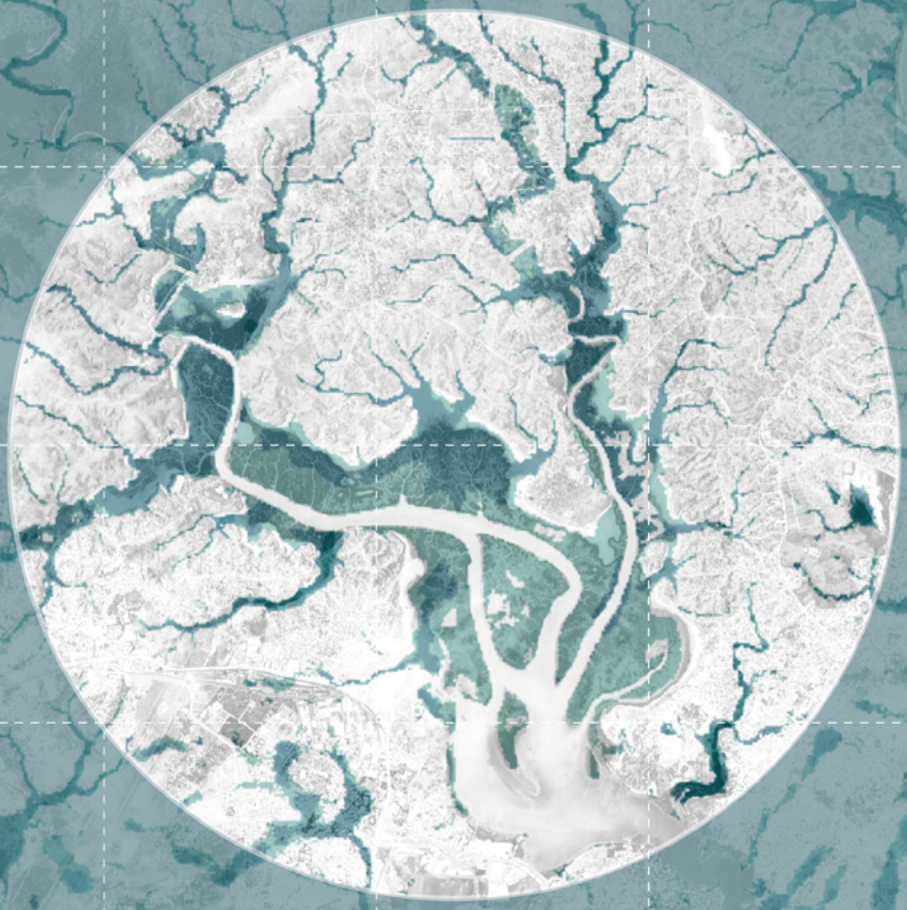
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Handbook for Livable and Resilient Cities

Integrating Hazard and Risk Information into Urban Planning

City Resilience Program
GFDRR
Global Facility for Disaster Reduction and Recovery
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Foreword

Cities are centers of opportunity, innovation, and economic growth —home to more than half of the world's population and responsible for over 80% of global Gross Domestic Product (GDP). They are where most private sector jobs are created and where people seek better livelihoods. Yet cities are also at the frontline of climate change, disaster risk, and social vulnerability. To remain competitive and inclusive, urban areas must be planned with a forward-looking approach—one that integrates risk considerations into land use, urban governance, and infrastructure investments while fostering livability.

The *Handbook for Livable and Resilient Cities. Integrating Hazard and Risk Information into Urban Planning* serves as an important guide for decision-makers, planners, and practitioners committed to building cities that are not only resilient but also livable and economically vibrant. Livable cities are key for a livable planet. They connect people to jobs, attract investment, and create pathways out of poverty. When guided by risk-informed planning principles, cities can transform challenges into opportunities—generating employment, strengthening local economies, and improving quality of life. The challenges of rapid urbanization are evident: inadequate infrastructure, exposure to hazards, and growing inequality. As climate change intensifies and urbanization expands, urban risks continue to evolve, often amplifying inequalities and disproportionately affecting the most vulnerable populations. Without deliberate action, urban growth can become a driver of risk rather than a driver of resilience. However, when guided by risk-informed planning principles and proactive resilient investments, cities can transform these challenges into opportunities yielding significant returns—not only by protecting lives and property but also by safeguarding and creating jobs.

This handbook offers a comprehensive framework for integrating hazard and risk information into urban planning. It combines key concepts with practical methodologies and actionable measures that empower cities to anticipate, reduce, and adapt to disaster and climate risks. Moving beyond traditional planning approaches, it acknowledges the interconnected nature of urban systems and the systemic nature of risk, promoting integrated, layered strategies that deliver sustainable solutions. Central to this vision is inclusive, multistakeholder collaboration—ensuring that resilience planning not only safeguards communities but also supports economic vitality and livability. As we navigate an increasingly complex and uncertain urban landscape, this handbook offers a path forward—one that will be further refined through continued collaboration, field application, and integration of emerging evidence and good practices. By embedding resilience into urban development strategies, we can build cities that withstand shocks and stresses, thrive in uncertainty, and deliver on their promise as engines of growth and opportunity-, ensuring a more livable, equitable, and resilient future for all.



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Abbreviations and Acronyms

ALARP	As Low as Reasonably Practical
BCP	Business Continuity Plan
CASA	Environmental Housing Certification
CCA	Climate Change Adaptation
CEDD	Civil Engineering and Development Department of Hong Kong
CRM	Climate Risk Management
CRP	City Resilience Program
DEM	Digital Elevation Model
DFI	Development Finance Institution
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
EAD	Expected Annual Damage
EDGE	Excellence in Design for Greater Efficiencies
EP&R	Emergency Preparedness and Response
EWS	Early Warning System
GDP	Gross Domestic Product
GEJE	Great East Japan Earthquake
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	Greenhouse Gases
GIS	Geographic Information System
Ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
ISC	International Science Council
LEED	Leadership in Energy and Environmental Design
LPMitP	Landslip Prevention and Mitigation Programme of Hong Kong
LVC	Land Value Capture
NBS	Nature-based Solutions
NGO	Nongovernmental Organization
PDC	Pyroclastic Density Current
PGA	Peak Ground Acceleration
PPP	Public-Private Partnership
PRA	Probabilistic Risk Assessment
RCP	Restrict, Condition, Promote
RIUP	Risk-informed Urban Planning
RUDP II	Second Rwanda Urban Development Project

SA	Spectral Acceleration
SBA	Scenario-Based Assessment
SMCE	Spatial Multi-Criteria Evaluation
SUDS	Sustainable Drainage Systems
TDR	Transfer of Development Rights
TR	Return Period
UHI	Urban Heat Island
UNDRR	United Nations Office for Disaster Risk Reduction
VEI	Volcanic Explosivity Index
WUI	Wildland-Urban Interface

Executive Summary

Rapid urbanization in cities worldwide has led to significant environmental, social, and economic challenges. These include heightened exposure to extreme weather and climate events, increased air and water pollution, rising poverty levels, shrinking green spaces, and greater risks to lives, livelihoods, and assets from natural hazards, disasters, and climate shocks. As these risks intensify, national and local governments must work together to improve urban livability and resilience through risk-informed urban planning. In this handbook, livable and resilient cities are defined as urban areas and their surroundings, where green urban growth, social inclusion, resilient built environments, and shared prosperity are promoted. The focus is on preventing and reducing the impacts of natural hazards and risks and the effects of climate change. In a livable and resilient city, planned and sustainable growth ensures people have access to healthy environments, affordable housing, basic services, jobs, and low-carbon transportation and economic opportunities.

The Challenge

Projections show that by 2050, two-thirds of the global population—around 7 billion people—will be living in cities (Ritchie et al. 2024). Meanwhile, urban areas are experiencing rising social, environmental, and economic losses linked to disasters. Climate change and multihazard interactions are contributing to more frequent, intense, and complex events, causing compounding and cascading impacts that disrupt urban systems and urban life.

Urbanization and risk are closely intertwined. As cities grow—often rapidly and informally—urban expansion transforms land use, disrupts natural ecosystems, and concentrates people, assets, and infrastructure in hazard-prone areas. Inadequate planning, weak enforcement of regulations, and inequitable access to services heighten exposure and vulnerability to existing—and emerging—hazards. Urban development itself can generate new risks, such as surface water flooding from impervious surfaces or landslides on destabilized slopes. These processes, intensified by climate change and deep-rooted socioeconomic inequalities, are fueling a hazardous buildup of risk in cities worldwide.

Climate change is affecting the frequency, intensity, and impacts of hydrometeorological and climatological hazards, such as cyclones and storms, floods, rainfall-triggered landslides, droughts, and heat waves. Altered precipitation patterns disturb the availability of water resources and affect ecosystems, food production, and water supply. Global warming is leading to sea-level rise, increasing the vulnerability of coastal cities to storm surges, coastal inundation, and saltwater intrusion into freshwater resources. Climate models project further increases in average temperatures, heat waves, and extreme rainfall events (Potsdam Institute for Climate Impact Research 2023). The number of weather- and climate-related disasters more than doubled over the past 40 years (Centre for Research on the Epidemiology of Disasters and United Nations Office for Disaster Risk Reduction 2019). Under projected climate and development trends, river flood damage is expected to rise dramatically, potentially increasing by a factor of 20 by the end of the century unless mitigated (Winsemius et al. 2016).

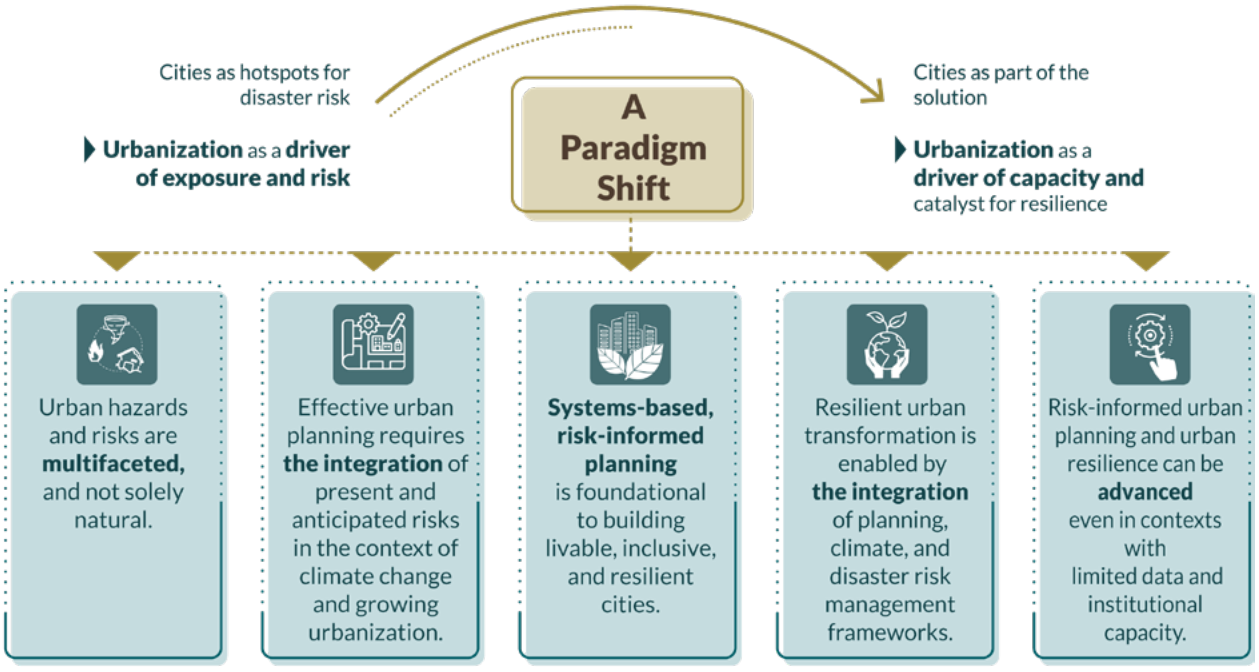
Rapid, unplanned urbanization and inadequate infrastructure can exacerbate hazard exposure, environmental degradation, socioeconomic disparities, and vulnerabilities that undermine livability and prosperity, affecting the current and future well-being of urban communities. Yet, conventional urban planning often fails to incorporate risk considerations, overlooking existing hazards and long-term vulnerabilities. This disconnect contributes to the accumulation of risk over time, leaving cities ill-prepared to cope with current and future shocks and stresses—and underscoring the need for a fresh approach to urban planning.

The Solution

Promoting livability and resilience through risk-informed urban planning enables cities to shift from reactive approaches focused on emergency response and postdisaster recovery to proactive, forward-looking strategies to reduce climate- and disaster-related impacts before they occur, minimizing human and economic losses. By embedding risk prevention and reduction into urban development processes, cities can anticipate hazards, minimize human and economic losses, and strengthen adaptive capacity, safeguarding people, ecosystems, infrastructure, livelihoods, and assets.

This handbook proposes a fundamental paradigm shift, informed by lessons learned. It explores how risk is shaped by the dynamic interplay between urbanization, social systems, and the natural and built environments. It overturns the notion of cities as passive arenas of disaster and climate exposure. Instead, it recognizes urbanization itself as a key driver that can either increase or decrease risk. From this perspective, planning decisions become proactive expressions of evidence-based risk reduction. Thus integrating risk into planning is both a technical necessity and a governance imperative (figure ES.1).

Figure ES.1: Risk-informed Urban Planning Approach



Source: Original for this publication.

This approach recognizes that hazards in urban environments are multifaceted and not solely natural, underscoring the need to transform urban planning practices to systematically integrate hazard and risk information. It calls for close collaboration among urban planning, disaster risk management (DRM), and climate risk management (CRM) practitioners to transform urbanization, from a source of risk into a force for resilience and capacity. Through this integration, the approach seeks to advance four interlinked objectives: promoting green growth, strengthening social inclusion, fostering resilient built environments, and enabling shared prosperity (figure ES.2).

Figure ES.2: Risk-informed Urban Planning Goals for Achieving Livable and Resilient Cities



Source: Original for this publication.

The broad scope of risk-informed urban planning requires sustained multistakeholder commitment at all stages of the process, even in cities with limited capacities to develop complex plans, to avoid the creation of new risks and to strengthen long-term urban resilience. From an operational standpoint, this approach seeks to encourage action across all cities, regardless of their size, institutional capacity, or availability of detailed hazard and risk information. In contexts with limited resources and data, risk-informed planning can begin with foundational steps and basic regulations—then progressively evolve as more data and capacity become available. These steps include the following:

- Developing straightforward regulatory frameworks and statutes;
- Defining clear institutional responsibilities and coordination mechanisms for risk management and urban planning;
- Drawing on available hazard and risk data from credible sources—even if of limited resolution—supplemented by historical records, observations, and local knowledge;

- Establishing simple, practical mechanisms to prevent the escalation of existing risks or the emergence of new ones, such as designating no-build zones, enforcing basic setback requirements, or controlling development in hazard-prone areas; and
- Training local officials in hazard and risk data utilization, spatial planning tools, monitoring and evaluation techniques.

As legal, institutional, and technical capacities strengthen, cities could move from basic hazard identification to more comprehensive and detailed multihazard and risk assessments and use these assessments to enhance urban planning decisions—guiding where, what, and how to build, and under what conditions. As risk information improves and cities continue to transform, planning instruments can be progressively refined. To support this progression, planners should treat the hazard and risk assessment as a multiscale, iterative process that evolves alongside planning needs and capacity. It typically begins with general-scale screening to understand the overall risk landscape, flag priority areas, and inform early planning and investment decisions. Detailed modeling, such as hydraulic modeling, seismic microzonation, or slope stability analysis, should be prioritized in high-risk locations and rapidly urbanizing areas, enabling the design of tailored risk reduction measures and more precise planning interventions.

To move from planning to implementation, cities should apply instruments suited to their capacity and context. Those with limited operational capacity and less dynamic development can rely on simple tools such as basic zoning, land-use planning, building codes, awareness campaigns, and targeted incentives to encourage resilient development. Cities with stronger institutions and more dynamic markets can adopt advanced mechanisms such as land value capture, green finance, and insurance schemes to fund and enforce the implementation of resilient urban development.

Recognizing the wide range of urbanization challenges and understanding that urban planning is a multidimensional and complex process, this handbook does not seek to be an exhaustive compendium on the subject, but rather a practical guide on how cities can integrate hazard and risk information into the planning process, including implementation recommendations.

This handbook is intended for practitioners, government officials, policy makers, decision-makers, and researchers working at the intersection of urban planning, disaster risk reduction (DRR), and climate resilience. It also speaks to nongovernmental organizations (NGOs) and grassroots organizations engaged in promoting more livable and resilient cities through diverse approaches, such as ecosystem-based adaptation, climate justice, and inclusive urban development. For these actors, the measures presented here can serve as a foundation for action and advocacy.

How to Use This Handbook

It unfolds in three parts, offering a comprehensive framework to embed climate, hazard, and risk information in urban plans. It sets out planning measures that can transform urbanization from a driver of risk into a catalyst for resilience and capacity.

PART I. CONCEPTUAL FRAMEWORK



- Introduces the main concepts, principles, goals, governance structures, planning scales, and capacities needed for undertaking risk-informed urban planning processes;
- Describes the restrict, condition, promote (RCP) measures for risk-informed urban planning; and
- Examines the interplay between urbanization and risk, emphasizing the multifaceted nature of hazards in urban settings.

PART II. PROCESS AND INSTRUMENTS FOR PLANNING AND IMPLEMENTATION

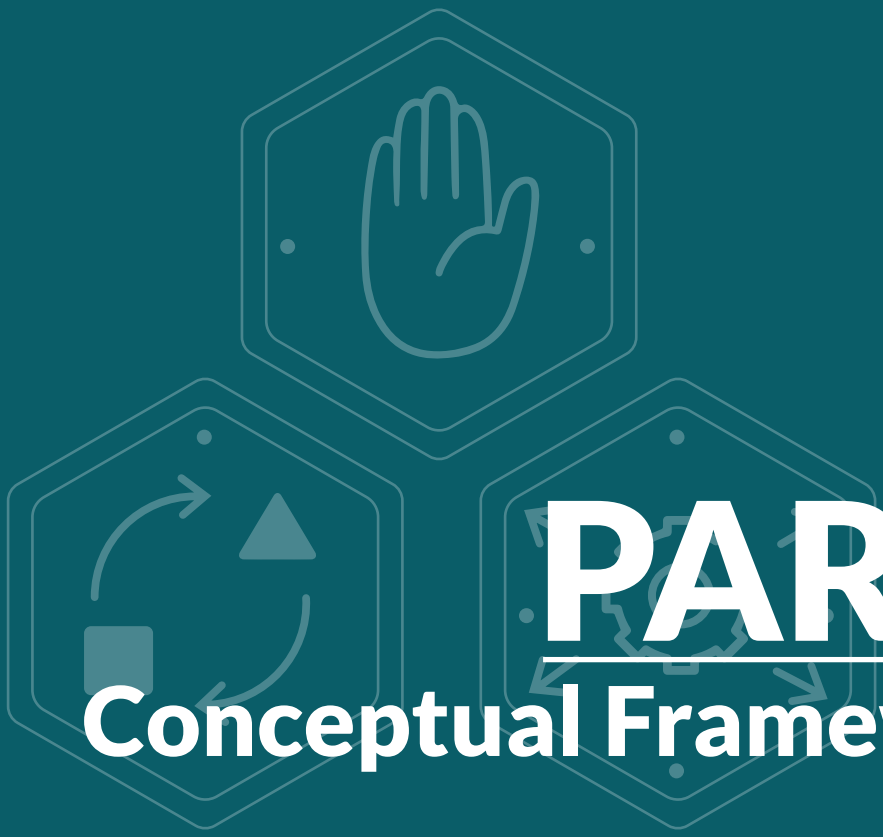


- Elaborates on the operational process to embed hazard and risk information in urban plans;
- Addresses regulatory, financial, and nonfinancial instruments and capacities for implementation; and
- Explains the importance of monitoring and evaluation to update and enhance risk-informed urban plans.

PART III. RCP MEASURES FOR INTEGRATING HAZARD AND RISK INFORMATION INTO URBAN PLANS



- Describes the key characteristics of hydrometeorological hazards, geohazards, and climatological hazards;
- Provides a catalog of examples of how the RCP framework can be used to guide risk-informed planning decisions; and
- Closes the handbook with some final remarks and conclusions.



PART I:
Conceptual Framework

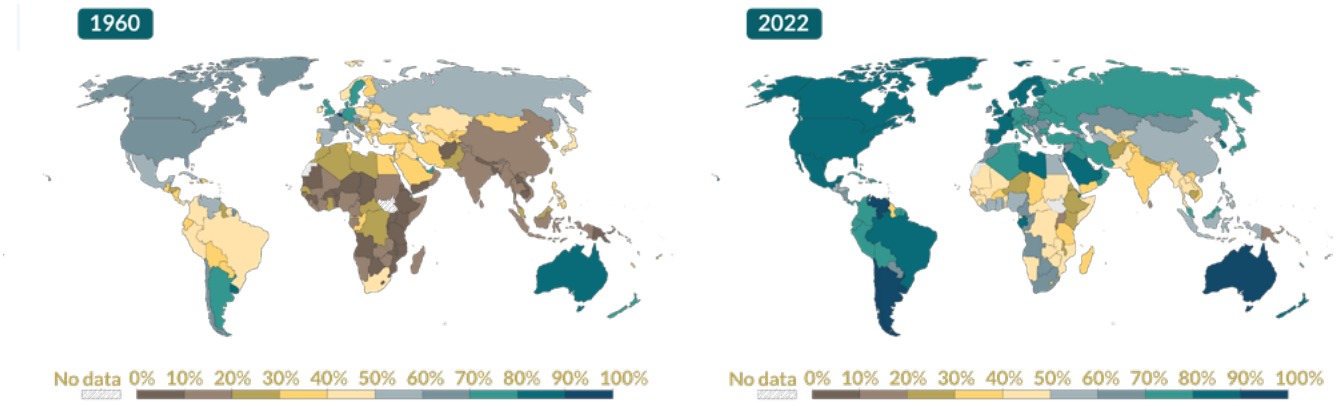
Understanding and addressing the dynamic relationship between urbanization and risk is central to shaping livable and resilient cities. Risk-informed urban planning requires embedding climate change, hazard, and risk information into urban plans, transforming them into effective instruments for reducing current and future climate and disaster risks. Chapter 1 illustrates the urgency of risk-informed urban planning with an overview of the issue from global and regional perspectives. It also introduces key concepts, principles, goals, and measures that can be implemented through regulatory instruments, alongside the governance structures, planning scales, and capacities needed to create an enabling environment. Chapter 2 examines the concept of risk within the urban planning framework and explores the relationship between urbanization and risk, showing how urban growth patterns can either exacerbate or reduce hazards and risks. It also addresses the critical concept of acceptable risk, offering insights into how cities can balance development priorities with safety and resilience.

Chapter 1

Why Risk-informed Urban Planning?

In line with the World Bank's mission and vision, risk-informed urban planning is an important instrument for achieving a livable planet, understood as "a healthy and sustainable planet on which people can prosper" (World Bank 2023a, 1). In practice, achieving a livable planet through risk-informed urban planning requires coordinated plans, programs, and projects across multiple scales, ensuring that local and intermediate actions support global objectives. From this perspective, given the planet's rapid urbanization, the development of effective urban plans is increasingly critical (figure 1.1). The World Bank Group and other agencies estimate that 56 percent of the world's population currently lives in cities, and this figure is expected to reach 70 percent by 2050 (World Bank 2022a).

Figure 1.1: A Comparison of the Global Population Living in Urban Areas in 1960 and 2022

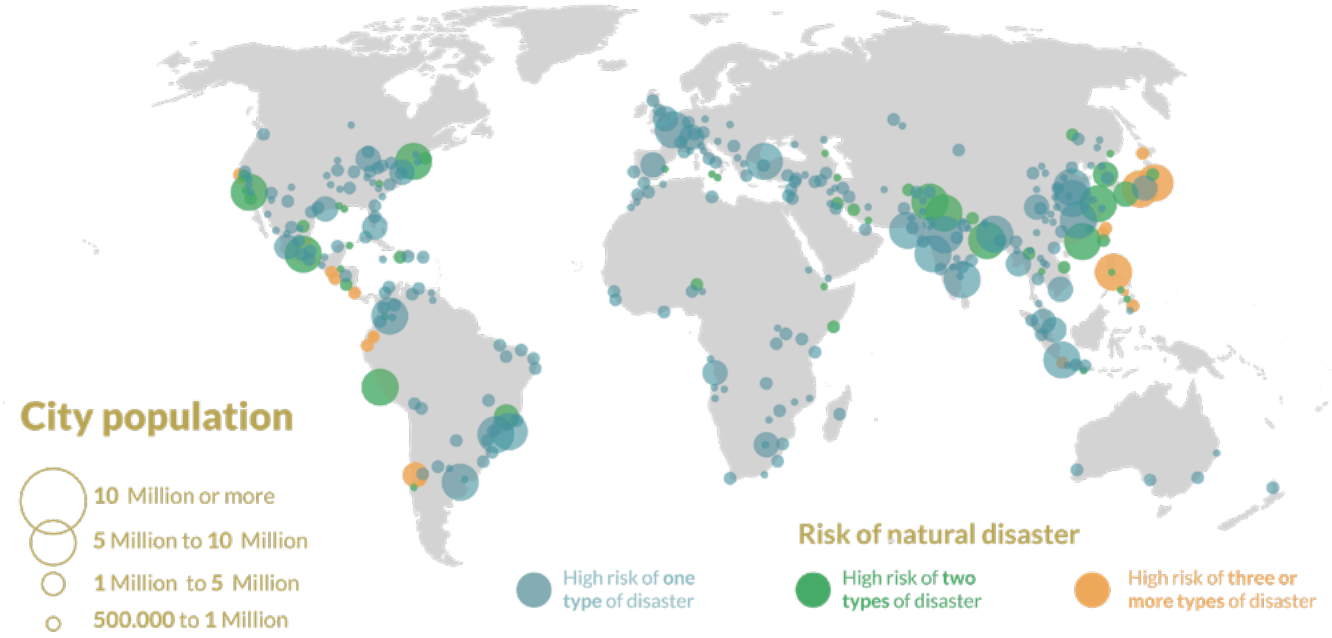


Source: Redrawn from Our World in Data 2025.

Urban life underlies much of the world's social, cultural, and economic activity. For instance, 80 percent of global gross domestic product (GDP) is produced in urban areas, and cities have become hubs for sociocultural exchange, innovation, generation of livelihoods, and efficient service delivery. Meanwhile, the challenges confronting modern cities are formidable. For example, urban expansion outpaces population growth by up to 50 percent, more than 50 percent of forcibly displaced people seek refuge in cities, 70 percent of greenhouse gas (GHG) emissions occur in cities, and cities account for nearly 70 percent of global energy consumption (World Bank 2022a).

The vulnerability of urban populations to disasters and climate shocks rises with accelerated growth, overconsumption of land and nonrenewable resources, environmental degradation, extreme poverty, inadequate infrastructure, and poor urban planning. As shown in figure 1.2, 59 percent of cities (679) with at least 500,000 inhabitants are exposed to at least one of the analyzed hazards (cyclones, floods, droughts, earthquakes, landslides, and volcanic eruptions). Among these, 189 cities face exposure to two or more, and 26 cities face exposure to three or more hazards (United Nations 2018). Climate change further exacerbates this situation, disproportionately affecting the urban poor, women, children, the elderly, ethnic minorities, and those affected by conflict (World Bank 2023b).

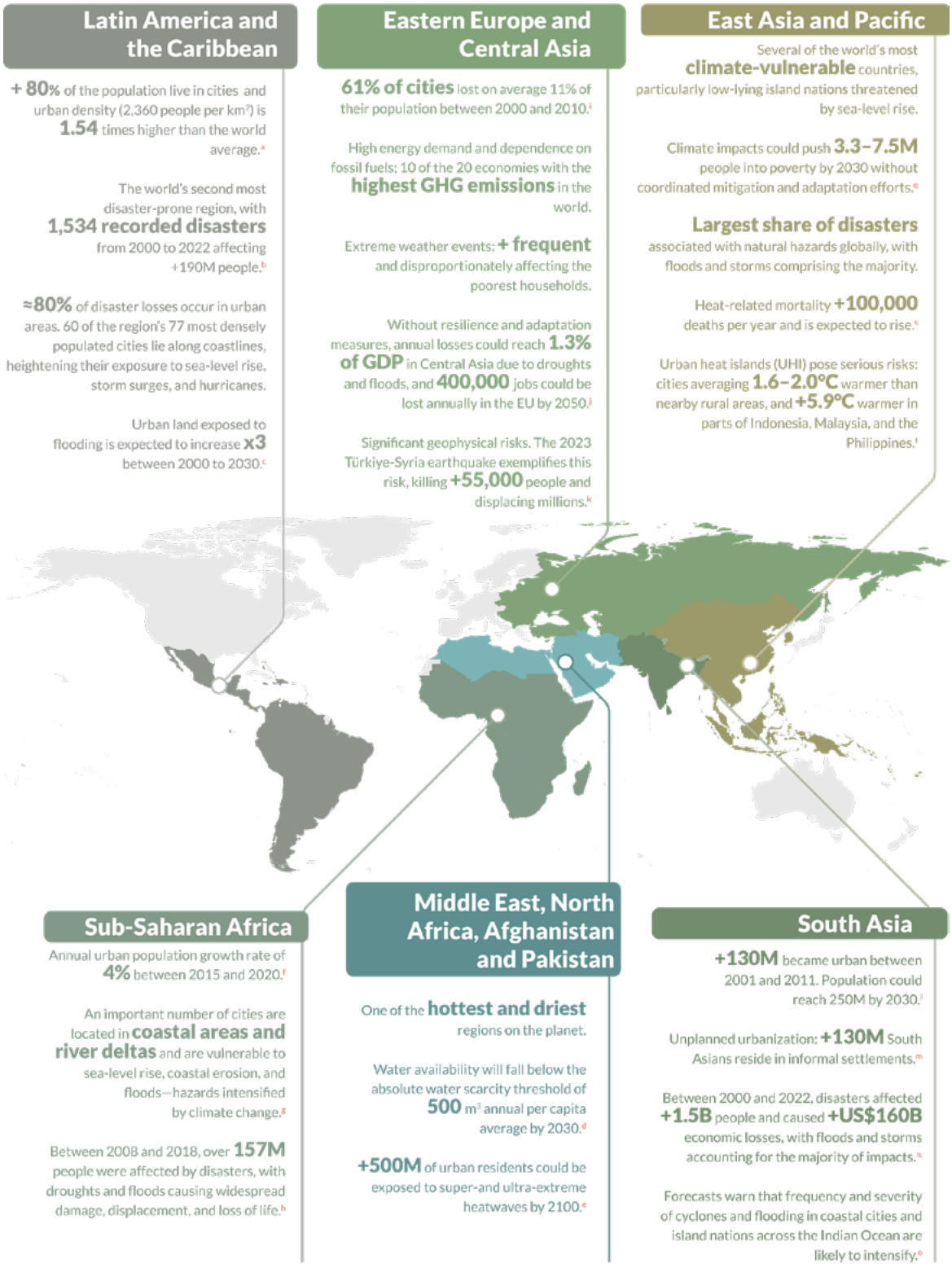
Figure 1.2: Cities' Exposure to Natural Hazards



Source: Redrawn from United Nations 2018, 9.

All regions of the planet are facing major challenges in urbanization, each with its own nuances but sharing a common factor: increasing hazards and risks from climate change and environmental degradation (figure 1.3). Data from some countries show related impacts, such as the impoverishment of the most vulnerable families, the impact of disasters on regional economies, job losses, and other effects of unplanned and accelerated urbanization.

Figure 1.3: Urbanization and Risk: Overview of Urban Areas by Region



Source: Original for this publication.

1.1 Risk-informed Urban Planning for Livable and Resilient Cities

A livable and resilient city is an urban area and its surroundings where green and resilient growth, social inclusion, resilient built environments, and shared prosperity are promoted, with a focus on preventing and reducing the impacts of natural hazards and climate change. It is a place where planned, resilient, and sustainable growth ensures access to healthy environments, affordable housing, essential services, jobs, and low-carbon transportation and economies.

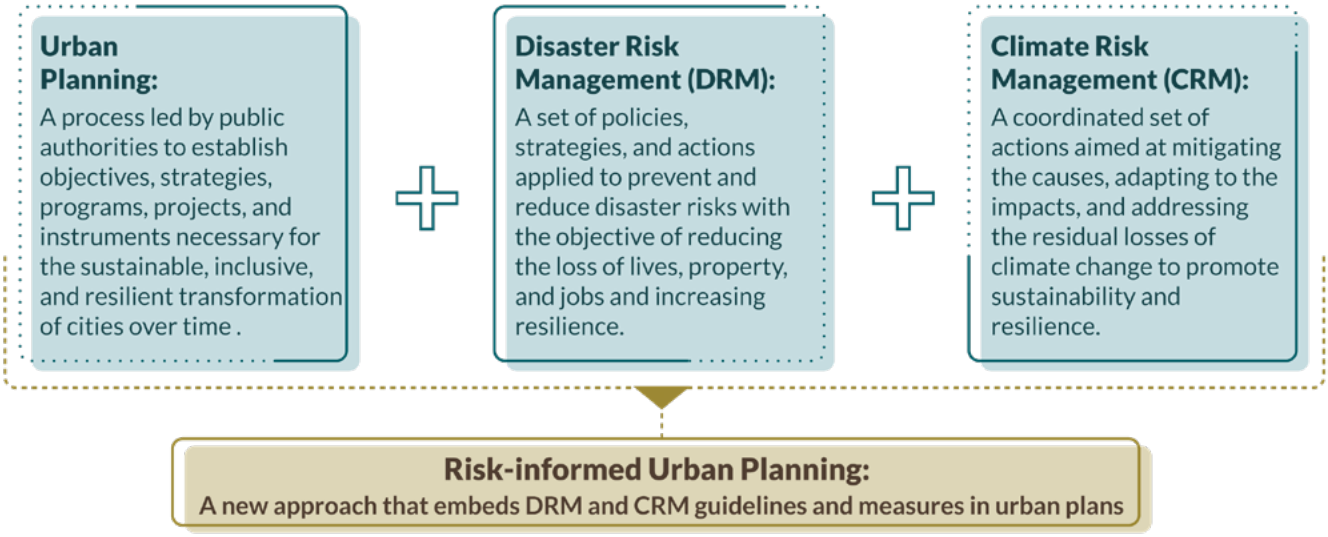
Although no single formula solves current urban challenges arising from the interplay between inadequate urbanization and risks, risk-informed urban planning offers a pathway to prevent and reduce disaster impacts. These impacts can otherwise have devastating consequences for people, the environment, and economies. Recent approaches have sought to integrate planning with CRM and DRM, but practitioners still need to make this integration more workable. Some documents consider hazard and risk data as components of urban plans and explain how to incorporate them into land-use regulations, while others focus on resilience frameworks, technical recommendations, and indicators for monitoring progress. Yet many remain siloed and overlook systemic drivers of risk, ecosystem protection, and the potential of nature-based solutions (NBS). As a result, recognition of these principles has not yet translated into effective implementation.

This handbook proposes a paradigm shift, drawing on lessons learned and an understanding of how urbanization interacts with social, cultural, and economic systems and the natural and built environments. It discards the notion that cities are destined for disaster, emphasizing instead that although urbanization can create hazards and risks, it can also reduce them. The way forward is through:

- Acknowledging that **hazards in urban settings are multifaceted** and not solely natural;
- Reframing **spatial planning to embed hazards, climate change, and risk** information in a comprehensive manner;
- Adopting and promoting a **holistic approach** to achieving livable and resilient cities;
- Bringing together **urban planners, disaster risk managers, and climate risk managers** to reorient urbanization to drive resilience instead of risk; and
- Creating **enabling environments** to formulate, implement, and enforce risk-informed urban plans through strong governance and enhanced capacities.

From this perspective, figure 1.4 summarizes the primary concepts that support the handbook's guidelines and proposals.

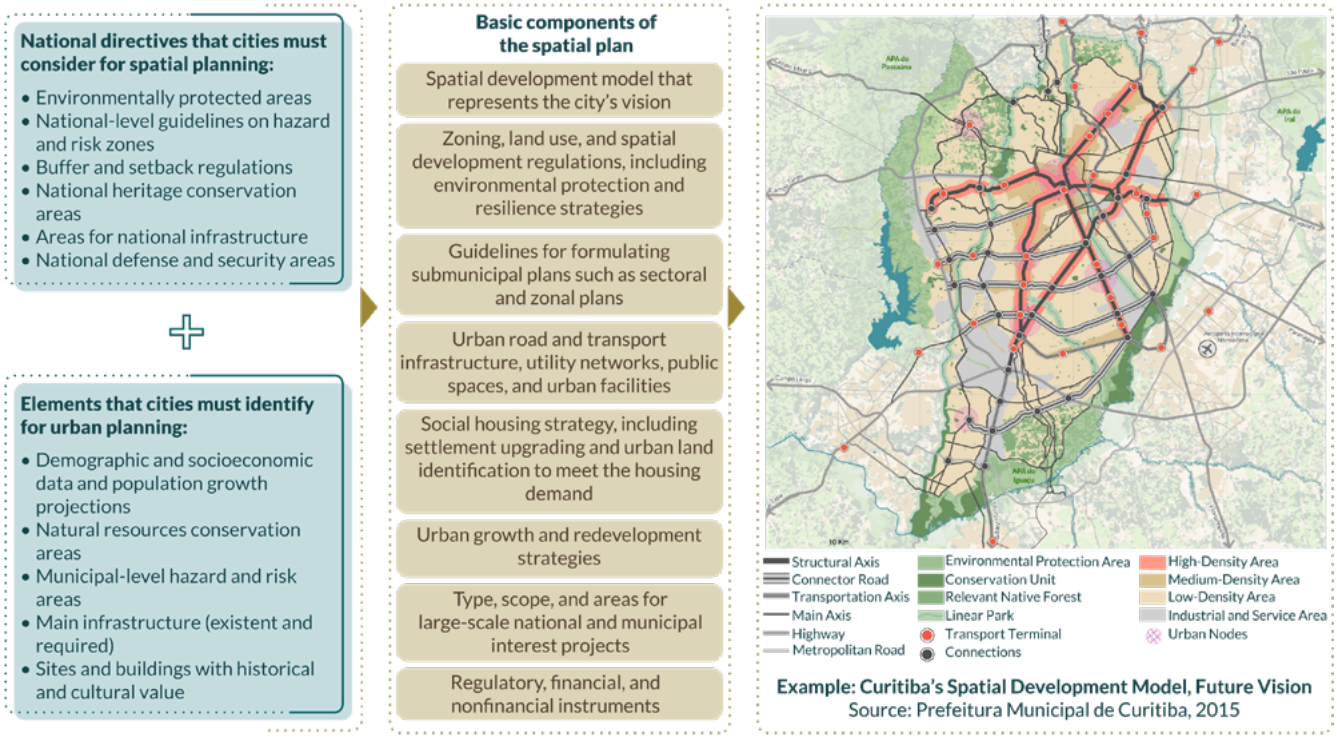
Figure 1.4: Risk-informed urban planning primary concepts



Source: Original for this publication.

Risk-informed urban planning acts as a comprehensive platform for action. Aligning national directives and local dynamics with spatial plans that include livability and resilience guidelines enable cities to envision a safer, more inclusive future for their citizens, balancing economic growth and environmental sustainability (figure 1.5).

Figure 1.5: Basic Components of Spatial Plans

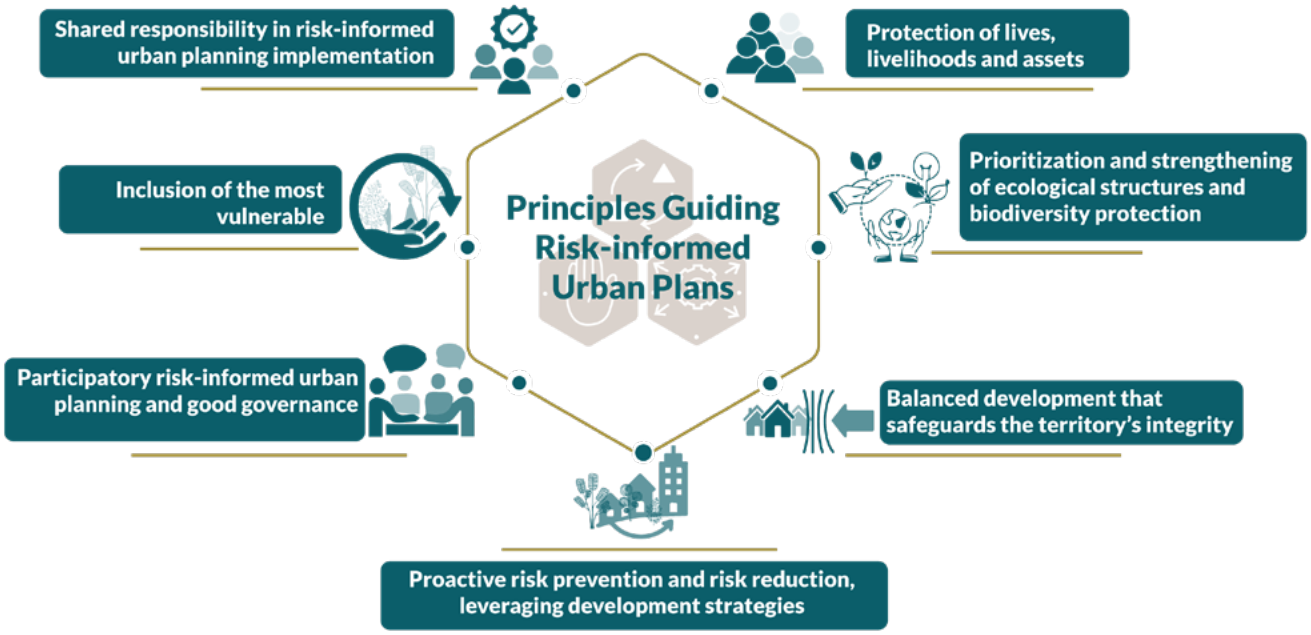


Source: Original for this publication.

Principles

Achieving livable and resilient cities requires risk-informed urban plans that include innovative instruments to ensure implementation. This new approach, which places CRM and DRM at the core of planning, aligns decisions with the values and objectives of environmental sustainability, social inclusion, resilience of the natural and built environments, and equitable economic growth (figure 1.6).

Figure 1.6: Risk-informed Urban Planning Principles



Source: Original for this publication.

This approach entails:

- **Protection of lives, livelihoods, and assets,** considering that safeguarding life must prevail in all decisions and understanding that a healthy and balanced relationship between natural and built environments is necessary to ensure environmental, social, and economic sustainability;
- **Prioritization and strengthening of ecological structures and biodiversity protection** to avoid risk generation
- **Balanced development that safeguards the territory's integrity**—ensuring ecological, spatial, and functional wholeness—and incorporates resilience across environmental, economic, infrastructural, sociocultural, and governance dimensions, with a long-term perspective;
- **Proactive risk prevention and risk reduction, leveraging development strategies** to minimize exposure and vulnerability and increase resilience by avoiding the creation of new, complex risks through poorly informed planning choices;

- **Participatory risk-informed urban planning and good governance,** ensuring that decisions made in the city are the result of a broad and inclusive process;
- **Inclusion of the most vulnerable,** to reduce the gaps that have existed historically and ensure that urbanization processes benefit all people equally. The aims are to guarantee universal access to basic services and the enjoyment of the city through the consolidation of safer and more sustainable environments; and
- **Shared responsibility in risk-informed urban planning implementation,** involving a whole society approach so that risk prevention and risk reduction actions are a responsibility of all and have more effective long-term outcomes.

Goals

Reaching livability and resilience in urban contexts requires going beyond the physical-spatial dimension to integrate CRM and DRM with an approach centered on people and nature. Risk-informed urban planning pursues the following goals:

Natural Environment: Green and Resilient Urban Growth



Preserving natural capital and biodiversity will underpin the livability and resilience of urban areas. Green and resilient urban growth means promoting NBS, safeguarding natural buffers to strengthen their protective functions, managing water and land resources, and planning compact, energy-efficient cities with sustainable transport and low-carbon economies. Livable and resilient cities must prioritize environmental protection, restoration, human-scale planning, pollution control, waste management, sustainable zoning and construction practices, and green cover improvement to build healthier relationships between natural and built environments and prevent or reduce hazard exposure.

People: Social Inclusion



Poverty and inequality significantly amplify the risk of disasters and climate shocks for households, communities, and societies, while limiting their capacity to prevent, withstand, and recover from these impacts. Inclusive urban planning must place people at the center of action, integrating all segments of society—particularly the most vulnerable—into decision-making. Urbanization processes must promote the equitable distribution of costs, benefits, and opportunities of development. They must include participatory planning practices that recognize social and cultural diversity as a benefit. Special instruments must also be developed to prevent or reduce exposure to hazards and risks. The combined efforts must reduce nonplanned urbanization and thereby advance environmental justice, help to eradicate poverty, provide universal access to basic services, secure land, safeguard property rights, and develop affordable housing. In addition to prioritizing vulnerable and historically underserved groups in risk prevention and reduction, it is also important to recognize women and youth as agents of change.

