural irrigation in China involves the use of canal water supply. A judicious approach to scheduling canal operations is essential for enhancing the efficiency of agricultural water resources and conserving water in farming. The effective management of irrigation canal systems contributes to a sustainable and productive agricultural water supply, leading to improved crop yields and increased agricultural income (Zhou et al., 2021).

Practical Implication

This measure is deployed on existing flood channels, adding water distribution-related control functions to them. It is implemented in conjunction with detention basins, wetland restoration, restoration of intermittent streams, decentralized water storage, and seawater desalination.

Belong to

A5 Hybrid infrastructure system

Synergies

E8, E9, E12, I1, I4

Conflicts

E10, E13

Sell-by date

2035

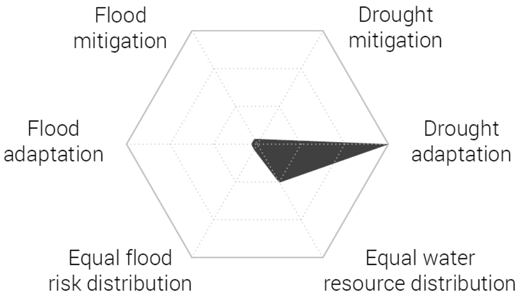
Stakeholders

Ministry of Water Resources
Local government
Infrastructure developer
Water management entrepreneur

References

Zhou, S., Hu, T., Zhu, R., Huang, J., & Shen, L. (2021). A novel irrigation canal scheduling approach without relying on a prespecified canal water demand process. Journal of Cleaner Production, 282, 124253. https://doi.org/10.1016/j.jclepro.2020.124253

I3
Precision irrigation



- - Cost - Initiate
- Cost - Maintain
+ Side effects - Water control capacity
+ Side effects - Job opportunity
+ + Side effects - Environmental impact

Hypothesis

Precision irrigation optimizes water use in agriculture by deploying technology to deliver water precisely where and when needed, enhancing efficiency and minimizing waste based on factors like soil moisture and weather conditions.

Theoretical Backup

Precision irrigation involves the efficient and targeted application of water to meet the specific needs of individual plants or management units, minimizing environmental impacts and addressing water scarcity through adaptable and responsive operational systems (Liang et al., 2020).

Practical Implication

This measure is deployed in agricultural areas with a high risk of drought. It involves implementing coordinated actions such as the use of adapted crops and varieties, decentralized water storage, greywater recycling, agro-industrial wastewater reuse, rainwater harvesting, and farmland consolidation. It also requires providing education on new skills through the Water Resilience Knowledge Hub.

Belong to

A4 Efficient water use

Synergies

I4, I5, I6, I9, I10, W2, W3

Conflicts

-

Sell-by date

2045

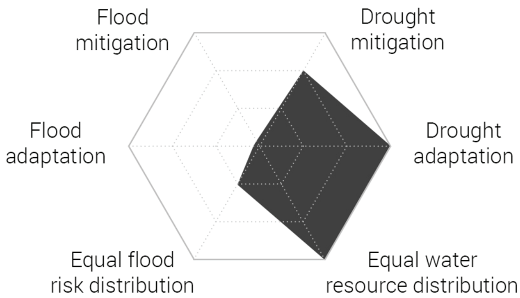
Stakeholders

Villager
Villagers' committee
Ministry of Water Resources
Ministry of Agriculture and Rural Affairs
Ministry of Ecology and Environment
Local government
Water management entrepreneur

References

Liang, Z., Liu, X., Xiong, J., & Xiao, J. (2020). Water Allocation and Integrative Management of Precision Irrigation: A Systematic Review. Water, 12(11), 3135. https://doi.org/10.3390/w12113135

I4
Decentralized water storage



- - Cost - Initiate
- Cost - Maintain
+ + Side effects - Water control capacity
+ Side effects - Job opportunity
Side effects - Environmental impact

Hypothesis

Decentralized water storage provides an additional layer of protection to ensure water availability for both urban residents and farmers, mitigating drawbacks associated with large reservoirs in the region.

Theoretical Backup

The inevitable reliance on reclaimed water for sustaining current living standards worldwide necessitates the critical implementation of satellite and decentralized systems, particularly in large cities with inadequately located treatment facilities, until broader acceptance of indirect potable reuse is achieved, ultimately requiring methods like groundwater recharge and surface water augmentation to optimize reclaimed water usage (Gikas & Tchobanoglous, 2009).

Practical Implication

This measure is prioritized for deployment in high drought risk areas. It involves implementing a linked approach with detention basins, wetland restoration, dam removal, precision irrigation, channels as distributors, greywater recycling, seawater desalination, agro-industrial wastewater reuse, rainwater harvesting, and climate-proofing structures.

Belong to

A5 Hybrid infrastructure system

Synergies

E8, E9, E13, I1, I2, I3, I5, I6, I9, W8

Conflicts

-

Sell-by date

2050

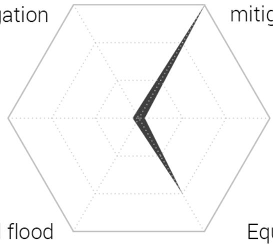
Stakeholders

Villager, Villagers' committee, Ministry of Water Resources , Ministry of Agriculture and Rural Affairs

References

Gikas, P., & Tchobanoglous, G. (2009). The role of satellite and decentralized strategies in water resources management. Journal of Environmental Management, 90(1), 144–152. https://doi.org/10.1016/j.jenvman.2007.08.016

I5
Greywater recycling



-	Cost - Initiate
-	Cost - Maintain
+	Side effects - Water control capacity
+ +	Side effects - Job opportunity
+ +	Side effects - Environmental impact

Hypothesis

Greywater recycling involves collecting and treating relatively clean household or commercial wastewater for non-potable reuse, contributing to sustainable water management and resource conservation.