Infrastructure: Resilient Built Environment



Resilient infrastructure and services are able to absorb and rapidly recover from disruptions caused by natural hazards and climate-related shocks. Achieving resilient built environments entails developing urban infrastructure that helps protect people and property from hazards, is capable of withstanding such shocks, and maintains the continuity of lifelines and services (such as power, water and sanitation, transport, and telecommunications) to "function and meet user's needs" during crises to support effective disaster response and postdisaster recovery (Hallegatte et al. 2019). Critical systems should be designed to maintain functionality during disruptive events through robust construction, redundancy across networks or components, and the flexibility and adaptability needed to handle evolving conditions. This involves incorporating DRM and climate change adaptation (CCA) considerations from the earliest stages of planning and design through to implementation and operation and maintenance, embedding resilience principles throughout the infrastructure life cycle (Hallegatte et al. 2019). In doing so, infrastructure becomes a proactive enabler of safety, continuity, and long-term resilience and sustainability amid a changing climate.

Economy: Shared Prosperity



Cities drive productivity and economic growth. As centers of economic activity, jobs, innovation, and cultural exchange, cities play a pivotal role in economic development and prosperity. Shared prosperity ensures that no one is left behind, and that vibrant economies contribute directly to poverty reduction and resilience through direct investments in disaster prevention and reduction. As shown in box 1.1, public and private investments in risk reduction are no-regret measures. Every dollar invested in increasing infrastructure resilience will yield an estimated net benefit of four dollars (Hallegatte et al. 2019).

Box 1.1:

Risk-informed Urban Planning as a Driver for Economic Growth in Beira, Mozambique

Disasters and climate-related shocks are increasingly threatening lives and livelihoods, particularly in low- and middle-income countries. According to the Emergency Events Database, more than 10,000 natural, hazard-induced disasters have occurred between 2000 and 2024, causing more than 1.6 million deaths and leaving more than 4.6 million people affected and damages exceeding US$4,500 billion (EM-DAT 2025). While the primary goal of resilience investments is to save lives and reduce losses, evidence shows they also unlock economic potential by encouraging the mobilization of private capital, increasing property values, improving fiscal stability, and facilitating access to credit (Tanner et al. 2015).

Beira, Mozambique offers a compelling example. With support from the World Bank, the German KfW Development Bank, and other development partners, the city implemented a US$60 million **stormwater drainage system** to reduce flooding. It covers 2,630 hectares and benefits 250,000 people, including 70,000 in informal settlements. This urban resilience initiative was carried out as part of the Mozambique Cities and Climate Change Project implemented between 2012 and 2021 under the leadership of the government of Mozambique's Administration for Water and Sanitation Infrastructure (AIAS). Aligned with national policies to increase climate resilience, this project included the construction of green urban infrastructure to improve the urban drainage system and the rehabilitation of the Chiveve River (figure B1.1.1), plus actions to transform degraded urban areas into green infrastructure assets. During Tropical Storm Desmond and Cyclone Idai the system significantly reduced flood impacts and enabled faster drainage—even under power outages, thanks to manual floodgate operation and solar-powered street lighting.

Figure B1.1.1: Computed Result for Climate Change Scenario for 2050 With and Without Project Implementation.



Source: Ministry of Public Works and Urban Settlement, Mozambique et al. 2013, 57.
Left: Scenario with project. Right: Scenario without project.

According to the World Bank (2021a), the drainage rehabilitation project reduced annual flood damage costs by nearly US$10 million per year, with an internal return rate of 15.8 percent. Likewise, the Chiveve River project has significantly extended its impact beyond flood-risk reduction, boosting the local economy by improving mobility, reducing health hazards, creating public spaces, and revitalizing neighborhoods known for their social cohesion and local entrepreneurship. The economic impact of the project includes the creation of jobs, spaces for small businesses, and a local market in the new recreational areas (photo B1.1.1). Functioning as a flood buffer and a public space that generates additional income to the city, this park is managed by an independent municipal park administration that ensures its financial sustainability (KfW Development Bank 2022).

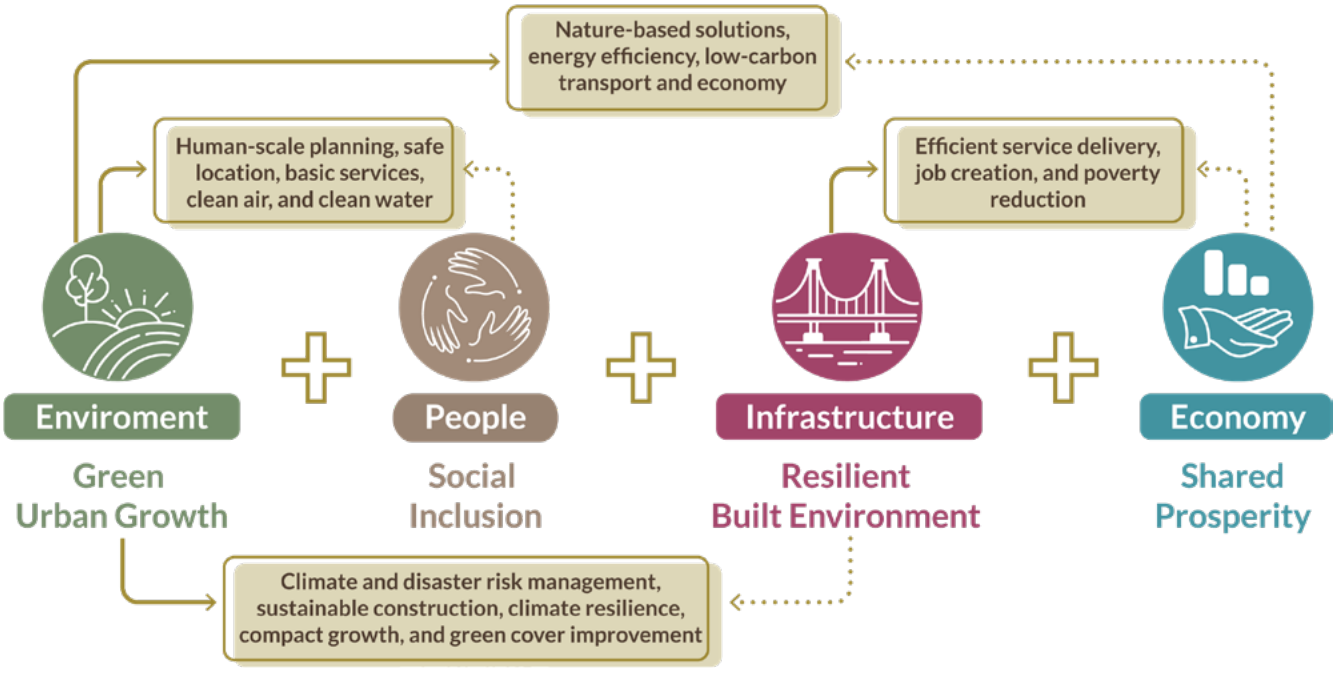
Photo B1.1.1: Chiveve River Green Infrastructure Project



Source: Left: © Administração de Infraestruturas de Abastecimento de Água e Saneamento (AIAS) Government of Mozambique, CES, and Inros Lackner. Right: © Michel Matera / World Bank

The four goals for achieving livable and resilient cities are intimately interconnected (figure 1.7) in the sense that risk-informed urban planning facilitates the formulation of more far-reaching measures that produce diverse benefits.

Figure 1.7: Risk-informed Urban Planning: Interconnected Goals



Source: Original for this publication.

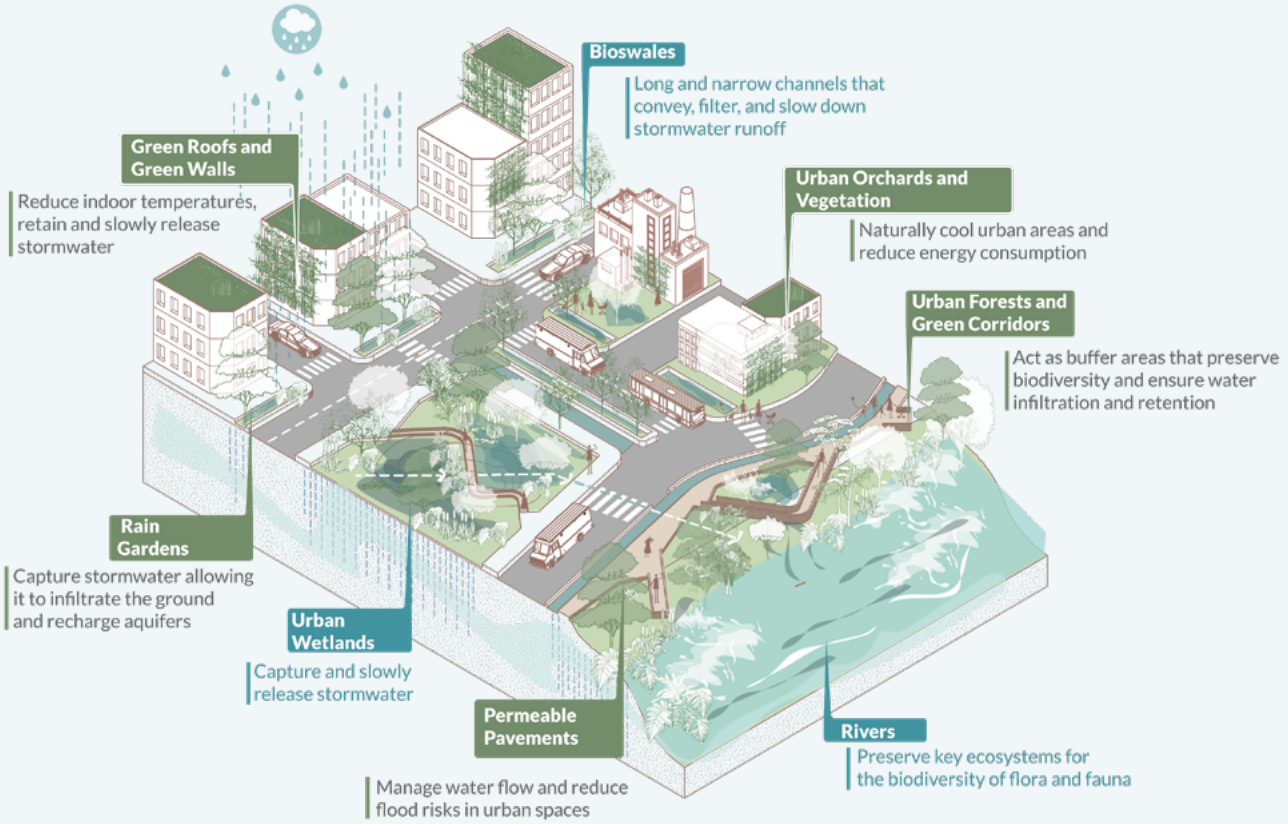
The emphasis on livability and resilience invites cities to develop and implement solutions that align with natural dynamics (box 1.2), preventing and reducing disaster and climate risks while promoting sustainable urban growth and enhancing quality of life. Consequently, measures like setbacks (such as separation from a nearby river), the restoration of key ecosystems, and increasing urban permeable surfaces must be viewed not only as environmental safeguards, but as risk-reduction measures that enhance human safety and well-being and support sustainable urban development.

Box 1.2:

Nature-based Solutions for Risk-informed Urban Planning

Nature-based solutions (NBS) are a set of actions inspired by the dynamics of nature, used to restore the natural functioning of ecological systems, reduce exposure to hazards, prevent or reduce disaster risks, and adapt cities to climate change, once their impact and effectiveness have been assessed according to specific situations. These solutions use green (vegetation) and blue (waterbodies) elements to complement or replace hard engineering solutions (figure B1.2.1).

Figure B1.2.1: Examples of NBS Implementation in Cities



Source: Original for this publication.

Although its value is not in doubt, the feasibility and efficacy of NBS should be determined on a case-by-case basis. In some contexts, an acceptable level of risk cannot be achieved by NBS alone, making it necessary to prioritize complementary, integrated approaches that combine nonstructural and structral measures.

An example of the application of NBS is the Sponge Cities Initiative that the government of China launched in 2014. The term "sponge" refers to the ability of urban spaces to absorb rainwater and stormwater and gradually release it to prevent the collapse of drainage systems during extreme weather events, adopting natural ecosystems dynamics. The sponge city guidelines inspire the design of Kunshan Forest Park in southeastern Jiangsu Province between Taihu Lake and the Yangtze River Delta (photo B1.2.1).

Photo B1.2.1: Kunshan Forest Park West Entry Project



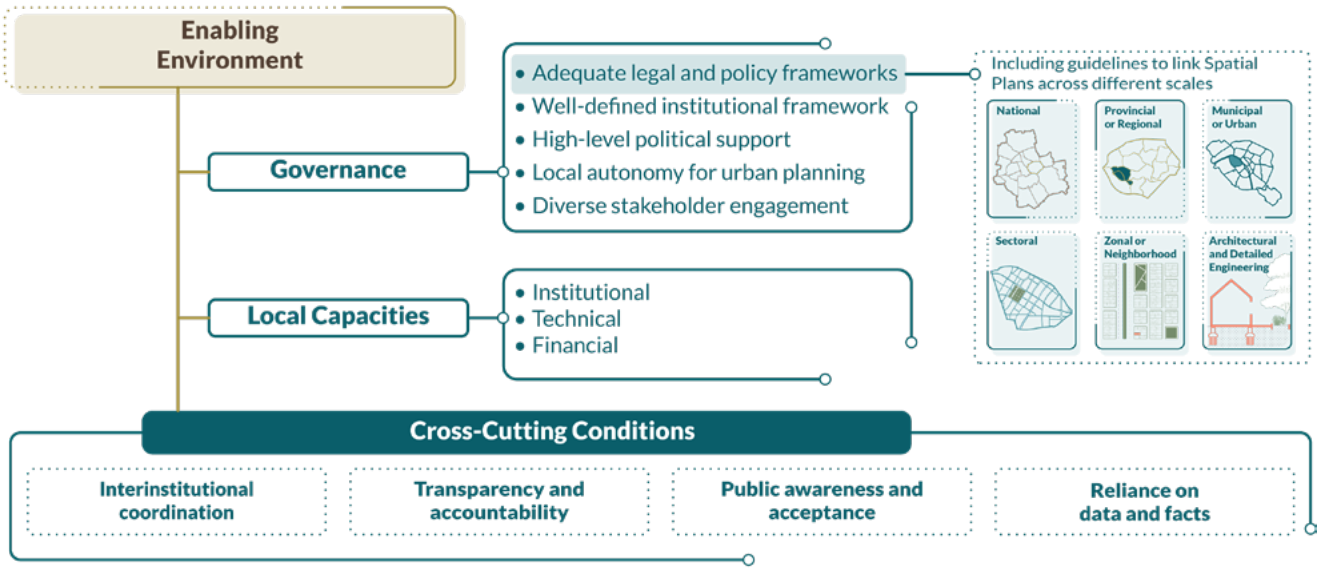
Source: © PLAT Studio.

This project was developed to restore wetlands and build additional lakes to enhance infiltration and stormwater storage and increase the park's hydraulic capacity to strengthen flood resilience. It also helped to improve air and water quality, reduce the urban heat island (UHI) effects, and increase the availability of public spaces for leisure, allowing visitors to have direct contact with nature through interaction with characteristic flora and fauna of wetland ecosystems.

1.2 Enabling Environment

Successful risk-informed urban planning requires an enabling environment built upon sound governance, adequate legal and institutional structures, and good leadership. Political will is also required to formulate and execute strategies that reconcile diverse interests and align with a common vision and comprehensive development strategies to achieve livability and resilience (figure 1.8). Shifts in demographics (especially population growth), climate, and economic factors continually reshape the dynamics of urban areas and territories, altering their risk profiles. As these conditions evolve, planning processes must adapt to address emerging vulnerabilities and ensure resilient development. This section summarizes the main components of the governance structure, planning scales, and capacities required for risk-informed urban planning.

Figure 1.8: Key Elements of an Enabling Environment for Risk-informed Urban Planning



Source: Original for this publication.

Governance

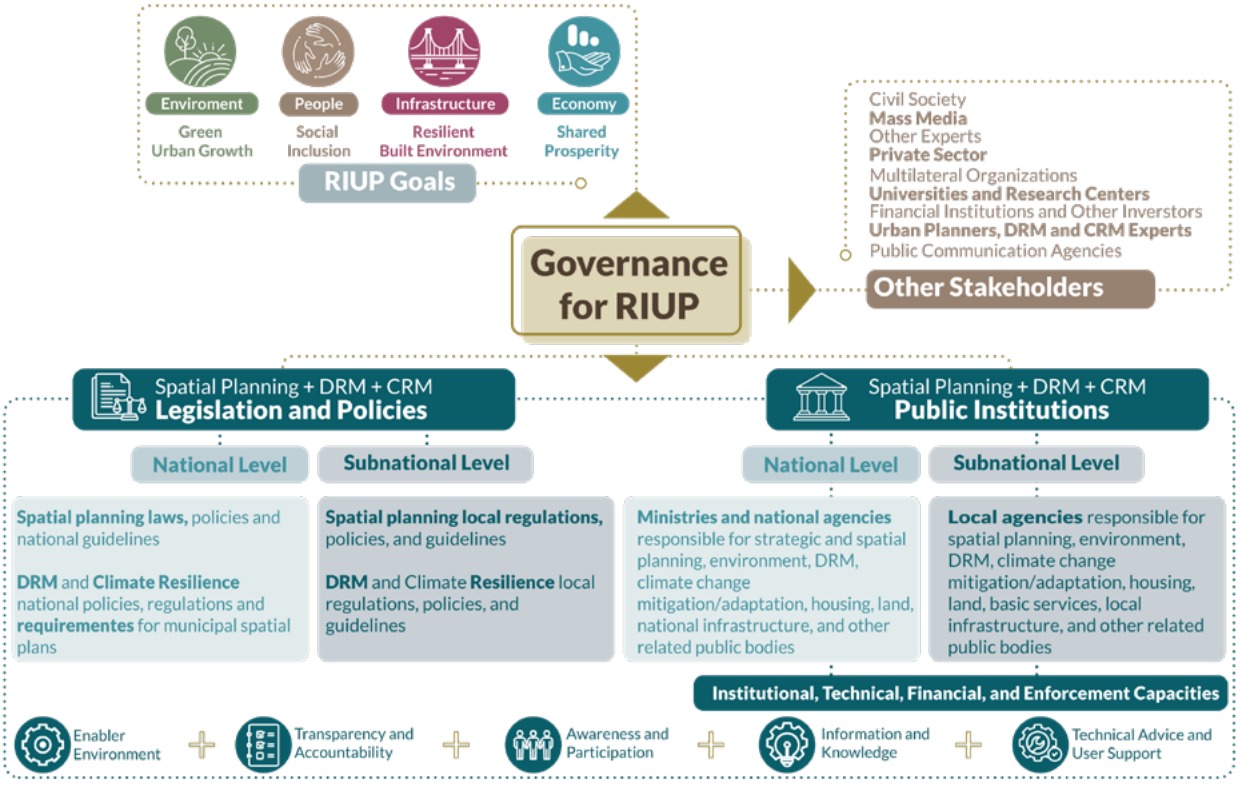
Risk-informed urban planning governance is the system of legal frameworks, policies, and institutions that guides urban development planning to achieve sustainable, equitable, and efficient outcomes. Through sound governance, it is possible to balance competing interests and minimize discretionary interpretation of planning instruments, ensuring transparency and creating an environment of trust to encourage public, private, and third-sector (nonprofit) investments to achieve urban transformations.

- **Legal and policy framework:** This includes the national and municipal laws, policies, and regulations that guide risk-informed urban planning. It defines norms, guidelines, enforcement and funding

mechanisms, and the institutions responsible at the national and subnational levels. It starts by positioning sustainable urban development and overcoming the rural policy bias that is still present in many countries. Meanwhile, it is determined by the prevailing policy context and the ways in which stakeholders articulate their priorities and decisions. For instance, the development of urban planning processes should be based on enforceable regulations. From a legal standpoint, an urban plan approved by a city council carries regulatory weight, while an informal plan functions only as guidance. Facilitating the decentralization of spatial planning decisions and empowering local authorities are other important factors. Local governments must have the option to make decisions and the capacity to raise funds through planning instruments such as land-related financing or taxes based on building density. These locally generated resources then become a prerequisite for investing in urban development. Frameworks must be context-specific yet sufficiently comprehensive to support risk-informed urban planning goals and the achievement of the city's long-term vision.

- **Institutional framework:** This encompasses relevant organizations—including public agencies, private sector entities, civil society groups, academic institutions, and other stakeholders—and defines their respective roles within the risk-informed urban planning process. Analyzing this framework at both the national and subnational levels enables the identification of agencies best positioned to lead and participate in planning and implementation efforts. It also clarifies the responsibilities of relevant stakeholders, fostering greater participation and commitment throughout the process (figure 1.9).

Figure 1.9: An Example of a Governance Structure for Risk-informed Urban Planning



Source: Original for this publication.

- **Stakeholder mapping:** Building consensus in decision-making for DRM and CRM is often challenging, as planning processes may be hindered by conflicting interests. Although public institutions hold primary responsibility, effective risk-informed urban planning requires the active involvement and participation of other stakeholders to build a shared vision and strategy for managing risk and utilizing the territory in a sustainable way. Establishing a common understanding of disaster and climate resilience provides a foundation for constructive dialogue and coordinated action. Every city should conduct a tailored stakeholder analysis to match its context and capacity, thereby defining the most effective forms of collaboration. Table 1.1 shows an example of stakeholder mapping, which will be used as an example in chapter 3 to show how each actor can be engaged in each step of the risk-informed planning process.

Table 1.1: An Example of a Risk-informed Urban Planning Stakeholder Map

Stakeholder	Role	Main responsibilities
Public institutions	Legislators, formulators, implementers, public utility providers, and disseminators	- Promoting and formulating laws, policies, plans, and strategies - Facilitating participation - Ensuring compliance with the plan's mandates - Providing public services for current demands and planning future demands - Implementing educational programs and other dissemination strategies
Civil society	Coparticipants in decision-making, advocates, and overseers	- Ensuring decisions that protect their rights - Complying with agreed guidelines and regulations - Advocating for decent housing and property rights and access to basic services, with a focus on underrepresented groups - Protecting key ecosystems
Urban planners, DRM and CRM experts	Technical advisers, and coparticipants in decision-making	- Translating hazard and risk assessments into specific planning measures - Assisting the process through all its stages
Universities and research centers	New knowledge and innovation generators, technical advisers, and monitors	- Providing new knowledge and innovation to improve all planning stages - Creating and testing new technologies for mapping and monitoring hazards and risks and assessing climate change impacts - Developing environmentally friendly construction techniques and materials
Other experts	Technical advisers, coparticipants in decision-making, and monitors	- Advising formulator and implementer teams in accordance with technical expertise - Monitoring the plan's implementation
Multilateral organizations	Technical and financial supporters, new knowledge generators, and good practice disseminators	- Supporting cities technically and financially in planning formulation and implementation - Promoting risk prevention, risk reduction, climate change adaptation, and resiliencew - Producing and disseminating new knowledge
Private sector	Developers, utility service providers, and property insurance	- Ensuring building projects follow the plan guidelines - Providing private services for current demands and planning future demands - Seeking to reduce the vulnerability of public and private buildings through the formulation and enforcement of regulatory instruments and building codes

Stakeholder	Role	Main responsibilities
Financial institutions and other investors	Financial supporters	- Financing the development of public and private real estate projects - Maintaining a dynamic construction market - Supporting sustainable construction initiatives through financial instruments (for example, soft loans or green mortgages)
Public communication agencies and mass media	Disseminators, awareness raisers, and monitors	- Disseminating information through written press, public and private radio and television, social networks of governmental entities, and private mass media - Following the plan's formulation and implementation process

Source: Original for this publication.
Note: CRM = climate risk management; DRM = disaster risk management.

Planning Scales

The level of information and detail needed for planning decisions varies depending on the geographic scale. Coordination among various planning levels—including those spanning municipal or urban areas as well as sectoral strategies—does not operate as a classic, hierarchical structure or a seamless sequence of plans. Instead, policies, regulations, investment plans, and designs are generally formulated through more intricate processes and are interconnected in diverse and overlapping ways (table 1.2).

Table 1.2: Spatial Planning Scales

Scale	Objectives and scope	Who leads?
	Establish spatial planning, DRM, and climate change guidelines through policies, regulations and standards. National directives constitute the legal framework that define aspects such as key urban nodes, national multimodal corridors, logistics infrastructure, mining zones, specific rules for protected areas (such as water bodies, forests, and natural reserves), and use of ecosystem services. National DRM and CRM regulations promote safe and sustainable environments, guiding the formulation and implementation of risk-informed plans at the provincial and municipal levels. National governments are also responsible for leading and funding assessments for complex phenomena such as climate change, droughts, floods, large-scale mass movements, and earthquakes, that go beyond the capacity of local governments and for developing large-scale projects to reduce hazards and risks beyond municipal boundaries.	National government through the relevant ministries and national agencies
	Define detailed guidelines at the provincial level that must be included in urban plans, which are subject to national directives. These plans establish the boundaries of regional protected areas (such as basins, estuaries, and regional forests) and define the location of key infrastructure for regional connectivity and economic competitiveness (for example, power generation and renewable energy facilities and industry hubs). Cities must ensure that their spatial plans are consistent with regional planning goals.	Provincial or regional governments, with the support of provincial-level agencies and the participation of civil society

Scale	Objectives and scope	Who leads?
	Guide the city's development actions to ensure that the urbanization process takes place in an organized and safe manner. These plans must adhere to national and provincial directives. They address several components such as natural environment management, infrastructure development, basic urban service coverage, location of public spaces and facilities, and protection of heritage assets, among others. In terms of DRM and CRM, these plans seek to reduce or mitigate disaster risks and climate-related shocks and avoid the creation of new risks through zoning and land-use regulations and controls to restrict or condition new developments. They also define densities (inhabitants per hectare or square kilometer), setbacks, and buffer zones based on national and provincial directives on natural ecosystems.	Municipal governments, with the support of municipal agencies and the participation of civil society
	Establish specific sectoral purposes in a coordinated manner. In risk-informed urban planning, sectoral master plans are complementary instruments that target specific goals. Building on overall plan directives, they address concerns such as urban drainage systems, water management at the urban level, and location of critical infrastructure, among others. These plans require targeted studies to support informed decisions aligned with the city's needs, capacities, and budget.	Municipal agencies in charge of designing and implementing resilience measures to ensure safe conditions for settlement upgrading, densification, and green growth
	Establish detailed, area-specific regulations for particular zones, districts, or neighborhoods. These plans target specific areas such as special economic zones, watersheds, and historic neighborhoods, and define precise norms for greenfield and brownfield projects. Given their local scope, these plans must adhere to the overarching directives and guidelines determined in urban plans.	Municipal planning office or similar agency, developers, landowners, and communities

Source: Original for this publication.
Note: CRM = climate risk management; DRM = disaster risk management.

This handbook focuses on the **municipal or urban scale**[1] since it provides the ideal level for translating higher-level national and regional directives into specific regulations and guidelines, enabling effective local actions that improve urban livability and resilience.

Capacities

Strengthening capacities across institutional, technical, and financial domains is essential to ensure that risk-sensitive land-use planning is feasible, effective, and sustainable. However, in many cities limited technical capacity and the high costs of hazard and risk assessments continue to be major barriers to advancing risk-informed urban planning. Urban plans can nonetheless be developed with different scopes and levels of information. Even when information and data are basic, spatial planning remains a powerful instrument for reducing risks and boosting urban resilience in contexts with limited capacity.

- **Institutional Capacities**

These are the abilities of government organizations to effectively plan, manage, and implement risk-informed urban plans: encompassing human resources, governance structures, and knowledge. These capacities are built through a multilevel approach, including individual staff development, organizational

[1] In many countries, municipal plans and urban plans have the same connotation and refer to plans focused on urbanized land and areas of future growth. In this handbook, the terms urban planning and urban plans will be used to refer to this scale.

improvements, and strengthening the broader enabling environment to ensure more sustainable and responsive urban governance. The effectiveness of leadership, internal processes, and collaboration across different departments and levels of government is another crucial factor in connecting spatial aspects with the economic, social, and environmental dimensions required for livable and resilient cities.

Cities must define which agency leads hazard and risk assessments, who oversees decision-making based on assessment results, and which legal mechanisms translate those decisions into public policies and planning regulations. If city and environmental authorities lack capacity or experience in disaster and climate risk modeling, they should partner with national agencies, academic institutions (geological survey, hydrometeorological agencies, and so forth) or private consulting firms. Strong institutional capacity for climate and disaster risk assessment and implementation underpins risk-informed urban planning and enables cities to sustain services and respond effectively during and after a disaster.

- **Technical Capacities**

To ensure that cities have the technical capacities to formulate, implement, monitor, and evaluate risk-informed plans, urban planners need to strengthen their technical knowledge to collect, analyze, and use data to make informed decisions, interpret hazard and risk assessments, and effectively embed this information in urban plans. Conversely, DRM and CRM experts need to expand their knowledge on planning instruments to actively participate in the design of risk-sensitive planning measures. Cities should also invest in data management systems and digital tools—such as Geographic Information System (GIS) platforms, open data repositories, and risk modeling frameworks—to ensure that risk information is regularly updated, interoperable, and accessible. Capacity for continuous monitoring and evaluation should be strengthened to assess the effectiveness of risk-informed planning measures over time.

Broadly, cities must offer training programs, awareness campaigns, and user support instruments with different levels of complexity to expand technical knowledge on regulations, land management, green growth, urban resilience, and NBS, among other topics. Partnerships with universities, research centers, and professional associations can help institutionalize these training programs and promote applied research on urbanization processes, hazards and risks, and climate change.

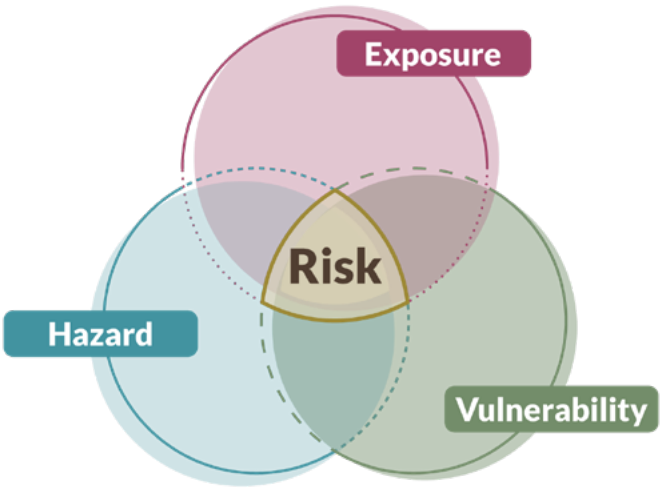
- **Financial Capacities**

Financial systems provide the capital and infrastructure needed to fund and implement risk-informed urban plans, while urban plans guide where and how to invest, ensuring that green and resilient growth, social inclusion, resilient infrastructure, and shared prosperity goals are met. Effective urban finance and planning are interdependent: planning will guide development to create economic benefits, and this growth, in turn, will generate the financial resources for future projects, creating a virtuous cycle. However, as mentioned in section 4.2, not all the financial resources for urban transformations need to be public funds, as urban plans should be designed to stimulate the active participation of taxpayers, private developers, and investors. Despite the complexity of its implementation, land-based finance represents a highly promising yet often overlooked source of local revenue that cities can use to enhance overall urban management.

1.3 Risk-informed Urban Planning Measures

Risk is a function of hazard, exposure, and vulnerability. Understanding these interdependent components is essential for identifying and implementing effective measures to reduce disaster impacts in cities (figure 1.10).

Figure 1.10: Factors of Disaster Risk



Source: Original for this publication.

Hazard refers to the potential occurrence of natural- or human-induced physical events that may cause harm to vulnerable and exposed elements. It encompasses processes, phenomena, or human activities that can lead to loss of life, injury, property damage, adverse health effects, social and economic disruption, or environmental degradation. Hazards can be categorized as natural, anthropogenic (human-induced), or socio-natural, arising from the interaction between human activities and natural processes (Cardona et al. 2012; UNDRR 2017a).

Exposure refers to the presence, location, and inventory of physical, biological, social, and economic systems, resources, and infrastructure in hazard-prone areas. Exposure is a necessary determinant of risk but not a sufficient one, in the sense that elements can be exposed without being vulnerable, but to be vulnerable, they also need to be exposed (Cardona et al. 2012).

Vulnerability describes the propensity or predisposition of a community, system, or asset to be adversely affected by hazards. It is shaped by a combination of physical, social, economic, and environmental factors that increase susceptibility to harm (UNDRR 2017b).

Risk is "the potential for loss of life, injury, or destroyed or damaged assets which could occur to a system, society, or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability, and capacity" (GFDRR 2014).

> **Resilience** is "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" (UNDRR 2017d).

The characterization of hazard events differs depending on the type of hazard (ISC and UNDRR, 2020). Different variables, such as duration (the length of time a hazard persists), frequency (how often a hazard occurs over a specific period), magnitude (the size or scale of the hazard), and intensity (the strength or severity of the hazard's effects), are used to describe certain natural hazards. As hazards may occur independently, in combination, or compound with others, or trigger cascading effects, proper hazard assessments must account for these interactions.

To support consistent and evidence-based planning decisions, hazard and risk levels are often classified into categories such as high, moderate, and low, based on the probability and expected severity of hazard events. Classification methods may be qualitative (for example, high, medium, and low), semi-quantitative (for example, using value ranges), or quantitative (for example, specific numerical thresholds), depending on data availability. The level of impact is not solely determined by the hazard characteristics, but also by the vulnerability of the territory and its inhabitants.

Understanding and assessing hazards is essential to anticipate their potential effects on people, infrastructure, services, and livelihoods; to delineate hazard and risk zones; and to guide spatial plans that protects lives and promotes sustainable development. These classifications are not fixed standards but context-dependent references shaped by each city's risk tolerance (see section 2.6). Practitioners should clearly define what each hazard or risk level means in terms of likelihood, magnitude, and potential impacts. They should also indicate whether it is feasible and appropriate to reduce risks to acceptable levels, considering technical factors (feasibility of works or actions), economic factors (costs and benefits), social factors (acceptance and effects on the community), and political fators (political will and regulatory framework). Categories presented in table 1.3 represent a commonly used classification derived from a comparative review of national and local systems.

Table 1.3: Hazard Categories

High-hazard areas	Areas with a significant likelihood of severe damage or loss of life and are generally unsuitable for permanent human settlement. These areas require strict restrictions to prevent the escalation of risks and the creation of new risks.
Moderate-hazard areas	Areas that may be developed but require specific adaptation or protection measures, such as reinforced infrastructure or hazard buffers, to reduce potential impacts.
Low-hazard areas	While generally considered safer for development. These areas must be monitored, particularly in the context of climate change and rapid urbanization, which may elevate hazard and risk levels over time.

Source: Original for this publication.

This hazard-level classification is a key input for zoning, permitting, and designing risk reduction strategies, ensuring that new development does not exacerbate existing risks and that appropriate resilience measures are integrated from the outset. Risk-informed urban planning thus plays a central role in guiding urban growth to reduce exposure and vulnerability. It requires avoiding development in high-hazard areas where risk cannot be reduced, conditioning it in moderate-risk areas, and promoting strategic interventions to reduce existing and future risks while improving the balance between human activity, ecosystem dynamics, and climate change.

Planning measures must be context-specific and account for existing land use, distinguishing between undeveloped and developed areas. Rules and guidelines for land use should strategically determine sites for densification[2] or expansion based on both intended use (housing, commerce, facilities, infrastructure, industry, and so on) and territorial characteristics (accessibility, topography, disaster risk, proximity to contamination sources, climate change effects, and so on). These rules must be based on a comprehensive hazard analysis to understand how human activity may exacerbate or create new risks. The guiding principle is that any new development or change in land use must not increase existing risk levels and should, whenever possible, contribute to their reduction.

In practice, spatial planning translates these rules into zoning and land-use regulations that restrict, condition, or enable development depending on hazard levels. In areas with environmental sensitivity or significant hazard or risk levels, future development decisions are often conditioned on detailed, site-specific hazard and risk assessments. Based on these studies, urban plans can define measures that either restrict development in high-hazard or high-risk zones, or condition it on the completion of risk reduction measures and compliance with resilience standards.

Such risk-informed planning decisions demand a clear understanding of the hazards, exposure, and vulnerability of people and assets under current and future conditions, as well as the technical and economic feasibility of reducing risk to acceptable levels. The feasibility of risk reduction—and tolerance for risk or acceptable risk—is essential for decision-making as it determines whether risk reduction measures should be implemented or alternatives such as resettlement or the nonexecution of certain activities should be considered (see section 2.6).

The feasibility of risk reduction varies across cities and by land use. For example, flood-prone land might be designated for lower-risk use like agriculture or open land, while housing or critical facilities are typically prohibited due to stricter safety and habitability requirements. Conversely, certain infrastructure might be permitted in some hazard-prone areas if it is engineered to withstand the associated hazard (for example, using hurricane- or earthquake-resistant designs). In some cases, cities may accept higher levels of risk or choose to invest in costly risk reduction measures to enable development, particularly when facing strong development pressures, limited land availability, or other social and economic constraints.

Moreover, not all hazards are managed identically. Slow-onset, slow-rising floods may permit limited development, for example, if adequate design and resilience measures are implemented. By contrast, sudden flash floods (with little warning and high-velocity flows) demand much stricter avoidance due to

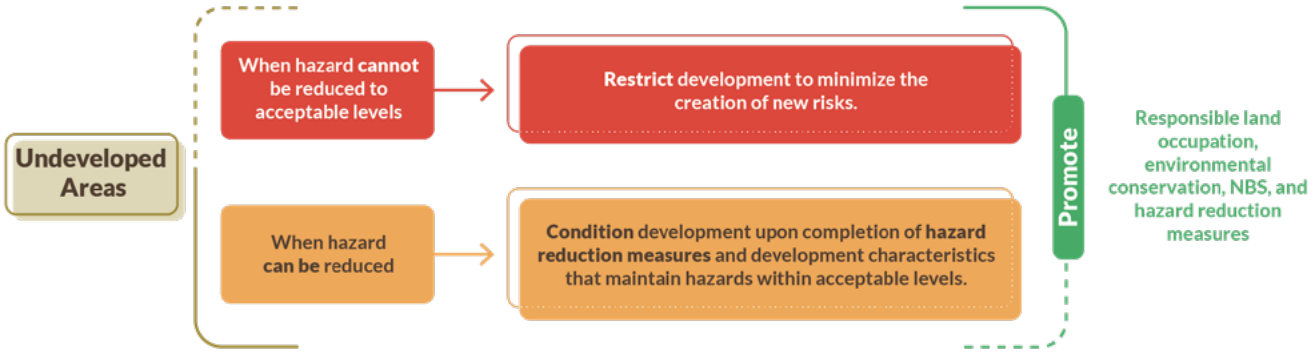
[2] At its simplest, densification means increasing the population density. In practice it involves redevelopment, infill, or vertical construction, often to combat urban sprawl. It typically entails multiple sustainability challenges (the provision of jobs, services, and so on).

their high threat to life. Similarly, while areas facing a very high tsunami hazard often warrant prohibitions on new construction given the extreme impacts of tsunamis, seismic (earthquake) risk is generally addressed through robust building codes and engineering measures tailored to local conditions.

In practice, areas that are typically subject to strict development restrictions are those that are exposed to high hazards or at elevated risk, face life-threating conditions, and have limited warning time, where even the use of sophisticated technical and engineering interventions is not possible or cost-effective. These include areas prone to fast, high-energy and very destructive events, like flash floods or fluid-driven mass movements (sudden, high-velocity, debris-laden flows that can sweep away people and infrastructure with little warning), tsunamis (in areas of rapid onset, immense force, deep and widespread flooding, debris impact, and severe disruption), massive landslides (especially in regions with steep terrain, intense rainfall, seismic activity, or severe human-induced slope destabilization), or volcanic pyroclastic flows (extremely hot, fast-moving currents of gas and volcanic debris that can incinerate everything in their path).

Applying restrictions is a decision that has social, economic, and political implications. Practitioners must therefore delimit and document as precisely as possible the affected area, the characteristics of the event, the exposed elements, the population and its characteristics, the risk impacts, and the cost-benefit-based decision. Development may only proceed where there are no life-threating conditions, or where risks to life or social and economic development can be reduced to acceptable levels through technically and economically feasible measures. Even then, such development is contingent on the full implementation of these measures and compliance with stringent resilience standards (figure 1.11).

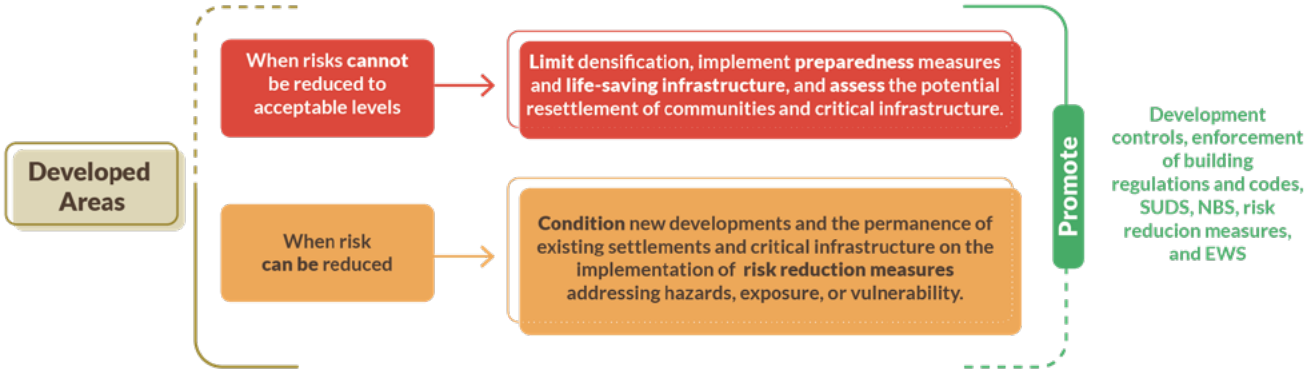
Figure 1.11: Hazard-Based Planning in Undeveloped Areas



Source: Original for this publication.

In developed areas where risk levels are deemed unacceptable, urban plans must include corrective measures to reduce risks to acceptable levels and condition the permanence of settlements and infrastructure on their implementation. These actions include density regulations, resilience standards, risk mitigation through integrated strategies combining nonstructural and structural solutions, retrofitting programs, and preparedness measures to reduce disaster impacts on life, well-being, and the economy. Where risk cannot be reduced to acceptable levels and lives are at stake, cities should consider resettlement options while ensuring the protection of people's rights, social ties, cultural identity, and livelihoods (figure 1.12).

Figure 1.12: Risk-based Planning in Developed Areas



Source: Original for this publication.

Developed areas with tolerable or manageable risks require the incorporation of comprehensive risk reduction strategies prior to densification or expansion, ensuring that any growth is aligned with resilience standards and building provisions.

If, after weighing the trade-offs, decision-makers determine that resettlement is the most appropriate option, the process must be approached comprehensively and governments should implement a raft of integrated actions. They should regulate compatible land uses in vacated areas to harmonize human activities with environmental dynamics (that is, protected environmental areas or recreational areas). They should strengthen institutional capacities to guarantee good planning and development controls in vacated areas (including transferring the management to environmental agencies). They should ensure housing supply for resettled households seeking to maintain neighborly bonds and livelihoods opportunities; ensure monitoring to prevent reoccupation and generation of new risks; and control human activities that could aggravate natural hazards (Ramírez 2011).

The understanding and inclusion of restrict, condition, and promote (RCP) measures in urban plans facilitates the implementation of DRM and CRM strategies to ensure risk prevention, risk reduction, and the consolidation of resilient natural and built environments (figure 1.13).

Figure 1.13: Restrict, Condition, and Promote Measures for Risk-informed Urban Planning



Source: Original for this publication.

Restrict

RESTRICT applies when hazard and risk levels are unacceptably high (that is, events with high probability and severe potential impacts) and cannot be reduced to acceptable levels through feasible, cost-effective measures. Planning tools such as zoning, land-use prohibitions, and setback requirements are used to prevent new development, expansion, or the construction of buildings and critical infrastructure in unsafe areas. Restrictions also apply to environmentally sensitive sites, key ecosystems, and buffer zones (for example, wetlands, forests, and floodplains) to prevent environmental degradation that could exacerbate risks.

In areas where formal or informal growth has already occurred, resulting in high-risk conditions, corrective measures must be implemented. These measures may involve applying risk reduction strategies to reduce risk to acceptable levels or relocating vulnerable communities to safer locations. In addition, restrictions can be focused on reducing the environmental impacts of development by controlling densification or prohibiting any polluting construction practices and materials. The determination to restrict rather than condition development is guided by risk acceptability thresholds as well as the technical and economic feasibility of risk reduction measures.

Condition

CONDITION applies where hazards or risks are relevant but can potentially be reduced to acceptable levels through appropriate planning, design, and construction practices. This may entail conducting additional technical studies and implementing specific risk reduction measures tailored to the specific hazard and local context. New developments or densification are permitted if risk reduction measures are technically and economically feasible and resilience standards are fully met. Conditions must be grounded in robust hazard and risk assessments and tailored to local characteristics, applying to specific land uses, building types, densities, or functional activities.

Where risks are potentially manageable, development may proceed only after site-specific studies (for example, geotechnical, hydrological, or infrastructure capacity and cost-benefit analyses) confirm that risks can be reduced to acceptable levels through feasible measures. These include physical interventions designed to control, divert, or withstand hazards; enhanced structural design or retrofitting measures; and adjustment of land-use type or density. In some cases, environmental or functional incompatibility may limit safe occupation, requiring additional safeguards or design modifications.

In already occupied areas with relevant risk, conditional measures may involve upgrading infrastructure, managing water flows, stabilizing slopes, or retrofitting existing buildings. The application of such conditions must be supported by technical evaluations of existing vulnerabilities and be accompanied by mechanisms for ongoing monitoring and enforcement. This ensures that risk remains controlled over time, that no new risks are generated, and that safety and serviceability standards are maintained, minimizing disruption and potential disaster losses while supporting long-term urban resilience and functionality. In low-data or

low-capacity contexts, where detailed assessments are not immediately available, a precautionary first level of conditioning may be applied. In such cases, development or densification may be permitted only after site-specific studies are completed to verify the feasibility of risk reduction. This approach allows planning to proceed responsibly under uncertainty while avoiding the creation of new risks.

Promote

PROMOTE refers to actions that complement restriction and conditioning measures to incentivize appropriate use of natural resources. These actions support the preservation and recovery of fragile ecological areas, an equitable and sustainable provision of urban services, and the implementation of risk reduction measures in hazard- and risk-prone areas. Cities can employ public infrastructure investments, financial and nonfinancial instruments, incentives, development controls, and penalties to promote land-based financing as a tool for disaster risk prevention and reduction.

Promotion measures aim to boost the overall livability of cities by expanding green areas, investing in critical infrastructure and public spaces, and encouraging compact, mixed-use growth that ensures accessibility to essential services while reducing emissions and GHG generation. Other strategies, such as permeable pavements, energy-efficiency standards, sustainable drainage systems (SUDS), sustainable construction practices, bioclimatic design, and Zero Waste programs, help reduce urban heat island (UHI) effects, prevent infrastructure overload during extreme events, and mitigate risks linked to environmental degradation (for example, erosion, drainage failures, or the occupation of buffer zones).

Building on the above-mentioned principles, goals, governance structure, and risk-informed urban planning measures, chapter 2 elaborates on the analysis of the interplay between urbanization and risk as well as basic definitions and classifications of natural hazards. It also addresses the different types of assessments and explains what acceptable levels of risk mean in the urban planning context.

Chapter 2

Understanding Urban Risk for Risk-informed Urban Planning

The concept of risk involves the probability of a hazardous event occurring and the potential consequences it may have. Urban risk is shaped by the dynamic interaction between hazards, exposure, vulnerability, and the capacity to cope and adapt. In cities, these components are influenced by the pace and pattern of urbanization, land-use decisions, infrastructure systems, governance structures, and socioeconomic conditions. As urban areas expand, often in hazard-prone locations and without adequate planning, the physical and social fabric of cities becomes increasingly susceptible to disasters.

Hazard, exposure, and vulnerability are dynamic, varying across temporal and spatial dimensions. They are intensified by climate change, skewed development processes, rapid and unplanned urbanization, environmental degradation, anthropogenic pressures, and a range of social, economic, cultural, institutional, and environmental factors. Meanwhile, the ability of cities to manage risk is frequently constrained by institutional fragmentation, limited technical capacity, and inadequate data. Practitioners must understand the multifaceted nature and interrelated underlying factors of risk before designing and implementing appropriate and sustainable management strategies, including risk-informed urban planning.

This chapter introduces the key concepts and components of disaster and climate risk in cities, highlighting the interlinkages between urbanization and risk. It also provides the conceptual and methodological foundations for hazard and risk assessment that underpin risk-informed urban planning and the design of effective, context-specific measures for reducing and managing urban risk.

2.1 The Interplay Between Urbanization and Risk

While natural events are part of our planet's normal processes, hazards and risks are greatly influenced by human activity and unplanned urban growth. For instance, climate change has led to alterations in the climate system, resulting in more frequent and intense weather events and altered weather patterns. Hazards can be further intensified by land-use changes, greater demand for natural resources, and increased deforestation. Unplanned urban growth also increases the exposure and vulnerability of human populations and infrastructure to these hazards.

Risk from natural hazards is inherently systemic, involving complex interdependencies and feedback loops between social, environmental, and economic factors. Changes in one aspect of the system can cascade onto others, amplifying or reducing risk. Risks are becoming increasingly systemic, arising from the interconnectedness and interdependence of various elements within a system (UNDRR 2022). These interactions can either amplify or reduce the overall impact of individual components through positive or negative feedback mechanisms. Understanding these interconnections in the context of urban systems is crucial for holistic risk management and urban planning.

> **Urban system:** A system refers to a set of interconnected components that interact with one another within a defined boundary, working together to achieve a specific purpose or function. Systems can be natural (for example, ecosystems), human-made (for example, transportation networks), or a combination of both. They are characterized by interdependencies and feedback loops, where changes in one part of the system can influence other parts, often in complex ways. An urban system is a type of human-made system comprising the social, economic, environmental, and physical infrastructure elements that function together within an urban area. Urban systems include transportation networks, energy grids, water and sanitation systems, housing, and social services, all of which are interlinked with the natural environment and the communities they serve. Urban systems are inherently dynamic and interconnected, where changes in one component can ripple through and affect multiple sectors.

Increasing economic losses in urban settlements can be attributed to single, compound, cascading, and systemic events (Dodman et al. 2022). Systemic losses emerge when impacts affect entire systems and may even jump from one system to another. Multiple hazards often occur simultaneously or interact with nonclimatic risks, leading to cascading impacts across sectors and regions. Disasters and climate shocks damage infrastructure and disrupt economies beyond the hazard's immediate footprint (IPCC 2022). Extreme climate events are also displacing populations (IPCC 2022), leading to unplanned urbanization, resulting in the expansion of informal settlements and increasing exposure to extreme climate events (Cardona et al. 2012).

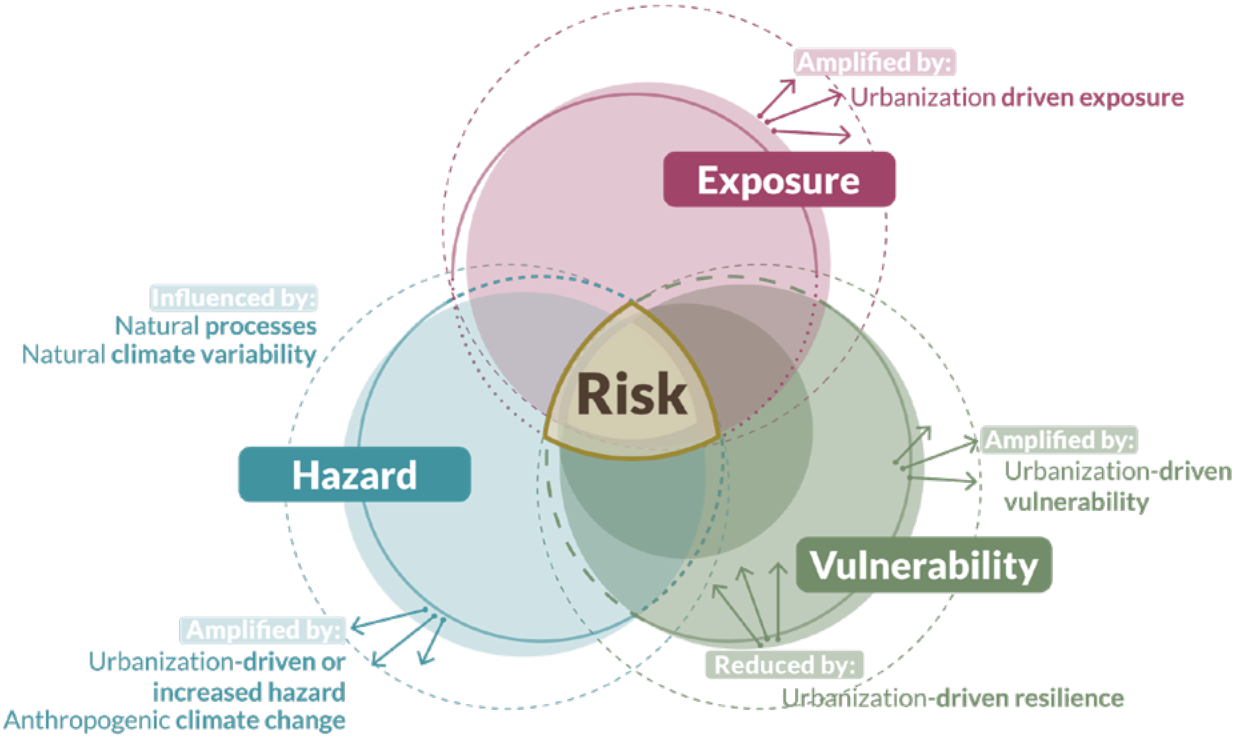
- **Single events** refer to individual hazards, such as floods or earthquakes, occurring in isolation.
- **Compound events** involve multiple hazards occurring simultaneously or in close succession, where their combined effects exacerbate one another. For example, a heat wave coinciding with drought conditions can intensify water scarcity and stress ecosystems, amplifying the overall impact.
- **Cascading events** describe scenarios where one hazard triggers subsequent hazards, like an earthquake causing a tsunami, which then leads to flooding.
- **Systemic risks** emerge from interdependencies within and between systems, where impacts cascade across multiple sectors, amplifying vulnerabilities. For instance, a cyclone-triggered power outage can disrupt water supply, cooling systems, and health care services, diminishing the ability to cope with subsequent extreme heat events. A more complex example is the systemic nature of urban flash flooding. Climate change and the UHI effect contribute to altered rainfall patterns that, coupled with increased runoff from extensive impervious surfaces in cities, overwhelm drainage systems. Inadequately designed infrastructure exacerbates the situation. For example, culverts and bridges with insufficient cross-sectional capacity obstruct floodwaters and cause sediment, debris, and solid waste to accumulate, triggering dam-break phenomena that lead to structural failures and downstream devastation.

Urban systems can either amplify or reduce risks. Inadequate spatial planning, overdevelopment in hazard-prone areas, and degradation of ecosystems can increase hazard, exposure, and vulnerability. Meanwhile, socioeconomic factors such as poverty, inadequate housing, limited access to resources, and social exclusion contribute to the vulnerability of certain groups, further exacerbating risk (figure 2.1). Conversely, well-designed infrastructure, green spaces, and resilient urban design can reduce vulnerability and enhance the capacity to withstand hazardous conditions.

Urbanization can bring significant changes to the local environment and compound hazards. A notable example is the UHI effect, where urban areas experience higher temperatures compared to their surrounding rural areas due to factors such as concrete structures, asphalt roads, and reduced green spaces. The UHI effect can influence precipitation by boosting the low-level convergence of air currents, linked to increased surface roughness and atmospheric boundary layer destabilization (Steensen et al. 2022).

In urban areas, climate change has been observed to have significant effects on human health, livelihoods, and strategic infrastructure (IPCC 2022). The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) highlights with "high confidence" the interactions of climate and non-climate hazards in cities, leading to heightened impacts, particularly affecting marginalized groups. The intensification of heat waves in cities and other extreme and slow-onset events have resulted in loss of life, infrastructure damage, service disruption, and declines in physical and mental well-being. Extreme heat and heat waves are expected to increase ill health and the number of premature deaths, affect air quality and the functioning of strategic infrastructure services, and lead to water-borne, and vector-borne diseases.

Figure 2.1: Interplay between Urbanization and Risk



Source: Original for this publication.

2.2 Urbanization: A Driver of Risks or a Driver of Resilience

As global urbanization accelerates, cities have become hubs of opportunity and innovation but also centers of heightened risk. The rapid growth of urban areas, particularly in low- and middle-income countries, has amplified exposure, vulnerability, and hazard levels. Conversely, urbanization also holds the potential to enhance resilience to manage and mitigate risks. The challenge lies in striking a balance between leveraging the benefits of urbanization and minimizing its unintended consequences.

- **Urbanization as a driver of increased hazards**

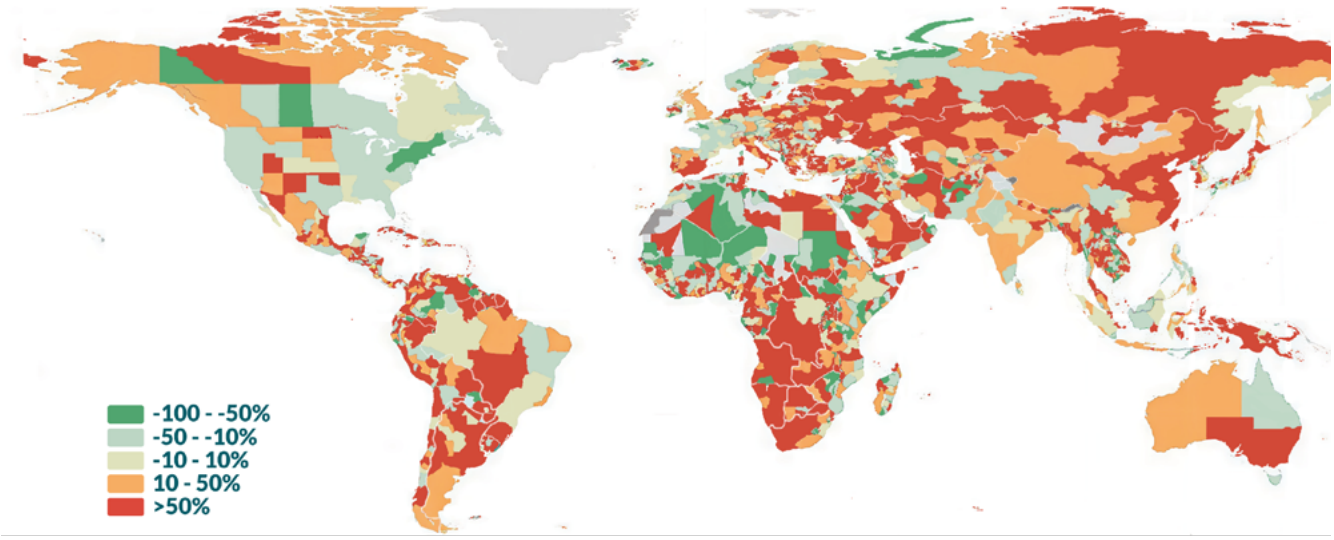
  Urbanization reshapes landscapes and ecosystems, often intensifying hazards. Land-use changes, deforestation, vegetation loss, and the expansion of impervious surfaces exacerbate hazards like floods, landslides, and extreme heat. As cities grow, the pressure to accommodate expanding populations frequently leads to development in hazard-prone areas, altering the natural landscape and therefore amplifying the severity and frequency of these hazards. For example, urban expansion into steep terrain and hilly areas significantly increases the likelihood of landslides, as slopes become destabilized by vegetation removal, excavation, and heavy construction loads. Urban landslide hazard is up to 10 times

more sensitive to variations in precipitation than rural areas (Johnston et al. 2021). Urban settlements along hills and valleys also disrupt natural drainage systems, compounding flood and landslide hazards.

- **Urbanization as a driver of exposure**

  The urban population has nearly quadrupled over the past 50 years, with about 4.2 billion people now living in urban areas. This rapid urbanization has led to increased exposure to various hazards, particularly in unplanned and informal settlements and across flood plains, hilly terrain, and coastal strips (Cardona et al. 2012). As cities grow, development increasingly occurs in previously avoided hazard-prone areas. Between 1985 and 2015, global settlement areas grew by 85 percent while those exposed to a high flood hazard increased by 122 percent. This risky growth was particularly pronounced in middle-income countries (Rentschler et al. 2022; figure 2.2). Similarly, in port cities, the combined impacts of sea-level rise, subsidence, storms, and population growth could increase the number of people exposed to coastal floods to 150 million by the 2070s, while assets at risk may exceed US$35 trillion—a tenfold increase (Nicholls et al. 2007).

Figure 2.2: Safe versus Risky Growth: Relative Difference between Settlement Growth in Safe and High-Risk Areas, 1985–2015



Source: Redrawn from Rentschler et al. 2022, 13.
Note: The authors classify flood risk using the 2019 Global Fathom 1-in-100-year flood dataset, assigning each settlement pixel to a flood-risk category: high risk for depths between 0.5 and 1.5 m, and very high risk for depths exceeding 1.5 m.

- **Urbanization as a driver of vulnerability**

  Urbanization often exacerbates vulnerability by magnifying social disparities, inequality, and poverty.Financial pressures, governance challenges, environmental degradation, and overburdened infrastructure further compound these vulnerabilities. Critical service disruptions, such as interruptions to water, energy, and health care systems, leave urban populations increasingly exposed to risks. Comprehensive vulnerability profiles must account for environmental, social, and economic dimensions.

In many emerging economies, rapid population growth in cities has not been matched by the urbanization of capital or comparable investment in housing, infrastructure, and other capital investments, especially outside the city center (Lall et al. 2017). In Africa, for example, approximately 60 percent of the urban population lives in informal settlements (Lall et al. 2017), and people living in slums are particularly vulnerable to climate shocks and disasters (Bates et al. 2008). While monetary flood exposure (the financial value of buildings and other assets in flood-prone areas) tends to bias attention toward risks in high-income countries, the interaction between flood exposure and poverty significantly amplifies the risk in low-income countries (photo 2.1). Among the 170 million individuals facing both high flood risk and extreme poverty (living on less than US$1.90 per day), 44 percent of them are in Sub-Saharan Africa (Rentschler et al. 2022).

Photo 2.1: Houses in Kaibata, Indonesia Submerged by the Overflowing of Ciliwung River, 2007



Source: © Toto Santiko Budi / Shutterstock.

- **Urbanization as a driver of resilience**

  Urbanization can also play a role in strengthening resilience to natural hazards and risks. It leads to the development of infrastructure, advanced communication systems, and emergency services, which enhance the city's resilience. Urban centers concentrate expertise, usually have a more diverse economy and greater access to resources, and can foster the development of social networks and community organizations, more developed governance structures, and institutions. Drivers of capacity include: an integrated economy; urbanization; information technology; attention to human rights; agricultural

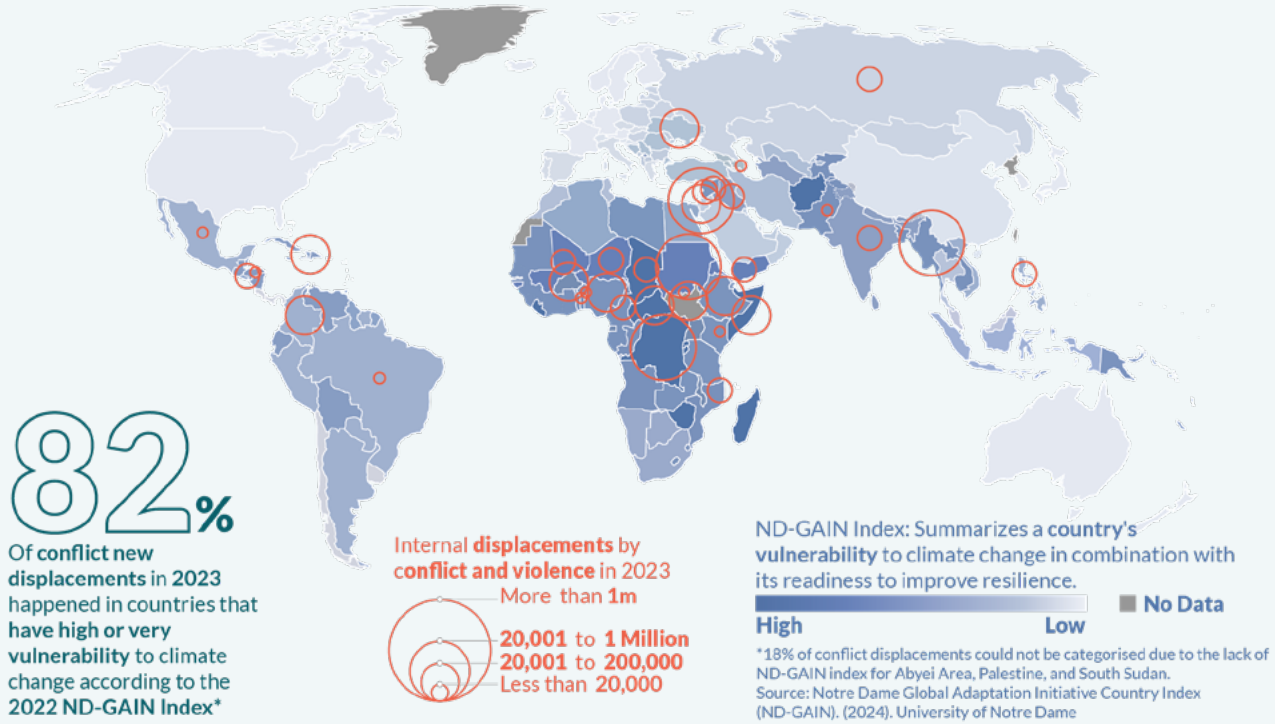
capacity; strong international institutions; access to insurance; class structure; life expectancy, health, and well-being; degree of urbanization; access to public health facilities; community organizations; existing planning regulations at national and local levels; institutional and decision-making frameworks; existing warning and protection from natural hazards; and good governance (Cardona et al. 2012). The case of Kigali in Rwanda (box 2.1) shows how risk-informed urban planning as a tool for guiding informal settlement upgrading processes can help cities transform unplanned areas into resilient and sustainable neighborhoods.

Box 2.1:

Informal Settlement Upgrading and Urban Resilience in Kigali, Rwanda

Currently, more than 1 billion people live in informal settlements (UN-Habitat 2022). This is largely attributed to ineffective land and housing provision policies, accelerated unplanned urbanization, poverty, low income, and lack of affordable housing. In addition, forced displacement due to risks, climate change, and armed conflicts have increased migration of people seeking refuge in cities (figure B2.1.1) and most of them end up living in informal settlements (UN-Habitat 2024).

Figure B2.1.1: Internal Displacement by Conflict and Violence and Country's Vulnerability to Climate Change



Source: Redrawn from Baillat 2024.
Note: ND-GAIN = Notre Dame Global Adaptation Initiative.

Over half of the people living in precarious neighborhoods are concentrated in East, South, and Central Asia, and 23 percent live in Sub-Saharan Africa (UN-Habitat 2022). For instance, in Kigali, the capital of Rwanda, 79 percent of the residents live in informal settlements, where poor-quality housing, lack of infrastructure, and low access to basic services are compounded by flood and erosion risks (IEG 2022). This case shows that rather than being a driver of economic transformation, as expected by the government, rapid urbanization in Rwanda is instead driving exposure, vulnerability, and increased hazards. However, since the proportion of urban population is still very low (20 percent), the government, with the support of the World Bank, has undertaken the Rwanda Urban Infrastructure and City Management Project 2005–2009 and Second Rwanda Urban Development Project (RUDP II) 2016–2021, focused on improving infrastructure, upgrading informal settlements, promoting resilient urbanization, enhancing environmental protection, and strengthening sustainable urban management in Kigali and secondary cities. Fostering planned urbanization through these projects is key as it is expected that half of the population will be urban in 2035 and that this figure will reach 70 percent in 2050 (Government of Rwanda 2022, 5).

As part of the RUDP II, a landscape and prefeasibility analysis for increasing urban resilience using nature-based solutions (NBS) was conducted in Kigali with cofinancing from the Africa, Caribbean, and Pacific–European Union Natural Disaster Risk Reduction Program, managed by the Global Facility for Disaster Reduction and Recovery (GFDRR). This study, led by Defacto Urbanism in cooperation with Ecorys, HKV , Royal HaskoningDHV, Sher Consultants, and the Centre for Geographic Information Systems and Remote Sensing (CGIS), identified flood hotspots in urban areas along wetlands and estimated a scenario of flood damage in 2050 if no measures are taken to reduce informal urbanization and increase resilience (table B2.1.1).

Table B2.1.1 Inundation along Wetlands in Kigali (Estimated Current and Future Flood Damage)

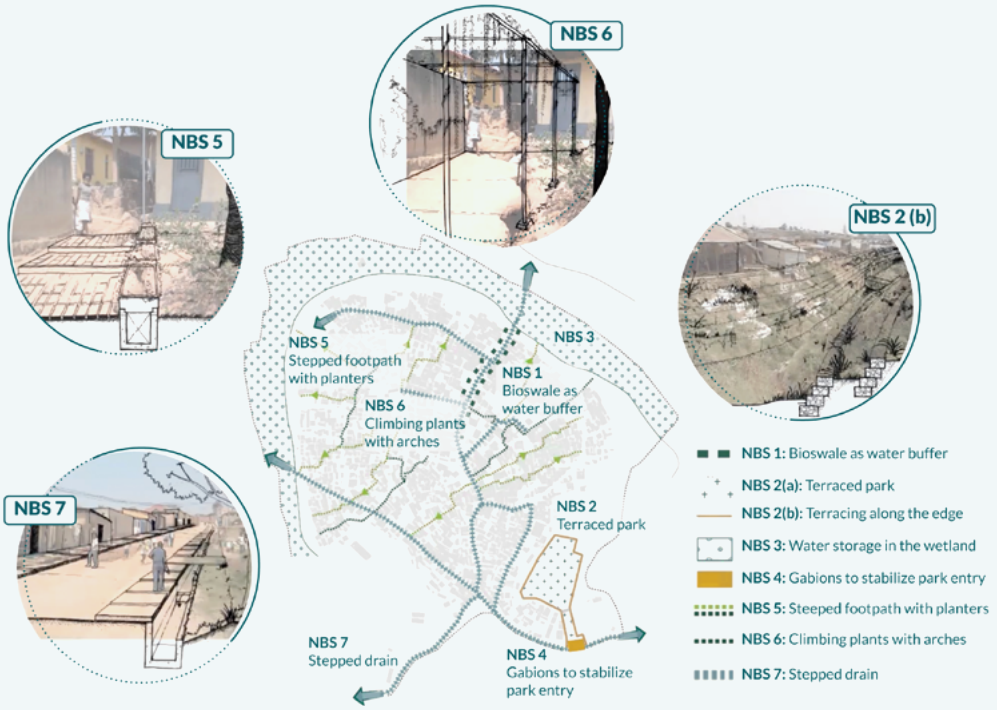
Location	Current flood damage (in US$ Million)	Estimated flood damage in 2050 with climate change + urbanization (in US$ Million)
Nyabugogo Downstream	4.4	31.6
Mpazi	1.5	9.6
Rugunga	0.2	2.5
Kinamba	6.8	51.1
Kavure	0.5	4.9
Nyandungu	0.7	5.8
Masaka	1.0	5.7

Source: Based on Defacto Urbanism 2021.

The project is based on the principle that informal settlement upgrading in at-risk areas can become a driver of resilience through the gradual implementation of NBS in a cost-effective way to reduce flooding and erosion. Solutions included wetland restoration, the consolidation of edge parks, reforestation, and measures to reduce runoff peak and speed, such as stepped drains (delay in drain) and the creation of rough surfaces with vegetation (delay on surface). The project also proposed water storage in ponds and microstorage devices to impound rainwater flowing down the hills to avoid floods and erosion of unpaved roads.

The example of Nyabisindu settlement shows how NBS can be included within an informal settlement upgrading program to optimize investments aimed at increasing resilience. In this project, the pedestrian road network was upgraded using permeable pavements and roadside drains to reduce runoff. The project also recommended the ecological restoration of the surrounding wetlands to maintain their water storage function and the consolidation of terraced parks and gabions to stabilize slopes (figure B2.1.2).

Figure B2.1.2 NBS Application in the Nyabisindu Settlement Urban Upgrading Area, Kigali



Source: Redrawn from Defacto Urbanism 2021.

Risk-informed planning in informal settlements enhances urban resilience and helps to integrate socio-natural dynamics into disaster risk reduction (DRR), ensuring that investments have a direct impact on the protection of people, biodiversity, assets, and livelihoods. Designing and implementing NBS as part of informal settlement upgrading initiatives ensures that vulnerable communities have access to basic services and infrastructure, and, crucially, that they and their assets are protected from disasters and climate-related shocks.

2.3 Definition and Classification of Natural Hazards

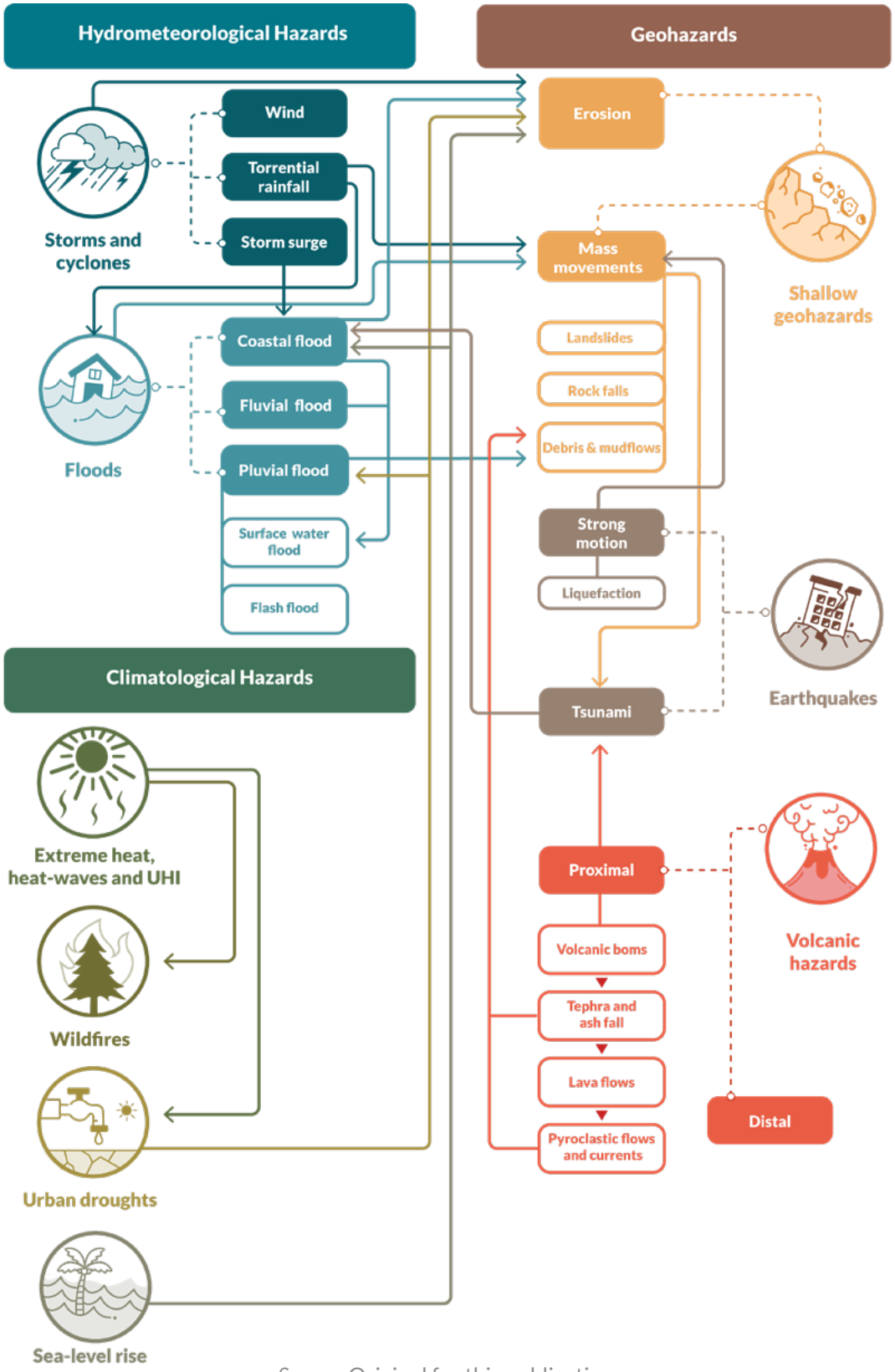
Natural hazards encompass a wide range of phenomena, including cyclones, earthquakes, floods, landslides, droughts, wildfires, and heat waves. They arise from natural processes but can pose significant risks to urban areas and their populations. A clear and universally recognized definition of hazards, as provided by the Sendai Framework Terminology on Disaster Risk Reduction (UNDRR 2017a) facilitates consistency in the collection and analysis of damage and loss data and supports the development of comprehensive hazard and risk assessments.

Hazards are often classified as natural, socio-natural, environmental, social or human-induced, and technological. Socio-natural hazards, such as floods and landslides, arise from the interaction between natural processes and human activity. Recognizing the human-influenced nature of these hazards is critical for spatial planning as it enables strategies that address both immediate risk and the underlying drivers that lead to urban disasters. For the purposes of this handbook, we focus on the following hazard categories:

- **Hydrological and meteorological (hydrometeorological) hazards** are those "resulting from the state and behavior of the Earth's atmosphere, its interaction with the land and oceans, the weather and climate it produces, and the resulting distribution of water resources" (UNDRR 2017a, 28). This category includes weather, water, and climate-related hazards. For practical purposes, this handbook distinguishes between hydrometeorological and climatological hazards to better address their specific implications for risk-informed urban planning. Hydrometeorological hazards—such as storms, heavy rainfall, and floods—are typically short-term, high-intensity events triggered by atmospheric and weather-related processes. Climatological hazards—such as droughts, heat waves, and long-term shifts in rainfall patterns—develop more slowly and persist over longer durations. Differentiating between these categories allows urban planners to tailor strategies according to the characteristics of each hazard.
- **Geohazards** are "hazards with a geological origin" (UNDRR 2017a, 28). They are further subdivided into seismogenic, volcanogenic, and shallow geohazards, the first two resulting from the Earth's internal geophysical processes and the third from surface or near-surface processes, such as erosion or mass movements (for example, landslides, mudflows, and rockfalls).

The range of hazards impacting urban areas is broad and interconnected (figure 2.3). While each hazard originates from distinct processes, they can interact with one another—and with urban systems—in complex ways. Hazards can occur simultaneously, in cascading sequences where one event triggers another, or in compound scenarios where multiple hazards intersect, amplifying their overall impact. For instance, storms can trigger floods and landslides, while earthquakes can lead to tsunamis or mass movements, and they can occur concomitantly, exacerbating hazardous conditions and potential impacts. Flooding can damage energy systems, which may already be strained by extreme heat, leading to power outages that disrupt cooling systems and heighten health risks for vulnerable populations.

Figure 2.3: Examples of Common Hazards and their Interactions



Source: Original for this publication.
Note: UHI = urban heat island.

In urban areas, these hazards are often amplified due to the unique characteristics of each city. High population densities and critical infrastructure concentration increase exposure, while unplanned urbanization, poor drainage systems, and impervious surfaces exacerbate flood and landslide risks. UHIs intensify the effects of extreme heat events, and air pollution can worsen health impacts during the heat waves. Even small changes in urban systems, such as blocked drains or increased impervious surfaces, can significantly alter hazard dynamics, making cities highly sensitive to even seemingly minor disruptions. Moreover, the interactions between different hazards in urban areas often produce compounded effects that are greater than the sum of their parts (photo 2.2).

Photo 2.2: Devastating Floods and Mudslides in Valencia Province, Spain, 2024.



Source: © Natursports / Shutterstock.

Effective urban planning requires a nuanced understanding of the diverse hazards and risks that affect both developed and undeveloped areas. Integrating hazard and risk assessments into urban planning decisions is critical for ensuring that new developments are located in safe areas and that existing urbanized areas become more resilient. In undeveloped areas, planning should be guided by hazard conditions to avoid the creation of unacceptable risk. In developed areas, planning efforts must focus on reducing existing and potential future risks through corrective or adaptive measures that address hazards, limit exposure, and reduce vulnerability while supporting resilient urban growth.

2.4 Assessing Hazards, Exposure, and Vulnerability

Risk arises from the dynamic interactions of hazards, exposure, and vulnerability. In practical terms, this means identifying: what hazards a city faces; what people, assets, and economic activities are in harm's way; and how susceptible those elements are to direct and indirect damage or disruption. Urban planners and DRM professionals use this triad to shape risk-informed development policies, land-use plans, and building standards. Together, these components provide a solid foundation for spatial risk mapping and support evidence-based decision-making for urban resilience.

Hazard assessments identify the types, frequency, and intensity of events that could cause harm, such as floods, earthquakes, or storms. Exposure assessments determine which people, infrastructure, and economic assets are in areas prone to these hazards. Vulnerability can stem from hazard-dependent factors, such as structural fragility during earthquakes, as well as hazard-independent conditions, including poverty, limited access to basic services, and weak governance capacity.

Hazard Assessment

Hazard assessment involves identifying relevant events (for example, earthquakes, floods, and tropical storms) and analyzing their characteristics, such as location, intensity, frequency, and probability of occurrence. This process usually produces hazard models and maps that show where and how severe events can be. Hazard assessments provide a probabilistic or scenario-based estimation of physical events that can lead to loss or disruption. Key parameters include the following:

- **Hazard type** refers to the origin and nature of the hazard, which can be hydrometeorological (for example, storms and floods), geophysical (for example, earthquakes and landslides), climatological (for example, heat waves and droughts), technological (for example, industrial accidents), or biological (for example, pandemics). Each type presents distinct characteristics, impacts, and implications for risk assessment and urban planning.
- **Intensity** refers to the severity or magnitude of a hazard at a specific location, measured through quantitative indicators. For instance, earthquakes can be measured by peak ground acceleration (PGA) or spectral acceleration at period T (Sa(T)), and floods by water depth or velocity. Intensity levels are critical for understanding potential damage and often serve as key inputs for vulnerability functions, which describe how different elements respond to varying levels of hazard severity.
- **Frequency or probability** is typically expressed as return periods. Return period estimation is a widely used method to quantify hazard frequency. For example, a "100-year flood" means there is a 1 in 100 (1 percent) chance of the specified flood level being exceeded in any given year. In earthquake-prone regions, probabilistic seismic hazard assessments are used to estimate metrics like peak ground

acceleration with a specified return period (for example, 10 percent probability of exceedance in 50 years) for building code design.

- **Spatial extent** refers to the geographic coverage of hazards or zones sharing similar hazard characteristics. For instance, a flood hazard map may delineate areas with different probabilities of flooding, where shorter return periods (high probability scenarios) typically correspond to higher hazard categories and longer return periods (lower probability scenarios) to lower hazard categories. Many hazard zonation methods combine probability with intensity metrics, such as flood depth, velocity, or duration, to define hazard levels more comprehensively according to damage potential. The delineation of hazard zones should be adapted to local context, available data, and planning objectives.
- **Onset speed** describes how quickly a hazard develops. Some hazards are of sudden or rapid onset (for example, earthquakes), giving little to no warning, while others develop gradually over time (for example, droughts and sea-level rise).
- **Cascading and compound potential** refers to the potential for hazards to trigger or amplify other events, either simultaneously or sequentially.

Effective hazard assessment must integrate a multihazard perspective, recognizing that urban hazards are often interconnected. In practice, one event can trigger others in a cascade (for example, an intense storm triggering floods and landslides), or multiple threats can occur concurrently as compound events (for example, an earthquake followed by a tsunami), amplifying overall impacts. Planners should explicitly analyze such hazard interdependencies—for instance, evaluating how an earthquake might compromise flood defenses, or how extreme rainfall combined with high tide could overwhelm drainage.

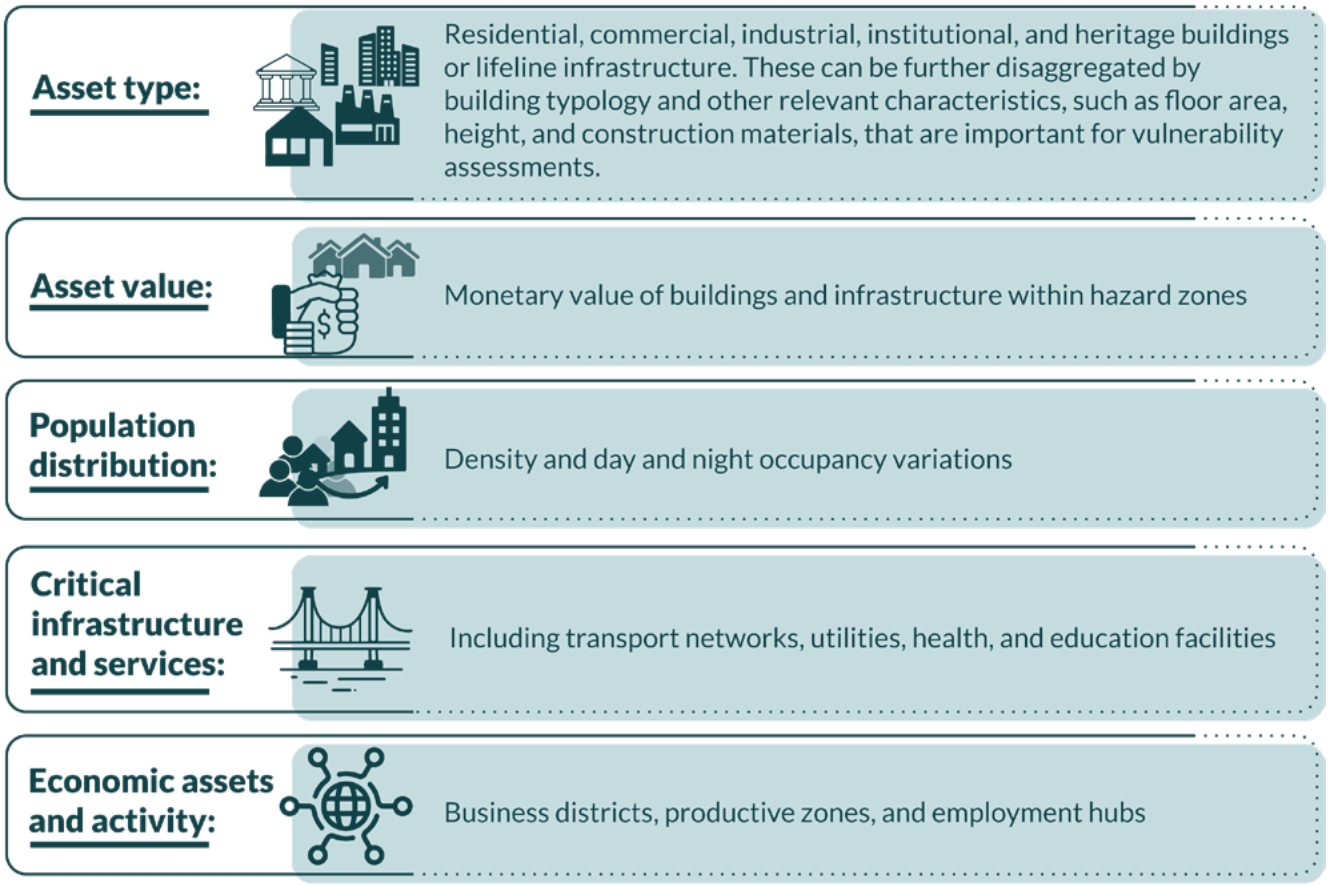
Beyond characterization, effective hazard assessment must inform planning and decision-making by linking each hazard type and its impact to appropriate territorial development responses. For instance, flood-prone areas typically require land-use regulations that restrict or condition development, including zoning overlays, elevation requirements, and setback controls. Seismic hazards necessitate the application of technical design parameters (such as site-specific ground motion values) within building codes and infrastructure design. In contrast, climatological hazards like droughts may not dictate structural regulations but can reshape water resource strategies, land-use priorities, and long-term development trajectories, particularly in agriculture-dependent or water-scarce regions. Integrating hazard-specific implications into spatial planning ensures that assessments lead to actionable, risk-reducing interventions tailored to the local context.

Exposure Assessment

Once hazards are understood, an exposure assessment identifies and quantifies what lies in harm's way. It is a spatial exercise that overlays hazard maps with data on population, land use, buildings, critical facilities, and economic assets. For example, an exposure assessment could estimate how many people, housing units, and infrastructure elements fall within a low-lying area potentially susceptible to a 100-year flood event. Tools like GIS allow this at various scales. Figure 2.4 shows common indicators.