Theoretical Backup

The growing emphasis on environmental consciousness, coupled with the significant impact of water costs, drives the demand for advanced greywater treatment plants in buildings, with typical amortization costs ranging from 5 to 7 years, favoring systems incorporating advanced biological treatment and UV disinfection (Nolde, 2005).

Practical Implication

This measure is deployed in small towns and rural areas, prioritizing high drought risk area. It involves coordinated implementation with Precision Irrigation, Decentralized Water Storage, Agro-industrial Wastewater Reuse, and Village Relocation. It requires motivating residents to transition through increasing public risk awareness, while providing education on new skills through the Water Resilience Knowledge Hub.

Belong to

A6 Non-conventional water resources

Synergies

I3, I4, I6, W1, W3, W4

Conflicts

-

Sell-by date

2035

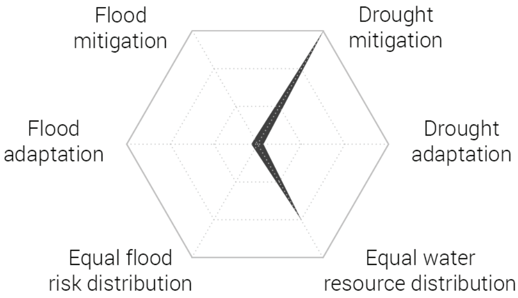
Stakeholders

Villager, Villagers' committee, Ministry of Water Resources , Ministry of Agriculture and Rural Affairs

References

Nolde, E. (2005). Greywater recycling systems in Germany—Results, experiences and guidelines. Water Science and Technology, 51(10), 203–210. https://doi.org/10.2166/wst.2005.0368

I6
Agro-industrial wastewater reuse



- -	Cost - Initiate
-	Cost - Maintain
+	Side effects - Water control capacity
+	Side effects - Job opportunity
+ +	Side effects - Environmental impact

Hypothesis

Agro-industrial wastewater reuse involves treating and repurposing agricultural and industrial wastewater to address water scarcity, promote sustainable water management, and minimize environmental impact.

Theoretical Backup

A 1.5-year field study demonstrates the successful reuse of agro-industrial wastewater for irrigating processing tomatoes and broccoli. The study reveals that tertiary treatment, involving ultrafiltration and UV disinfection, allows effective recycling of agro-industrial effluents for irrigation (Libutti et al., 2018).

Practical Implication

This measure is deployed in industrial zones surrounding small towns and rural areas, prioritizing high drought-risk regions. It involves implementing coordinated measures such as precision irrigation, decentralized water storage, greywater recycling, village relocation, and farmland consolidation. Achieving this requires motivating farmers and entrepreneurs to transition by raising public awareness of risks, while also offering education on new skills through the Water Resilience Knowledge Hub.

Belong to

A6 Non-conventional water resources

Synergies

I3, I4, I5, W1, W2, W3, W4, W6

Conflicts

-

Sell-by date

2050

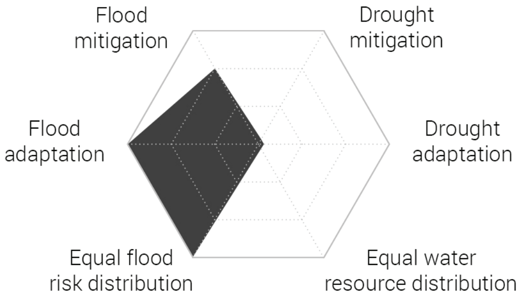
Stakeholders

Villager
Villagers' committee
Ministry of Water Resources
Ministry of Agriculture and Rural Affairs
Entrepreneur
Ministry of Ecology and Environment
Local government
Research institute
Water management entrepreneur

References

Libutti, A., Gatta, G., Gagliardi, A., Vergine, P., Pollice, A., Beneduce, L., Disciglio, G., & Tarantino, E. (2018). Agro-industrial wastewater reuse for irrigation of a vegetable crop succession under Mediterranean conditions. Agricultural Water Management, 196, 1–14. https://doi.org/10.1016/j.agwat.2017.10.015

I7
Dikes as flood-proof road network



- - - Cost - Initiate
- - Cost - Maintain
+ + Side effects - Water control capacity
+ Side effects - Job opportunity
- - Side effects - Environmental impact

Hypothesis

The dike system safeguards flood-prone areas by forming barriers along water bodies. Incorporating these barriers into road networks boosts flood resilience, creating a flood-proof transportation system.

Theoretical Backup

Climate change poses a critical threat to the reliability and safety of essential road infrastructure, necessitating timely adaptation due to its vital role in supporting the uninterrupted functioning of society. (Bles et al., 2015)

Practical Implication

This measure will be prioritized for towns and rural areas with a high flood risk, ultimately forming a flood-proof disaster relief transportation network. It will be implemented in conjunction with streambed re-naturalization, village relocation, and climate-proofing structures. Cost and environmental impact will be reduced by utilizing sediment from dredging and reservoir maintenance.