Data sources often include cadastral and census records, satellite imagery, and global datasets such as WorldPop[3] for population exposure, particularly when local information is unavailable. However, local datasets are generally preferred due to their higher resolution and accuracy, while global datasets often require adjustments to reflect the local context. The Global Exposure Model[4] is an example of publicly available country-level and first-level administrative data, incorporating information on building typologies, occupancy, and replacement costs. While this offers a useful reference, the spatial resolution may be insufficient for detailed urban analysis and should be supplemented with local data whenever possible.

Figure 2.4: Common Indicators for Exposure Assessments



Source: Original for this publication.

Vulnerability Assessment

Even under severe hazard conditions and high exposure, actual disaster impacts are largely determined by vulnerability—the propensity of exposed elements to suffer damage or loss at given hazard intensities. Vulnerability reflects a set of physical, social, economic, and environmental conditions that increase susceptibility to harm (UNDRR 2017b). For example, two cities may face the same flood hazard and similar levels of exposure, but if one has resilient infrastructure, effective early warning systems (EWS), and

[3] WorldPop – School of Geography & Environmental Sciences, University of Southampton. Open spatial demographic data and research. https://www.worldpop.org/.
[4] Global Exposure Model – GEM Foundation (Global Earthquake Model). https://www.globalquakemodel.org/product/global-exposure-model.

strong institutions, while the other has poor infrastructure and socioeconomic fragilities, their risk levels will differ significantly. Vulnerability assessments evaluate how prone people and assets are to damage, considering both hazard-dependent factors (for example, structural fragility in earthquakes) and hazard-independent factors (for example, poverty and governance capacity). Vulnerability dimensions relevant for urban planning are presented in figure 2.5.

Figure 2.5: Relevant Vulnerability Dimensions

Physical or structural vulnerability:	Refers to the susceptibility of buildings and infrastructure to damage when exposed to hazards. This depends on factors such as construction quality, design standards, building age, and materials used. Methods like fragility curves (which show the likelihood that a structure will reach or exceed a certain level of damage at a given hazard intensity) and vulnerability functions (which estimate the expected damage or loss—often as a damage ratio or monetary value) for different hazard intensities are commonly used to quantify potential damage from hazards.
Social vulnerability:	Encompasses the characteristics of individuals and communities that affect their ability to prepare for, respond to, and recover from disasters. Key factors include individual, community-level, or national-level indicators, such as age, disability, education, poverty, and social networks.
Economic and institutional vulnerability:	Relates to the resilience of livelihoods, businesses, and governance systems. It considers how well local economies can withstand shocks and how capable institutions are in enforcing building codes, managing emergencies, and coordinating recovery. Cities with strong institutions and diverse economies tend to exhibit lower vulnerability.
Service and functional vulnerability:	Focuses on the availability, accessibility, and redundancy of critical services such as health care, electricity, water, and transport. It also considers the degree to which people and systems rely on services that are likely to be disrupted by hazards. Communities highly dependent on fragile infrastructure or single-service providers are more vulnerable to cascading impacts.

Source: Original for this publication.

Risk Mapping

Risk mapping synthesizes hazard, exposure, and vulnerability information into spatial outputs that inform urban policy and investment. These maps identify high-risk areas, reveal differential risk across neighborhoods, and guide targeted mitigation and adaptation strategies. Effective risk maps should integrate current and projected risk conditions, accounting for factors like climate change and urban expansion, and be calibrated to local planning scales and data availability. In a risk-informed planning framework, such tools are critical for guiding zoning, infrastructure development, and community-based resilience actions.

To maximize their utility, risk maps should be self-explanatory and include clear, contextual information that defines what each risk level means in terms of causes, consequences, magnitude, and potential impacts, alongside any other details necessary for correct interpretation and use. This enables users—from policy makers to community members—to understand the underlying drivers and implications of risk classifications. Their development should follow rigorous technical standards and be carried out by a multidisciplinary team of qualified professionals with relevant expertise, ensuring that the resulting products are fit for purpose and can be confidently applied.

2.5 Methods for Risk Assessment and Mapping

Risk can be quantified through various methodologies, each offering unique insights to support decision-making. Table 2.1 offers a comparison between qualitative and quantitative risk assessment methods.

Table 2.1: Qualitative and Quantitative Risk Assessment Methods

Aspect	Qualitative methods	Quantitative methods
Overview	Rely on descriptive evaluations and expert judgment to estimate risks, categorizing them into levels like low, medium, or high; focus on simplicity and accessibility, often emphasizing stakeholder engagement and community-based input	**Focus on numerical analysis, using statistical models, historical data, and computational tools to calculate probabilities, potential impacts, and risk metrics; provide data-driven insights**
Key features	Cost-effective and intuitive, requiring minimal data and offering a flexible approach to initial risk prioritization and decision-making; ideal for rapid assessments and engaging diverse stakeholders	**Offer robust, reproducible outputs that account for uncertainties; use data-intensive techniques to evaluate risk scenarios and optimize resource allocation for long-term resilience**
Data requirements	Minimal data requirements; rely on expert judgment, participatory inputs, and descriptive indicators	**High data requirements; depend ozn extensive datasets, probability distributions, and historical records to ensure accuracy**
Addressing uncertainty	Primarily descriptive; often highlight uncertainties through expert narratives or stakeholder perspectives without numerical quantification.	**Directly address uncertainties through probabilistic modeling, sensitivity analysis, and scenario simulations, offering insights into potential variations and likelihoods of outcomes**
Risk representation	Represent risks descriptively or categorically (for example, low, medium, or high), often visualized through risk matrices or spatial overlays	**Represent risks numerically, often using exceedance probability curves, expected annual losses, or risk maps based on probabilistic modeling**

Aspect	Qualitative methods	Quantitative methods
Integration of scenarios	Explore scenarios narratively or through participatory approaches to envision future risks and prioritize actions, typically without numerical modeling	**Scenarios modeled quantitatively to simulate potential events under varying conditions, integrating probabilistic or deterministic parameters to evaluate outcomes**
Applications	Best suited for initial risk prioritization, community-based disaster risk reduction, stakeholder engagement, and vulnerability profiling	**Ideal for detailed planning, infrastructure design, financial risk modeling, climate adaptation strategies, and technical risk mitigation**
Outputs	Produce descriptive results, such as categorized risk levels or qualitative maps; include outputs like matrices, narrative reports, or spatial overlays	**Produce numerical outputs, such as probability distributions, financial loss estimates, and exceedance probability curves**
Strengths	Accessible, flexible, and cost-effective; foster stakeholder engagement and support rapid or resource-constrained assessments	**Accurate and reproducible; ideal for complex planning and mitigation efforts where data availability supports detailed analysis**
Limitations	Lack numerical precision, subject to biases in expert judgment, and may produce inconsistent results across different assessors or contexts	**Resource-intensive and technically demanding; limited applicability in areas with insufficient data or newly emerging hazards**
Techniques used	Risk matrices, indicator-based analysis, hazard mapping, and Spatial Multicriteria Evaluation (SMCE).	**Probabilistic modeling (for example, Monte Carlo simulation), catastrophe modeling, stochastic simulations, and scenario-based analyses**

Source: Original for this publication.

Qualitative methods rely on descriptive evaluations and expert judgment, categorizing hazards into levels such as low, medium, or high. These classifications are usually based on subjective criteria, including stakeholder perceptions, historical experiences, and comparative analyses of hazard, exposure, and vulnerability.

Common tools include risk matrices, hazard mapping, spatial overlays, and participatory techniques. Many of these methods are well suited for stakeholder engagement and initial risk prioritization and are particularly useful in data-scarce environments given their accessibility and cost-effectiveness. However, they lack the numerical precision of quantitative methods. Even so, they provide a valuable starting point for integrating risk considerations into planning. Risk assessment is best understood as a progressive, iterative process, where different types of decisions are made based on the level and quality of available information. As more data and resources become available, assessments can be refined and complemented with more detailed quantitative analysis to support increasingly complex planning decisions. Commonly used qualitative methods are:

- **Risk matrix approach:** The risk matrix is a widely used tool that evaluates risks based on the likelihood of occurrence and potential impact. Risks are plotted on a grid, categorizing them into levels (for example, low, medium, high). The risk matrix approach can be used to evaluate how risk reduction measures

decrease the likelihood and severity of potential impacts to reach predefined levels of acceptable risk (see section 2.6 for more details on acceptable risk). Importantly, although risk matrices are often associated with qualitative approaches, they are not exclusive to them. Quantitative methods can also generate numerical outputs that are subsequently translated into categorical levels, which are then visualized using matrix-based frameworks.

- **Indicator-based analysis:** This method uses predefined qualitative or semiquantitative indicators[5] representing hazard, exposure characteristics, vulnerability, coping capacity, or risk itself. Indicators are often weighed and aggregated to provide an overall risk profile, useful for comparing different areas or systems.
- **Spatial multicriteria evaluation:** SMCE combines spatial analysis with multicriteria decision-making to evaluate risks geographically. By integrating various datasets (for example, hazard maps and population density), it produces spatially explicit risk maps.

Quantitative methods, in contrast, focus on absolute risk, employing diverse methodologies of varying complexity, such as deterministic modeling, probabilistic or statistical models, and scenario-based approaches. As quantitative methods provide numerical risk estimation, risk levels may be assigned using predefined thresholds based on metrics such as probability of exceedance or other risk indices. However, in practice, numerical results are often translated into qualitative risk categories using matrix-based approaches, rather than applying direct thresholds to define risk levels (see section 2.6).

Deterministic modeling examines specific events, such as worst-case scenarios, without quantifying their likelihood. Scenario-based approaches explore a range of potential outcomes under varying conditions as multiple "what-if" scenarios but similarly do not assign explicit probabilities. Consequently, neither deterministic nor scenario-based models fully capture the likelihood and inherent uncertainties of hazard events, exposure, and vulnerability, limiting their adaptability in dynamic contexts.

Probabilistic risk assessments (PRAs), by contrast, explicitly incorporate uncertainties (through probability distributions), capturing the full range of possible hazard events and their likelihood. Unlike deterministic methods, which rely on single worst-case scenarios or historical events alone, PRAs use statistical models to estimate probabilities and impacts across many scenarios, including low-probability high-impact events. Outputs such as exceedance probability curves, expected annual losses, and confidence intervals provide nuanced insights into both the severity and probability of losses, making PRA especially valuable for risk-informed urban planning.

Techniques such as Monte Carlo simulations, Bayesian networks, and catastrophe modeling are commonly employed in PRAs. These methods account for variability in key factors—from hazard intensity and frequency to the exposure of assets and their vulnerabilities. Table 2.2 provides an overview of key quantitative risk assessment techniques commonly used in probabilistic modeling. Notably, some of these methods (such as catastrophe modeling and event tree analysis) can also be applied using deterministic or scenario-based approaches, but they are included here due to their prevalent use in PRAs.

[5] An indicator is a variable or combination of variables that provides a quantitative or qualitative expression of a concept or phenomenon. It simplifies complex information to make it more accessible and serves as a replicable tool for tracking changes over time and across locations. Bories et al. 2019, Mapping Narratives of Urban Resilience in The Global South, https://doi.org/10.1016/j.gloenvcha.2019.01.001.

Table 2.2: Probabilistic Quantitative Methods

Methodology	Overview	Strengths	Limitations
Monte Carlo simulation	Uses repeated random sampling to model uncertainties in hazard parameters, exposure, and vulnerabilities, producing probabilistic outputs like exceedance curves.	Accounts for a wide range of uncertainties and provides detailed probabilistic outputs for decision-making.	Computationally intensive and requires high-quality data, which can be challenging in data-scarce regions.
Catastrophe modeling	Combines hazard modules, exposure databases, and vulnerability functions to estimate potential losses from catastrophic events	Effective for large-scale assessments and produces detailed loss estimates useful for insurance and mitigation planning.	Highly dependent on quality of input data and may oversimplify localized contexts.
Bayesian networks	Probabilistic graphical models representing variables and their conditional dependencies, ideal for modeling interdependencies in urban systems.	Effectively captures interdependencies and feedback loops and integrates expert judgment and observational data.	Computationally intensive and requires expertise in Bayesian modeling and detailed input data.
Stochastic modeling	Represents random variables through statistical distributions, enabling simulation of rare or extreme events.	Effective for rare events where historical data is limited and generates a wide range of plausible scenarios.	Dependent on assumptions about statistical distributions and may oversimplify real-world complexities.
Hybrid models	Combines deterministic and probabilistic approaches to balance detailed scenario analysis with uncertainty estimation.	Balances precision with uncertainty analysis and is suitable for complex systems requiring multimethod approaches.	Resource-intensive and requires interdisciplinary expertise and extensive datasets.
Event tree analysis	Visualizes sequences of events leading to multiple outcomes, assigning probabilities at each step, particularly for cascading hazards.	Captures cascading hazard interdependencies and is highly useful for multihazard scenarios.	Requires precise probability estimates for each event and is limited in its ability to account for nonlinear interactions.

Source: Original for this publication.

However, probabilistic methods require extensive datasets, technical expertise, and significant computational resources. In data-scarce regions or for newly emerging hazards, obtaining this information can be difficult, as high-quality input data on hazards, exposure, and vulnerability are essential for credible results. The models themselves can be complex and computationally intensive (for example, running tens of thousands of simulations).

The integration of PRAs and scenario-based assessments (SBAs) empowers decision-makers to prioritize risk reduction measures, develop flexible strategies, and address broader challenges like climate change and population growth. The application of PRAs and SBAs in urban planning encompasses broader challenges like

climate change, population growth, and economic fluctuations. By incorporating climate change projections, demographic trends, and economic scenarios into the analysis, planners can proactively design climate-resilient infrastructure, establish adaptive zoning regulations, and anticipate demographic shifts.

> **Probabilis tic risk assessment (PRA)** involves quantifying the probabilities of different hazard events and their potential consequences, utilizing historical data, statistical analysis, and mathematical models to estimate the likelihood of hazards of a given magnitude and characteristics occurring within a given time frame, and the likelihood of the exposed assets and systems to be adversely affected by the hazards.
>
> **Scenario-based assessment (SBA)** involves developing hypothetical scenarios of potential hazard events and their impacts, constructed on the basis of scientific and local knowledge and historical data.

To support these methodologies, risk assessments increasingly rely on advanced tools and diverse data sources to improve precision and utility. GIS and risk modeling platforms enable the integration of hazard, exposure, and vulnerability data within probabilistic frameworks, supporting multihazard simulations and data-driven analysis. Emerging technologies—such as artificial intelligence, machine learning, and high-resolution remote sensing—are further improving hazard mapping and pattern detection, particularly in data-scarce or rapidly changing urban environments. Equally important is the use of historical records to calibrate and validate models, anchoring simulations in observed reality.

Building on the methodologies used in risk assessment, risk mapping translates these analyses into spatially explicit representations, making the information actionable for urban planning. The scale of risk mapping is particularly important, as it determines the objectives, methodologies, and applications. While global-scale information can highlight broad trends, its coarse resolution makes it unsuitable for urban planning. In rural areas, where population densities and exposure levels are lower, resolutions of up to 1:100,000 may be sufficient. Urban areas, however, require finer scales—typically 1:25,000 or larger—to provide the necessary detail for accurate risk assessments and targeted planning actions.

In urban settings, mapping at scales of 1:25,000–1:10,000 serves as a preliminary evaluation to identify hazard-prone areas and hotspots, while priority areas often require more detailed scales of 1:10,000–1:5,000 or larger for refined assessments and risk-informed decisions (PREDECAN 2009). This phased approach facilitates efficient resource allocation and prioritization. Table 2.3 presents an explanation of the scales commonly used in risk mapping and example applications relevant to urban planning purposes

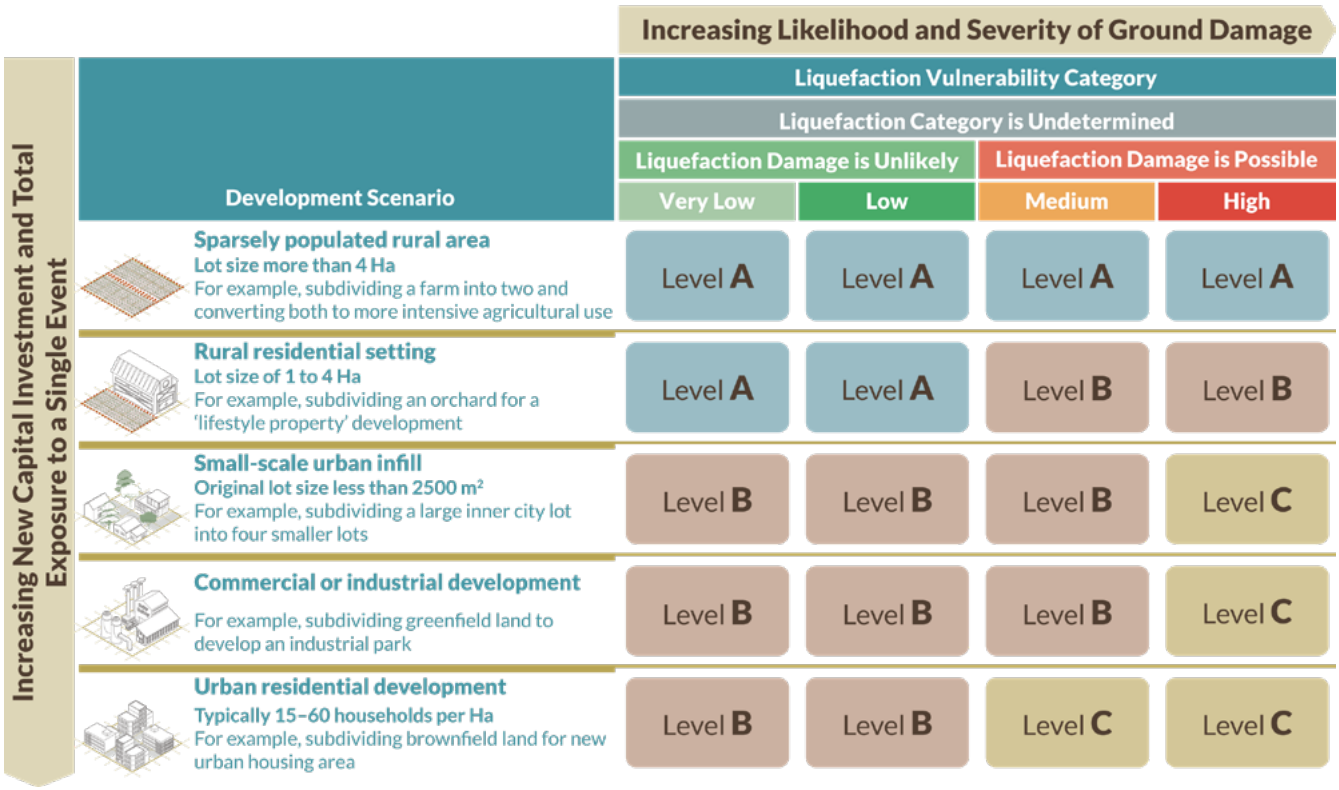
The level of detail required for risk mapping depends not only on planning scope but also on the complexity of local hazard and risk conditions. As an example, figure 2.6 illustrates the level of detail required for liquefaction assessments for land-use or subdivision consent in New Zealand, based on both planning needs and hazard severity.

Table 2.3: Scales Commonly Used in Hazard and Risk Mapping and Example Applications

Scale		Example applications for planning purposes
Provincial to municipal scale	1:100,000–1:25,000	- Developing municipal response plans - Prioritizing critical infrastructure upgrades - Developing provincial or municipal building regulations
Municipal to urban and communal scale	1:25,000–1:5,000	- Establishing zoning regulations - Establishing urban planning and development control regulations - Identifying vulnerable urban neighborhoods for targeted interventions - Prioritizing urban greening projects to mitigate heat island effects.
Neighborhood or site-specific scale	1:5,000 or larger	- Designing resilient infrastructure projects (for example, hospitals and schools) - Planning retrofitting interventions in vulnerable communities and infrastructure

Source: Adapted from C.J. van Westen 2014.[6]

Figure 2.6: Example Matrix for Determining Minimum Level of Detail Required for Land-use or Subdivision Consent in New Zealand



Source: Redrawn from Berg et al. 2017, 25.
Note: Level A refers to basic desktop assessment, Level B to calibrated desktop assessment, Level C to detailed area-wide assessment, and Level D to site-specific assessment. Ha = hectare.

[6] Caribbean Handbook on Risk Management (CHARIM), Section 5.5: Methods for Risk Assessment – CDEMA (Caribbean Disaster Emergency Management Agency). https://www.cdema.org/virtuallibrary/index.php/charim-hbook/methodology/5-risk-assessment/5-5-risk-assessment-methods.

Incorporating climate change into risk-informed urban planning is essential to promote livable and resilient cities and address escalating challenges and emerging risks. As anthropogenic activities continue to drive GHG emissions and the impacts of climate change on urban environments become increasingly pronounced, cities must foster adaptive and sustainable urban development. Regional and local climate projections, derived from climate models and downscaling techniques, are utilized to develop climate scenarios and assess the range of potential impacts of climate change on urban systems and populations, from both extreme and slow-onset events.

2.6 The Concept of Acceptable Levels of Risk for Urban Planning

In risk-informed urban planning, the concept of acceptable levels of risk is essential in shaping decisions on development and land use. Acceptable risk or risk tolerance refers to the degree of potential harm or loss that a community, government, or stakeholder considers tolerable within a given context. This threshold may be explicitly defined through formal regulations, building codes, or urban planning policies, or it may be implicitly shaped by societal norms, historical precedents, and political choices.

> **Acceptable level of risk** is the degree to which disaster risk is considered acceptable or tolerable, influenced by prevailing social, economic, political, cultural, technical, and environmental factors.[7]

Risk itself can be quantified as the combination of an event's probability and the severity of its consequences. However, its acceptability is determined by subjective, context-dependent factors. It is important to note that while hazard and risk studies constitute critical technical inputs that inform evidence-based policy making, they do not, by themselves, define policy outcomes. The final determination of acceptable levels of risk is ultimately a governance decision—anchored in national development priorities and requiring a careful balance between scientific evidence, societal values, economic considerations, and governance judgment. Establishing acceptable risk is a complex process at the intersection of science, economics, politics, and ethics. "How safe is safe enough?" is not defined by a fixed scientific threshold but rather reflects a contextual and value-based judgment.

[7] For a full definition of disaster risk, see United Nations Office for Disaster Risk Reduction (UNDRR) at https://www.undrr.org/terminology/disaster-risk. It is important to note that definitions of acceptable and tolerable risk may vary across frameworks. The UNDRR (2017c) uses the terms interchangeably. In contrast, the IPCC distinguishes between the two: acceptable risks are those deemed so low that further adaptation efforts are not justified, whereas tolerable risks refer to situations where adaptive risk management is required and effective in keeping risk within reasonable levels. This handbook aligns with the UNDRR approach and does not make a formal distinction between acceptable and tolerable risk, as adaptive risk management is considered an inherent component of maintaining risk within acceptable or tolerable thresholds.

Acceptable risk is not a static target; it functions as a dynamic social contract that evolves with societal values, technological capabilities, and environmental conditions. Because perceptions often diverge from technical assessments, acceptable risk is deeply influenced by cultural, social, and economic factors. Development pressures and institutional capacities to reduce risks are also key factors in determining acceptable levels of risk. In cities with strong economic growth and limited land, risk acceptability may be higher, while in areas with ample safe land, restrictions in high-hazard zones may be stricter. Box 2.2 highlights how different cities define and operationalize acceptable levels of risk in distinct ways, based on their unique geographic, economic, social, and institutional contexts.

Box 2.2:

Acceptable Levels of Risk in Practice: Context Matters

Acceptable risk thresholds in urban planning vary widely across different contexts. The following examples illustrate how what is deemed an "acceptable" level of risk is shaped by local economic resources, land constraints, social values, and the degree of community involvement in decision-making.

Manizales, Colombia: In Manizales, a middle-income city built on steep Andean slopes, land constraints mean some hazard exposure is unavoidable. Manizales has developed a detailed multihazard risk zoning system that classifies areas by their level of risk. In earlier plans, risk maps used the typical color-coding of red, orange, and yellow to mark high-, medium-, and low-risk areas. The latest approach goes further. By building on decades of georeferenced hazard and impact data, the city set quantitative risk thresholds to determine which hazards can be tolerated, considering the likelihood that a given area will be affected by hazards. In practice, high-risk areas are often designated as conditionally developable land, where development is permitted only if rigorous technical mitigation measures (for example slope stabilization works and site-specific hazard studies) are implemented to reduce risk to tolerable levels. Conversely, if the risk cannot be reduced below the safety threshold, development is restricted, and communities may be relocated.

Since 2003, Manizales has supported voluntary relocation through the *Guardianas de la Ladera* (Hillside Guardians) initiative, an urban risk monitoring program led by women from vulnerable neighborhoods. These women are trained and hired part-time to support the maintenance of slopes that have been recovered and stabilized, to monitor these areas to prevent the emergence of new settlements, and to create a culture of civic engagement in disaster risk reduction. Over 600 homes in 82 high-risk areas have been cleared through community-based relocation processes (Carrizosa, 2019).

Photo B2.2.1: Panoramic View of Manizales



Source: © Fausto Riolo / Shutterstock

The Netherlands: The Netherlands' approach to acceptable risk is shaped by its high economic resources, dense development, and cultural aversion to flood disasters. The new and updated flood-protection standards introduced in 2017 rest on the premise that every human life bears equal value and stipulate that the probability of death from flooding for people who live behind a "primary dyke" should be no more than 1 in 100,000 per year (de Vries et al. 2024). The country follows a risk-based approach: while a basic level of flood protection is guaranteed by the state for all, in line with the distributive principle of sufficiency, higher protection standards may be applied in densely populated or economically significant areas where flood risks and potential impacts are greater.

This protection policy, though broadly supported, entails high costs and requires continuous investments, particularly in regions facing greater flood risks (photo B2.2.2). The Netherlands has a well-established flood-protection financing framework, combining national allocations with decentralized water-system taxes managed by regional water boards, which operationalize both the "beneficiary pays" and "solidarity" principles (de Vries et al. 2024).

Photo B2.2.2: Flood Defense Structure. Longitudinal view on Afsluitdijk, North Holland



Source: © Topview Nederland 2017

Australia: Australia defines "acceptable" disaster risk in urban planning through collaborative, community-informed processes grounded in both science and public values. In practice, national and state frameworks may mandate participatory decision-making. For example, New South Wales' planning policy requires that, where no explicit standard exists, planners determine tolerable risk thresholds via consultation with local governments, hazard experts, and the community (New South Wales Department of Planning and Environment 2021). Australian practice often adopts the "as low as reasonably practicable" (ALARP) principle applied in land-use planning to keep residual risks within levels society deems tolerable (Australian Institute for Disaster Resilience 2020). Tools such as risk matrices and scenario testing are also used to categorize risks. Notably, major disasters have prompted tighter risk thresholds in planning instruments. After the 2009 Black Saturday bushfires, planning instruments like Victoria's Bushfire Management Overlay were revised to reflect reduced public risk tolerance for development in hazard-prone zones (Australian Institute for Disaster Resilience 2020 and Department of Environment, Land, Water and Planning 2017).

Acceptable risk evolves as both perceptions and conditions change. As urban capacities grow, risks once tolerated may come to be seen as unacceptable, reflecting rising expectations for safety. Conversely, as climate change intensifies hazards, and adaptation gaps widen, communities may be forced to reconsider previously unacceptable risks as tolerable due to limited alternatives. Beyond perception, actual risk levels can shift: increasing exposure—such as unplanned development in flood-prone areas can push risks beyond acceptable thresholds, while targeted mitigation measures like drainage upgrades, land-use regulation, or building retrofits can reduce risk to a tolerable level (figure 2.7). Planners must therefore treat acceptable risk as both a social judgment and a dynamic outcome of changing hazard, exposure, and vulnerability conditions.

For practical purposes, acceptable risk can emerge through various context-appropriate channels rather than one strict guideline. Options include regulatory benchmarks (for example, annual exceedance probabilities and life-safety or service-continuity performance levels), economic appraisal (for example, cost-benefit and multicriteria analyses, with sensitivity checks for distributional effects), and social agreement (for example, stakeholder deliberation, expert panels, and public consultation). Thresholds can differ by scale (citywide standards versus site-specific conditions) and land-use criticality, and be stress-tested under climate and urban growth scenarios. Furthermore, thresholds can be revisited in response to defined triggers, such as new hazard evidence, near-misses, major events, or shifts in exposure, so judgments continue to be aligned with evolving contexts. Documenting the rationale and evidence base can help keep these judgment calls transparent, defensible, and implementable.

Spatial planning is a fundamental mechanism for applying acceptable risk in practice. Integrating risk thresholds into planning requires coordination among multiple stakeholders and can be a source of local conflict due to the discrepancy between private and public interests. Meaningful community involvement is therefore critical as participatory processes help ensure that the chosen level of acceptable risk is technically sound, socially equitable, and broadly supported. For instance, planners may present flood inundation scenarios and facilitate discussions until residents and officials agree on which zones can be safely developed (Australian Institute for Disaster Resilience 2002). In this way, acceptable risk becomes a socially negotiated benchmark integrated into law and practice. These decisions are then embedded in engineering codes and land-use regulations, which specify design standards—such as construction above the "100-year flood" elevation—reflecting chosen risk tolerances.

The establishment of acceptable risk has broad governance implications. By defining which losses are acceptable, governments implicitly decide how responsibilities and resources are allocated. This distinction shapes the division of responsibilities: while governments may provide levees, shelters, or emergency services, individuals may be expected to assume residual risks through insurance or home retrofitting (Kuhlicke 2019).

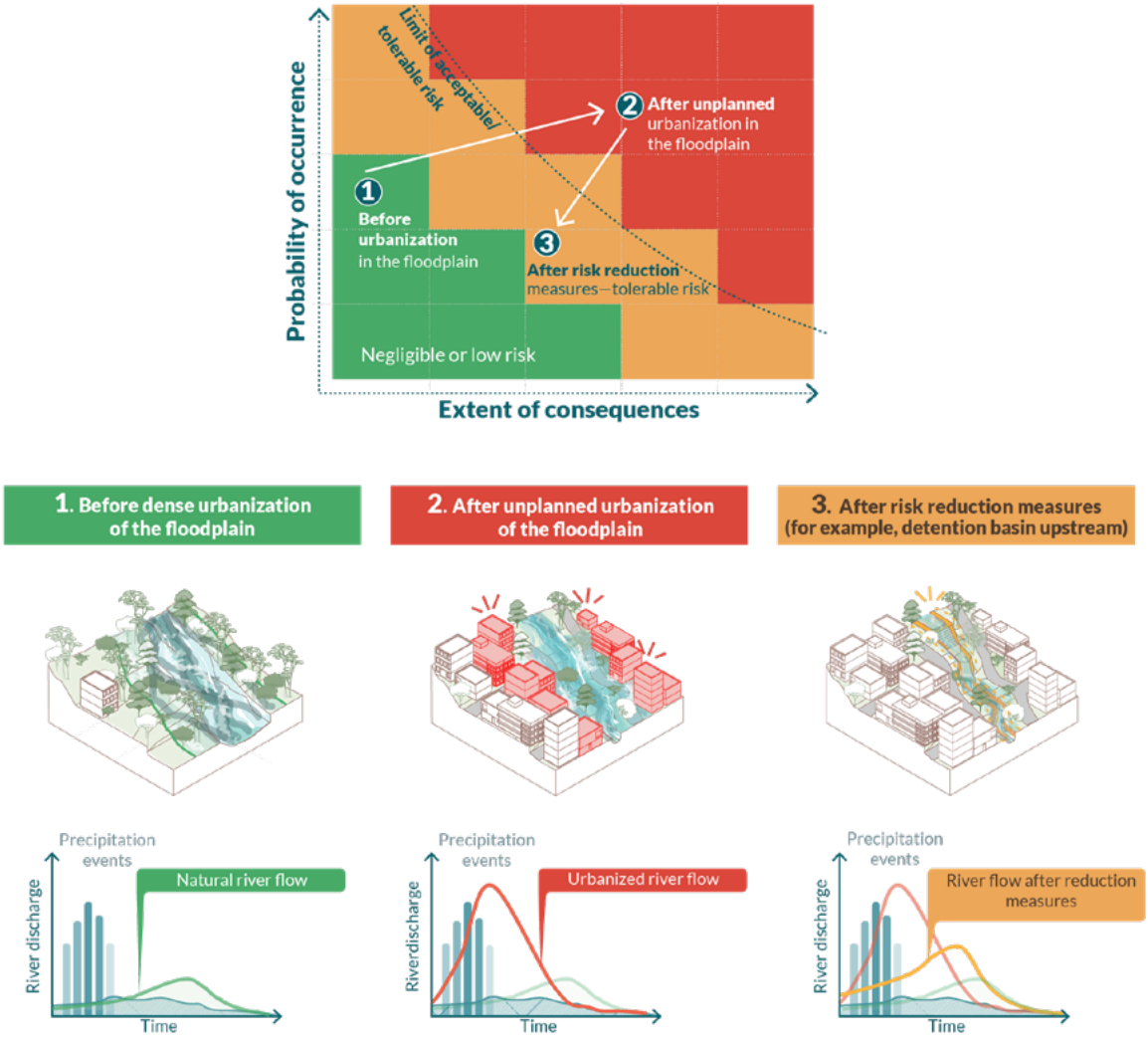
Setting a risk threshold acknowledges that absolute safety is unattainable. Resilience-building then focuses on living with residual risk (UNDRR 2017e). In practice, this means if a certain level of risk is deemed acceptable, planners must still invest in EWS, evacuation drills, social safety nets, and recovery support to

handle events at or above that level (Japan's multilayered approach to seismic risk management described in box 6.2 exemplifies this principle).

For instance, levees built to withstand a 50-year flood must be supported by evacuation plans for larger events. In policy terms, this is built into disaster management. Acceptable risk underpins the need for emergency services. Thus, infrastructure design and land-use limits focus on one part of risk reduction, while emergency response planning addresses the remainder—together forming a holistic approach.

In short, acceptable risk guides policy choices, and its establishment makes disaster risk a matter of governance—balancing safety, cost, and development priorities. Figure 2.7 presents an example of a potential development zone in a high-hazard area, which illustrates how these concepts inform land-use decisions.

Figure 2.7: Example of Potential Building Zone in a High-Hazard Area and Illustration of the Proposed Solutions



Source: Original for this publication.

In this example, a risk matrix is used to differentiate between acceptable, tolerable, and unacceptable levels of risk, represented through a color-coded scheme: green indicates acceptable risk, yellow denotes tolerable risk (which may require conditional measures), and red reflects unacceptable risk levels. Zoning decisions and risk management strategies can alter the risk levels in developed and undeveloped land. The threshold between the yellow and red zones marks the limit of acceptable risk, beyond which development would typically require significant risk reduction measures or may be restricted entirely.

The concept of acceptable risk is central to determining development restrictions in urban planning. Effective risk management aims to balance risk reduction interventions with societal and economic stability. In high-risk areas, stringent restrictions are imposed, while moderate-risk areas may allow development under specific resilience conditions. Low-risk areas offer more flexibility, though safety and sustainability standards still apply. The capacity to reduce risks through resilient infrastructure and risk reduction measures plays a key role in determining development restrictions, allowing for greater flexibility in urban expansion when risks can be effectively mitigated. This balance requires continuous assessment, considering the changing risk landscapes due to changing hazards, exposure and vulnerabilities, resource availability, and evolving societal expectations.



PART II:

Process and Instruments for Planning and Implementation

Part II of the handbook provides practical guidance on how to integrate hazard and risk into urban plans, explaining the phases, milestones, steps, and stakeholders of the risk-informed planning process. Chapter 3 presents the step-by-step operational framework emphasizing the phases of spatial planning where hazard and risk information are crucial for decision-making, implementation, monitoring, evaluation, and enforcement. This chapter shows how the RCP framework operates and includes some examples. Chapter 4 focuses on regulatory instruments, incentives for compliance, financial and land management tools, and strategies that cities can use for building capacity and fostering public engagement. This chapter closes with a section on monitoring and evaluation to ensure that livability and resilience goals are met and the city's vision achieved at the end of the plan's term.

Chapter 3

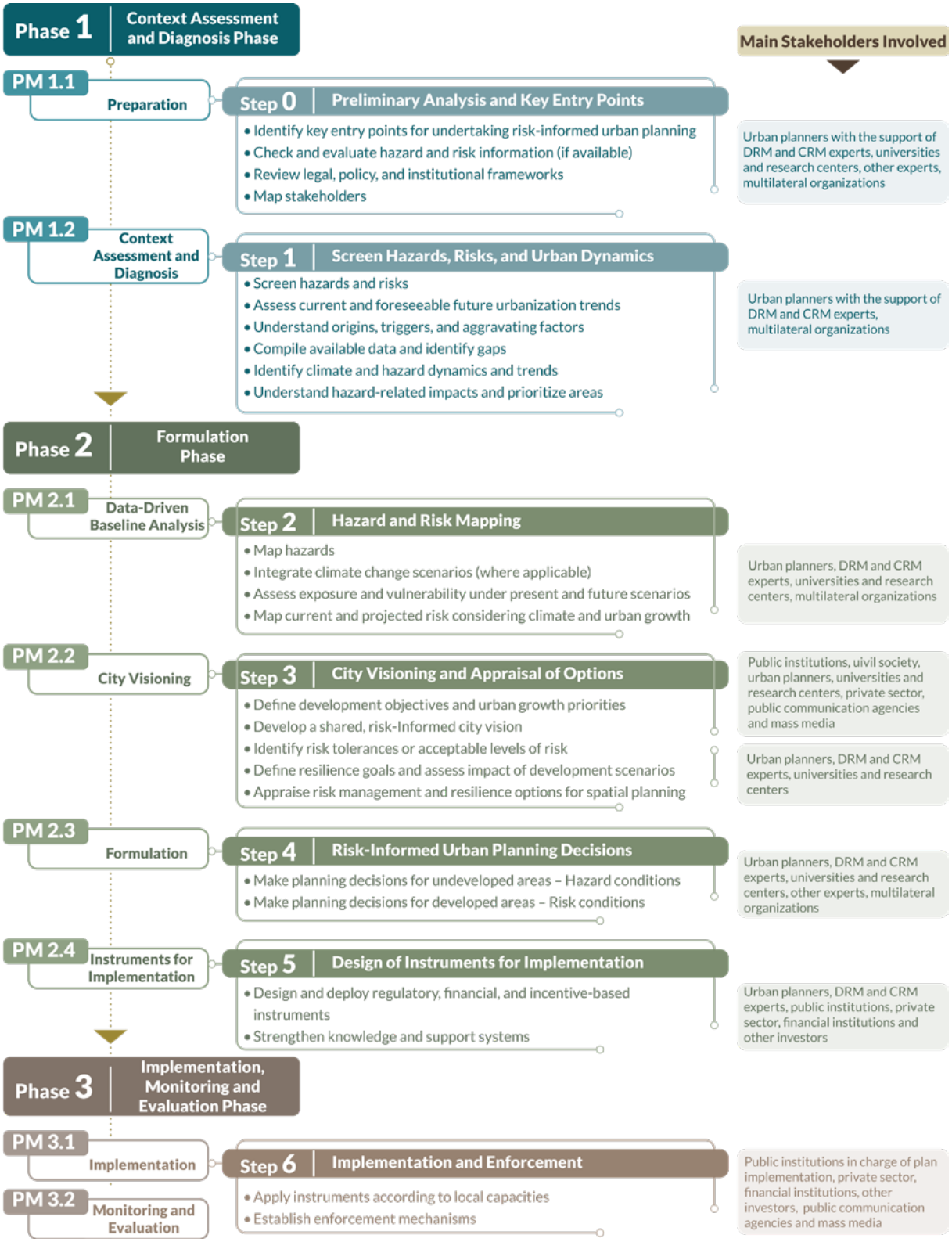
Operational Framework: Embedding Hazard and Risk Information in Urban Plans

This chapter presents the operational framework for integrating hazard and risk information into urban plans. It can be applied in diverse institutional, technical, and data contexts—from cities with limited capacity and informality to those with advanced modeling tools and strong governance systems. This flexibility ensures that all cities, regardless of starting point, can pursue risk-informed, resilient, and sustainable urban development.

The framework consists of **three phases**—context assessment and diagnosis, formulation and implementation, and monitoring and evaluation—and guides cities from preliminary risk screening to planning decisions, execution, enforcement, and monitoring. Within each phase, **planning milestones** represent key planning outputs, such as completing a baseline assessment, generating scenarios, or implementing actions. Milestones are operationalized through **steps** that provide actionable guidance on how to conduct risk assessments, make spatial planning decisions, and apply regulatory or financial instruments (figure 3.1). This structure allows cities to advance through the process in a modular and scalable way, depending on local capacities and needs.

Although presented linearly for readability, urban planning is inherently iterative and works as a cycle that involves reviews and updates. The framework accommodates tiered assessment depth—from rapid screenings to comprehensive studies—aligned with available data, resources, and decision stakes (magnitude of potential consequences), and embeds feedback loops so that monitoring and evaluation feed into earlier phases and subsequent cycles. Option appraisal is therefore tailored to stage and scale, keeping decisions adaptive, proportionate, and feasible. Option appraisal is therefore tailored to stage and scale, keeping decisions adaptive, proportionate, and feasible.

Figure 3.1: Operational Framework for Risk-informed Urban Planning



Source: Original for this publication.
Note: CRM = climate risk management; DRM = disaster risk management.

3.1 Phase 1. Context Assessment and Diagnosis

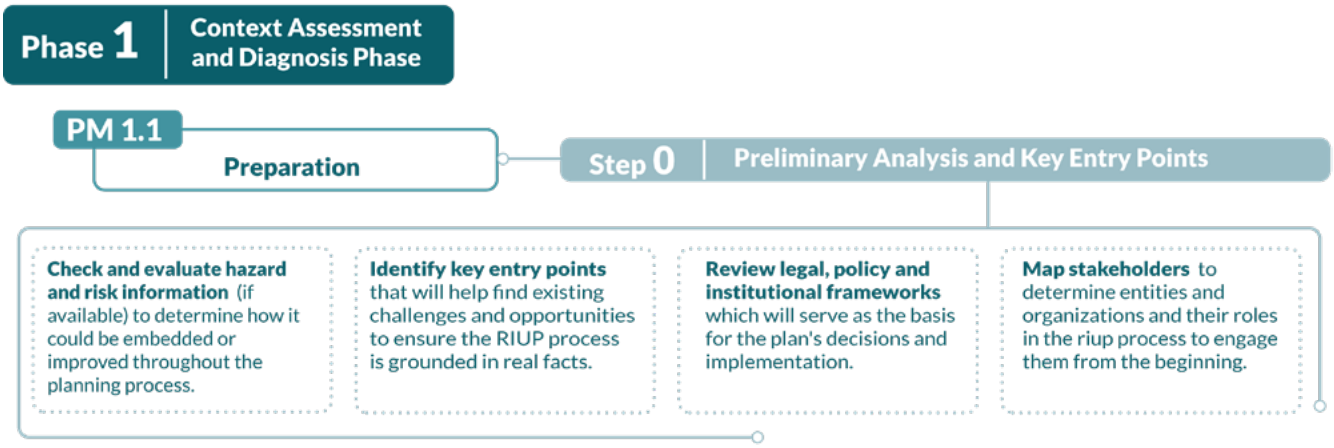
Planning Milestone 1.1: Preparation

Critical activities in this phase are: a preliminary analysis and assessment of existing and missing information; the identification of key entry points for carrying out the risk-informed urban planning process; a review of legal and institutional frameworks; and the development of an initial stakeholder map. In Step 0, planners establish the baseline information for the process, prioritize key resources and data, identify capacities that need strengthening, and define participating entities along with their roles and responsibilities.

Step 0: Preliminary Analysis and Entry Points

At this stage, city practitioners collect, check, and evaluate hazard and risk information (if available) and determine key entry points for embedding disaster risk and climate change considerations in urban planning. They should review existing institutions to determine who needs to be involved, what each party's role is, and how to keep them engaged throughout the process. Once the stakeholders' map is developed, cities have a better sense of the roles of leading agencies, who has the necessary information and data, who are supporters or detractors, and who should be involved directly or indirectly in the planning process (figure 3.2). This work can then shape a participation strategy to be implemented throughout the context assessment, diagnosis, and formulation phases.

Figure 3.2: Step 0. Preliminary Analysis and Key Entry Points



Source: Original for this publication.
Note: RIUP = risk-informed urban planning.

Step 0.1. Check and evaluate hazard and risk information (if available)

- Gather and scan existing hazard and risk information and define and rate it according to its level of usefulness and relevance.
- Determine what existing information is useful, and what needs expansion, or updating in line with the city's technical and financial capabilities.

Step 0.2. Identify key entry points

- Note coordination challenges, technical or operational constraints, and potential institutional entry points for integrating hazard and risk considerations into the urban planning process.
- Identify political and institutional opportunities, existing projects, and public and private resources that could finance the formulation and/or implementation of the urban plan.

Step 0.3. Review legal, policy, and institutional frameworks

- Take stock of relevant legal and policy instruments for spatial planning, land use, DRM, and climate adaptation.
- Identify institutions that will help coordinate, carry out, and implement the risk-informed urban plan.

Step 0.4. Map stakeholders

- Identify the key public institutions, agencies, universities and research centers involved in planning and risk management, including their mandates and roles.
- Map civil society, nongovernmental organizations, private actors, financial institutions, and other investors that should be engaged in the planning and implementation process.

Planning Milestone 1.2: Context Assessment and Diagnosis

A detailed context assessment supports accurate diagnosis of interlinked issues and the formulation of plans that reflect each city's environmental, hazard, risk, social, and economic conditions. In risk-informed urban planning, assessment may include institutional, technical, and financial capacities to determine the scope of the spatial plan to be developed. In cities where hazard and risk information is scarce or outdated, identifying hazard- and risk-prone areas and climate change impacts is key to determining which assessments are required, following step 1 guidelines.

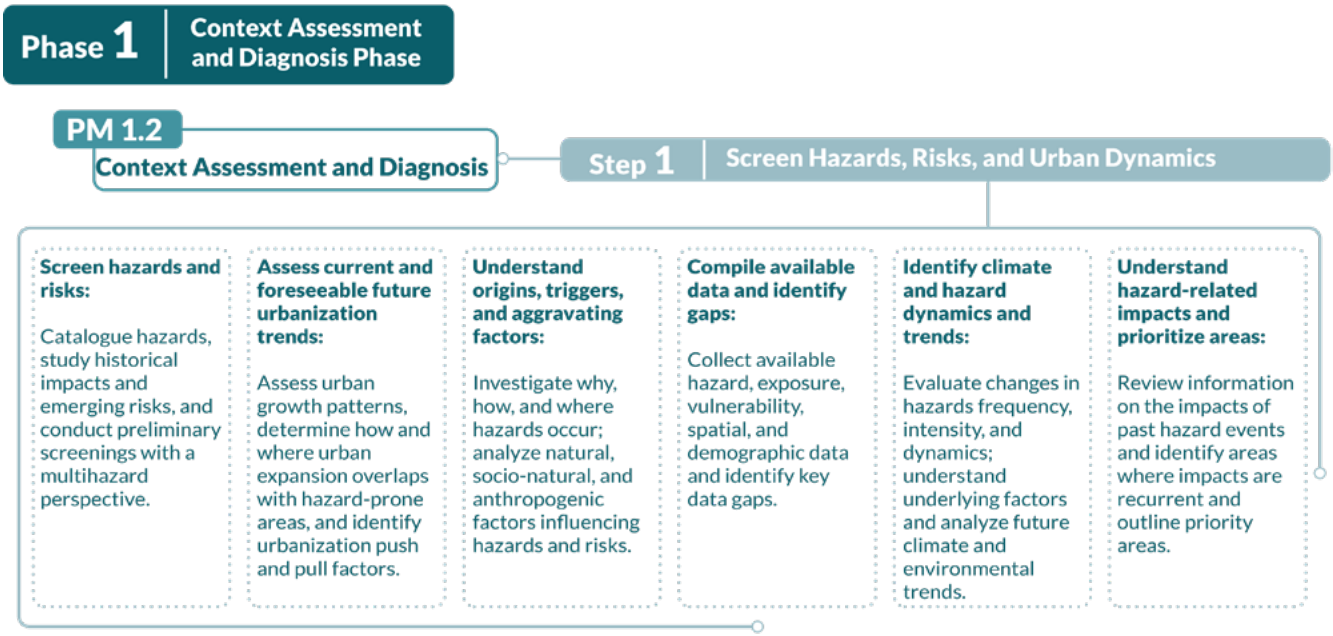
Step 1: Screen Hazards, Risks, and Urban Dynamics

Step 1 of the risk-informed urban planning process focuses on the preliminary screening and contextual diagnosis of hazards, risks, urban development dynamics, and institutional frameworks. Its objective is

to provide a rapid, qualitative understanding of the urban risk landscape and to inform the scope, scale, and priorities for more detailed assessments to be undertaken in step 2. This phase seeks to identify and characterize key hazards and multihazard dynamics and their interaction with urban growth. It highlights systemic, compounding, and emerging hazards and risks; assesses climate, environmental, and institutional trends; and defines when and why further studies and spatial analyses are required.

This rapid diagnostic is particularly valuable in data-limited contexts, helping to prioritize high-risk areas and anticipate development pressures to integrate risk considerations into urban planning processes. Step 1 is organized into six substeps that guide the rapid screening of hazards, risks, urban trends, and institutional factors (figure 3.3).

Figure 3.3: Step 1. Screen Hazards, Risks, and Urban Dynamics



Source: Original for this publication.

Step 1.1. Screen hazards and risks

- Identify the main hazard types and subtypes that may affect the city, including hydrometeorological, geophysical, climatological, and anthropogenic hazards.
- Review records of past events and existing hazard classifications to understand historical patterns and known hazard-prone areas.
- Conduct a preliminary screening of how these hazards could intersect with urban systems, providing a starting point for identifying areas of concern. Adopt a multihazard perspective by screening for both individual hazards and potential interactions or cascading effects. Where relevant, consider emerging hazards associated with climate change and urban system dependencies.

Step 1.2. Assess current and foreseeable urbanization trends

- Analyze recent urban growth patterns, including formal and informal expansion, densification, and land conversion.
- Identify areas where expansion is occurring or is planned, especially where it may encroach upon hazard-prone zones or environmentally sensitive areas.
- Note urban trends that may increase future exposure, such as infrastructure pressure or development near drainage paths, slopes, or shorelines.

Step 1.3. Understand origins, triggers, and aggravating factors

- Examine the underlying natural and anthropogenic conditions that influence hazard occurrence (for example, topography, drainage, vegetation cover, and land-use change).
- Identify urbanization-related factors that may exacerbate hazard conditions, such as deforestation, land cover change, soil sealing (by concrete and asphalt), or alterations to natural drainage and water flow patterns.
- Flag socio-natural dynamics where human activity interacts with natural systems to exacerbate risk.

Step 1.4. Compile available data and identify gaps

- Collect available hazard, exposure, and vulnerability data from official sources, past studies, and local knowledge.
- Take stock of spatial data (for example, land-use maps and elevation models), demographic information, and infrastructure inventories.
- Identify key data gaps, inconsistencies, or outdated information that limit hazard, exposure, or vulnerability assessments. Document the implications of these limitations, particularly where they may restrict detailed analysis in step 2. This helps define where additional studies or conservative planning approaches may be required to support decision-making.

Step 1.5. Identify climate and hazard dynamics and trends

- Note observed changes in the behavior of hazards over time (for example, more frequent flooding or shifting seasons).
- Summarize known or anticipated effects of climate change on hazard patterns, based on existing assessments or institutional knowledge.
- Highlight broad trends that may influence hazard intensity or timing—without conducting full projections or modeling.

Step 1.6. Understand hazard-related impacts and prioritize areas

- Review available information on the impacts of past hazard events, including damage to housing, infrastructure, livelihoods, and public services.
- Identify areas, sectors, or systems that have experienced significant or recurrent impacts, particularly those involving vulnerable populations.
- Based on this screening, outline priority areas or themes for further assessment in step 2, focusing on where hazard conditions, exposure, and potential consequences intersect. Use a combination of spatial screening, qualitative inputs, and institutional knowledge to identify areas of potential concern, even if detailed impact data are not yet available.

The context assessment establishes the foundation for a clear, evidence-based diagnosis that will guide the formulation of the urban plan. Identifying existing hazards, emerging risks, and information gaps helps define strategic priorities to reduce disaster- and climate-related risks and informs the development of risk scenarios to support resilient urban growth. Hazard and risk assessments are best understood as progressive processes that evolve from coarse to more detailed scales depending on the objectives, available data, resources, and institutional capacities. At broader scales, assessments provide an overview that helps identify priority areas, while finer scales enable detailed analysis to inform design standards, land-use regulations, and infrastructure investments. This approach reflects the principle of fit-for-purpose analysis, where the level of detail must match the decision at stake. Strategic planning requires generalized information, while zoning or project design needs detailed data.

By the end of step 1, cities should have identified priority hazards, mapped areas of potential concern, noted key data gaps, and outlined institutional constraints. Based on this information, cities can establish their own frameworks to sequence the hazard and risk assessment process, starting with general studies that match available technical and economic capacities. They can then advance to more detailed analyses in areas that require greater detail—areas with higher or more complex risk conditions, the presence of critical infrastructure, planned development, or specific policy priorities. These outputs provide the analytical and operational basis for targeted hazard and risk assessments and planning decisions explained in the following phases and steps.

3.2 Phase 2. Plan Formulation

Planning Milestone 2.1: Data-Driven Baseline Analysis

Data gathered through hazard and risk assessments, including climate change projection, are the basis for establishing inputs that become the baseline for the formulation phase. The baseline analysis helps planners make informed spatial decisions on such issues as land uses, developable or undevelopable areas, and key ecosystems and buffer areas that must be protected. The main activities needed to develop a data-driven baseline analysis covered in step 2 are as follows:

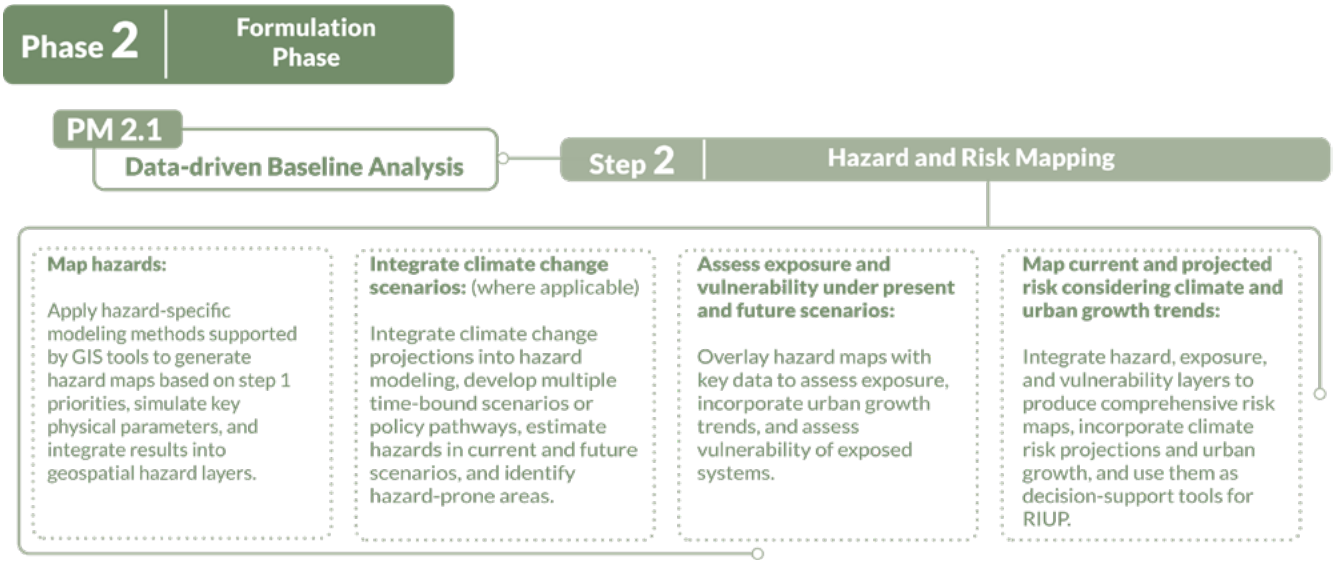
Step 2: Hazard and Risk Mapping

Step 2 focuses on generating a data-driven baseline through the development of hazard and risk maps, which form the analytical foundation for defining land-use decisions, development constraints, protection of critical ecosystems, and risk-informed zoning. The objective of this step is to move from preliminary screening (step 1) to the quantitative and spatial assessment of hazards, exposure, vulnerability, and risk, both under current and future climate and urbanization scenarios.

This step involves the application of hazard-specific modeling methods (for example, hydraulic, seismic, or slope stability models), the integration of climate change scenarios, and the combination of model outputs with exposure and vulnerability data to produce comprehensive, actionable risk maps. Emphasis should be placed on ensuring technical rigor, transparency, and fitness-for-purpose. These outputs serve as technical inputs for planners to define areas suitable or unsuitable for development, apply risk-informed restrictions or conditions, and prioritize interventions. The integration of climate change projections must include management of uncertainty, using multiple scenarios or climate models when feasible. Urban growth projections should be treated similarly. Scenario-based approaches (for example, compact growth versus peripheral expansion) can be overlaid on hazard maps to visualize how exposure might evolve over time.

Even without detailed models or data, planners can use other information to create basic hazard and risk maps. A precautionary approach is key: if formal data are missing, proxies like the worst observed events or geomorphological clues can be used to delineate susceptibility zones. Preliminary maps guide planners to apply caution in these zones and inform the subsequent phases of the planning process. Step 2 is illustrated in figure 3.4.

Figure 3.4: Step 2. Hazard and Risk Mapping



Source: Original for this publication.
Note: GIS = Geographic Information System; RIUP = risk-informed urban planning.

Step 2.1. Map hazards

- Apply hazard-specific modeling methods (for example, hydraulic, seismic, or geotechnical models), supported by GIS tools, to generate multihazard maps for priority hazards identified in step 1.
- Simulate key physical parameters (for example, flood depth and velocity or ground motion for seismic risk) across different return periods or intensity levels.
- Integrate modeling results into geospatial hazard layers that delineate the extent, severity, and probability of hazard occurrence, forming the analytical base for exposure and risk assessments.

Step 2.2. Integrate climate change scenarios (where applicable)

- Integrate climate change projections into hazard modeling to assess how hazard frequency, intensity, and spatial extent may shift under future conditions.
- Develop multiple time-bound scenarios (for example, near-term, mid-century, long-term) or policy pathways to reflect uncertainty and range of possible outcomes.
- Estimate hazards under both current and future scenarios, considering how climate change might alter hazard frequency and intensity, and identify both current and future hazard-prone areas and characteristics under climate change to support decision-making.

Step 2.3. Assess exposure and vulnerability under present and future scenarios

- Overlay hazard maps with data on population, building footprints, infrastructure, critical facilities, and economic assets to assess exposure.
- Incorporate urban growth trends from step 1.2 to understand how exposure may evolve over time.
- Assess vulnerability of exposed systems, using a combination of structural fragility, human vulnerability, and socioeconomic indicators.

Step 2.4. Map current and projected risk considering climate and urban growth

- Integrate hazard, exposure, and vulnerability layers to produce comprehensive risk maps for current and future scenarios.
- Incorporate both climate change projections and projected urban growth to visualize how risk patterns may change over time.
- Use these multihazard and risk maps as decision-supports to inform risk-sensitive spatial planning, zoning regulations, land use, infrastructure investments, and resilience-building measures.

Hazard classification and risk level classification serve as foundational inputs for risk-informed planning in undeveloped and developed areas, respectively. As noted above, hazard and risk categories may vary between countries and cities, reflecting differing levels of risk tolerance and acceptability. This classification approach should align with the city's vision and acceptable risk levels (step 3.2) and should not be treated as an automated or generic process carried out without careful consideration.

Planning Milestone 2.2: City Visioning

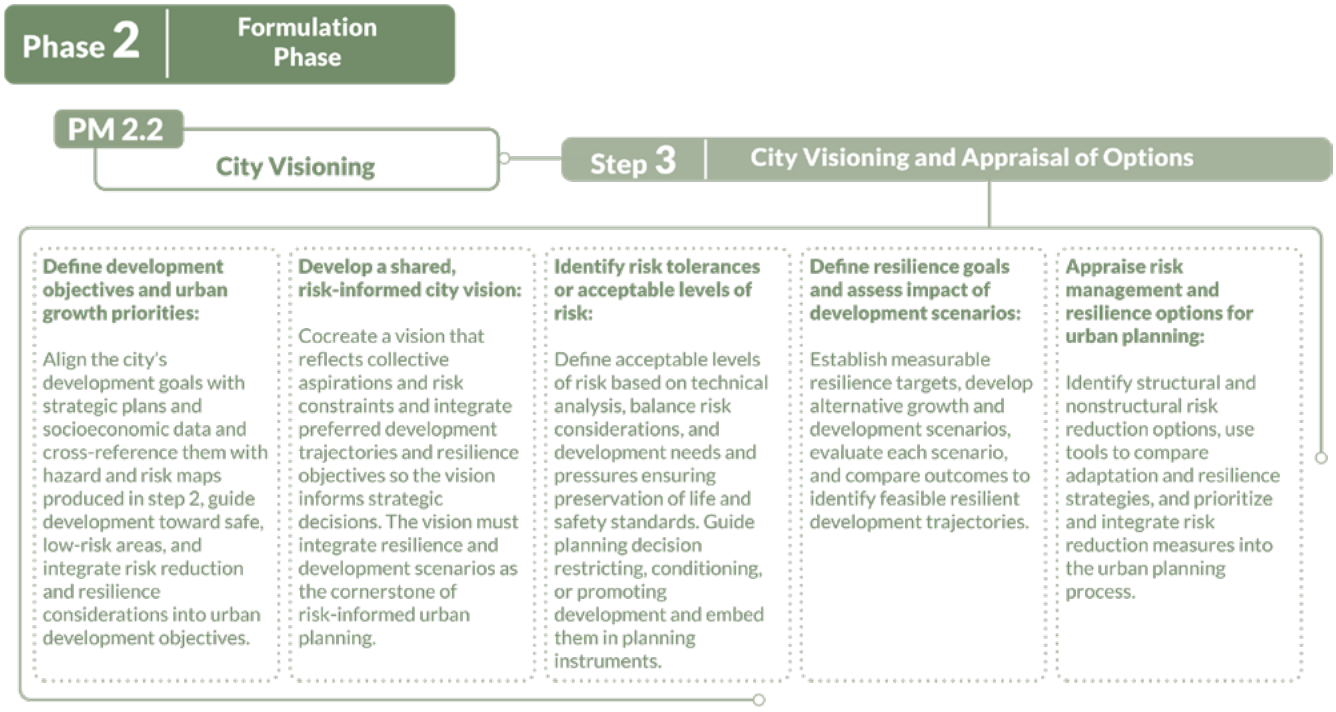
Once livability and resilience goals are established—grounded in comprehensive data analysis—cities can define their long-term vision, which will guide strategies, programs, projects, and actions over the life of the risk-informed urban plan. At this stage, cities should evaluate the potential impacts of urban development scenarios and risk management strategies, including city growth, environment, and infrastructure, alongside social, and economic development policies and strategies.

Step 3: City Visioning and Appraisal of Options

This step focuses on translating technical risk and climate data into strategic vision and actionable development pathways. Based on the analytical baselines developed in steps 1 and 2, this step enables cities to align their development objectives with resilience goals and acceptable levels of risk. It involves defining urban growth priorities, establishing risk thresholds, and comparing alternative development and risk management scenarios. These elements come together in a shared vision that guides long-term, risk-informed decision-making.

This step emphasizes both technical appraisal and inclusive engagement. Incorporating five linked substeps, it supports city leaders and planners in evaluating trade-offs between development patterns, investment needs, and resilience outcomes (figure 3.5). It also enables the cocreation of a vision that reflects collective aspirations while addressing the city's risk context. Importantly, this step ensures that the outputs—resilience targets, acceptable risk and thresholds, preferred development scenarios, and the shared vision—serve as a direct foundation for the spatial planning decisions, regulations, and instruments formulated in step 4.

Figure 3.5: Step 3: City Visioning and Appraisal of Options



Source: Original for this publication.

Step 3.1 Define development objectives and urban growth priorities

- Align the city's development goals with broader strategic plans and socioeconomic data and cross-reference development goals with the hazard and risk maps produced in step 2, ensuring they reflect the city's evolving hazard and risk profile.
- Define spatial growth and strategic priorities based on land suitability, infrastructure capacity, and exposure to hazards, guiding expansion toward safe, low-risk areas.
- Ensure that risk reduction and resilience considerations are fully integrated into urban development objectives, guiding where and how growth should occur.

Step 3.2 Identify risk tolerances or acceptable levels of risk

- Define acceptable levels of risk based on technical analysis and accounting for social, economic, political,

and cultural context, balancing risk considerations and development needs and pressures, while ensuring preservation of life and minimum safety standards.

- Use these thresholds to guide planning decisions restricting, conditioning, or promoting development and embed them into planning instruments, with provisions for periodic review as risk conditions and societal expectations evolve.

Step 3.3 Define resilience goals and assess impact of development scenarios

- Establish measurable resilience targets that are aligned with urban development and risk tolerance objectives (for example, reduced exposure and continuity of lifeline systems).
- Develop alternative growth and development scenarios (for example, compact, sprawling, or infrastructure-led) reflecting demographic, spatial, and economic assumptions.
- Evaluate the implications of each scenario on resilience and sustainability, identifying trade-offs and synergies to support informed decision-making.

Step 3.4 Appraise risk management and resilience options for spatial planning

- Identify structural and nonstructural risk reduction measures suitable for different hazards, sectors, and spatial scales.
- Use tools such as cost-benefit analysis, multicriteria evaluation, and feasibility assessments to compare adaptation and resilience strategies.
- Prioritize and integrate risk reduction measures into the urban planning process, aligning interventions with long-term development objectives.

Step 3.5 Develop a shared, risk-informed city vision

- Facilitate inclusive and participatory processes to cocreate a long-term vision for the city that reflects community needs, resilience goals, and risk constraints.
- Integrate preferred development trajectories and resilience objectives so the vision is clear, actionable, and informs strategic planning, investment, and regulatory decisions.
- Develop a compelling, shared vision that integrates resilience targets and preferred development scenarios as the cornerstone of risk-informed urban planning. This vision should guide long-term decision-making, ensuring that urban growth becomes a driver of resilience rather than a source of risk. This risk-informed city vision should directly inform urban planning decisions (step 4).

Disaster risk reduction should be embedded as a core consideration in the city's vision and strategic planning, even in contexts with limited data or capacity constraints. Under uncertainty, planners can still evaluate development options using hazard scenarios to inform resilient choices. Where detailed models

are unavailable, screening-level assessments can be used to test how different development pathways might perform. Stress-testing the vision against a range of potential risks helps identify robust strategies that hold up across future uncertainties. In these settings, adopting no-regrets strategies and precautionary planning is especially valuable. These include steering growth away from known or suspected hazard zones, investing in green (land-based) and blue (water-based) infrastructure, and improving service provision in ways that also strengthen resilience. Such actions deliver near-term benefits while safeguarding against future risks.

Planning Milestone 2.3: Formulation Document

In the formulation phase, cities define their urban development model, zoning and land-use regulations, and the strategies and budget needed to implement the plan. As explained below, the RCP framework must be applied to ensure that the urban plan is risk informed.

Step 4: Risk-informed Urban Planning Decisions

Step 4 focuses on translating hazard and risk assessment results into spatial planning decisions that guide the use, intensity, and regulatory control of land development. This includes defining whether development should be restricted, conditioned, or promoted, based on a clear understanding of the hazard levels, existing risk, and acceptable thresholds established in step 3. This step uses different approaches to undeveloped and already developed areas. In undeveloped areas, the emphasis is on avoiding the creation of new risks by steering development away from high-hazard zones, ensuring new developments do not exacerbate hazard and risk conditions, and applying conservative safety standards, even in low-hazard zones. In developed areas, the focus shifts to managing and reducing existing risks through structural and nonstructural measures, planning conditions, and retrofitting. The example of the Ruzizi catchment in Bujumbura, Burundi (box 3.1), shows how hazard and risk modeling scenarios enable cities to define their development model and determine which measures, projects and development controls should be included in the urban plan to increase resilience.

Box 3.1:

Flood Hazard and Risk Modeling and Strategic Spatial Planning in Bujumbura, Burundi

Bujumbura, the former capital and the most populated area of Burundi (61 percent of the total urban population), is bordered by Lake Tanganyika, and several rivers and streams flow down the hills from the east toward the lake. This topography, amid increasing extreme rainfall events, and unplanned urbanization, has exacerbated pluvial (surface water, rainfall-driven) and fluvial (river) flooding in the city (Photo B3.1.1). In addition, the lake level has steadily increased over the past decade, resulting in severe flooding of the communities and infrastructure along the lakefront, particularly in the rural province of Gatumba located within the Ruzizi River catchment on the north side.

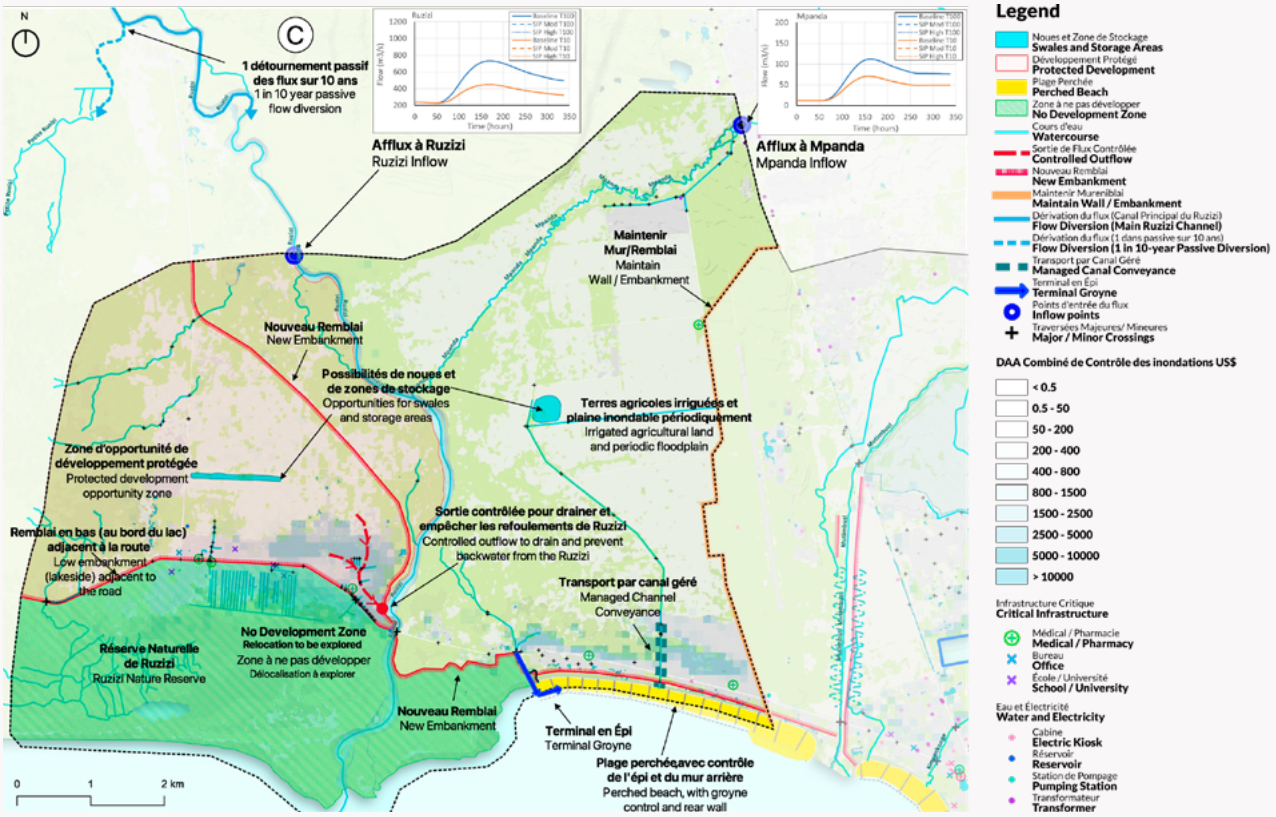
Photo B3.1.1: Massive Flooding in Gatumba in 2020



Source: © Prinsloo / UNICEF

To enhance urban resilience, the World Bank supported a flood-risk assessment that relied on risk-based analytics to evaluate existing and future risk scenarios at the catchment level. This formed the basis of the strategic investments proposed to reduce the impact of floods in the area. The inclusion of climate change (hazard model) and possible land-use variations based on projections of population growth (risk model) facilitated the simulation of two scenarios. The mid-future scenario showed that the total expected annual damage (EAD) could reach ~US$63 million and the average annual number of people at risk would be ~157,000, while the upper-future scenario (2050) revealed that EAD would extend to ~US$85 million and the average annual number of people at risk would be ~206,000. Once hazard assessments and scenarios were completed, the strategic investment plan localized a combination of non-infrastructural and infrastructural flood mitigation strategies to optimize flood hazard management and minimize exposure and vulnerability at the subcatchment level, leading to a measurable reduction in risk (figure B3.1.1).

Figure B3.1.1: Hazard and Risk Modeling and Strategic Plan for Flood Risk Management in Ruzizi Catchment



Source: JBA Consulting, Landell Mills, and Sayers and Partners 2023.

This case illustrates how comprehensive hazard assessments (step 2 of the operational framework), are translated into spatial planning and nature-based solutions (NBS) modeling (step 4) to regulate urban growth, establish development controls, and guide investments to increase livability and resilience.

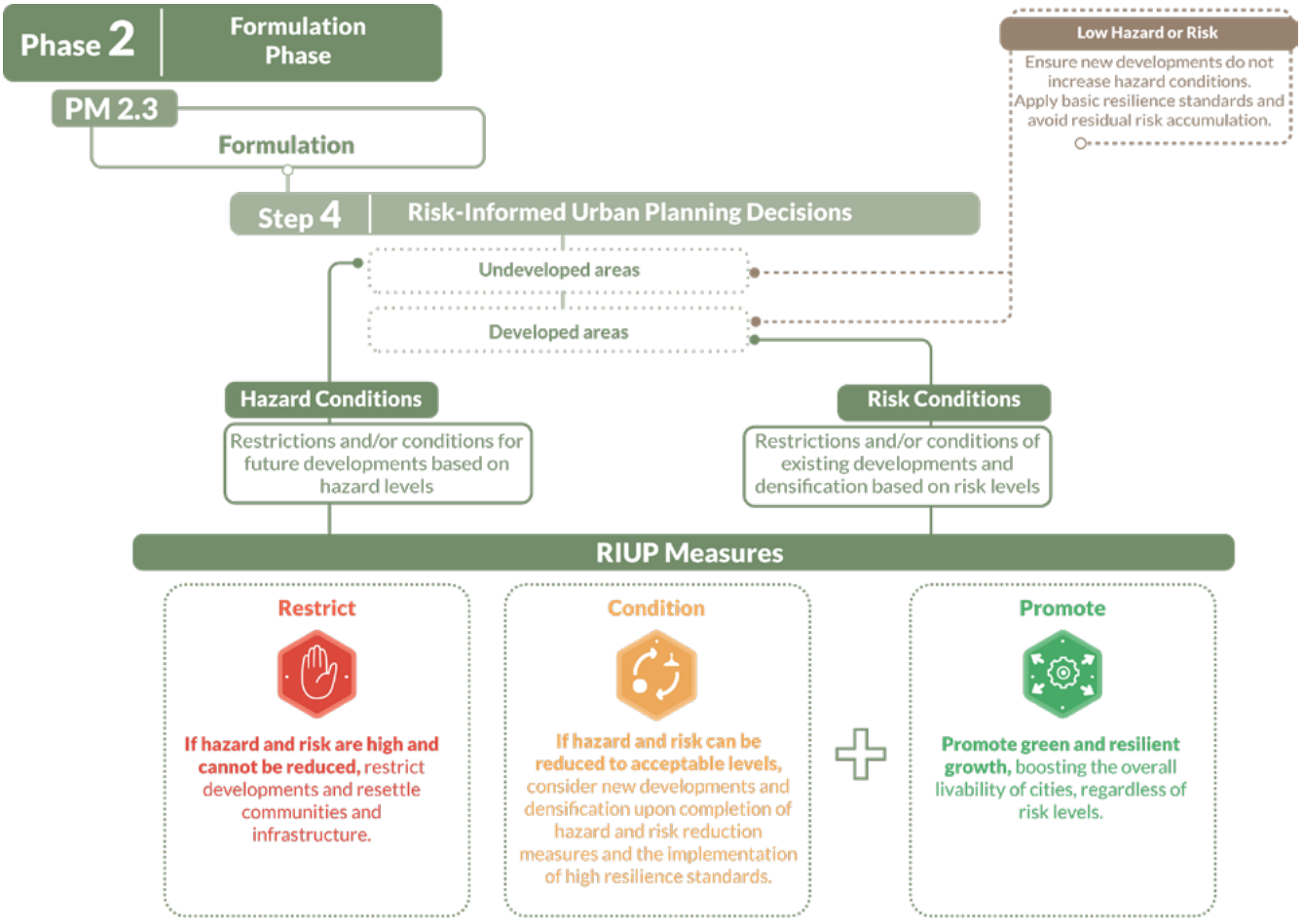
Urban planning decisions are operationalized through the RCP framework, which enables cities to apply differentiated and context-sensitive measures based on risk severity, risk tolerance, resilience priorities, and land-use function. These decisions should be integrated into risk-informed land-use and zoning plans, development controls, and building regulations to ensure enforceability. Each zone or land-use category should reflect the findings from steps 1 to 3 and be matched with an appropriate set of planning restrictions or incentives.

During the planning decision-making process, cities should apply a precautionary and adaptive approach, particularly in low-data or low-capacity contexts. In line with the safety-first principle and the imperative to avoid creating new risk, development in areas suspected to be hazard-prone should be restricted unless

detailed assessments demonstrate that risk is acceptable and manageable. This first level of conditionality allows planning to proceed under uncertainty while preventing irreversible decisions that could increase exposure or vulnerability. Zoning and land-use regulations can establish provisional restrictions or conditions for high-sensitivity uses—such as critical infrastructure, essential services, or dense development—pending further studies. Conditional permitting frameworks enable development to proceed only if specific risk reduction measures are implemented and link final approval to compliance with technical standards. Phased development controls offer an additional safeguard, allowing multistage projects to advance only when updated assessments confirm that risk remains within acceptable thresholds.

The presence of low hazard or low risk does not imply that no action is needed. Even in these areas, residual risks may persist due to climate change, system failures, or planning uncertainty. Therefore, contingency planning, design standards, and adaptive measures remain critical to avoid future risk accumulation. Risk-informed urban planning decisions made during step 4 are operationalized through the RCP framework, described in figure 3.6.

Figure 3.6: Step 4. Risk-informed Urban Planning Decisions – RCP framework



Source: Original for this publication.

Step 4.1. Planning Decisions for Undeveloped Areas – Hazard Conditions

- Use hazard assessment results to classify undeveloped areas into zones based on current and future hazard levels.
- In areas with high or very high hazard levels that cannot be reduced, restrict new development and consider nature-based buffers or protective zoning.
- In areas with relevant hazard levels, allow development only if risk can be reduced to acceptable levels through mitigation and resilience standards.
- In low-hazard areas, ensure that new developments do not increase hazard and risk— apply basic resilience and contingency measures, recognizing that even low-frequency events may result in impacts.
- Ensure that all planning decisions for undeveloped land minimize future exposure and avoid creating new hazards and risks under changing climate and urban dynamics.

Step 4.2. Planning Decisions for Developed Areas – Risk Conditions

- Use risk assessment results to classify developed areas by current and projected risk levels, considering hazard exposure, vulnerability, and asset concentration.
- In high-risk zones, consider risk reduction measures including density control, infrastructure upgrades, retrofitting, or—in extreme cases—relocation.
- In moderate-risk areas, condition continued occupation and future densification on the implementation of risk reduction and resilience measures and compliance with safety standards.
- In low-risk areas, maintain risk awareness by integrating contingency planning, early warning coverage, and resilient infrastructure standards.
- Ensure that all planning decisions minimize future exposure and avoid creating new hazards and risks under changing climate and urban dynamics.
- Integrate a long-term perspective that considers urban transformation, climate change, and socioeconomic shifts.

Applying the RCP Framework

The RCP framework offers a structured way to translate hazard and risk data into spatial regulations and planning instruments:

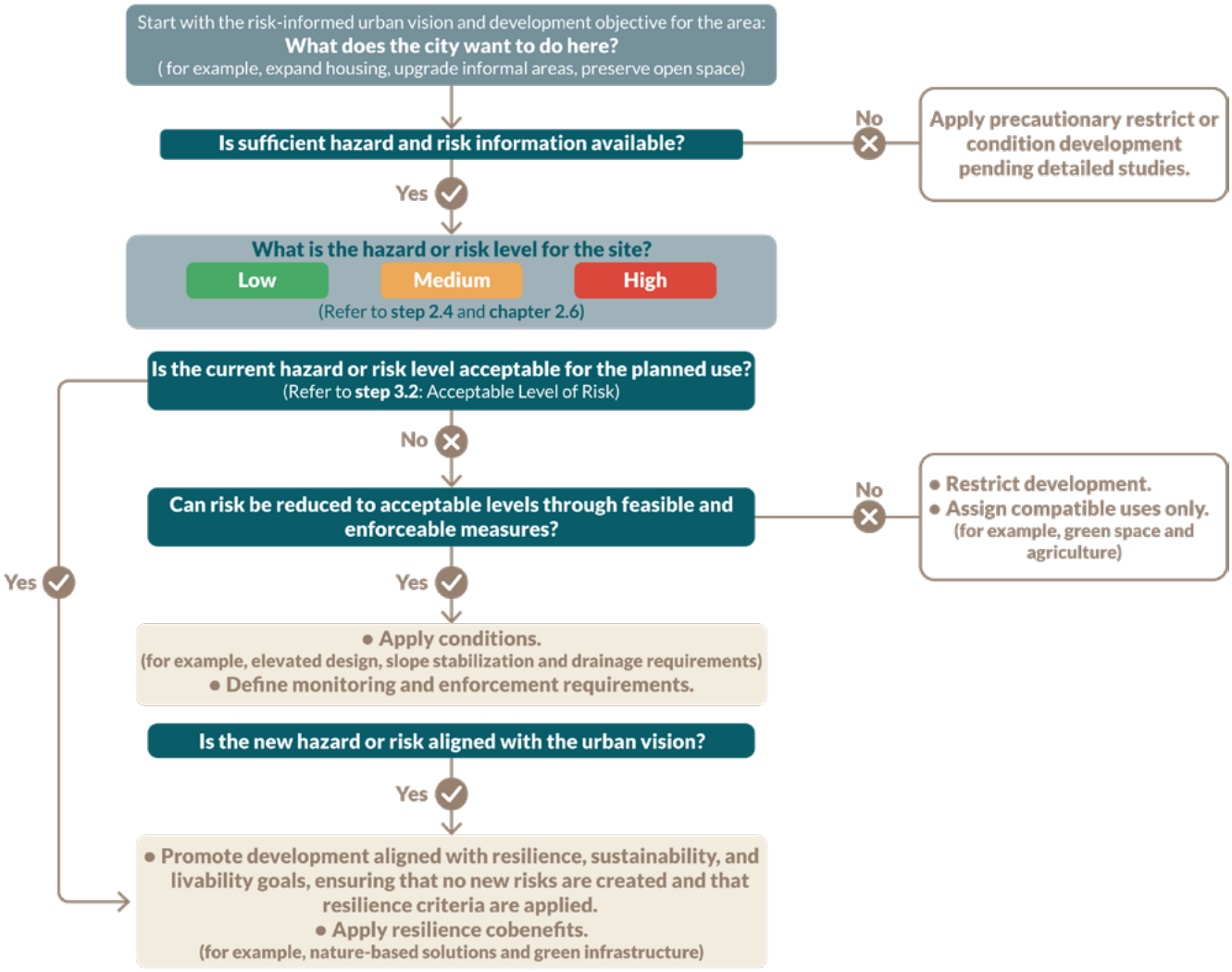
- **Restrict:** This decision is applied where hazard and risk are high and cannot be reduced to acceptable levels. Development is prohibited or strictly limited. In developed areas, relocation or land-use conversion may be considered. This should reflect the risk tolerance thresholds defined in step 3.2 and be embedded in zoning maps as a no-build or exclusion zone.

- **Condition:** This is used where hazard or risk exists but can be reduced to acceptable levels through specific measures. Development or densification is allowed if hazard or risk reduction measures are implemented, developments meet resilient design standards, or other resilience conditions are met.
- **Promote:** This decision is applied in areas with low hazard and low risk to encourage development and densification aligned with resilience, sustainability, and livability goals. More broadly, promotion strategies—such as NBS, sustainable drainage systems, bioclimatic design, and energy efficiency—should be applied across all areas regardless of their hazard and risk levels to enhance livability, reduce emissions, and address residual risks.

Risk-informed urban planning may involve difficult trade-offs, particularly when existing informal settlements or underserved areas are located in high-risk zones. Planners should ensure that restrictions or relocation policies are accompanied by inclusive engagement, compensation, and viable alternatives. Community upgrading, phased interventions, and access to basic services can help reduce risk while preserving rights and livelihoods.

This approach enables cities to apply differentiated, context-sensitive measures that reflect hazard levels, risk tolerances, and resilience priorities, ensuring that spatial planning actively contributes to hazard and risk reduction and prevention, alongside climate change adaptation (CCA). Step 4 translates the city's vision (step 3), resilience targets, and risk tolerance thresholds into spatial planning decisions—specifically, where development should be restricted, conditioned, or promoted. This step also sets the stages for implementation (figure 3.7) that are explained in practical terms in the case presented in box 3.2.

Figure 3.7: Step-by-Step Decision Process for the RCP Framework



Source: Original for this publication.

Box 3.2:

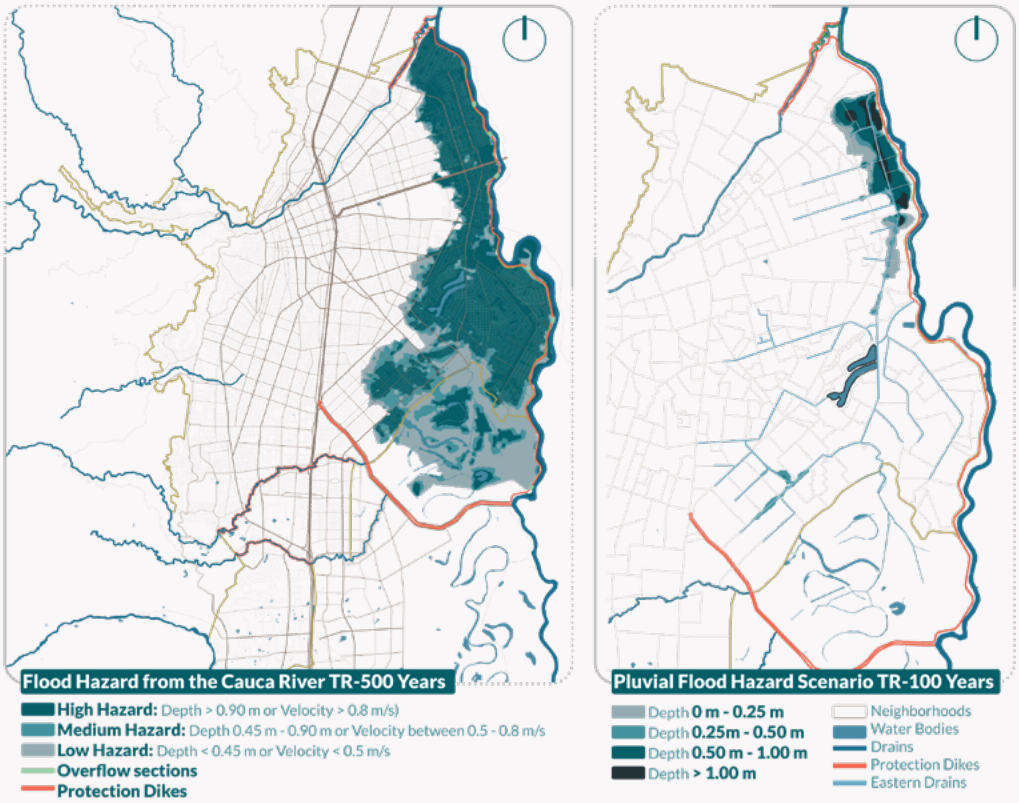
Urban Planning Conditioned by Acceptable Risk in Cali, Colombia

In the late 1950s, the city of **Cali, Colombia,** built a 17-kilometer dike along the Cauca River and complementary pluvial (surface water) drainage works to protect farmland from flooding. However, once the land was drained, unplanned settlements started to emerge, and the city gradually expanded social housing projects into that area until it was completely developed. The low availability of affordable land and the massive influx of internally displaced persons between 1980 and 2010 due to armed conflict led to a gradual informal occupation of the crest (crown) of the dike by nearly 8,000 vulnerable households, compromising its structural stability. During the 2010/11 La Niña event, the

inadequacy of the urban drainage system that discharges into the Cauca River resulted in losses exceeding US$28 million (Corporación OSSO et al. 2013). Even more seriously, the dike was almost overtopped, threatening families occupying the crown, roughly 900,000 people living in the nearby area, and critical infrastructure such as Cali's water purification and wastewater treatment plants. Comprehensive studies conducted subsequently revealed significant fluvial and pluvial flood risks.