Belong to

A5 Hybrid infrastructure system

Synergies

E11, I8, W1, W8

Conflicts

E10

Sell-by date

>2060

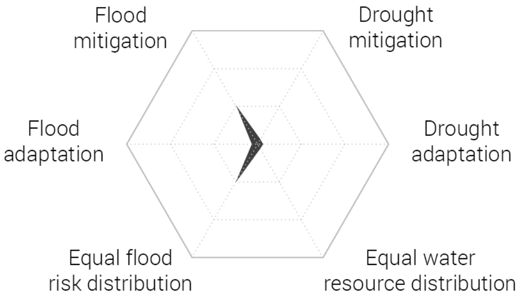
Stakeholders

Ministry of Water Resources, Ministry of Transport

References

Bles, T., Bassembinder, J., Chevreuil, M., Danielsson, P., Falemo, S., & Venmans, A. (2015). Roadapt. Roads for today, adapted for tomorrow. Guidelines. CEDR Project.

I8
Reuse of sediment



	Cost - Initiate
-	Cost - Maintain
	Side effects - Water control capacity
+ +	Side effects - Job opportunity
+ +	Side effects - Environmental impact

Hypothesis

Reusing sediment from river and reservoir projects is an eco-friendly approach that enhances water body health and provides multiple benefits in sediment management.

Theoretical Backup

Using sediments with high nutrient content can result in a 25% cost savings compared to conventional fertilization, but costs are 9% higher when using sediments with low nutrient content; sediments with nitrogen content above 1.5 g kg^{-1} are considered cost-efficient as a nitrogen source based on local conditions (Braga et al., 2019).

Practical Implication

This measure obtains raw materials from the maintenance of flood channels and reservoirs to support the implementation of other measures. It is implemented in conjunction with streambed re-naturalization, dikes as flood-proof road networks, village relocation, and climate-proofing structures to reduce costs and environmental impact.

Belong to

A5 Hybrid infrastructure system

Synergies

E9, E11, I7, W1, W8

Conflicts

-

Sell-by date

2025

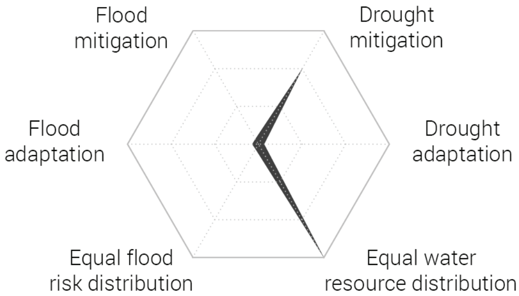
Stakeholders

Ministry of Water Resources
Ministry of Ecology and Environment
Water management entrepreneur

References

Braga, B. B., De Carvalho, T. R. A., Brosinsky, A., Foerster, S., & Medeiros, P. H. A. (2019). From waste to resource: Cost-benefit analysis of reservoir sediment reuse for soil fertilization in a semiarid catchment. Science of The Total Environment, 670, 158–169. https://doi.org/10.1016/j.scitotenv.2019.03.083

I9
Rainwater harvesting



Cost - Initiate
- Cost - Maintain
+ Side effects - Water control capacity
+ Side effects - Job opportunity
Side effects - Environmental impact

Hypothesis

Rainwater harvesting is the collection and storage of rainwater for later use, promoting sustainable water management and reducing reliance on conventional water sources.

Theoretical Backup

Rainwater harvesting and storage systems (RWHSS), mandated in certain countries like China, Brazil, Australia, and India for city planning approval, serve as self-supply alternatives, offering economic savings and addressing water scarcity and contamination in both rural and urban communities through a straightforward structure comprising catchment, storage, and distribution components (García-Ávila et al., 2023).

Practical Implication

This measure is deployed in small towns and rural areas, prioritizing areas with high precipitation. It involves coordinating actions with detention basins, wetland restoration, precision irrigation, decentralized water storage, and village relocation. Implementation requires motivating residents to transition by raising public awareness of risks and providing education on new skills through the Water Resilience Knowledge Hub.

Belong to

A6 Non-conventional water resources

Synergies

E8, E9, I3, I4, W1, W3, W4

Conflicts

-

Sell-by date

2030

Stakeholders

Villager
Villagers' committee
Ministry of Water Resources
Ministry of Agriculture and Rural Affairs
Water management entrepreneur

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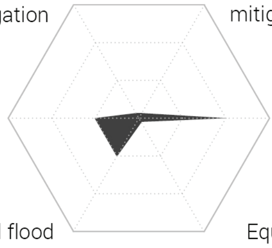
I10
Use of adapted varieties



- Cost - Initiate
- Cost - Maintain
Side effects - Water control capacity
+ Side effects - Job opportunity
Side effects - Environmental impact

Hypothesis

Using adapted crops and varieties, both herbaceous and tree crops, to mitigate climate change impacts, enhance biodiversity, and ensure stable agricultural production.

Theoretical Backup

Adopting resilient crops, including adapted and heritage varieties, mitigates the impact of extreme weather and climate events, enhances biodiversity, and promotes soil carbon storage for increased ecological resilience (European Environment Agency., 2019).

Practical Implication

This measure is deployed in agricultural areas with high drought risk. It involves coordinated implementation with Agri-managed aquifer recharge, Precision irrigation, and Farmland consolidation. It requires providing education on new skills through the Water Resilience Knowledge Hub.

Belong to

A4 Efficient water use

Synergies

E4, I3, W2, W3

Conflicts

-

Sell-by date

2030

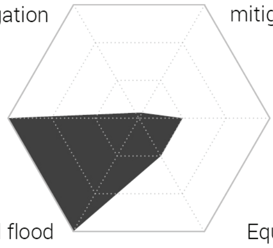
Stakeholders

Villager
Villagers' committee
Ministry of Agriculture and Rural Affairs
Local government
Research institute
Water management entrepreneur

References

European Environment Agency. (2019). Climate change adaptation in the agriculture sector in Europe. Publications Office. https://data.europa.eu/doi/10.2800/537176

W1
Village relocation



- - - Cost - Initiate
- - Cost - Maintain
Side effects - Water control capacity
+ + + Side effects - Job opportunity
+ Side effects - Environmental impact

Hypothesis

Village relocation is a proactive strategy involving the organized transfer of communities from flood-prone areas to safer locations to mitigate the adverse effects of recurring floods on human lives and property.