- **Fluvial risk:** Simulations for dike failure for TR-100, TR-250, and TR-500 year events (TR = return period) showed that a TR-500 event could inundate 3,730 ha with average water depths of 1.86 m, requiring up to 4.5 months for water evacuation (figure B3.2.1). The dike's stability was compromised by added loads (debris and informal constructions), geometric alterations, and natural processes (erosion and paleodrainage crossings: ancient channels beneath the dike that form weak, permeable zones).
- **Pluvial risk:** The urban drainage system was considered insufficient for events with return periods greater than 10 years. For a TR-100 rainfall event, overflows would affect historically flood-prone neighborhoods, with inundation durations of several hours and significant direct losses (figure B3.2.1).

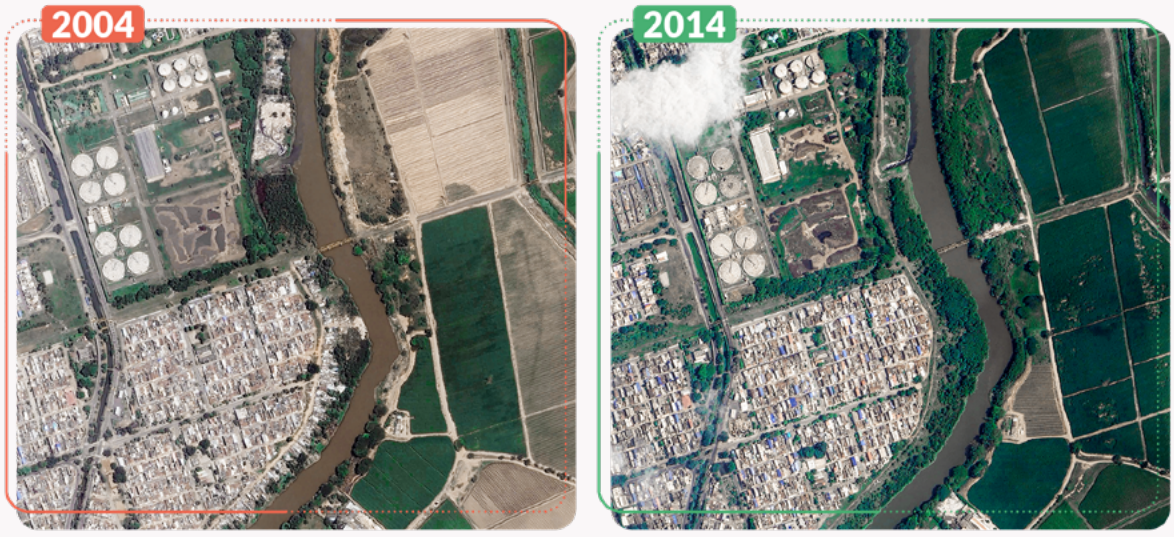
Figure B3.2.1: Fluvial and Pluvial Hazard Maps



Source: Redrawn from Concejo de Santiago de Cali 2014 (fluvial model) and Corporación OSSO 2013 (pluvial model).
Note: TR means return period.

Given the magnitude of the risk identified, the Colombian Climate Change Adaptation Fund and the municipality of Cali agreed to launch the Plan Jarillón de Cali Macroproject. The assessments conducted to appraise risk reduction measures demonstrated that upgrading the dike's protection level from TR-100 to TR-500 was the most cost-effective option. While the incremental investment was marginal (3–5 percent), the avoided losses increased dramatically, raising the benefit-cost ratio to approximately 1:34. This finding highlighted the need to redefine acceptable risk thresholds in an urbanized setting. Protection levels that were once sufficient to safeguard farmland at TR-100 had become inadequate to protect the area's residents and critical infrastructure and assets valued at billions of dollars. Option appraisal combined measures of different types, such as reinforcement of the flood protection structure and resettlement of families living on the dike (where residual risk remained unacceptably high even after infrastructure works). Investments of nearly US$250,000 included: raising and reinforcing the dike; seismic and geotechnical reinforcement of critical infrastructure; construction of new regulation ponds and channels; recovery of existing lagoons; increasing canal freeboard; and resettlement of nearly 8,000 households occupying the dike, berms, and drainage infrastructure, ensuring settlers' rights to decent housing through social engagement strategies (photo B3.2.1).

Figure B3.2.1: Section of the Dike Before and After the Plan's Implementation



Source: Google, © Maxar Technologies, 2014 and Google, © Airbus, 2025.

Flood-risk scenarios and risk reduction projects from the Plan Jarillón de Cali were included in the city's spatial plan adopted in 2014. Cobenefits from risk reduction investments were also recognized, including opportunities to enhance urban quality in the east side through the creation of an ecological corridor along the dike, restoration of biodiversity on the riverbanks. Expanded green coverage now promotes water retention and slow release rather than rapid water evacuation, while simultaneously reducing the UHI effect. Ensuring strict monitoring and enforcement to prevent the emergence of new settlements on the dike and the improvement of drainage channels has also been essential to safeguarding infrastructure integrity.

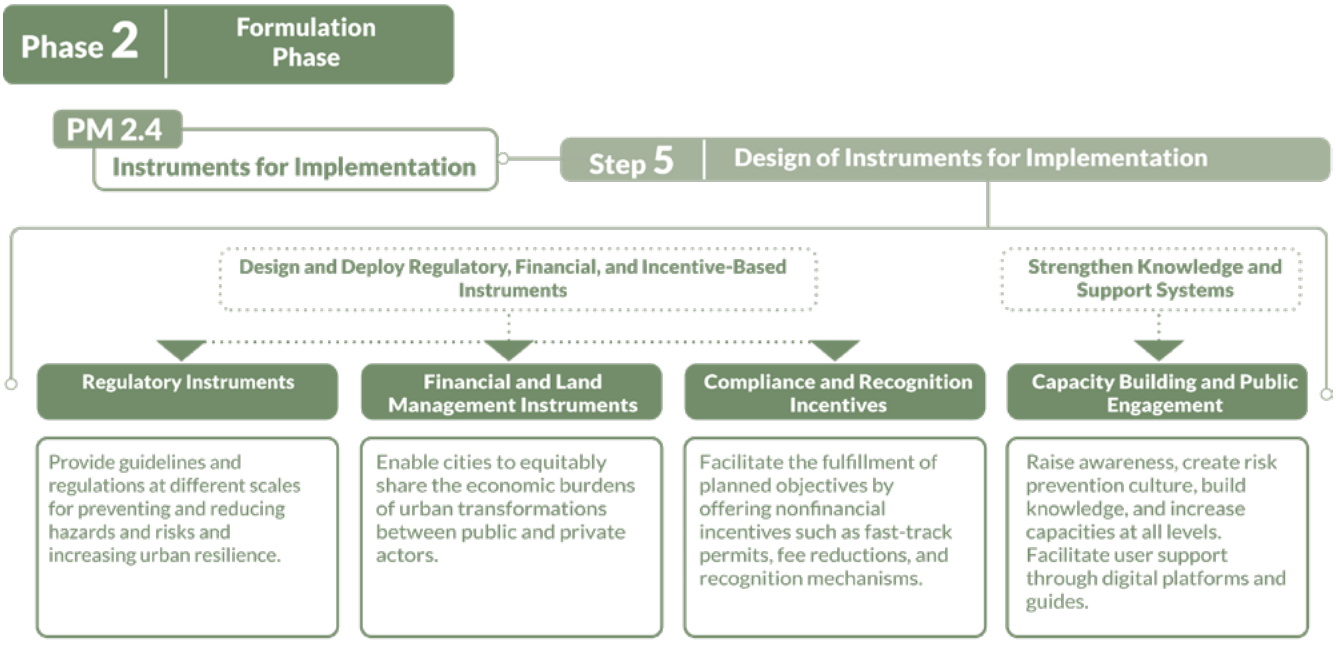
Planning Milestone 2.4: Instruments for Implementation

After risk-informed decisions are made, the next step is to define the instruments that will enable cities to move from planning to implementation. As explained in the next section, these instruments ensure that the measures adopted under the RCP framework are supported by practical tools and enforcement mechanisms. Hazard-specific guidance and examples on how to apply the RCP framework for hydrometeorological, geohazard, and climatological hazards are provided in chapters 5 to 7.

Step 5: Design of Instruments for Implementation

This step focuses on identifying and deploying the instruments required to operationalize the urban development strategies, risk prevention and reduction measures, and resilience goals defined in the formulation phase. Instruments can be regulatory, financial, and nonfinancial, and include knowledge and support systems. Step 5 comprises two components (figure 3.8). Chapter 4 presents detailed information on how each of these instruments operates according to geographic scales and cities' technical and financial capacities.

Figure 3.8: Step 5. Risk-informed Urban Planning Instruments



Source: Original for this publication.

Step 5.1. Design and deploy regulatory, financial, and incentive-based instruments

- **Regulatory instruments** define land use, zoning, and construction requirements that reflect hazard levels, acceptable risk thresholds, and resilience standards. These may include land-use restrictions, building code provisions, development density limits, or mandatory green infrastructure measures.

- **Financial instruments** enable cities to mobilize and allocate resources for resilience, while equitably distributing the costs and benefits of urban transformation. These may include land value capture mechanisms (for example, betterment levies and development charges, in essence: windfall taxes), tax incentives, public-private partnerships (PPPs), green bonds, or subsidies for sustainable construction. Financial tools can also support retrofitting and risk reduction in vulnerable areas.
- **Compliance and recognition incentives** facilitate the attainment of planning and resilience objectives by encouraging voluntary compliance through nonfinancial incentives. These can include fast-track permitting for resilient buildings, fee reductions, public recognition programs, or development bonuses for incorporating risk reduction measures.

Step 5.2. Strengthen knowledge and support systems

- Cities strengthen the implementation of regulatory, financial, and incentive-based instruments by improving institutional capacities, raising awareness, and facilitating user adoption. This effort includes training programs, technical guidance, and digital platforms that help planners, developers, and communities understand and comply with risk-informed planning tools. It also promotes collaboration across sectors and levels of government, enabling the effective application and enforcement of risk-informed urban plans.

To give effect to the city vision (step 3) and implement the RCP measures (step 4), these regulatory, financial, and incentive-based instruments provide a framework to enforce development controls, guide investments, raise awareness, and engage stakeholders across sectors.

3.3 Phase 3. Implementation, Monitoring, and Evaluation

Planning Milestone 3.1: Implementation

The implementation phase turns plans into action to realize the long-term vision. For planning strategies and regulations to achieve safer, more resilient cities, local authorities must be equipped with the necessary institutional capacity, legal backing, and technical resources to implement and enforce them effectively.

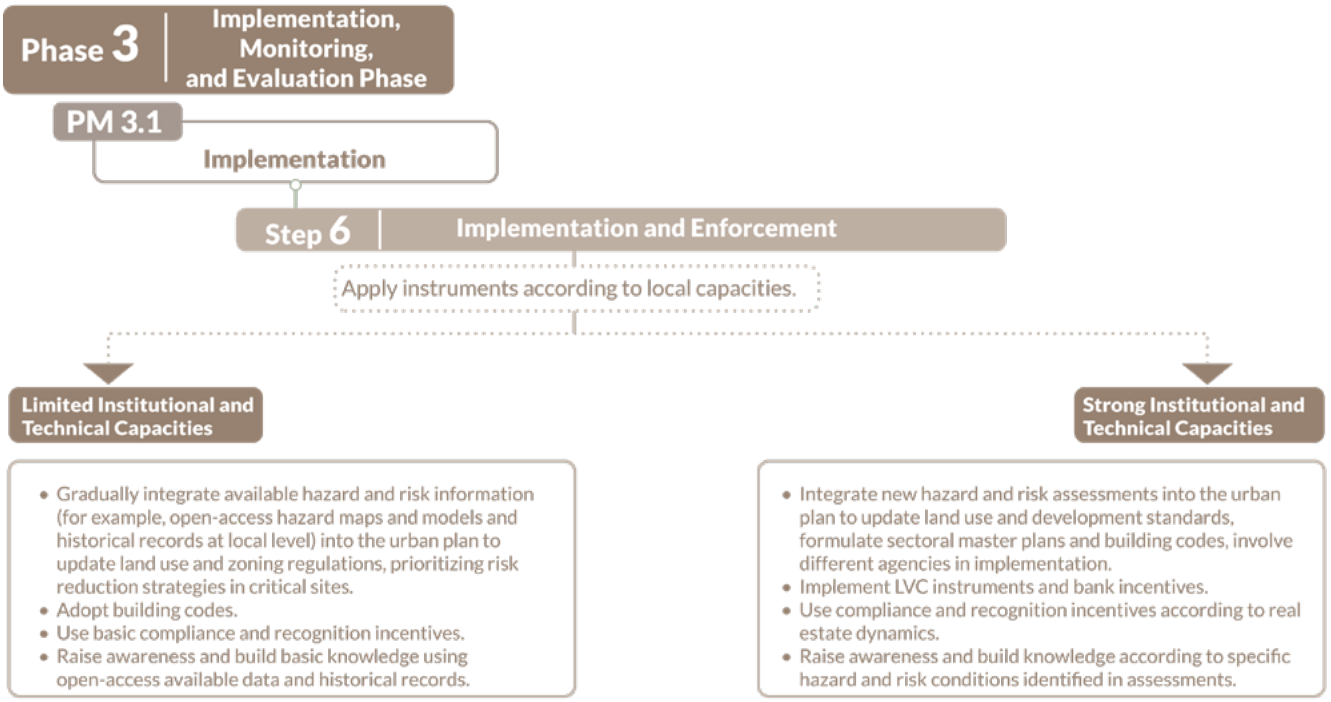
Step 6: Implementation and Enforcement

Step 6 moves from planning to execution by operationalizing the instruments developed in earlier phases. For risk-informed planning to result in meaningful change on the ground, cities must apply regulatory, financial, and support instruments in ways that are realistic, phased, and responsive to local capacities. Effective implementation depends not only on the availability of instruments, but also on institutional

readiness, legal authority, and operational coordination. In many cases, limitations in staffing, data, or enforcement capacity can slow progress. To support practical implementation, cities should develop a phased action plan or timeline outlining short-, medium-, and long-term priorities. This allows for quick wins (for example, enforcing no-build zones in high-risk areas) while preparing for using more complex instruments as capacity improves.

Cities are encouraged to conduct a self-assessment of their implementation and enforcement capacities early in the process. This helps determine whether to adopt simplified frameworks—focused on a few enforceable rules—or to proceed with more advanced tools and systems. Where institutional capacity is limited, cities may leverage community-based monitoring or coordination with higher levels of government. For cities with stronger capacities, digital permitting platforms, dynamic zoning enforcement, land value capture (LVC) tools, and incentives can be scaled accordingly. Therefore, step 6 emphasizes the importance of adaptation to local context, ensuring that all cities—regardless of capacity—can take steps toward risk reduction and resilience. This step also highlights the need for enforcement systems to ensure compliance with risk-informed regulations, including development approvals, inspections, penalties for violations, and mechanisms to regularly update standards in line with evolving risks. A coordinated enforcement strategy should be developed alongside the plan. This should detail institutional roles and responsibilities, required training for enforcement officers, inspection schedules, procedures for sanctioning noncompliance, and mechanisms for reporting and redress. Crucially, risk-informed regulations will achieve impact only if political will is paired with sustained investment. Step 6 is organized around the principle of applying instruments according to local capacities, as illustrated in figure 3.9.

Figure 3.9: Step 6. Implementation of Instruments According to Local Capacities



Source: Original for this publication.
Note: LVC = land value capture.

Step 6.1. Apply instruments according to local capacities

Cities with limited institutional and technical capacities

- Use available data (for example existing studies, historical records, and open-access hazard and risk datasets) to inform zoning and land-use regulations.
- Prioritize critical areas for basic risk reduction and building code enforcement.
- Apply simple incentives (for example, fast-track permits), compliance measures, and awareness campaigns.
- Build capacity through accessible data, training, and technical guidance.

Cities with strong institutional and technical capacities and dynamic real estate markets

- Integrate detailed risk assessments into planning instruments, codes, and master plans.
- Apply advanced tools such as LVC, tax incentives, and dynamic permitting systems.
- Coordinate across agencies and leverage PPPs for implementation.
- Tailor capacity building and outreach to specific hazards, risks, and regulatory needs.

Step 6.2. Establish enforcement mechanisms

- Establish clear rules, inspection procedures, and sanctions to ensure compliance.
- Coordinate enforcement across sectors and government levels.
- Develop mechanisms for reporting, redress, and empowering communities with clear communication channels.
- Monitor effectiveness and update instruments regularly to reflect changing risk conditions.

Planning Milestone 3.2: Monitoring and Evaluation

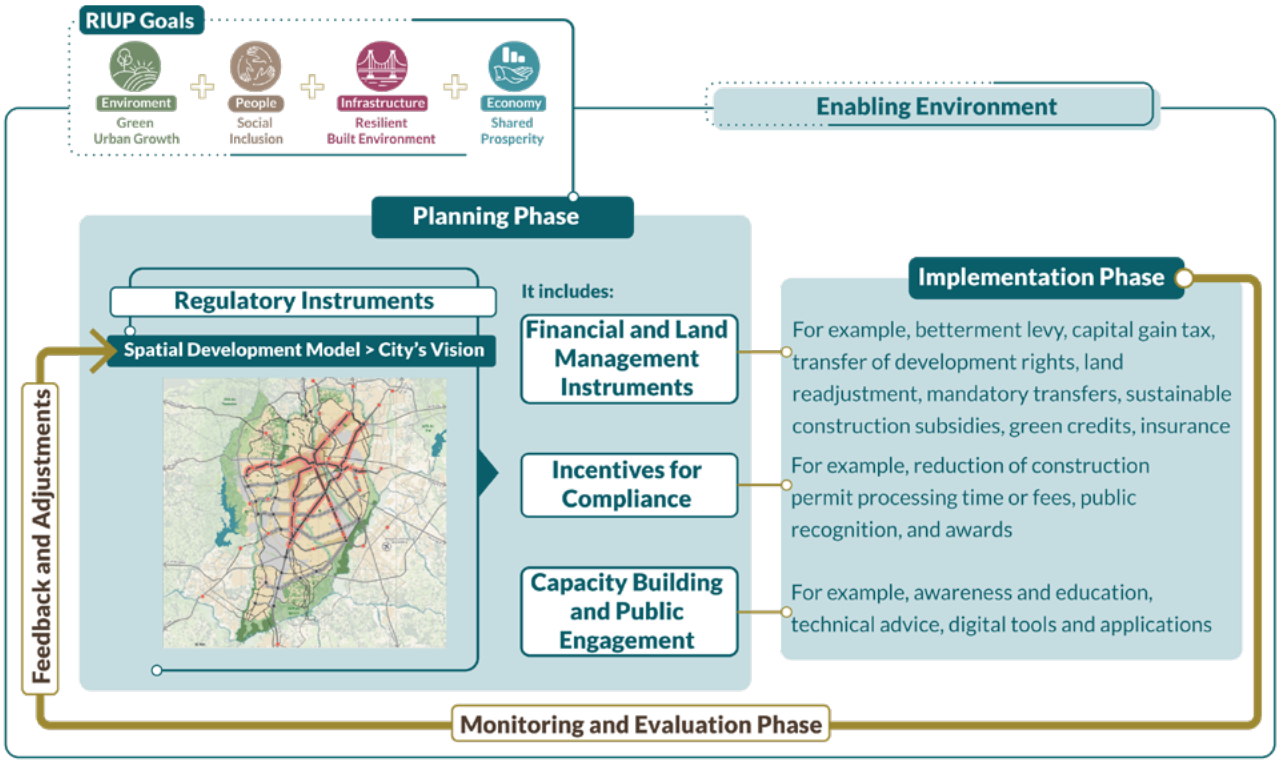
Systematically monitoring, evaluating, and updating the effectiveness of the risk-informed urban plan, particularly in disaster risk prevention and reduction, ensures that goals and targets are met in line with the action plan. Ongoing awareness of how the implementation of the plan is progressing will enable cities to fine-tune strategies to meet planned goals. Flexibility is also fundamental to refining targets, measures, and projects, particularly in response to newly detected hazards and risk trends. Applying the risk-informed urban planning operational framework, the following chapters analyze hydrometeorological hazards, geohazards, and climatological hazards as key contributors to urban risk. These chapters consider how these hazards materialize in urban settings; their implications for infrastructure, land use, and development; and highlight risk-zoning considerations. Each chapter presents a set of recommendations on the RCP measures that cities should integrate in their urban plans, tailored to specific hazard and risk scenarios.

Chapter 4

Instruments, Enforcement, Monitoring, and Evaluation

Cities can use regulatory instruments, incentives for compliance, financial and land management tools and promote capacity building and public engagement to implement risk-informed urban planning measures and actions. Outcomes (policies, plans, and designs) differ in both form and content across planning scales, reflecting the distinct objectives and expertise at each level. As outlined in the operational framework in chapter 3 (step 5), these instruments are used in spatial planning to guide and finance urban transformations, facilitate compliance with regulatory requirements, raise awareness, and promote good practices. A central challenge is to ensure effective coordination between the DRM and CRM components of the plan and the instruments that facilitate the execution of these measures (figure 4.1)

Figure 4.1: Integration of Instruments in the Spatial Planning Phases



Source: Original for this publication.

4.1 Regulatory and Incentive Instruments

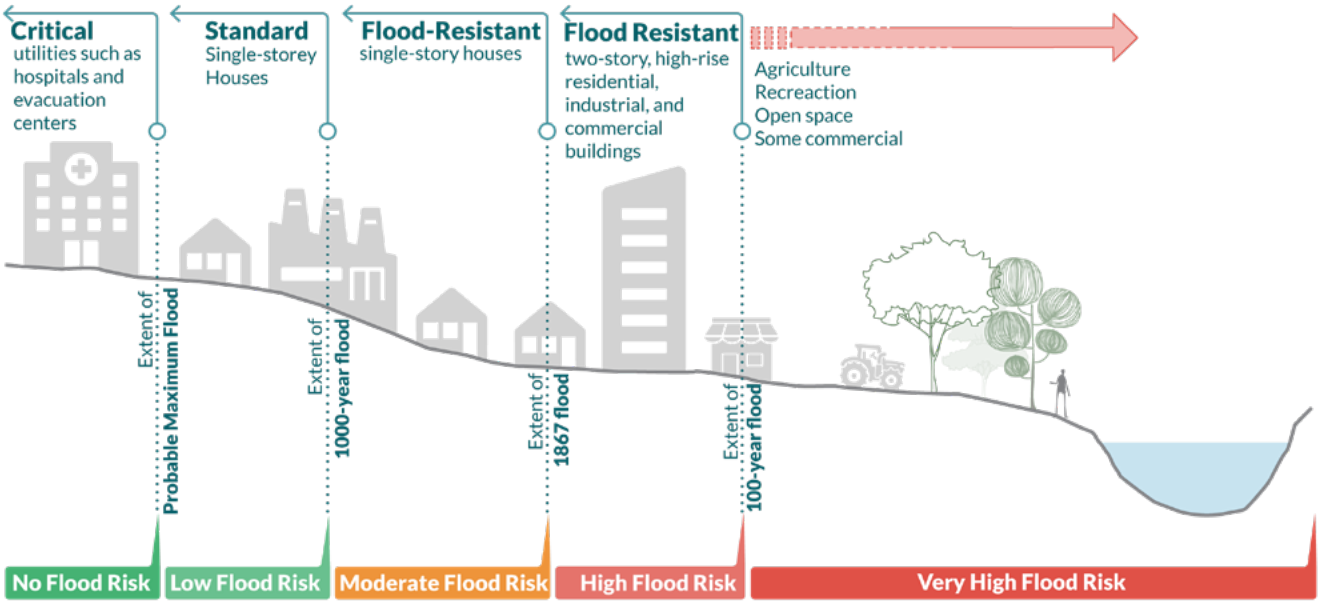
Regulatory instruments are policies, regulations, and guidelines that frame spatial planning at different scales. As explained in section 1.2.2, both scales and legal hierarchies need to be coordinated among instruments to ensure consistency between them. At all levels, hazard and risk data can inform urban plans to define zoning and land use to ensure suitable locations according to activities, densities and setbacks, and building provisions. These types of regulations enable cities to avoid the creation of new risks. Once the risk-informed plans are adopted, the implementation phase must be complemented with enforcement, reporting and redress mechanisms, development controls, and incentives to ensure that livability and resilience goals are met and the planned vision is achieved.

Zoning and Land-use Controls

Grounded in higher-level directives (national and provincial) and a local context-based analysis, cities use **zoning** to define where new developments and densification are suitable and, conversely, where urbanization and the construction of critical infrastructure should be avoided. Based on zoning, **land-use regulations** define permitted uses (residential, commercial, services, industrial, environmental conservation, public uses, and so on) and link these uses with specific norms, such as building heights, minimum lot size, and suitable densities (such as inhabitants per unit area of land in hectares or square meters). Land-use regulations and controls must take account of local hazards and risk assessments and put in place any setbacks (from rivers, coastlines, volcanoes, fault lines, and so on) or buffer zones required by national or provincial directives. In Australia's Hawkesbury–Nepean Valley, **graduated planning controls** guide land use, construction types, densities, and setbacks based on differing levels of vulnerability to flooding, showing how land-use regulation can operate in hazard-prone areas (figure 4.2).

If a city has not conducted hazard and risk assessments, it must address this as a short-term priority, as explained in step 1 of the operational framework (figure 3.3) to define compatible land uses and development standards. For the medium and long term, urban plans must establish the areas in which detailed risk assessments are required before defining the location of new critical infrastructure or granting permits for new developments. This means that the activities proposed in step 2 (figure 3.4) directly feed into the risk-informed decisions proposed in step 3 (figure 3.5) and step 4 (figure 3.6). Cities must ensure that spatial plans are flexible enough for new hazard and risk information to be gradually incorporated by updating zoning, land use, performance standards, and building regulations.

Figure 4.2: Graduated Planning Controls Developed in Hawkesbury-Nepean Valley, Australia



Source: Redrawn from Hawkesbury-Nepean Floodplain Management Steering Committee 2006.
Note: Recorded data indicates 27 significant flood events in the Hawkesbury-Nepean catchment during the 19th century, with the 1867 flood reaching the greatest magnitude.

Building Codes

Building codes—also referred to as building design and construction regulations—are powerful regulatory instruments for managing disaster and climate risks in the built environment. Building codes translate hazard and risk information into technical requirements for materials, design loads, and construction practices (photo 4.1). They define the minimum standards for the design, construction, and retrofitting of buildings to ensure life safety and meet performance criteria according to the expected use and importance of the structure. Most current building codes focus on safety and structural stability under gravity, earthquake, or wind loads, but they must now evolve to address additional hazards—including floods, wildfires, and extreme temperatures—that are affecting buildings with increasing severity and frequency.

While spatial planning, zoning, and land-use regulations prescribe where development is permitted and for which types of buildings and occupancies, building codes set minimum requirements for building performance, covering such areas as structural safety, fire safety, heating, cooling, ventilation, indoor air quality, plumbing, sanitary facilities, lighting, green building (including energy and water efficiency), and universal accessibility requirements. When integrated with spatial planning, zoning, and land-use regulations, building codes become an essential enabler of risk-sensitive and resilient urban growth.

Photo 4.1: Construction of Earthquake-resistant Steel Structure in Tokyo



Source: © Shigemi Okano / Shutterstock

Although certain hazards such as floods have been addressed predominantly through zoning and land-use controls that steer growth away from high-exposure areas, building codes are increasingly incorporating flood provisions, which markedly increase the effectiveness of risk reduction in the built environment. Key topic areas related to flood design—such as load procedures for flood loading, material requirements, wall openings, occupancy limitations below the design flood level, and the placement of critical equipment—are now being evaluated within building codes. These provisions address how structures withstand hydrostatic and hydrodynamic forces, ensure the use of flood-resistant materials, require vents or openings to equalize water pressure, limit occupancy in flood-prone areas, and mandate the elevation of essential equipment above the design flood level. Collectively, these measures help reduce structural damage, protect building occupants, and support faster recovery after flood events. Only be combining spatial avoidance, performance-based codes, and preparedness can a truly balanced, risk-proportionate approach be achieved.

Implementing building codes is especially critical for seismic risk and wind-resilient design, where life-safety performance hinges on construction details often concealed once works are completed. Effective enforcement of code provisions (for example, seismic detailing for system ductility and concrete confinement, continuous load paths, anchorage, diaphragm and roof connections, uplift and suction resistance, and

protection of openings) reduces the probability of collapse in earthquakes and prevents roof loss and progressive failure in high-wind events.

A risk-informed building code should therefore:

- Establish performance-based standards that address multihazard risks (for example, seismic, wind, flood, and heat).
- Integrate updated hazard maps, risk models, and climate projections to define design parameters.
- Differentiate requirements based on risk exposure, occupancy type, and importance of the structure.
- Provide clear guidance for the design and retrofitting of existing buildings and infrastructure.
- Facilitate iterative updates as new data and technologies become available.

It is important to note that while many countries have modern building codes on paper, cities often lack the implementation capacity to ensure enforcement, resulting in a persistent compliance gap. Building safety depends on the full enforcement chain. Budgeting for field inspections and continuous training for municipal staff and practitioners are as vital as the code itself. In high-risk settings—particularly where building-code implementation is relatively recent—programmatic retrofit initiatives are essential to reduce existing risk and deliver measurable life-safety gains. An example of the positive impact of building code implementation and retrofitting programs is shown in box 6.2, below.

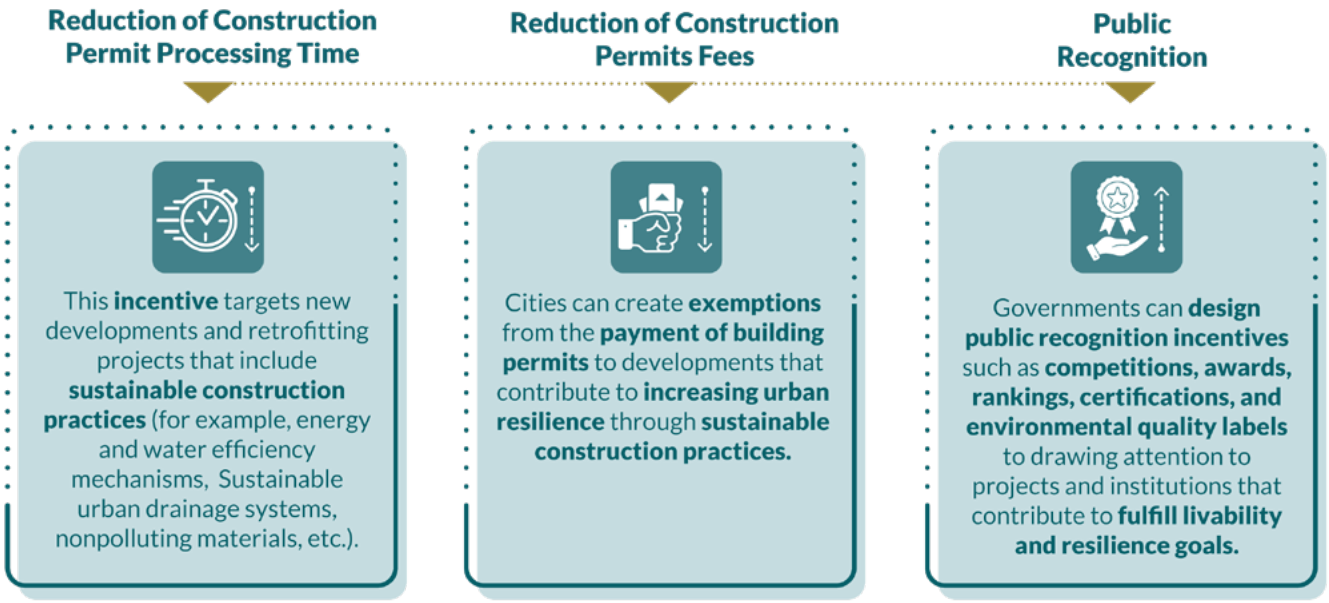
In some countries, building codes incorporate **green building provisions** to promote efficient use of water and energy, appropriate use of materials, and the inclusion of waste management initiatives. Not only do these provisions increase urban resilience through mechanisms such as green roofs or green walls (to retain and slowly release storm water and mitigate the UHI effect)—they also seek to reduce carbon dioxide emissions, and thereby minimize the impacts of global warming.

Local building regulations play a vital role in complementing national codes by tailoring risk reduction measures to the local contexts, defining specific design parameters to prevent or reduce risks. For instance, in cities with low-lying areas, local regulations can restrict the types of occupancy permitted in spaces below the design flood level for the building, or require buildings to be constructed at minimum (safer) elevations. In regions that are prone to heat waves, local regulations can define standards to enforce the use of appropriate building materials or passive cooling measures to reduce human and economic losses.

Incentives for Compliance

Incentives for compliance complement regulatory and enforcement tools to promote green, resilient, and inclusive urban development. Their primary goal is to encourage the adoption of resilience-enhancing actions aligned with the city's vision. These mechanisms include lower fees and shorter processing times for building permits, alongside public recognition for projects and institutions that successfully contribute to livability and resilience goals (figure 4.3).

Figure 4.3: Examples of Incentives for Compliance



Source: Original for this publication.

4.2 Financial and Land Management Tools

These mechanisms operationalize livability and resilience strategies by ensuring their financial and spatial feasibility. They enable cities to equitably share the economic burden of infrastructure between public and private actors. They channel resources into urban transformation and facilitate land acquisition using adaptive development strategies. These instruments can include compensation mechanisms for owners of land that is subject to development restrictions because of environmental concerns and risks. Some of them are complex and depend on more sophisticated real estate markets; however, cities with limited capacities can start with instruments that are easy to implement, such as betterment levies or green credits (discussed in more detail below).

Land Value Capture

This set of instruments enables cities to capture increased land value resulting from public investments to improve public infrastructure or regulatory shifts that increase development potential or alter land uses. In risk-informed urban planning, hazard and risk assessments—or the occurrence of disasters—could influence land values. For instance, the identification of safe zones or new climate change mitigation or adaptation infrastructure could lead cities to define new developable zones. These zones, typically accompanied by

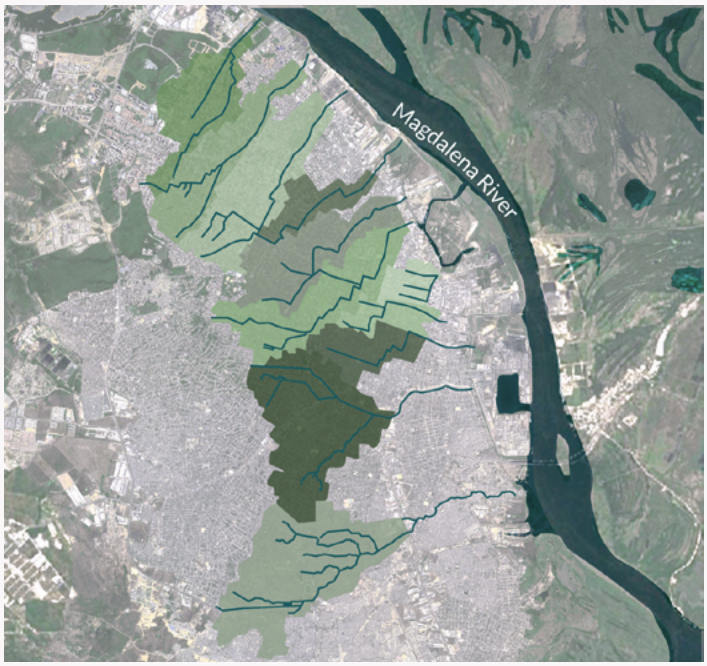
rising land prices, could be on greenfield land, or regulate higher densities in brownfield areas. Two of the most popular instruments for LVC are betterment levies and capital gains tax.

- A **betterment levy or development charge** is a mandatory tax or contribution levied by cities on landowners whose land value has increased due to the construction or improvement of public infrastructure such as roads, public transport lines, public utility networks, and risk mitigation works. By using this LVC tool, cities can obtain the necessary financial resources in advance to carry out the work previously defined by the competent authorities (box 4.1).
- A **capital gains tax** captures a portion of a landowner's capital gains from increased land value caused by a spatial planning decision on urban growth boundary expansion, rezoning, land-use change (to more lucrative activity), or regulations that allow higher densities.

Box 4.1:
Land Value Capture to Fund Flood Resilience in Barranquilla, Colombia

Home to almost 1.3 million inhabitants, Barranquilla sits on the northern Colombian coast, strategically positioned on the left bank of the Magdalena River and only 7.5 kilometers inland from the Caribbean Sea. Historically, the absence of an urban drainage system across 90 percent of the municipality created dangerous conditions (figure B4.1.1).

Figure B4.1.1: Main Waterways Flowing into the Magdalena River

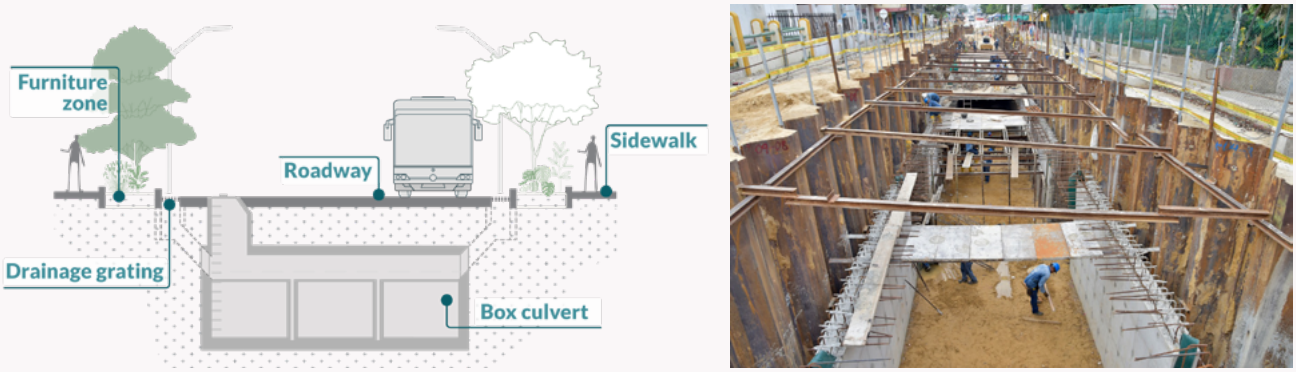


Source: Own elaboration based on Google, © Airbus, 2025.

During storms, streets with slopes ranging from 2 to 5 percent would rapidly accumulate runoff. This resulted in recurrent flash floods (known locally as arroyos) that reached flows of 30 to 100 m3 per second in short periods (Alcaldía de Barranquilla 2017). These uncontrolled torrents frequently caused human and property losses and undermined the city's economic competitiveness.

Following several failed flood control attempts, the Barranquilla District Infrastructure Agency launched a large-scale resilience project between 2008 and 2022. This initiative involved constructing over 70 km of canals, of which 25 km consist of reinforced concrete box culverts that utilize pipe drainage and steel and cast iron grates for rainwater collection (figure B4.1.2). Complementary works included surface channels and the creation of new public spaces in surrounding areas (Alcaldía de Barranquilla, 2017).

Figure B4.1.2 Box Culvert Section and Public Works



Source: Redrawn from Alcaldía de Barranquilla, 2017. Photo: Alcaldía de Barranquilla, 2020.

To successfully implement the flood resilience project, the city had to strengthen its institutional capacity and establish financial mechanisms to ensure continuity in the long term. This involved recovering public finances, improving property tax collection, and restoring citizens' trust in public institutions to encourage tax payment compliance (Restrepo 2018). Due to its substantial funding requirement of nearly US$455 million, the project was financed through a diversified strategy comprising four core instruments (Restrepo 2018):

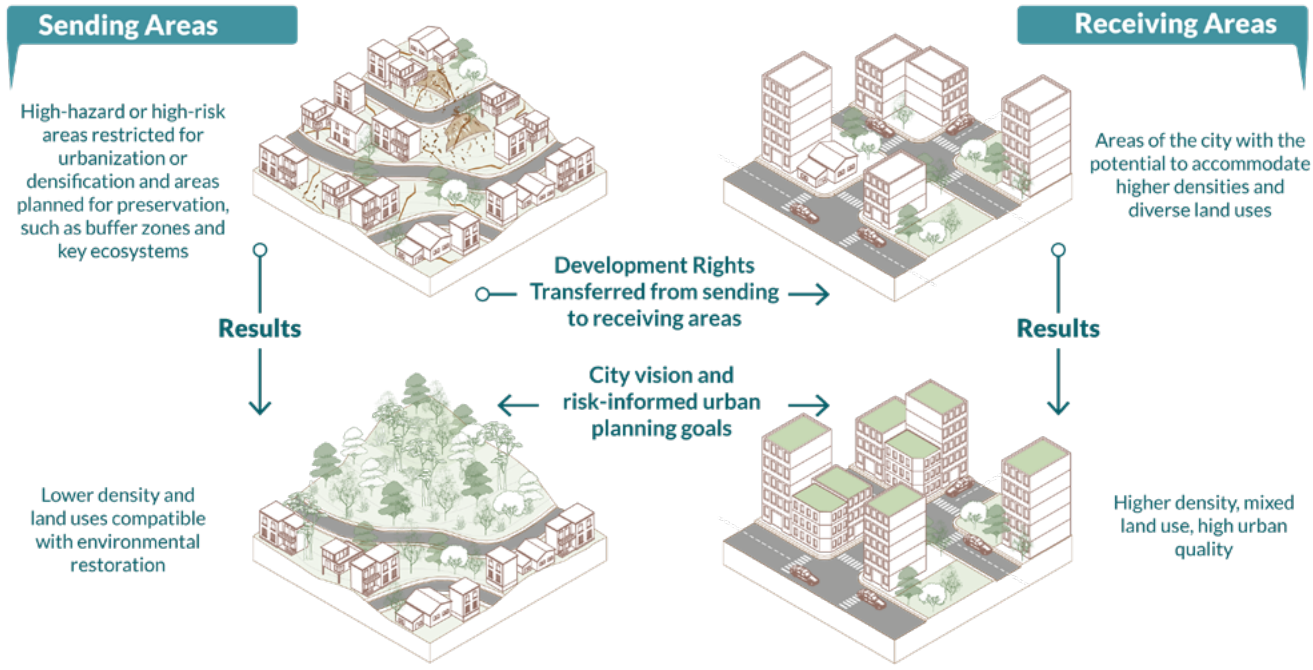
- **Future budgetary allocations:** Public funds were authorized for use until 2035 to guarantee long-term financial continuity.
- **Bank financing:** Direct loans were secured from national and international private banks.
- **Supplier credit (vendor financing):** This is a mechanism where the contractor simultaneously acts as the project financier, providing credit to the public entity.
- **Betterment levy:** This local charge was implemented to fund the resilience and road infrastructure project.

To secure City Council approval for the betterment levy, the mayor's office argued that canalizing the streams would provide a direct, measurable economic benefit to nearby property owners by eliminating flood risk, thereby increasing property values. This strategy was designed to mobilize nearly US$200,000 from taxpayers between 2012 and 2016. To estimate the uplift in property values and collect the betterment levy, the city established rates per square meter that were differentiated by land use and zone. The highest fees were allocated to industrial, commercial, and institutional buildings as well as residential properties in wealthier districts. This approach is frequently used in Colombia to obtain the necessary funds upfront for immediate infrastructure development.

Transfer of Development Rights

Transfer of development rights (TDR) is the transfer of construction potential from a sending site to a receiving site. In risk-informed urban planning, sending sites are high-risk, high-hazard, or environmentally protected areas from which at-risk settlements must be relocated to reduce risk exposure (or where urbanization must be restricted to prevent the creation of new risks). Receiving sites are safe areas for urbanization where new developments or higher densities are feasible (figure 4.4). This instrument is used to compensate landowners of sending sites by granting them development rights, tradable according to local regulations. These transferable rights can be sold to developers seeking to build in receiving areas where regulations permit higher densities and more lucrative land uses.