Theoretical Backup

The relocation and settlement program (RSP) successfully achieves goals such as increasing ecosystem services, reducing dependence on ecosystem services, and restoring livelihoods by transforming households from traditional agricultural and forest production to more efficient non-farm activities, resulting in increased income, reduced poverty rates, and improved living conditions for relocated households (Li et al., 2018).

Practical Implication

This measure is deployed in the vicinity of small towns and rural areas, prioritizing high flood risk areas. It involves coordinating actions such as meadows and pastures preservation, increasing green cover, wetland restoration, utilizing dikes as a flood-proof road network, implementing greywater recycling and rainwater harvesting systems, consolidating farmland, diversifying the economy, and climate-proofing structures. It requires motivating residents to transition by raising public awareness of risks and providing education on new skills through the Water Resilience Knowledge Hub.

Belong to

A7 Water sensitive land consolidation

Stakeholders

Villager, Villagers' committee, Ministry of Housing and Urban-Rural Development

Synergies

E1, E3, E9, I5, I7, I8, I9, W2, W3, W4, W5, W7, W8

Conflicts

-

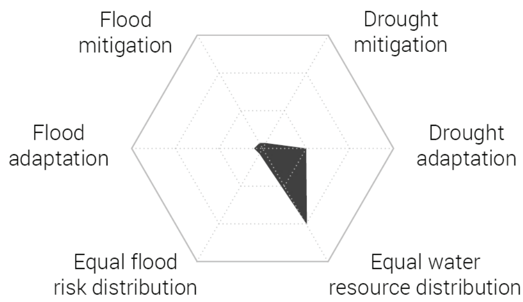
Sell-by date

>2060

References

Li, C., Li, S., Feldman, M. W., Li, J., Zheng, H., & Daily, G. C. (2018). The impact on rural livelihoods and ecosystem services of a major relocation and settlement program: A case in Shaanxi, China. Ambio, 47(2), 245–259. https://doi.org/10.1007/s13280-017-0941-7

W2
Farmland consolidation



-	Cost - Initiate
-	Cost - Maintain
	Side effects - Water control capacity
+ +	Side effects - Job opportunity
+	Side effects - Environmental impact

Hypothesis

Farmland consolidation refers to the process of merging or acquiring agricultural land holdings to create larger and more efficient farming operations, often resulting in increased productivity and economies of scale in the agricultural sector.

Theoretical Backup

To enhance food security, addressing physical farmland fragmentation involves employing strategies such as farmland consolidation for large heterogeneous farms in economies with high land availability, voluntary parcel exchange and on-field harvest sales for small heterogeneous farms in moderate and subsistence economies with land scarcity, land realignment for homogenous farms with contiguous plots, and farmland use consolidation or crop consolidation for multiple uses on small plots and farms (Ntihinyurwa & De Vries, 2021).

Practical Implication

This measure is deployed in farmland characterized by dispersed ownership or spatial fragmentation. It involves implementing a coordinated approach that includes meadows and pastures, buffer strips, forest riparian buffers, agri-managed aquifer recharge, afforestation in headwater areas, afforestation of reservoir catchments, detention basins, wetland restoration, precision irrigation, agro-industrial wastewater reuse, use of adapted crops and varieties, and village relocation.

Belong to

A7 Water sensitive land consolidation

Synergies

E1, E2, E4, E5, E6, E7, E8, E9, I3, I6, I10, W1

Conflicts

-

Sell-by date

2030

Stakeholders

Villager
Villagers' committee
Ministry of Agriculture and Rural Affairs
Local government
Water management entrepreneur

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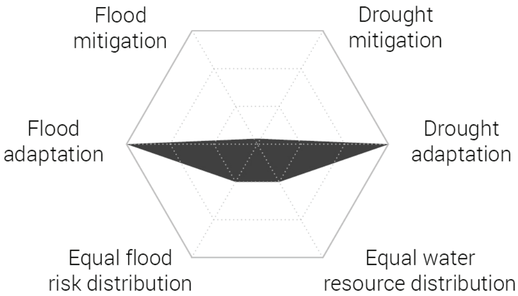
Ntihinyurwa, P. D., & De Vries, W. T. (2021). Farmland Fragmentation, Farmland Consolidation and Food Security: Relationships, Research Lapses and Future Perspectives. Land, 10(2), 129. https://doi.org/10.3390/land10020129

W3
Water resilience knowledge hub



-	Cost - Initiate
- - -	Cost - Maintain
	Side effects - Water control capacity
+ +	Side effects - Job opportunity
+	Side effects - Environmental impact

Hypothesis

The Water Resilience Knowledge Hub is a collaborative platform uniting experts and communities to advance knowledge and innovation for a resilient water future in the face of challenges like scarcity and flood.

Theoretical Backup

Effective sustainable water governance necessitates interdisciplinary collaboration among scientists, managers, policymakers, and stakeholders to cooperatively generate credible knowledge and solutions, promote social learning, and build enduring institutional capacity for freshwater management (White et al., 2019).

Practical Implication

This measure is deployed in towns and villages with drought and flood risk, prioritizing those with high risk. Considering meadows and pastures, forest riparian buffers, precision irrigation, use of adapted crops and varieties, greywater recycling, agro-industrial wastewater reuse, rainwater harvesting, all implemented in conjunction. It can serve as one direction for economic diversification.

Belong to

A8 Water-resilient communities

Synergies

E1, E4, I3, I5, I6, I9, I10 W1, W5, W7

Conflicts

-

Sell-by date

2040

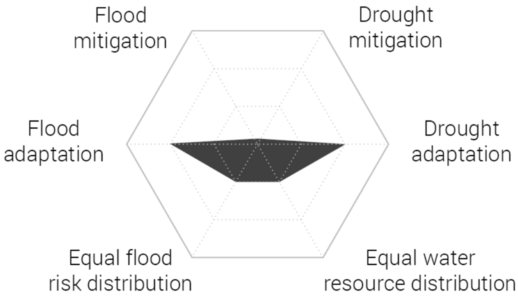
Stakeholders

Villager
Villagers' committee
Non-governmental organisation
Research institutes
Ministry of Water Resources
Ministry of Agriculture and Rural Affairs
Local government
Research institute
Water management entrepreneur

References

White, D. D., Lawless, K. L., Vivoni, E. R., Mascaro, G., Pahle, R., Kumar, I., Coli, P., Castillo, R. M., Moreda, F., & Asfora, M. (2019). Co-Producing Interdisciplinary Knowledge and Action for Sustainable Water Governance: Lessons from the Development of a Water Resources Decision Support System in Pernambuco, Brazil. Global Challenges, 3(4), 1800012. https://doi.org/10.1002/gch2.201800012

W4
Increasing public risk awareness



-	Cost - Initiate
- - -	Cost - Maintain
	Side effects - Water control capacity
+	Side effects - Job opportunity
	Side effects - Environmental impact

Hypothesis

Raising awareness about flood risks empowers communities to proactively prepare for potential devastation, educating individuals on vulnerable areas and effective actions for safety and mitigation.

Theoretical Backup

In the past decade, European countries have developed hazard maps for natural disasters, and in October 2011, Zurich's local authorities implemented a campaign to inform building owners in flood-prone areas about potential damage, flood probabilities, and protective measures, operating under the assumption that increasing citizen awareness of risks encourages proactive self-protection measures (Maidl & Buchecker, 2015).

Practical Implication

This measure is deployed in towns and villages with drought and flood risk, prioritizing those with high risk. It considers and implements linkage with meadows and pastures, forest riparian buffers, greywater recycling, agro-industrial wastewater reuse, rainwater harvesting, and economy diversification.

Belong to

A8 Water-resilient communities

Synergies

E1, E4, I5, I6, I9, W1, W7

Conflicts

-

Sell-by date

2035

Stakeholders

Villager
Villagers' committee
Ministry of Water Resources
Ministry of Agriculture and Rural Affairs
Non-governmental organisation
Local government, Research institute
Water management entrepreneur

References

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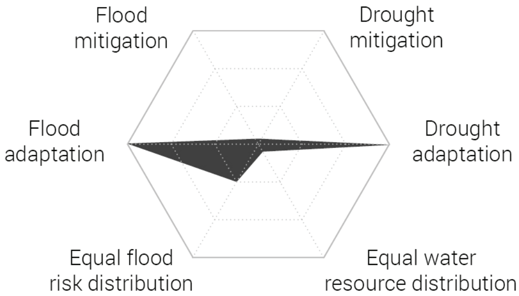
W5
Establishment of early warning systems



- Cost - Initiate
- - - Cost - Maintain
Side effects - Water control capacity
+ Side effects - Job opportunity
Side effects - Environmental impact

Hypothesis

Early warning systems are vital for climate adaptation and risk reduction, relying on community involvement, education, efficient communication, and sustained preparedness for effective hazard mitigation.

Theoretical Backup

Civil Society Organizations play a crucial role in strengthening Flood Early Warning Systems (FEWS) locally by addressing challenges through tailored solutions such as disaster risk reduction awareness campaigns, improved communication between communities and authorities, fostering a risk-informed and self-prepared community response, promoting gender inclusion in FEWS, and engaging in advocacy campaigns to enhance resilience to disasters (Maidl & Buchecker, 2015).

Practical Implication

This measure is deployed in critical water bodies and waterways, prioritizing those relevant to high-risk areas, and setting up emergency broadcasting stations in high-risk areas. It is implemented in coordination with village relocation, climate-proofing structures, and water resilience knowledge hubs.

Belong to

A8 Water-resilient communities

Synergies

W1, W3, W8

Conflicts

-

Sell-by date

2040

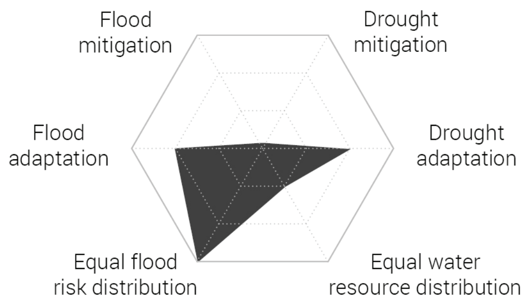
Stakeholders

Villager
Villagers' committee
Ministry of Water Resources
Ministry of Agriculture and Rural Affairs
Ministry of Housing and Urban-Rural Development
Non-governmental organisation
Local government, Research institute
Water management entrepreneur

References

Maidl, E., & Buchecker, M. (2015). Raising risk preparedness by flood risk communication. Natural Hazards and Earth System Sciences, 15(7), 1577–1595. https://doi.org/10.5194/nhess-15-1577-2015

W6
Monitoring and evaluation



-	Cost - Initiate
- - -	Cost - Maintain
+	Side effects - Water control capacity
+ +	Side effects - Job opportunity
+ +	Side effects - Environmental impact

Hypothesis

Monitoring and evaluation of water resilience involves systematically collecting, analyzing, and interpreting data to assess and enhance water systems' capacity to withstand natural disasters, climate change, and human-induced stressors.