Figure 4.4: Transfer of Development Rights

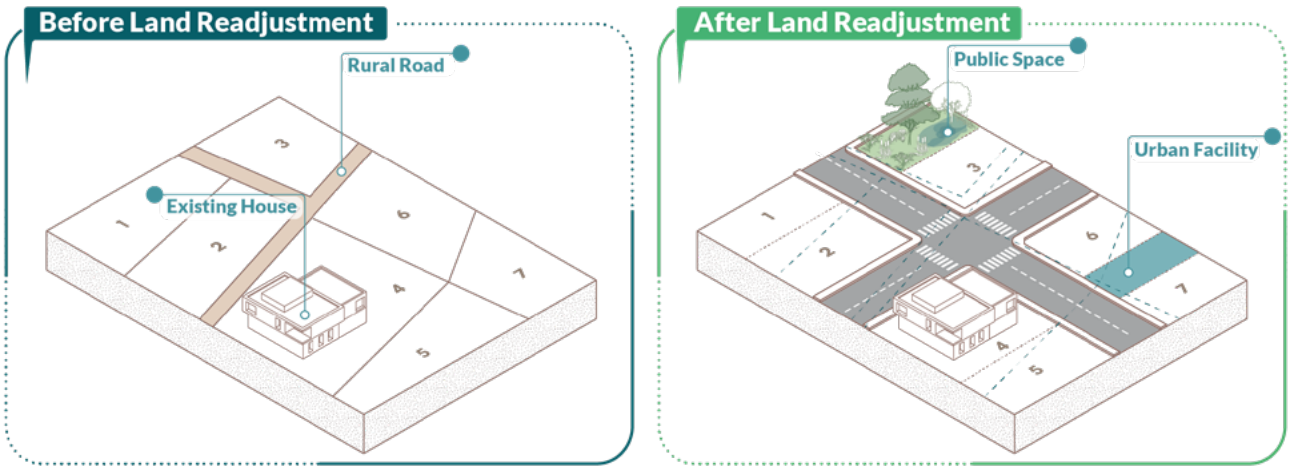


Source: Original for this publication.

Land Readjustment and Mandatory Transfers

Land readjustment entails agreement between landowners to reshape and resize their landholdings using a regular urban pattern to optimize the use of land (figure 4.5). Although owners could receive smaller plots after deducting public areas (such as roads, parks, or urban facilities), this reduction is offset—and often outweighed—by the increased value of regular shaped plots with access roads, amenities, and additional development potential. In risk-informed urban planning, this instrument helps to promote development or densification in safe areas. In postdisaster reconstruction, land readjustment has proven effective for urban land optimization.

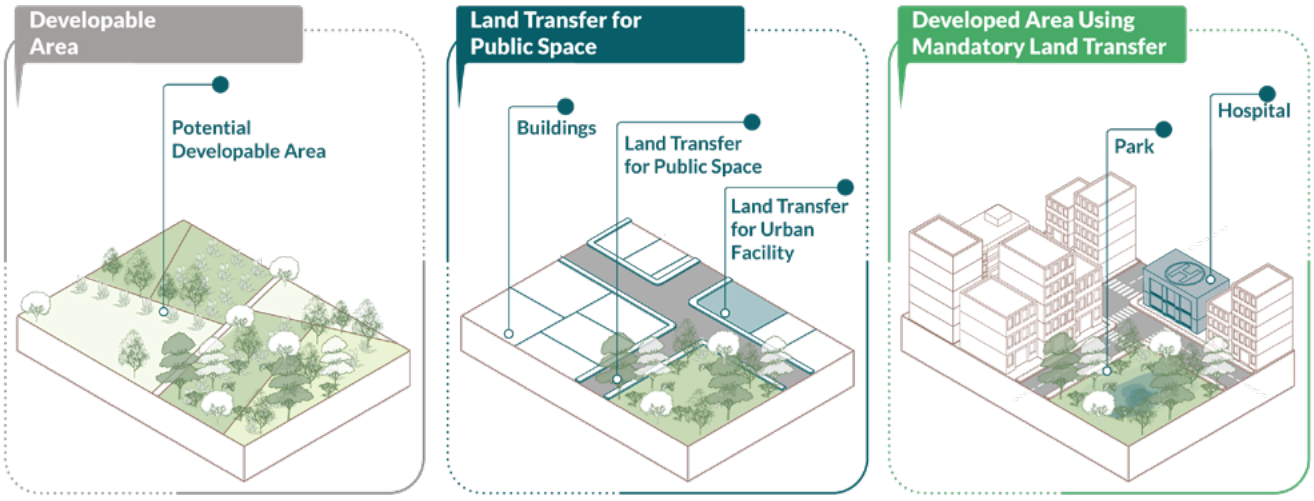
Figure 4.5: Example of Land Readjustment



Source: Original for this publication.

Mandatory land transfer for public space and urban facilities helps cities to increase public green areas and land for public facilities. It can be made a condition of new developments. These transfers are calculated as a percentage of the net developable area of a real estate project. If the site is not designated for increased public space in the urban plan, planners may request an alternative contribution. Developers must then either pay in cash or purchase land of equivalent value in targeted locations where the relevant amenities are required (figure 4.6).

Figure 4.6: Mandatory Land Transfer for Public Space and Urban Facilities



Source: Original for this publication.

Green Finance Instruments

Financial instruments supported by government funds: Urban resilience projects and sustainable construction practices can be encouraged by public initiative through financial instruments such as the following direct subsidies and tax exceptions. These instruments provide financial support to individuals and real estate developers to implement projects that focus on risk reduction and climate change mitigation or adaptation measures.

- **Sustainable construction subsidies:** These aim to improve the performance of buildings to make them more sustainable and adapted to climate change conditions. Some countries have already implemented this type of subsidy to stimulate the use of passive heating and cooling systems; increase individual renewable energy generation; and develop systems for runoff retention, rainwater harvesting, gray water recycling, and potable water saving, among others.
- **Tax exemptions to protect key ecosystems:** One way to fund the protection of key ecosystems is to grant tax exemptions to companies that manage and maintain critical natural areas identified in risk-informed urban plans, reducing hazard and risk exposure. This option is easy to implement but implies a fiscal cost for the city, as tax payments from participating companies are waived. However, the resulting green and resilient urban growth, increased quality of life in urban areas (and reduced potential postdisaster recovery costs) could substantially outweigh the foregone revenue.

Green credits supported by the banking system: These instruments contribute to stimulating sustainable construction through soft loans and mortgages granted to support projects using, for instance, renewable energies, integrated water management systems, passive cooling or heating systems, and environmentally friendly construction materials (box 4.2).

- **Soft loans for projects increasing urban resilience:** This type of credit supports projects that include sustainable construction practices such as mechanisms to reduce water consumption through gray water recycling or water harvesting, systems to improve energy efficiency, and clean energy generation. These loans are also used for promoting structural reinforcement projects to improve building resilience.
- **Green mortgages:** This corresponds to mortgage loans with financial incentives—such as lower interest rates, higher loan amounts, or rebates—for buyers of new homes or individuals carrying out home renovations that include environmentally friendly construction practices. Green mortgages seek to increase the interest of developers and homebuyers in sustainable housing projects to increase the environmental quality and reduce potential risks through mechanisms such as water retention, gray water reuse, energy-efficient systems, and clean energy generation.

Box 4.2:

Public and Private Finance to Scale Sustainable Construction in Colombia

In 2024, Colombia was identified as the country with the highest disaster risk in the Americas and ranked fourth globally (Bündnis Entwicklung Hilft/IFHV 2024). This is largely due to its high exposure to river floods, landslides, annual extreme heat, and earthquake hazards (World Bank 2023d). To address this situation, the national government established a robust legislative framework in the late 20th century that requires all municipalities to adopt a comprehensive spatial plan that must include disaster risk management (DRM) measures. To adapt the country to climate impacts, the government issued the National Climate Change Policy in 2017, followed by a set of legislative acts that seek to achieve carbon neutrality and increase climate resilience.

The climate change acts were complemented by the issuance of Latin America's first sustainable building code in 2015, updated in 2025. This code stipulates that the design and construction of new buildings must include passive and active systems for water and energy conservation. Passive systems include proper management of the local climate, building orientation for solar gain or control, thermal insulation, reflectivity, use of natural lighting and ventilation, rainwater harvesting, and gray water recycling. Active systems include the installation of sensors in mechanical or electrical systems (boilers, air conditioning, mechanical ventilation, electric lighting, and so on) to ensure efficient use, and alternative systems such as solar hot water, evaporative cooling, and radiant heating.

To ensure compliance with these measures, the code established a baseline consumption level from which the minimum mandatory water and energy savings percentages for new buildings were determined. Depending on the type of building and the altitude-based climate zone where it is located, water savings can range from 15 to 30 percent, and energy savings between 15 and 20 percent. The code entails control and enforcement measures as well as guidelines on incentives that cities can apply, such as tax reductions for the installation of active or passive systems that increase sustainability.

These measures have been supported by private banks, which have been involved in green building initiatives since 2016. Currently, six private banks and three development finance institutions (DFIs) offer green loans with interest rate reductions ranging from 0.5 to 2 percent to builders who meet sustainability standards such as Excellence in Design for Greater Efficiencies (EDGE), Leadership in Energy and Environmental Design (LEED), and Environmental Housing Certification (CASA). These loans can also be requested by individuals for the purchase of new homes (green mortgages) that meet sustainable construction standards and nonstructural renovations that include solar energy systems and thermal insulation. This offer from the banking system has accelerated the implementation of sustainable construction in the country (Deuskar et al. 2025). An example is the Jardines social housing project, developed by the Family Compensation Fund Comfama in Apartadó, Antioquia (Photo B4.2.1). This 650-unit project includes large green areas to increase rainwater infiltration and reduce the UHI effect for climatic comfort and energy efficiency systems. The architectural design also encourages sustainable everyday practices and was conceived to turn residents into agents of change (Comfama, 2025). These sustainable construction features qualified them for the Swiss Minergie Neighborhood Certification.

Photo B4.2.1: Jardines Curazaos Social Housing Project in Apartadó, Colombia



Source: © Isaac Ramírez / Hábitat Comfama.

The combination of strong legislation, public incentives, and green loans offered by private banks and DFIs has made Colombia a pioneer in sustainable construction, mobilizing more than US$11.5 billion in private investment. Between 2021 and 2022 alone, 27 percent of new construction in the country was EDGE certified (World Bank 2023e), demonstrating the effectiveness of public policies that bring together the banking sector, builders, buyers, and homeowners to meet environmental sustainability and urban resilience goals.

Market-based financial instruments: These instruments contribute to meeting livability and resilience goals, using trade platforms to buy and sell emissions allowances, carbon offsets, stormwater retention credits, and green energy credits, among others (table 4.1).

Table 4.1: Examples of Market-Based Financial Instruments

Type of instrument	How the instrument operates
Reduction of GHG emissions	Within a cap-and-trade system, it assigns financial value to companies' achievements in reducing environmental impacts by setting emissions limits. If a company exceeds its limit, it can buy green credits (emissions allowances) on the market as compensation. If the company reduces its emissions below the limit, it can sell surplus credits to other companies.
Carbon credits	Allows companies to buy or sell carbon offsets to promote carbon-neutral operations. While stimulating emission reductions, these credits also promote forest preservation when rural communities replace logging and selling timber, raising livestock, and mining with practices for restoring large tracts of forest as a sustainable livelihood.
Stormwater retention credits	Aims to increase rainwater retention in cities to reduce flood risk by promoting the installation of sustainable urban drainage systems (SUDS), such as green roofs and green walls, in private buildings. To stabilize the market and limit speculation, governments can introduce formal price-setting mechanisms, such as regulated price caps or floors, or participate as a buyer of last resort. These measures help ensure that investors receive a predictable and fair return while maintaining the effectiveness of the credit system.
Green energy credits	Helps reduce GHG emissions through clean energy projects that can sell credits in the market to companies that must offset their emissions to meet their carbon footprint reduction commitments. This stimulates the expansion of renewable energy projects and the participation of companies in environmental responsibility programs.

Source: Original for this publication.

Disaster and climate risk insurance: To alleviate financial losses caused by disasters and climate-related events, individuals, companies, and governments can purchase insurance policies to cover the financial resources for postdisaster reconstruction and recovery. Regular premium payments to insurance companies enable the creation of a pool of funds to cover compensation claims for damages. These funds can be invested in retrofitting, structural reinforcement, and reconstruction. Although insurance can be costly, it remains an efficient way to protect cities, companies, and individuals against property losses and business interruption.

4.3 Capacity Building and Public Engagement

Capacity building and public engagements instruments are actions implemented by governments to raise awareness and promote a culture of risk prevention, alongside good governance practices. These instruments

seek to increase knowledge among public institutions, decision-makers, grassroots organizations, NGOs, and citizens on critical issues, such as how to prevent or reduce the probability of disaster occurrence, how to react during an emergency, and how to support a postdisaster reconstruction and recovery process (photo 4.2).

Photo 4.2: Women in a community meeting to discuss village reconstruction, Yogyakarta, Indonesia, 2011



Source: © Nugroho Nurdikiawan Sunjoyo / Wold Bank

Awareness and education: Awareness and education campaigns include evidence-based and outcome-oriented training and learning programs focused on risk prevention and risk reduction. Knowledge materials should be tailored to the target audience. For example, technical content can strengthen the understanding of public officials and decision-makers, whereas campaigns with easy-to-understand materials serve to raise awareness among the general population of the importance of preventing the creation of new risks. They also outline simple, actionable steps to follow in the event of an emergency. These campaigns can use a combination of communication channels and methods, such as courses, social media, storytelling, and gamified approaches to engage children and young people.

Technical advice: Free guidance on building technologies, innovative materials, including their economic and environmental benefits, helps technicians and companies adopt safer, more sustainable construction

practices and improve urban resilience. This mechanism is particularly useful to support vulnerable communities that lack the financial means to pay for professional architectural or engineering advice on building their own homes and structural reinforcement projects.

Digital tools and applications: Multiple mechanisms can provide support, including digital and printed manuals on hazards, risks, and climate-related shocks as well as digital applications connected to early warning systems (EWS) for real-time disaster risk information. Public engagement can also be supported through hazard and risk simulators, web-based spatial data viewers, and housing vulnerability assessment apps. Table 4.2 summarizes instruments linked to risk-informed urban planning, showing their level of complexity and minimum requirements needed for implementation.

Table 4.2: Summary of Instruments

	Instrument	Complexity level			Basic requirements	Applicable or effective in short-term hazard scenarios	Appropriate for long-term adoption
		Low	Medium	High			
Regulatory and incentive instruments	**National policies and directives**	○			Supportive environment for passing laws and policies (legal framework) and defining roles and responsibilities (institutional framework).	○	
	Provincial and urban spatial plans		○		Decentralization of local planning, enhancement of technical capacities, and resources for plan formulation.	○	
	Sectoral master plans			○	Definition of sectoral plans to be formulated, underpinned by appropriate local, technical and financial resources.		○
	Zonal or neighborhood plans			○	Clear guidelines from urban plans and instruments for implementation.		○
	Building codes and green building provisions		○		Enhancement of technical capacities and resources for the development of regulations, enforcement mechanisms, and compliance controls.	○	
	Reduced construction permit times	○			Technical and financial capacity to meet the demand for building permits.		○

	Instrument	Complexity level			Basic requirements	Applicable or effective in short-term hazard scenarios	Appropriate for long-term adoption
		Low	Medium	High			
	Reduced construction permits fees	○			Financial capacity to cover the reduced costs of permits.		○
	Public recognition	○			Government or other stakeholders' programs, definition of recognition mechanisms (for example competitions, awards, and rankings).	○	
Financial and land management tools and incentive instruments	**Betterment levy**	○			Legal framework, definition of works, and calculation of each taxpayer's contribution as well as collection mechanisms.	○	
	Capital gains tax			○	Legal framework that includes regulations on land use and density, developable land appraisals, and collection mechanisms.		○
	Transfer of development rights			○	Legal framework including density regulations, study of sending and receiving sites, land appraisals, and collection mechanisms.		○
	Land readjustment			○	Legal framework, proposed land subdivision readjustment, and land appraisal.	○	
	Mandatory land transfers		○		Legal framework, designation of areas where public space and facilities are required, proportion of net developable areas to be transferred, and transfer procedures.	○	
	Sustainable construction subsidies	○			Definition of "sustainable construction," parameters to apply to benefits, and government resources for subsidies.	○	
	Tax exemptions for ecosystem protection		○		Establishment of rules for applying the exemption and financial resources to cover uncollected taxes.	○	

	Instrument	Complexity level			Basic requirements	Applicable or effective in short-term hazard scenarios	Appropriate for long-term adoption
		Low	Medium	High			
	Soft loans and green mortgages	○			Definition of "sustainable construction" and private banks' interest in exploring the green loan market.		○
	Market-based instruments	○			Enabling environment, national and/or local regulations, and private stakeholders' interest in participating.		○
	Disaster and climate risk insurance			○	Supportive environment to encourage a culture of insurance as well as public and private capital for insurance purchase.	○	
Capacity building and public engagement	Awareness and education	○			Financial capacity to create and disseminate campaigns.	○	
	Technical advice	○			Financial capacity or assistance management with institutions such as universities to provide free advice.		○
	Digital tools and applications	○			Financial and human resources to produce printed or digital materials, applications, and online simulators.	○	

Source: Original for this publication.

4.4 Enforcement, Monitoring, and Evaluation

As mentioned in chapter 1, an enabling environment ensures enforceable legal frameworks, strong policies, institutions with clear roles and responsibilities, reliable hazard and risk assessments (at a reasonable resolution or scale), and local capacities for conducting successful risk-informed plans and ensuring their implementation. This section focuses on enforcement, monitoring, and evaluation—key components to ensure that plans are effectively implemented, progress is measured, and outcomes are adjusted based on evidence and changing conditions. When monitoring and evaluation reveals that goals are not being met,

cities can review and update the plan to fine-tune its scope and adjust decisions in light of new evidence and observed outcomes.

Institutions involved in urban development must grant land-use approvals and building permits in accordance with established requirements to avoid the creation of new risks and guarantee the application of standards. Likewise, they must design instruments for development controls and inspections to ensure compliance with regulations, including mechanisms for reporting and redress. Without strong enforcement, violations go unaddressed and confidence in the planning system is undermined.

Periodic monitoring and evaluation of a risk-informed urban plan will enable cities to assess progress, identify gaps, and adjust their approach accordingly. The specific objectives of this phase of the planning process are to:

- Measure progress toward the goals and indicators proposed in the action plan;
- Analyze the effectiveness of implemented measures to determine whether it will be possible to fulfill the long-term objectives and vision;
- Identify the need to adjust strategies to ensure compliance with the short-, medium- and long-term objectives;
- Detect institutional, technical, or financial weaknesses in the agencies in charge of implementing the plan and propose corrective actions; and
- Determine whether new or updated studies—such as detailed hazard and risk assessments—require modifications to zoning and land-use regulations.

Cities can implement tools such as information systems to facilitate periodic review of the progress of the plan (for minimum data needed see table 4.3).

Table 4.3: Information Required to Monitor the Risk-informed Urban Plan

Data required for the information system	Definition
Baseline	Situation before implementation of the risk-informed urban plan
Target	Measurable and reachable value indicating expected results at the end of the plan
Indicators	Tools to monitor and evaluate progress toward quantified or clearly defined targets
Result	Figures that clearly represent implementation progress for each target according to each indicator

Data required for the information system	Definition
Date of information recording	Date marking the cutoff for monitoring and evaluation of the plan's progress
General comments	Details on progress or delays in implementation of the plan, indicating possible causes

Source: Original for this publication.

Table 4.4 presents sample data applying the structure outlined in table 4.3 to a flood-risk management target.

Table 4.4: Sample Data for a Specific Target

Data required for the information system	Definition
Baseline	75 homes at high risk of flooding
Target	- 0 homes at high risk of flooding - 5 awareness campaigns to prevent the occupation of high-flood-hazard areas
Indicators	- Number of homes at high risk of flooding relocated - Number of homes with flood risk reduced to acceptable levels through mitigation works - Number of awareness campaigns undertaken to prevent the occupation of high-flood-hazard areas
Result	- 35 homes relocated from high flood-risk areas - 40 homes benefited from flood-risk mitigation works - 5 awareness campaigns undertaken to prevent settlement in high flood-hazard areas
Date of information recording	Mid-term of the plan (8 years)
General comments	Some relocations heavily impacted the population, and the government decided to favor solutions to reduce risk to acceptable levels when possible. More efficient resource management is required to ensure that targets are met at the end of the plan.

Source: Original for this publication.

As multiple actors are involved in implementation, each agency remains responsible for follow-up and progress reporting, ensuring the monitoring system stays current and supports regular review. Risk-informed urban plans should remain flexible, allowing for adjustments when monitoring and evaluation indicate the need to update targets, indicators, budgets, or other variables. These updates should follow a rigorous process that ensures transparency and technical quality.

PART III:

Integration of Different Types of Hazards and Risks Into Urban Plans

Part III provides hazard-specific planning guidance by translating the RCP framework into practice. It focuses on three major hazard categories that directly affect urban systems, spanning hydrometeorological hazards in chapter 5 (with an emphasis on flooding), geophysical hazards in chapter 6 (such as earthquakes, landslides, and volcanic activity), and climatological hazards in chapter 7 (like heat waves, droughts, and wildfires). Guidance is tailored for both undeveloped lands and built-up areas, differentiating between hazard-based planning and a risk-based approach in developed areas. Planning approaches throughout this part reflect the distinct nature and dynamics of each hazard, their characteristics and impacts, triggering and aggravating factors, and opportunities for risk reduction. Instead of examining large-scale drivers such as cyclones or climatic trends, it focuses on the primary and secondary hazards they generate, which directly affect the built environment and shape urban risk. Each chapter identifies risk-informed planning measures to restrict or condition development and densification according to hazard and risk acceptability and to promote resilience-enhancing actions. These measures are consolidated in practical catalogs with examples to guide local planning and decision-making. This part concludes with takeaways in chapter 8, which summarizes why cities should move beyond reactive measures to proactive, integrated, and sustainable planning approaches to achieve livability and resilience goals.

Chapter 5

Hydrometeorological Hazards: Floods

Hydrometeorological hazards, driven by atmospheric and water-related processes, pose significant risks to urban areas by threatening lives and disrupting infrastructure and essential services, affecting livelihoods and the economy. These hazards include extreme precipitation, storms, cyclones, and associated phenomena such as flooding and landslides. As previously stated, for the purpose of this handbook, they are distinguished from climatological hazards like droughts and extreme heat, which are addressed separately. As cities continue to grow, the interaction between these hazards and the built environment becomes more complex, increasing the need for risk-informed planning.

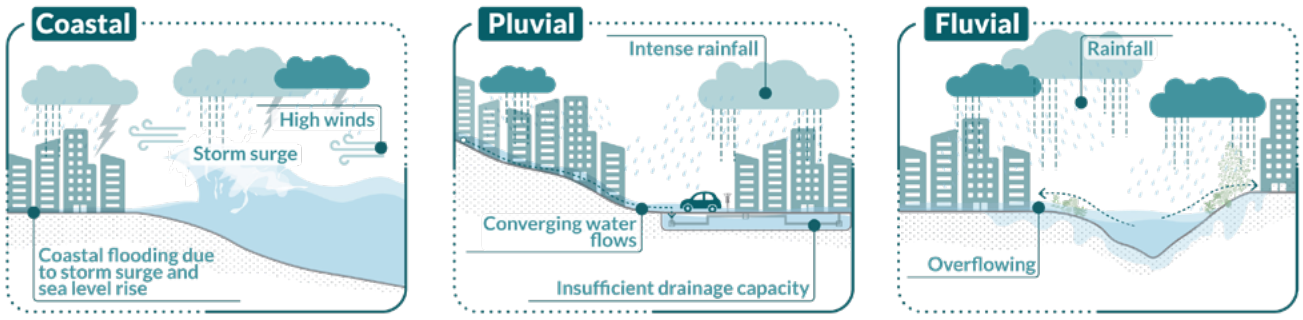
This chapter focuses on floods, one of the most frequent and destructive hydrometeorological hazards affecting urban areas. Consistent with the framework's emphasis on hazards with a direct territorial impact, the analysis centers on the spatial and physical implications of flooding rather than addressing large-scale triggering events like cyclones. Flooding can result from intense rainfall, river overflows, storm surges, or inadequate drainage systems, each with distinct consequences for land use, infrastructure, and urban functionality. By examining the characteristics, triggers, and impacts of floods, this chapter provides essential planning considerations to reduce exposure and vulnerabilities and integrate flood-risk management into urban development strategies.

Flooding stands as the most widespread hazard globally, affecting tens of millions annually and causing substantial economic losses. Flood-related vulnerabilities are closely tied to poverty as they impact low-income households disproportionately. The ramifications extend beyond immediate human and asset impacts, hindering development prospects, especially when affected communities have limited coping capacity and inadequate insurance coverage.

Cities can be exposed to different flood types, including flash floods and surface water or urban floods (pluvial), as well as riverine, coastal, and groundwater floods. These flood types vary in spatial-temporal characteristics and potential impacts.

Understanding the characteristics of different flood types is essential for risk-informed urban planning because it helps city planners, engineers, and policy makers develop strategies to reduce the impact and manage the risks associated with these events. Figure 5.1 shows some common flood types and their impact characteristics, along with implications for urban planning.

Figure 5.1: Coastal, Pluvial, and Fluvial Floods and Their Impact Characteristics



Source: Original for this publication.

Pluvial floods, including flash floods and urban floods, are among the most dangerous and costly types of floods affecting urban centers (De Almeida et al. 2016). Pluvial flooding, also known as surface water flooding, occurs when heavy rainfall overwhelms the drainage capacity of the local area. This type of flooding is caused by intense rainfall that cannot be absorbed by the ground or drained quickly enough. It often happens in urban areas due to the lack of adequate drainage and where impermeable surfaces like roads and pavements prevent water from soaking into the ground.

Unplanned urban expansion, weak land-use and building regulations, and lack of controls in land occupation can increase the risk of flooding in cities. As cities grow, natural areas like wetlands and floodplains are transformed into built-up areas. Environmental changes are driven by anthropogenic activity such as land-use changes, disruption of natural water flow patterns and dimensions, construction of flow regulation and hydraulic structures, and occupation of buffer strips, as well as natural phenomena like the alteration of weather patterns (including global variations through climate change, and localized UHI effects). The disruption of natural drainage patterns can exacerbate flood hazard and risk and significantly alter flow patterns, leading to more rapid and intense floods.

In many cases, flooding in cities results from the interaction of diverse flood types and additional hazards rather than from a single source. Identifying the compounding effects of various flood types in cities can be a difficult task, as interactions with the urban system and infrastructure may play a significant role. The precise evaluation of flood risk in urban areas is significantly hindered by the sensitivity of flood inundation to topographical variations and infrastructure interactions (De Almeida et al. 2016). Small changes in the elevation or topography of the land surface can significantly affect the dynamics, extent, and depth of flooding during a flood event. This sensitivity is particularly pronounced in urban areas where large areas are covered by impervious surfaces, such as paved roads, buildings, and urban drainage structures with limited capacity to convey runoff.

Flood hazard and risk maps are essential tools for urban planning, guiding flood-risk reduction strategies, and urban planning processes. Comprehensive flood hazard and risk assessments should integrate various flood types and their interactions, including riverine, coastal, flash, and pluvial floods, each requiring specific data and models. In developed areas, detailed flood-risk models are preferable. These typically rely on

hydraulic modeling to simulate flood characteristics, such as return periods, water depth, and flow velocity, and enable the use of depth-damage functions to estimate potential losses. In urban areas, even small differences in topography, land use, and infrastructure can significantly influence flood hazard and risk (photo 5.1). Accurate assessments depend on high-resolution elevation and infrastructure data. Urban flood hazard and risk assessment is a multiscale process and can require a progressive approach, beginning with a general-scale assessment to understand the overall flood-risk landscape and flag priority areas. Detailed modeling should be prioritized in high-risk areas, where understanding flow dynamics and infrastructure interactions, such as stormwater drainage systems, underground utilities, and buildings, is critical for effective planning and flood-risk management.

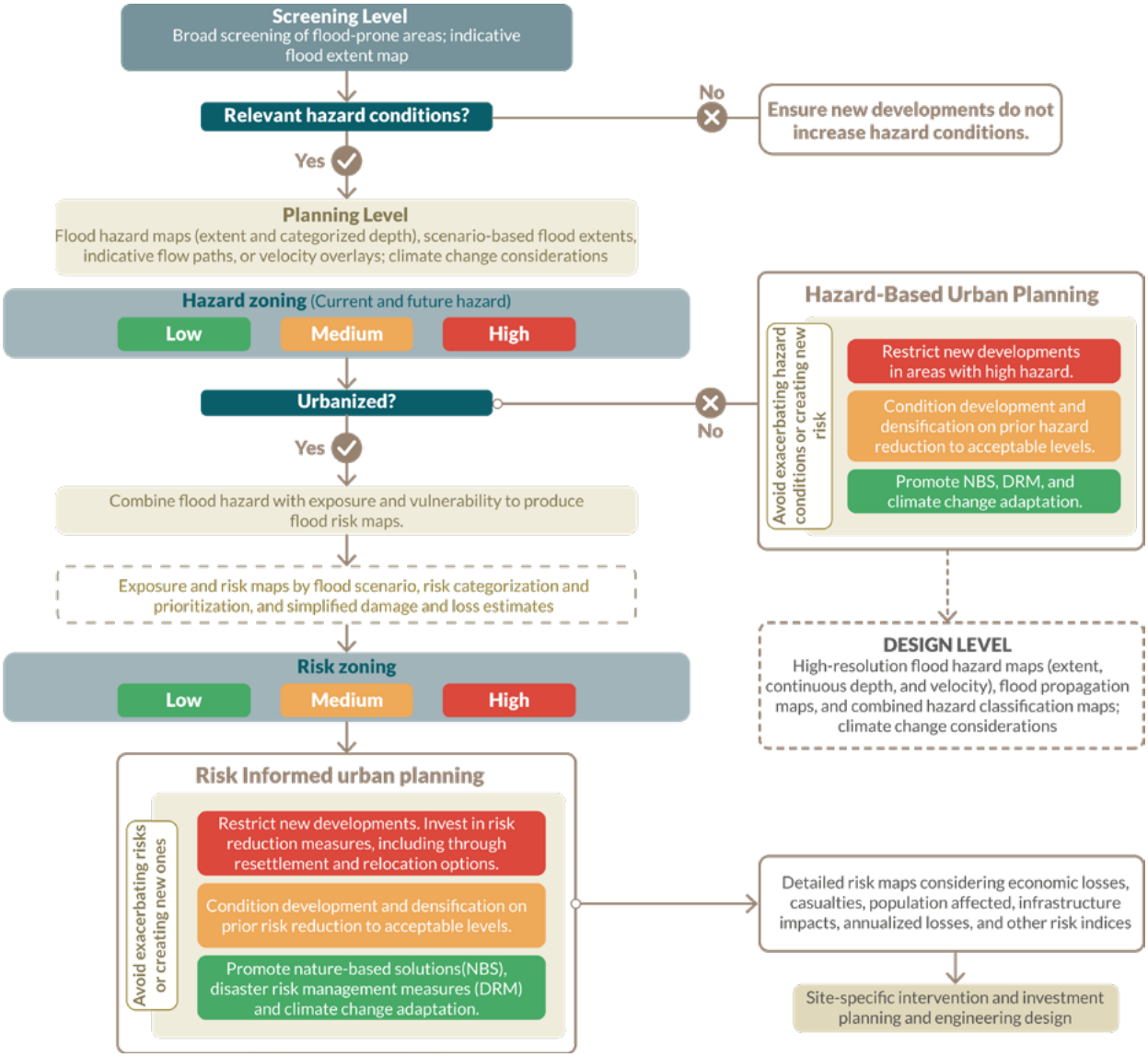
Photo 5.1: Water Level at the Flooded Abbey Mill in Tewkesbury, England



Source: © Philographer / Shutterstock.

Figure 5.2 and table 5.1 present the flood hazard and risk mapping process, highlighting key variables and decision points across three distinct assessment levels—screening, planning, and design[8]—each defined by its reference scale, purpose, methods, data needs, and outputs. These levels are directly aligned with the stepwise approach in the operational framework introduced in chapter 3, supporting a coherent progression from initial hazard screening to risk-informed planning. The framework also distinguishes between nonurbanized areas, where hazard mapping alone may inform spatial planning decisions, and urbanized areas, which require assessments incorporating exposure and vulnerability. This structure supports adaptive, fit-for-purpose planning and helps cities match analytical depth to their decision-making needs and resource availability.

Figure 5.2: Flood Hazard and Risk Mapping Flow Chart for Different Assessment Levels and Intended Applications



Source: Original for this publication.

[8]The screening, planning, and design levels presented in this framework conceptually align with the preliminary, strategic, and detailed assessment stages in the Urban Flood Risk Handbook (World Bank 2023), reinforcing methodological consistency. Urban Flood Risk Handbook: Assessing Risk and Identifying Interventions. 2023. Washington, D.C. World Bank Group. http://documents.worldbank.org/curated/en/099080123151036528.

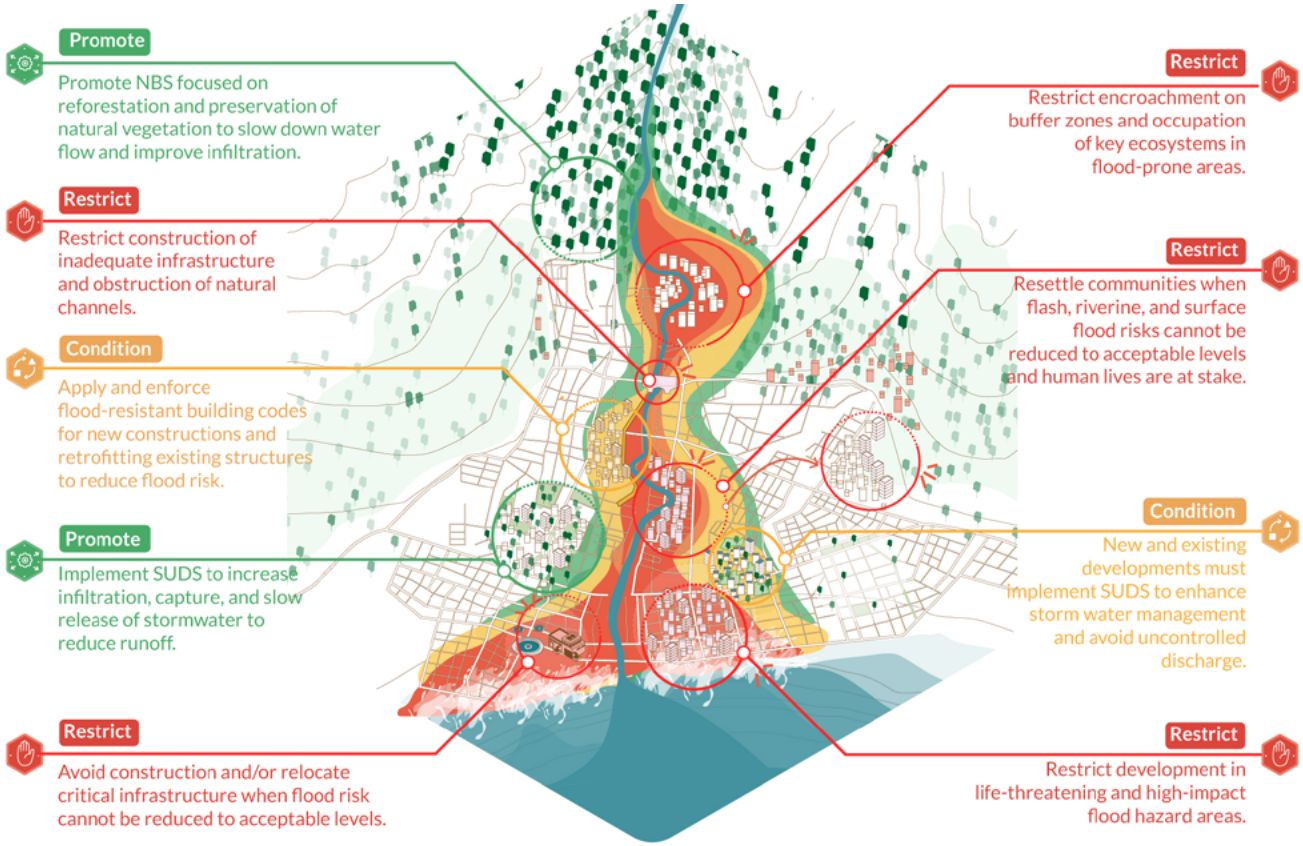
Table 5.1: Flood-risk Assessment Methods and Data Requirements by Scale and Level of Detail

Urbanized Area – Risk Assessment = F (Hazard, Exposure, and Vulnerability)							
Unurbanized Area – Hazard Assessment (Hazard Only) Complexity level							
Assessment level	**Key purpose**	**Methods**	**Data inputs**	**Main output (Hazard)**	**Exposure data and methods**	**Vulnerability data and methods**	**Main output (Risk)**
Screening level 1:100,000–1:25,000	Broad screening of flood-prone areas and high-level planning, identifying flood-prone zones or flood-risk hotspots requiring more detailed assessments	Historical flood footprint analysis, terrain-based susceptibility mapping	Coarse Digital Elevation Model (DEM, for example, 30 m), broad hydro-meteorological data, broad land use or land cover (to estimate runoff coefficients), historical flood data and footprints	Indicative flood extent maps (qualitative hazard zones), flood-prone area delineation susceptibility mapping	Aggregated exposure data (for example, population density grids, GDP per administrative unit, land-use classes), overlays of hazard zones with census or economic data, remote-sensing proxies	Omitted or assumed average vulnerability, may use basic fragility assumptions per land-use type	Qualitative or semiquantitative risk maps indicating population or assets in flood-prone zones, broad "hotspot" identification susceptibility mapping
Planning level reference scale: 25,000–1:5,000	Urban planning and prioritization, development controls, drainage improvements, guiding development and spatial planning away from high- and moderate-risk zones, prioritizing investments and flood-risk management options	Hydrological modeling (rainfall-runoff), hydraulic modeling, considers multiple event scenarios and climate change scenarios (for example, frequent, design, extreme floods like 10-, 100-, and 500-year)	Medium-resolution DEM (5–30 m), local rainfall intensity data and river flow statistics, land-use maps, primary drainage infrastructure (for example, canals and storm drains) in urban areas for pluvial modeling	Flood hazard maps (extent, categorized depth), scenario-based flood extents, indicative flow paths or velocity overlays	Disaggregated exposure, building footprints and counts, population distribution by district, locations of critical facilities, GIS-based overlays with hazard extents, counts of exposed assets per flood scenario	Vulnerability categories by asset type and quality, socio-economic indicators (for example, poverty index, social vulnerability index)	Exposure and risk maps per flood scenario, risk categorization and prioritization maps by zone, may include damage and loss estimations
Design level 1:5,000 or larger	Site-specific intervention and investment planning, engineering design, design of flood-risk reduction interventions (for example, levees, flood walls, and detention basins), building retrofitting, flood-proofing, and resettlement planning where risks cannot be otherwise reduced to acceptable levels	Advanced 2D or 3D hydraulic modeling with detailed hydrologic inputs; climate change scenarios; drainage networks explicitly included to simulate pluvial and surface-subsurface flooding; incorporates site-specific features like obstructions, roughness, and coupled sewer–surface flow	High-resolution DEMs (~1 m), detailed land use, local rainfall and hydraulic records, drainage infrastructure (pipes, manholes, and pumps), and site-specific features (building footprints, obstructions, surface roughness)	Indicative flood extent maps (qualitative hazard zones), flood-prone area delineation susceptibility mapping	Granular, asset-specific exposure data (for example, building use, structure type, floor elevation, replacement cost, and occupants); geolocated infrastructure and population demographics. Every significant asset and infrastructure in the area is catalogued.	Quantitative vulnerability assessment using intensity-damage curves, fragility functions, and social vulnerability indices; building-level analysis	Quantitative risk outputs, including economic losses, casualties, infrastructure downtime, population affected, and annualized risk by scenario; detailed risk maps per asset and indicator

Source: Original for this publication.
Note: 2D= two-dimensional; 3D = three-dimensional; DEM = digital elevation model; GDP = gross domestic product; GIS = Geographic Information System.

Flood-risk management measures include regulations like zoning, setback requirements, or density controls complemented with structural and nonstructural measures. Engineering interventions such as retention ponds, flow deflectors, sustainable storm water drainage systems, and so on, can be employed to reduce flood risk, while urban expansion should be guided by zoning regulations and land-use policies. Figure 5.3 illustrates different measures to address flood hazard and risk, tailored to the location along the basin, the level of hazard, and the degree of urbanization.

Figure 5.3: Risk-informed Planning Measures Along the River Basin



Source: Original for this publication.

Integrating flood-risk management into urban planning is essential for building resilient cities, especially in rapidly urbanizing regions that are vulnerable to climate impacts. Effective flood-risk management requires integrating flood-risk assessments, land-use planning, risk-informed infrastructure investments, and nonstructural measures to reduce existing and likely future risks.

5.1 Flash Floods

Flash floods are characterized by high-velocity and powerful currents with high destructive potential, often carrying debris and mud over their path, uprooting trees, and devastating structures (photo 5.2). Flash floods are triggered by intense rainfall over steep terrain and can be further intensified by heightened runoff resulting from extensive impermeable surfaces. The rapid-moving currents have the potential to initiate and propagate mud or debris flows. Flash floods can also be triggered by the sudden release of water from a dam or levee. Unintentional water retention or damming by hydraulic and transport infrastructure with inadequate cross-sections, debris, and landslides can also lead to a dam-break phenomenon and trigger flash floods.

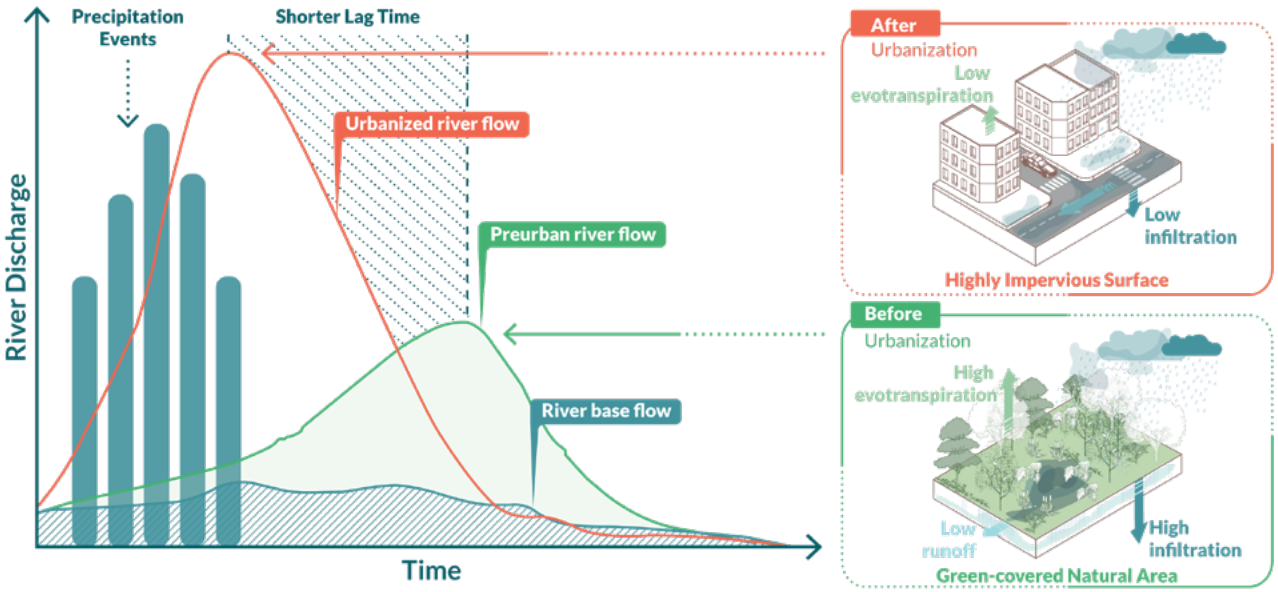
Photo 5.2: The Aftermath of the flash flood, in Donggala, Indonesia, 2025



Source: © hahahihi93 / Shutterstock

Urbanization increases impervious surfaces, reducing infiltration and amplifying runoff, which heightens flash flood risks (figure 5.4 and table 5.2). This increased runoff shortens lag time and raises flood peaks, leading to high-velocity flows that can carry debris, uproot trees, and damage infrastructure. Flow control measures, such as permeable surfaces, green infrastructure, and retention basins, help mitigate these hazards by enhancing infiltration, reducing runoff, and slowing floodwaters, ultimately lowering risks to lives and property in urban areas.

Figure 5.4: Effects of Urbanization and Flood Control Measures on Flow Velocity



Source: Adapted from Ding et al. 2022.

Table 5.2: A Summary of the Characteristics and Impacts of Flash Floods

Characteristics and Impacts

Flash floods are highly destructive and can lead to loss of life, damage to property, and infrastructure failures. Their rapid onset offers little or no warning.

Parameters most related to the severity of the impacts: Flow rate and peak discharge, flow depth, velocity, duration, and sediment and solid content.

Triggers

Intense precipitation or sudden release of water from a dam or levee.