Theoretical Backup

The Water Provision Resilience indicator assesses a city or water provider's capacity to sustain or enhance safe water access for its population by evaluating vulnerabilities in the water supply system and its management, offering valuable insights for managers to prioritize the development of policies or programs aimed at enhancing long-term system resilience. (Milman & Short, 2008)

Practical Implication

This measure is deployed in critical water bodies, waterways, and areas with novel interventions, prioritizing those relevant to high-risk areas, and establishing research facilities around them. The main monitoring research targets include the effectiveness and environmental impacts of streambed re-naturalization, dam removal, meadows and pastures, forest riparian buffers, wetland restoration, agri-managed aquifer recharge, afforestation of reservoir catchments, seawater desalination, and agro-industrial wastewater reuse.

Belong to

A8 Water-resilient communities

Synergies

E1, E4, E5, E7, E9, E11, E13, I1, I6

Conflicts

-

Sell-by date

2035

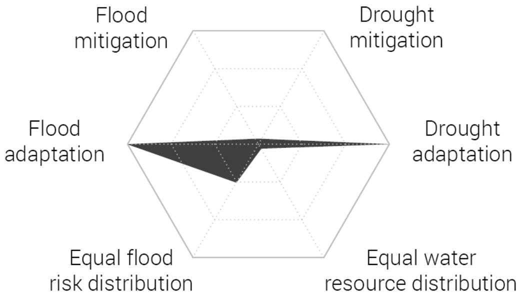
Stakeholders

Villager
Villagers' committee
Ministry of Water Resources
Ministry of Agriculture and Rural Affairs
Ministry of Ecology and Environment
Non-governmental organisation
Local government
Research institute
Water management entrepreneur

References

Milman, A., & Short, A. (2008). Incorporating resilience into sustainability indicators: An example for the urban water sector. Global Environmental Change, 18(4), 758–767. https://doi.org/10.1016/j.gloenvcha.2008.08.002

W7
Economy diversification



- - Cost - Initiate
- - - Cost - Maintain
Side effects - Water control capacity
+ + Side effects - Job opportunity
Side effects - Environmental impact

Hypothesis

Non-farm economy diversification involves the expansion of economic activities beyond traditional agriculture, often through the development of sectors such as tourism and industrial transfer, to enhance overall economic resilience and sustainability.

Theoretical Backup

Chinese villages experience a notable boost in agricultural land productivity due to the positive impact of non-farm revenue, as the slight reduction in labor dedicated to agriculture is overshadowed by the substantial improvement facilitated by infrastructure capital investment funded by non-farm earnings (Wang et al., 2011).

Practical Implication

This measure is deployed in the vicinity of small towns and rural areas, with the principle of encouraging spontaneous industrial restructuring. It involves coordinated implementation with measures such as meadows and pastures, forest riparian buffers, afforestation in headwater areas, afforestation of reservoir catchments, detention basins, wetland restoration, and village relocation. It requires motivating residents to transition by increasing public awareness of risks and providing education on new skills through the Water Resilience Knowledge Hub.

Belong to

A7 Water sensitive land consolidation

Synergies

E1, E5, E6, E7, E8, E9, W1, W3, W4

Conflicts

-

Sell-by date

>2060

Stakeholders

Villager
Villagers' committee
Ministry of Housing and Urban-Rural Development
Entrepreneur, Ministry of Finance
National Development and Reform Commission
Ministry of Agriculture and Rural Affairs
Ministry of Transport
Local government
Research institute
Water management entrepreneur

References

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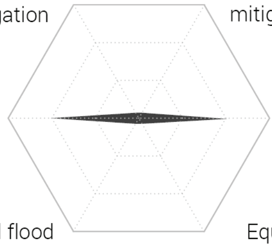
W8
Climate-proofing structure



- - Cost - Initiate
- Cost - Maintain
+ + Side effects - Water control capacity
+ Side effects - Job opportunity
Side effects - Environmental impact

Hypothesis

Climate-proofing infrastructure and buildings are resilient structures specifically designed, constructed, and maintained to withstand and adapt to the increasing impacts of climate change, including rising global temperatures and more frequent and severe extreme weather events.

Theoretical Backup

The R4 framework of resilience highlights key elements for promoting resilience in critical infrastructure, including robustness, redundancy, resourcefulness, and rapidity, which respectively refer to the ability to withstand stress, the existence of substitutable elements, the capacity to mobilize resources, and the capability to restore functionality promptly after disruptive events (Shakou et al., 2019).

Practical Implication

This measure is deployed in towns and villages facing drought and flood risks, prioritizing those at high risk. It involves the implementation of decentralized water storage, dikes as flood-proof road networks, reuse of sediment, and village relocation in a coordinated manner.

Belong to

A7 Water sensitive land consolidation

Synergies

I4, I7, I8, W1, W5

Conflicts

-

Sell-by date

2045

Stakeholders

Villager
Villagers' committee
Ministry of Water Resources
Ministry of Housing and Urban-Rural Development
Local government
Infrastructure developer

References

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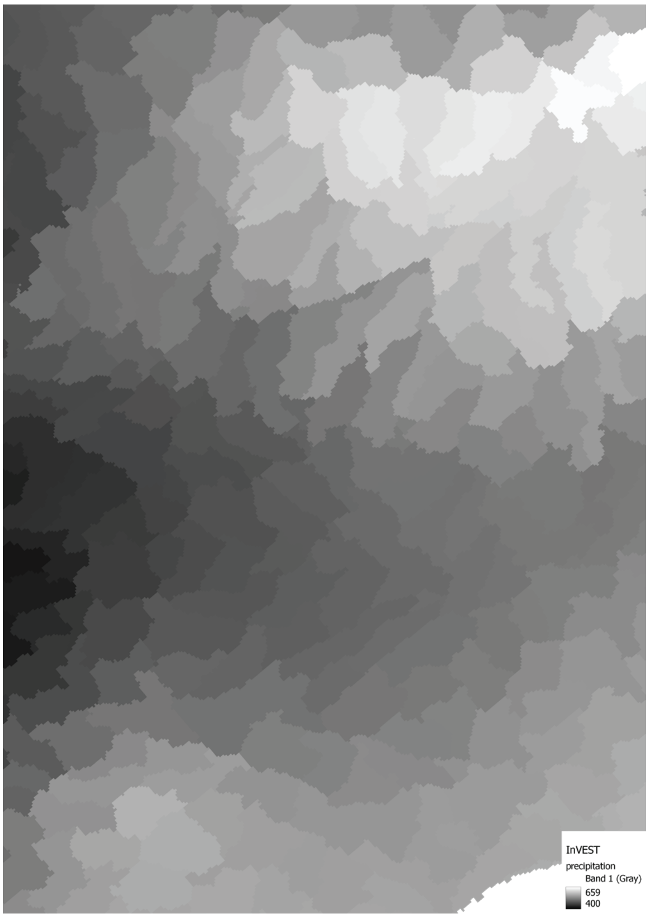
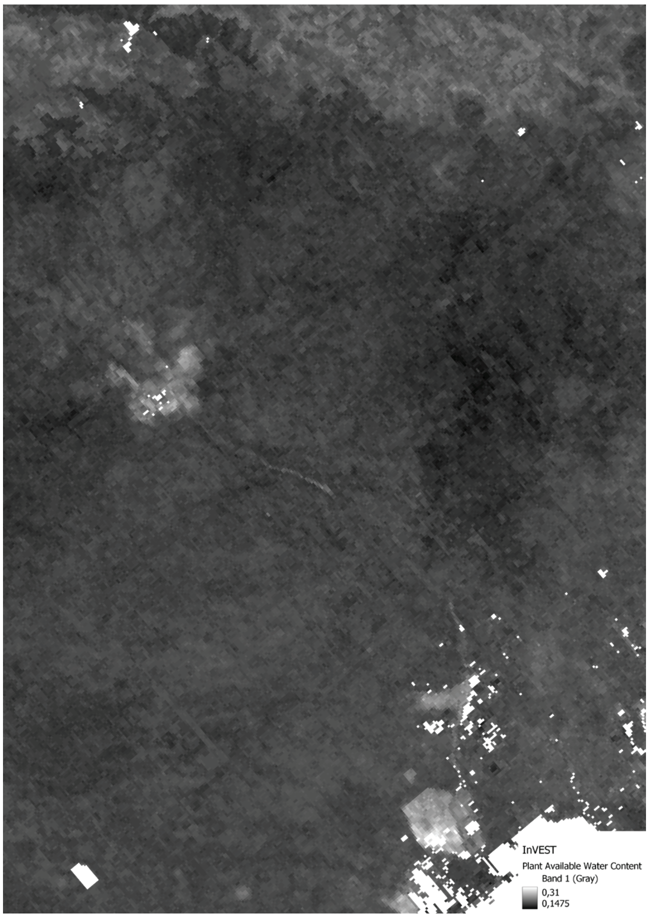
City boundary, Data: OSM

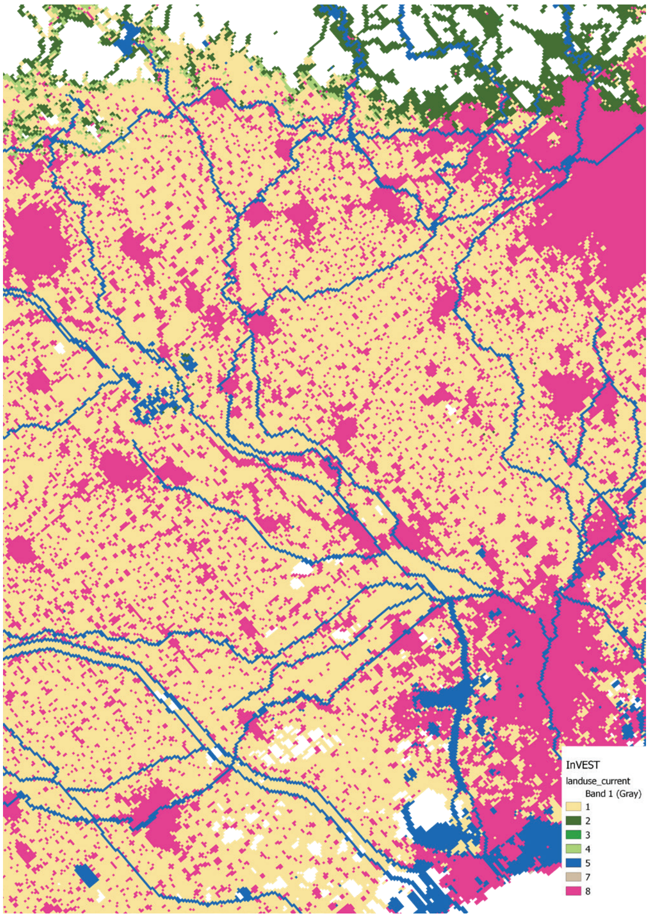
Evapotranspiration, Data: Global-AET



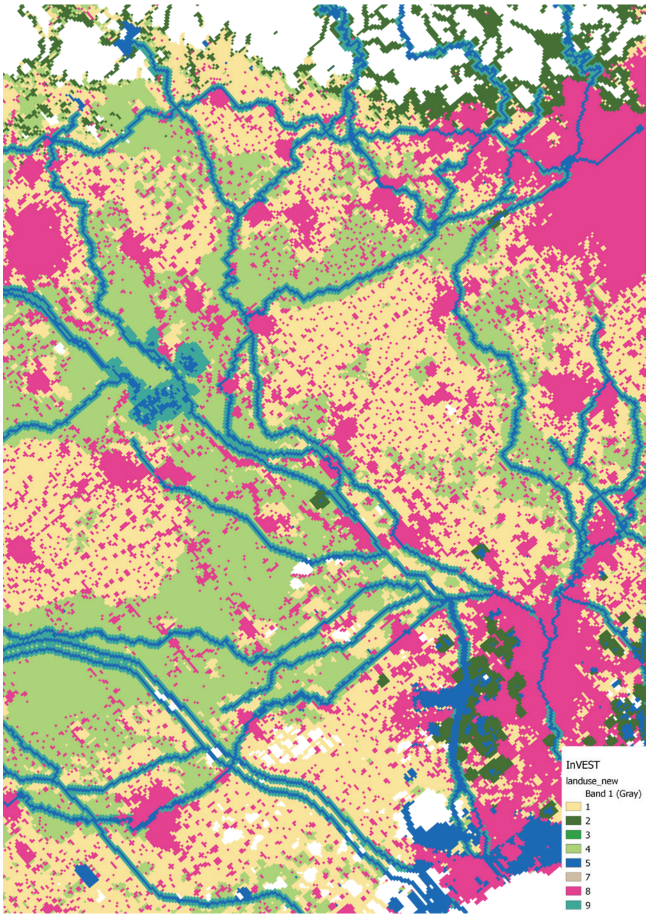
Precipitation, Data: WorldClim



Plant Available Water Content, Data: ISRIC Data Hub



Current landuse, Data: Yang & Huang (2021)

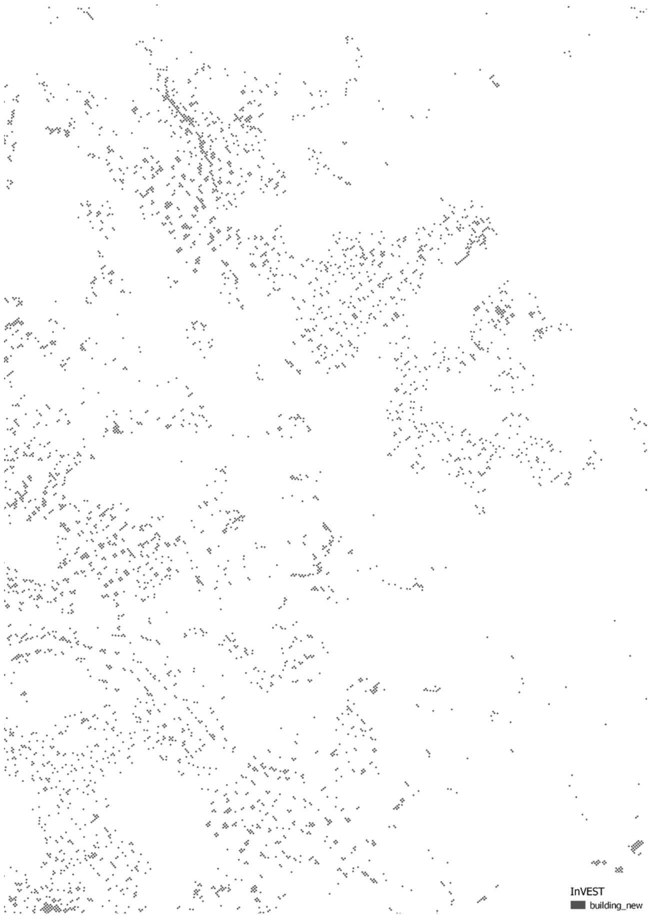


Proposed landuse, modified by author

Root restricting layer depth, Data: ISRIC Data Hub

Soil Hydrologic Group, Data: HiHydroSoil v2.0

Current buit-up areas under risks, modified by author



Proposed buit-up areas under risks, modified by author

descriptio	lucode	root_dept	Kc	LULC_veg	cn_a	cn_b	cn_c	cn_d
0	0	0	0	0	1	1	1	1
Cropland	1	1000	1.1	1	63	75	83	87
Forest	2	3500	1	1	36	60	73	79
Shrub	3	2000	0.9	1	35	56	70	77
Grassland	4	2000	0.9	1	49	69	79	84
Water	5	10	0.9	0	99	99	99	99
Sonw/Ice	6	10	0.9	0	99	99	99	99
Barren	7	0	0.5	0	77	86	91	94
Imperviou	8	0	0.2	0	89	92	94	95
Wetland	9	1000	1.2	0	30	58	71	78

Biophysical Table, Data: USDA handbook

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