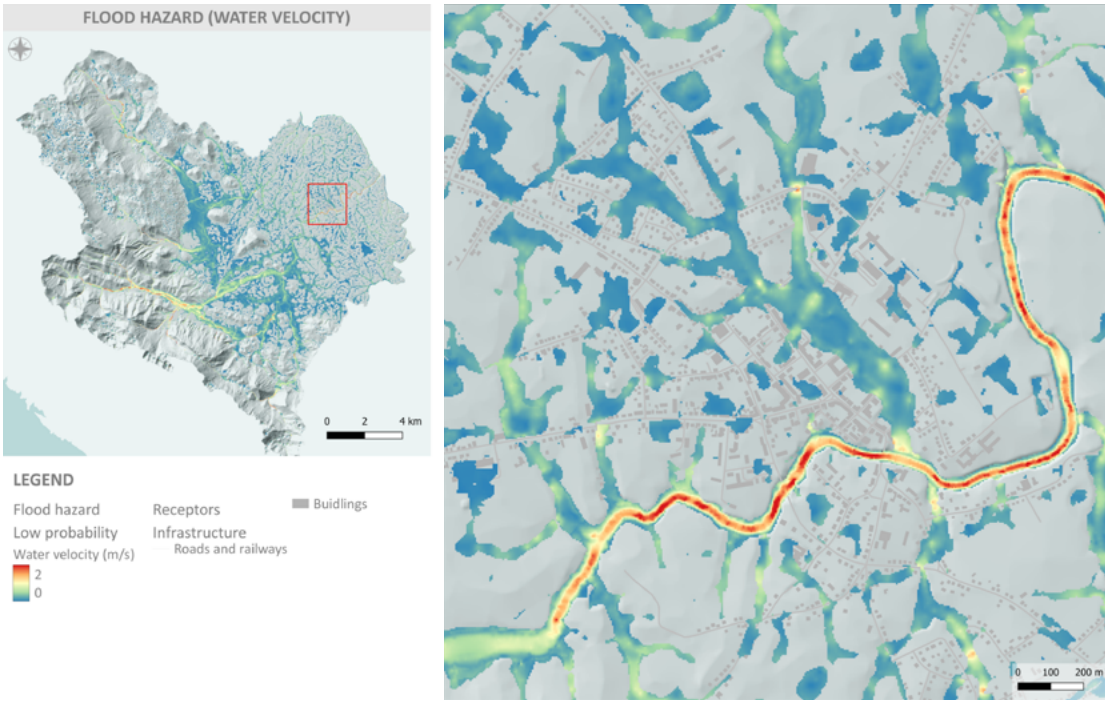
Aggravating factors

- Steep slopes, deforestation, and environmental degradation leading to increased surface runoff.
- Degradation of and encroachment upon natural drainage systems.
- Changing rainfall patterns: More intense precipitation due to climate change and urban heat island (UHI) effects.
- Natural factors such as steep topography, narrow valleys, and compact soils with low absorption capacity can exacerbate flash flooding. Areas with already saturated ground from previous rainfall are particularly vulnerable.
- Urbanization and impervious surfaces amplifying runoff and reducing infiltration.
- Obstruction of natural channels due to inadequately designed and constructed infrastructure, resulting in dam-break phenomenon.

Hazard and risk zoning

A flash flood hazard map focuses on rapidly occurring and localized flooding events caused by intense rainfall or sudden release of water (figure 5.2.1). It factors in terrain, soil properties, land cover, and rainfall patterns to estimate flood extent and parameters such as depth, velocity, and duration. Flash flood assessments support the understanding of the dynamics of flash flood propagation and the identification of areas potentially affected by flash floods.

Figure 5.2.1: Examples of a Flash Flood Hazard Map and a Flow Velocity Hazard Map, Croatia



Source: Krvavica 2023.

Due to the rapid onset (typically less than six hours) and potentially severe impacts of this type of flood on lives and property, urban plans must restrict development in high-hazard areas and relocate people and infrastructure in high-risk areas where risk cannot be reduced. Where hazard and risk are moderate or low, new development and the continued presence of existing settlements and infrastructure should be contingent upon implementation measures that achieve acceptable risk levels.

For instance, new development in moderate-risk areas must be conditioned to the implementation of flood protection and risk reduction measures such as: flow control infrastructure (retention ponds, gabion walls, and weirs) placed along or across riverbanks, streams, or slopes to dissipate the energy of flowing water, thereby reducing velocity and controlling erosion; flow deflectors, which are structures placed in rivers or streams to redirect the flow of water and reduce its velocity, often made of concrete or large rocks; and channel modifications to alter the shape or alignment of river channels with the aim of reducing flow velocity by increasing friction and dissipating energy.

Likewise, stormwater management, minimizing impervious surfaces, and discharge control measures can reduce the risk of flash floods to a certain extent. Cities should promote environmentally friendly actions by incentivizing green and resilient urban growth, using nature-based solutions (NBS),while ensuring universal access to early warning systems (EWS) and emergency preparedness and response (EP&R) services.

5.2 Pluvial Floods

Pluvial floods, often known as surface water floods, arise when the capacity of an urban drainage system is exceeded, resulting in the overflow of water onto roads and into adjacent buildings (photo 5.3). It can be exacerbated by poor drainage, stormwater management, solid waste management (clogging of drainage systems), and land-use practices.

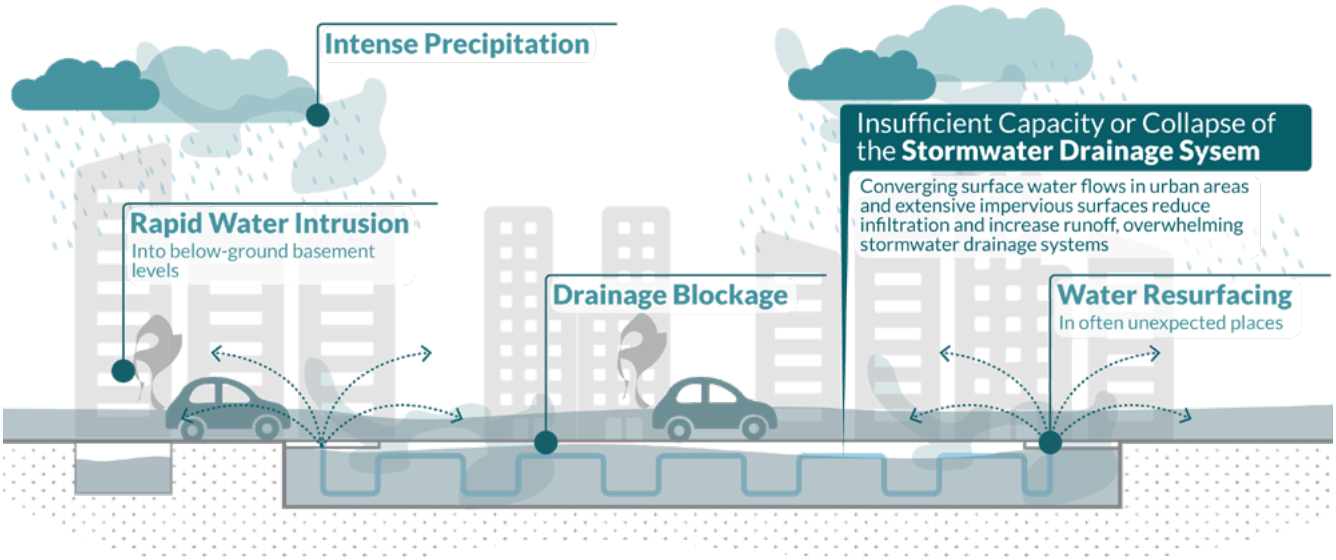
Photo 5.3: The Aftermath of Floods in Kinshasa, Democratic Republic of Congo, 2024



Source: © Mulala / UNICEF.

The causes of pluvial floods are multifaceted, and different flood sources may converge—often exacerbated by disruptions of the natural landscape and water flows. Intense precipitation and confluence of water flows in urban centers may lead to drainage and sewer systems failure if they lack the capacity to handle the water flow, sometimes leading to water resurfacing in unexpected places (figure 5.5 and table 5.3).

Figure 5.5: Illustration of Pluvial Flood and Urban Drainage System Collapse



Source: Original for this publication.

Table 5.3: A Summary of the Characteristics and Impacts of Pluvial Flooding

Characteristics and Impacts

Pluvial flooding can disrupt transportation and utility services, damage infrastructure and property, affect economic businesses, contaminate water sources, and lead to waterborne diseases.

Parameters most related to the severity of the impacts: Flood depth, flow velocity, and flood duration.

Triggers

Intense precipitation and confluence of water flows in specific spots of urban areas.

Aggravating factors

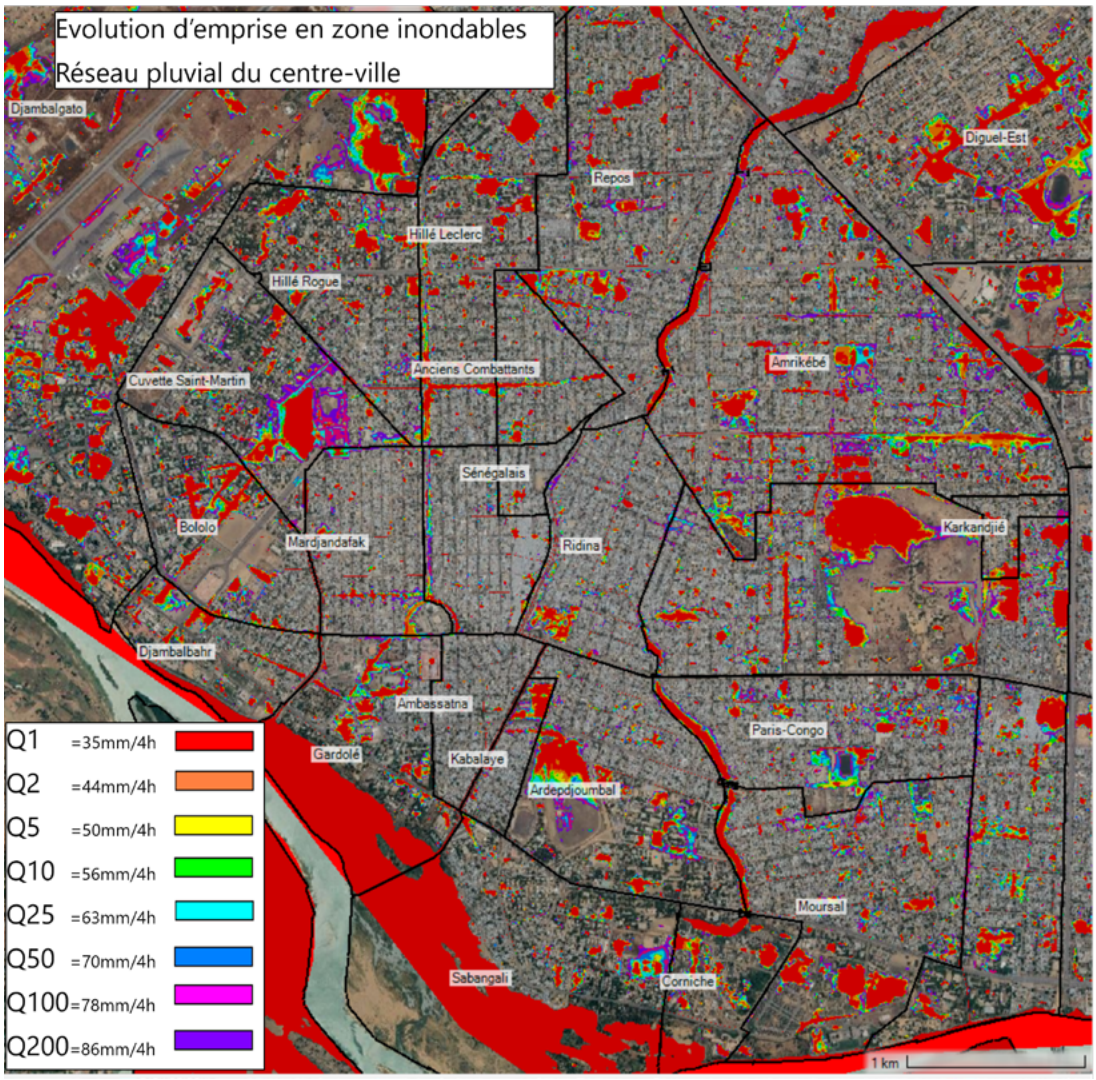
- Changing rainfall patterns: More intense precipitation due to climate change and urban heat island (UHI) effects
- Encroachment upon natural drainage systems
- Poor drainage systems and improper waste disposal
- Urbanization and impervious surfaces amplifying runoff and reducing infiltration

Hazard and risk zoning

Urban flood hazard depends on factors such as rainfall, stormwater drainage capacity, urban layout, and elevation data to identify flood-prone regions within cities (figure 5.3.1). Urban flood hazard assessments are essential for urban planners to implement effective stormwater management strategies and reduce flood impacts on infrastructure and communities. Pluvial floods, caused by

intense rainfall overwhelming drainage systems, are typically assessed at small scale, such as citywide or even localized areas within a city. At these scales, flood models are employed to simulate surface water behavior, providing valuable data on water depth, velocity, and inundation patterns during varying rainfall intensities (Ward et al. 2020).

Figure 5.3.1: A Flood Hazard Map for N'Djamena City Center in Chad



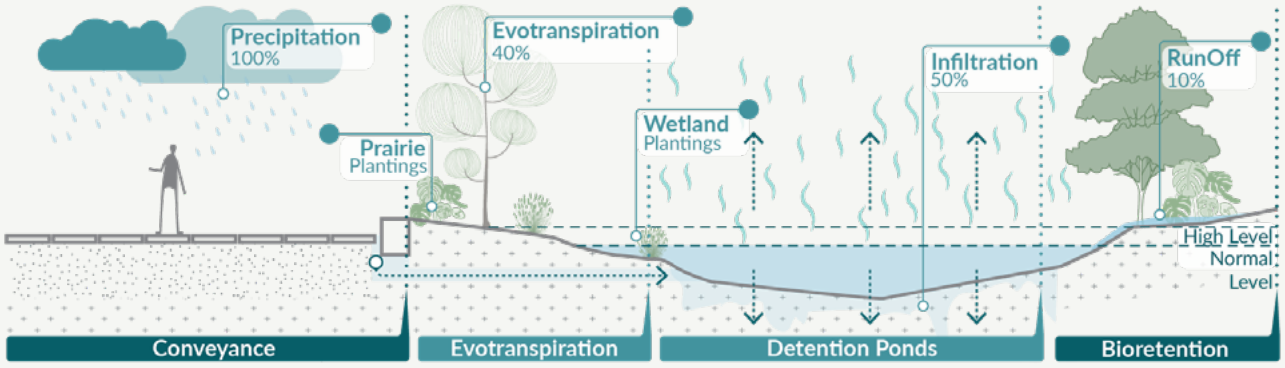
Source: Egis 2023.
Note: The map shows changes in flooded areas as a function of the rainfall return period under current conditions.

To prevent and reduce pluvial floods, urban plans can implement sustainable urban design practices, preserve natural drainage systems, improve stormwater management by enhancing drainage, and flow control infrastructure to meet present and future demand, and develop SUDS (box 5.1). Controlling high densities in low-laying areas must also be a priority, as is implementing essential measures like EWS and EP&R services to help prevent loss of life and assets.

Box 5.1:
Sustainable Drainage Systems

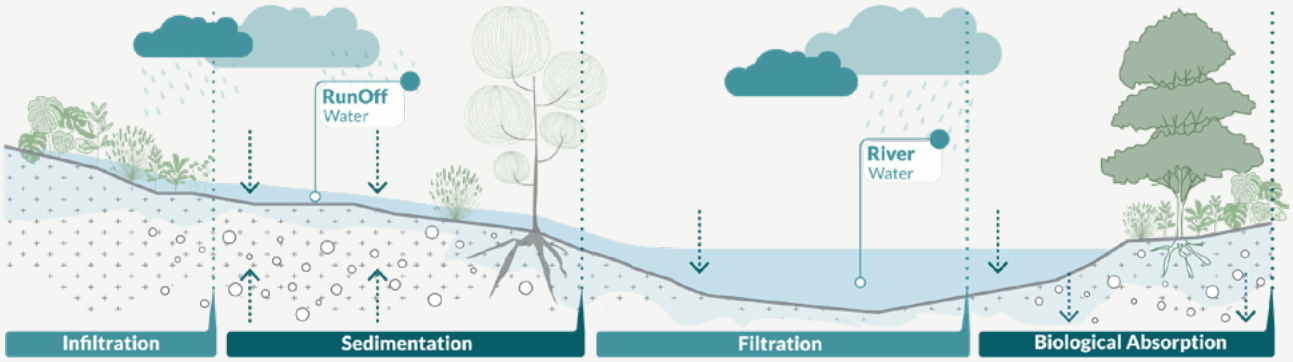
Sustainable drainage systems (SUDS) are an innovative approach to the sustainable management of surface water. These address **water quantity** to prevent flooding, **water quality** to reduce pollution of runoffs, protect and expand **biodiversity** in urban areas, and improve green and blue infrastructure to increase the **quality of life in cities** and promote more direct interaction with nature. SUDS integrate the water cycle in cities in a harmonious way with different resiliency targets and through a variety of urban design strategies, as outlined in figures B5.1.1 to B5.1.7.

Figure B5.1.1: Reduction of Flooding by Retaining and Gradually Releasing Surplus Water through Quality Control Mechanisms



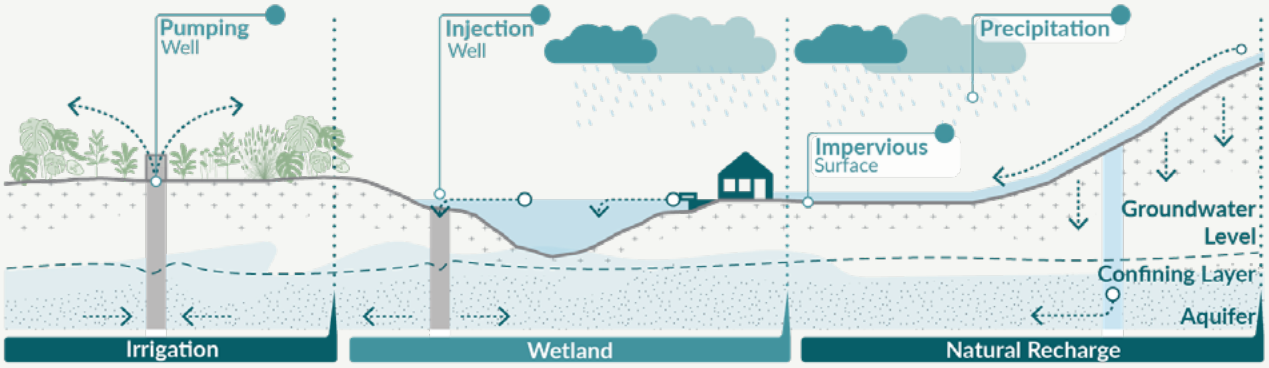
Source: Original for this publication.

Figure B5.1.2: Improvement of Runoff Water Quality through Environmentally Friendly Strategies



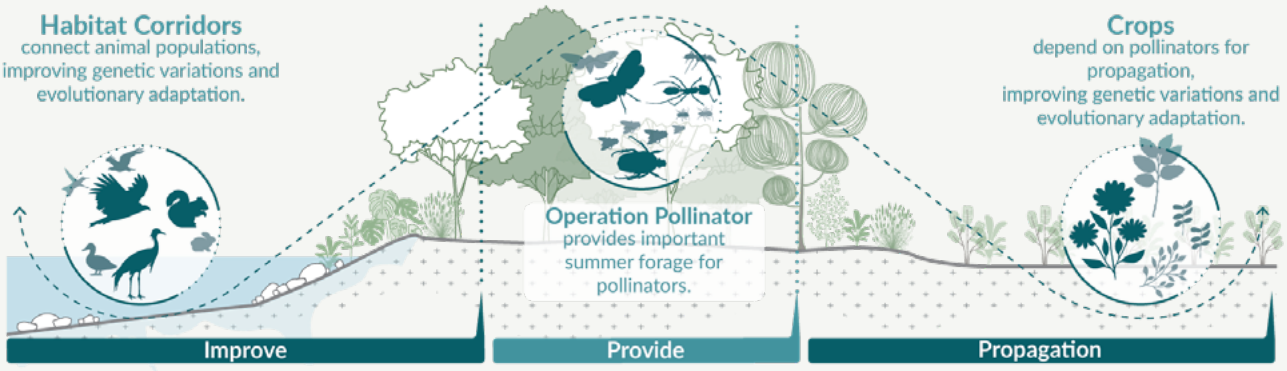
Source: Original for this publication.

Figure B5.1.3: Natural Recharge of Aquifers and Groundwater



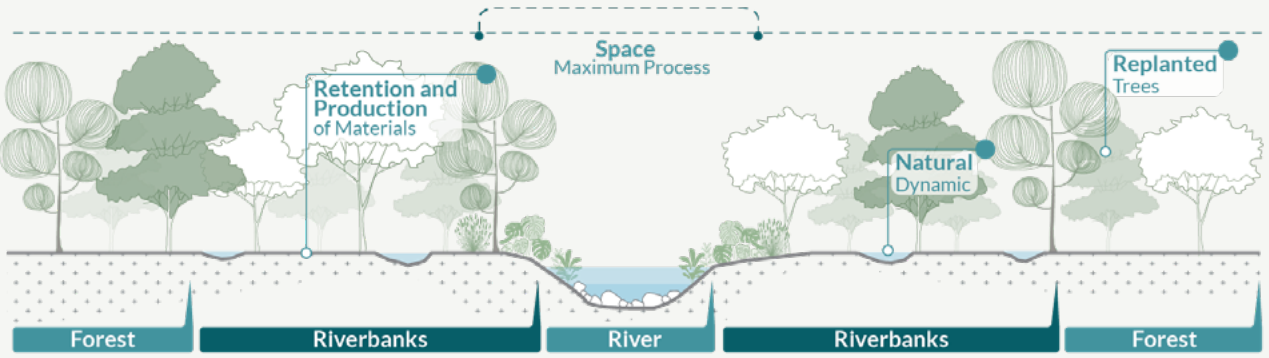
Source: Original for this publication.
Note: This ensures the natural equilibrium of water reservoirs and stores water for irrigation during dry seasons.

Figure B5.1.4: Increase of Environmentally Friendly Habitats to Protect Biodiversity and Improve the Quality of Life in Urban Areas



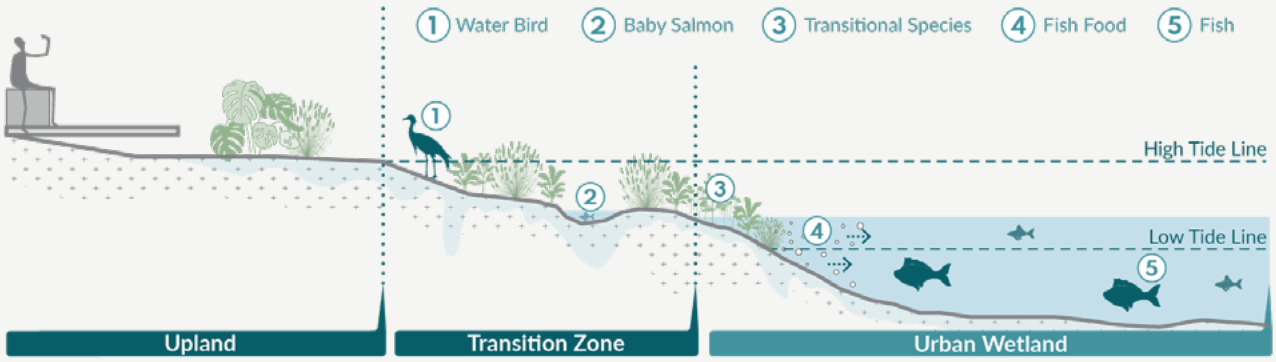
Source: Original for this publication.

Figure B5.1.5: Renaturalization of Riverbanks and Coastal Areas to Preserve the Ecosystem Balance



Source: Original for this publication.

Figure B5.1.6: Restoration of Urban Wetlands to Benefit from Their Natural Water Storage and Flood Regulation Functions



Source: Original for this publication.

Figure B5.1.7: New Green Spaces Designed to Increase Resilience and Biodiversity in Highly Urbanized Areas



Source: Original for this publication.

5.3 Riverine Floods

Riverine floods occur when a river overflows its banks during high discharge and inundates the surrounding land (photo 5.4 and table 5.4). Fluvial floods within urban environments exhibit distinct characteristics due to the interplay between natural watercourses and urban development. The urban landscape, characterized by impermeable surfaces, contributes to increased flow velocities and greater discharge into river systems during storms, ultimately intensifying flood risks. Moreover, urbanization may result in altered flow pathways, channelization of rivers, and the establishment of complex drainage systems.

Photo 5.4: Aerial view of flooded houses with dirty water of Dnister river, Ukraine, 2020



Source: © Bilanol / Shutterstock.

Table 5.4: A Summary of the Characteristics and Impacts of Riverine Flooding

Characteristics and Impacts
Riverine floods occur when rivers overflow their banks due to excessive rainfall, rapid snowmelt, or the failure of natural or man-made barriers, such as levees or dams. These floods are generally predictable and develop over days or weeks, allowing critical lead time for preparations and evacuations. Unlike flash floods, which occur suddenly, riverine floods often have a slow onset and tend to affect extensive areas along floodplains. The flooding can persist for several days or even weeks, resulting in widespread and prolonged disruptions. Their defining characteristics include predictability, the extensive geographical reach of inundation, and the prolonged duration of flooding. While riverine floods are often anticipated, their impacts can still be devastating, causing significant damage to infrastructure, agriculture, and communities. The advance warning they provide offers opportunities for mitigation and response, but the scale and duration of these events can pose considerable challenges for recovery efforts and lead to significant social and economic impacts. **Parameters most related to the severity of the impacts:** Flood extent, depth, velocity, and duration.

Triggers

Riverine floods are primarily triggered by intense precipitation, where prolonged or heavy rainfall overwhelms the hydraulic capacity. Rapid snowmelt during warming events also contributes, releasing large volumes of water into rivers. Additionally, upstream flooding in large catchment areas can exacerbate downstream conditions. Structural failures of dams, levees, or embankments can suddenly release stored water, causing severe flooding. Prolonged monsoons, cyclones, or El Niño or La Niña events can also intensify rainfall or snowmelt.

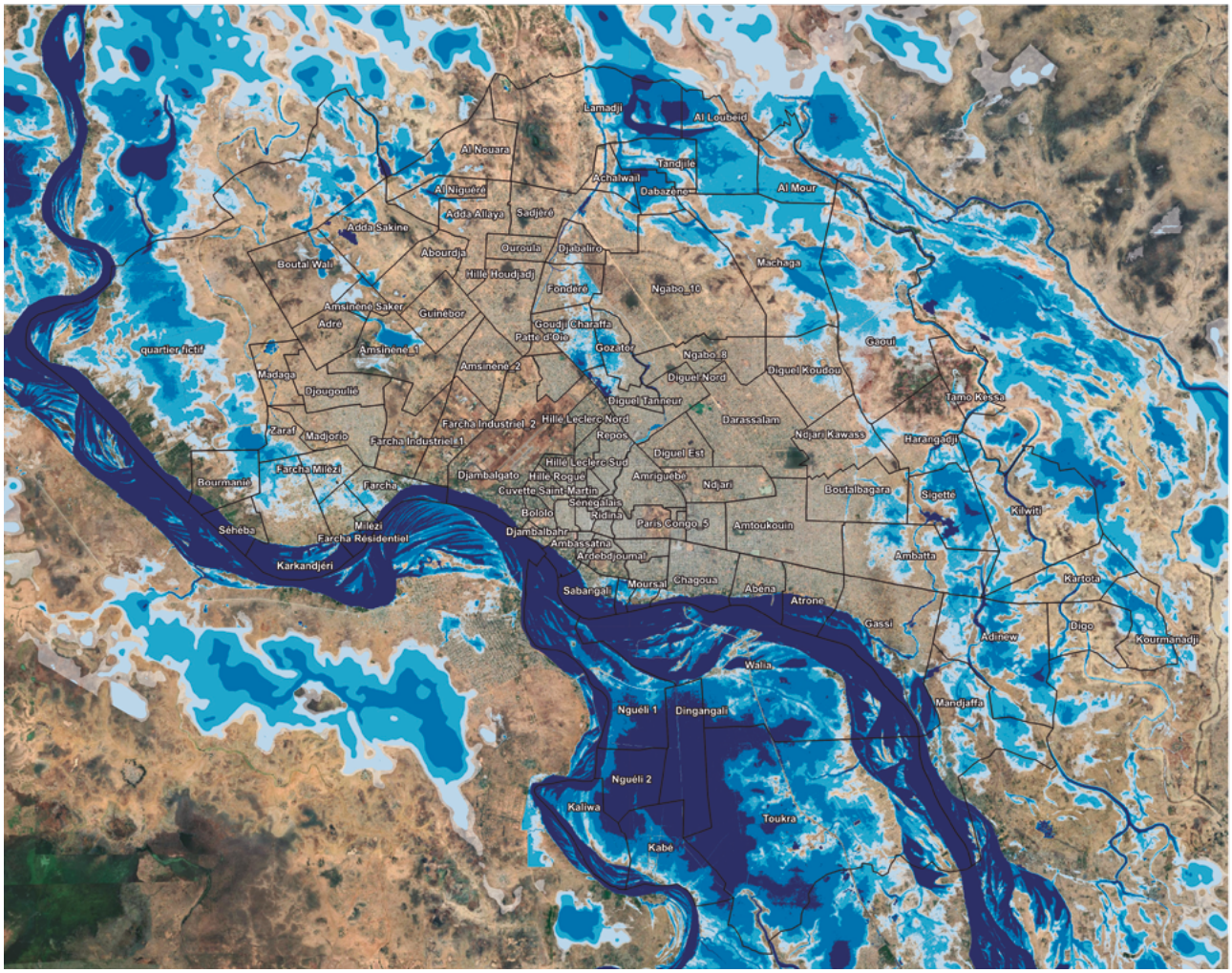
Aggravating factors

- Environmental degradation, such as the loss of wetlands and forests, reduces the land's capacity to absorb water and slows down water flow, increasing runoff and sedimentation.
- Topographical features like low-lying floodplains or steep riverbanks concentrate water in specific areas, while saturated soils from prior rainfall limit water absorption.
- The urban landscape, characterized by impermeable surfaces, contributes to increased flow velocities and greater discharge into river systems during storms, ultimately intensifying flood risks.
- Urbanization may result in altered flow pathways, riverbank encroachment, channelization of rivers, and the establishment of complex drainage systems.

Hazard and risk zoning

For the assessment of riverine floods, conducting thorough hydrological and hydraulic analyses is crucial to determine river discharge and understand inundation patterns. The riverine flood hazard map highlights areas prone to flooding along river channels, considering factors like rainfall intensity, catchment characteristics, and river flow rates (figure 5.4.1). Riverine hazard maps delineate flood-prone zones and potential inundation extents, frequency and spatial distribution of flood hazard indicators, and flooding parameters, such as flood depth, flow velocity, and duration.

Figure 5.4.1: A River Flood Hazard Map of the Chari and Logone Rivers in N'djamena, Chad, for a 100-Year Flood (2023 Status)



Source: Egis 2024.

Urban planning in riverine flood-prone areas should focus on zoning and land-use regulations that establish setback distances and restrict or guide construction in floodplains, depending on the hazard and risk level. Effective strategies include riparian buffer zone protection and floodplain zoning, establishment of green and gray measures to reduce flood impacts, and enforcement of appropriate building regulations to ensure that infrastructure can better withstand flooding. Additionally, urban planners should consider the dynamic nature of meandering rivers and their tendency to shift course over time. This enables them to incorporate meander migration considerations and setback regulations for infrastructure and development, allowing rivers space to naturally migrate within their floodplains. These measures should be supported by regulations that promote NBS for the ecological restoration of riverbanks and the gradual relocation of

buildings and infrastructure occupying areas where riverine flood cannot be reduced to acceptable levels. While relocation processes and risk-reduction measures are carried out, enhancement of EWS and EP&R services must be prioritized in high-risk areas.

The case presented in box 5.2 shows how achieving good coordination among flood management strategies and spatial planning allows for a balanced combination of structural and nonstructural solutions. A well-structured intervention ensures flood protection, while promoting community engagement, improving information systems, and strengthening institutional capacities.

Box 5.2:

Flood Protection in the Odra River Basin, Poland

Several factors have contributed to altering the natural downstream river flow in the upper Odra River basin, including extreme precipitation aggravated by climate change; land-use regulations enabling development in low-lying areas; gradual construction of flood regulation infrastructure, such as dams, lochs, and dikes that shortened the length of the river by 16 percent (from 1,020 km to 854 km); and levees and bridges that reduced the floodplain width (Zaleski et al. 2024). Of the 12 major floods recorded in the 20th century, the July 1997 flood was the most devastating. In total, 54 people lost their lives; 700,000 homes were flooded; 37,000 buildings, 866 bridges, and 2,000 km of roads were damaged; and 129 km of dikes were destroyed. This extreme event resulted in economic losses of approximately US$2.3 billion (World Bank 2021b).

Aiming to protect people, properties, and jobs from flooding, the government of Poland launched the Oder 2006 Program in 2001, involving integrated measures for flood mitigation, flood-risk management, inland navigation, spatial planning, hydropower production, and environmental conservation. With the support of the World Bank, the European Union (EU) Cohesion Fund, and other institutions, two large projects were implemented: the Racibórz Dry Polder and the improvement of the Wrocław Floodway System. These projects were complemented with the strengthening of institutional capacities in flood management and the installation of a flood forecasting system (World Bank 2021b).

The Racibórz Dry Polder, a reservoir designed to retain around 185 million m3 of flood water, is located on the upper Odra River (photo B5.2.1). When the project began, 70 percent of the polder's 2,630 hectares were used for agricultural purposes, and the area was inhabited by 260 households (689 people) distributed in two villages (Zaleski et al. 2024). The project included a resettlement plan that included several options, such as financial compensation for land and property, provision of land or property, or a combination of both. Existing businesses were relocated to neighboring areas, and the land-for-land option allowed farmers to resume their activities elsewhere.

Photo B5.2.1: Racibórz Dry Polder in the Odra River, 2025



Source: © Foto Franek / Shutterstock.

Additional investments in the modernization of the Wrocław Floodway System focused on improving dikes, increasing the capacity of both hydraulic structures and flood bypass canals. In total, this project covered a 20,250-meter stretch of the river within the boundaries of Wrocław. Nonstructural interventions encompassed enhancing capacity for system operation and maintenance and updating water management plans, including the improvement of the flood early warning system (EWS). During the heavy rainy season of September 2024 that caused catastrophic flooding in Central Europe, the interventions proved effective, saving more than 2.5 million residents of the Polish provinces of Silesia, Lower Silesia, and Opolskie from harm (Fusiek 2024), as predicted in hydraulic models.

In addition to the protection of life, property, infrastructure, and jobs, the economic benefits of the flood protection project have been appraised. Estimates presented by Yu (2019) show that the nearly €500 million invested in Wrocław would avoid expenditures of nearly US$2 billion in damages if a flood with the magnitude of the 1997 event should happen again.

Further analysis of indirect benefits for urban development reveals that in addition to increasing the quality of life and tourism in the city, land value in previously flood-prone areas has grown faster than in nonflooded areas. Likewise, real estate investments have grown in the areas affected by the flood protection project, where new spatial plans have been approved, possibly increasing property tax collection.

5.4 Coastal Floods

Coastal floods originate from both slow-onset and extreme events, which may also have compounding effects. They can cause saltwater inundation and saltwater intrusion in coastal areas. Coastal floods may result from storm surges associated with cyclones and storms, tsunamis, high tides, or extreme swells—all of which are being made worse by rising sea levels. The consequences of coastal flooding are wide-ranging, affecting both natural ecosystems and the built environment. Impacts include infrastructure damage, corrosion and weakening of structures, erosion, loss of habitat, disruption of services and livelihoods, and contamination of freshwater resources through saltwater intrusion (photo 5.5).

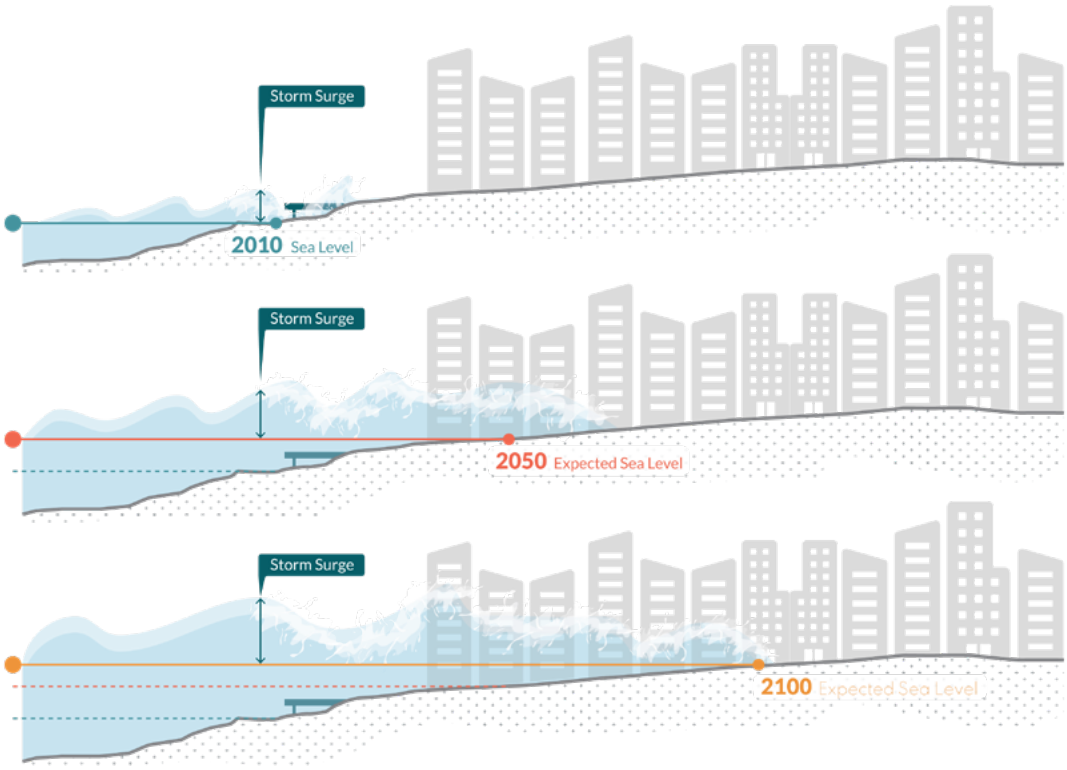
Photo 5.5: Coastal Flood in New Jersey as an effect of Hurricane Sandy, 2012



Source: © Rawpixel / Shutterstock

Figure 5.6 illustrates how coastal flood risk is expected to increase over time under climate change scenarios. It shows the progressive inland migration of the floodplain between 2010, 2050, and 2100 as sea levels rise and storm surges intensify. The graphic highlights how previously safe areas may fall within future flood zones, posing increasing risks to existing and planned development, infrastructure, and ecosystems. Anticipating these changes is critical to avoid locking in exposure and to guide resilient coastal development that reflects acceptable levels of risk under future climate conditions (table 5.5).

Figure 5.6: Coastal Flood Risk Under Current and Future Climate Projections



Source: Original for this publication.

Table 5.5: A Summary of the Characteristics and Impacts of Coastal Flooding

Characteristics and Impacts

Coastal floods have significant and diverse impacts on both natural ecosystems and the built environment, including property damage, corrosion, and structural issues, disruption of businesses and services, impacts to coastal ecosystems, erosion, and saltwater intrusion, which can affect freshwater sources and agricultural land. These events can also accelerate habitat degradation and harm biodiversity in affected regions.

Triggers

Coastal floods are triggered by a combination of factors, including sea level rise, storm surges, tsunamis, extreme swells, and high tides. Rising sea levels, caused by the thermal expansion of water and melting glaciers, increase the baseline for flood risks. Storm surges, often associated with tropical cyclones or hurricanes, push seawater onto land, causing sudden and severe flooding. Tsunamis, generated by undersea earthquakes or volcanic activity, bring catastrophic inundation. Heavy rainfall, particularly during high tides, compounds these risks by overloading natural and artificial drainage systems.

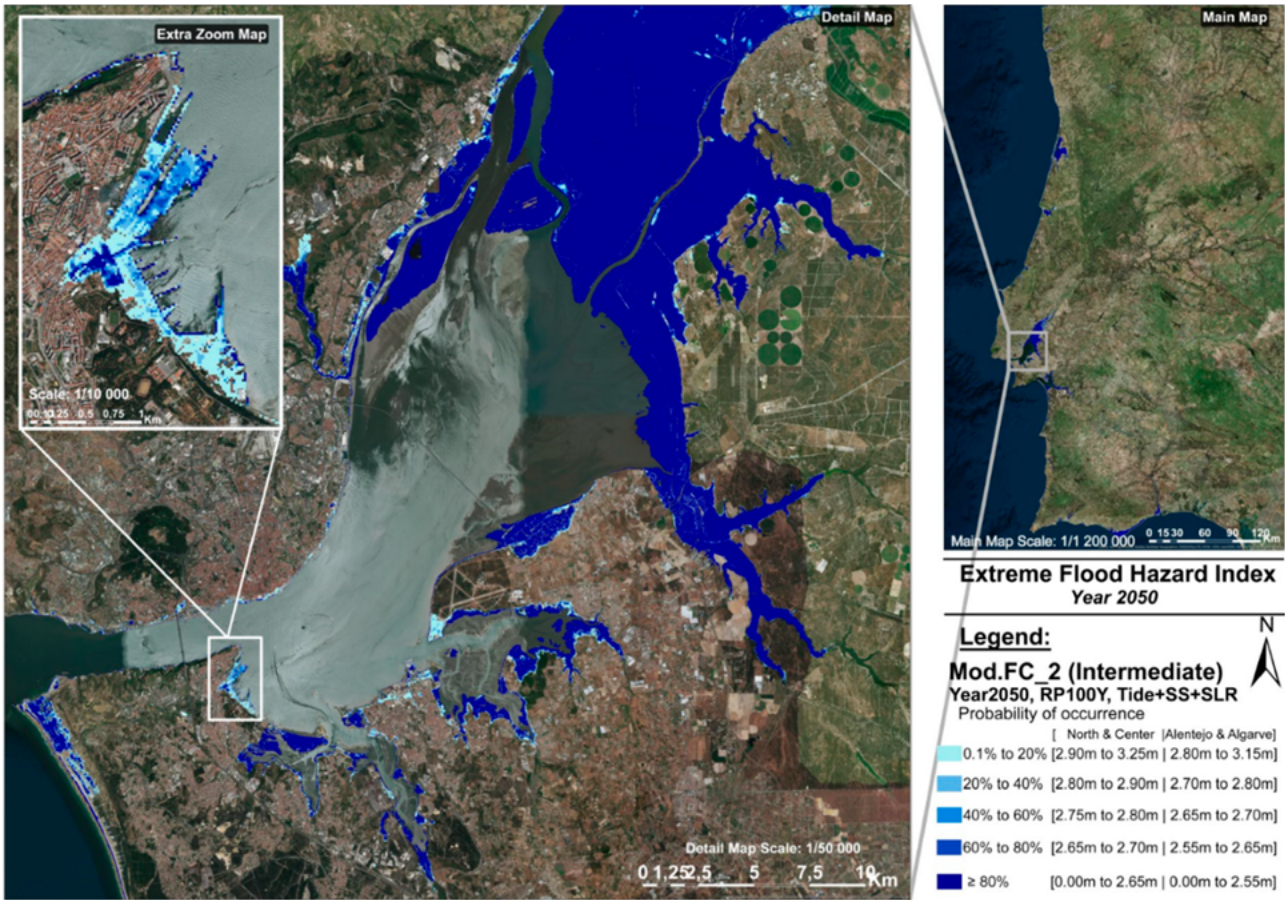
Aggravating factors

- Natural factors such as subsidence (where the elevation of land decreases due to natural compaction or extraction of groundwater) and loss of natural coastal barriers like mangroves, dunes, and coral reefs can aggravate coastal flooding.
- Coastal erosion, often accelerated by natural wave action, increases flood exposure.
- Climate change driven by human activity further intensifies coastal flooding through sea-level rise and more frequent and severe storms.
- Poor drainage systems as well as human activities, such as the destruction of natural barriers through land reclamation or deforestation, can significantly worsen coastal flooding impacts.

Hazard and risk zoning

The coastal flood hazard map addresses flooding along coastlines due to factors like tidal fluctuations, storm surges, and sea-level rise (figure 5.5.1). These maps incorporate data on coastal topography, tidal patterns, wave dynamics, and climate projections to predict both present and future flood risks.

Figure 5.5.1: Example of Portuguese Coastal Flooding Extreme Scenarios for 2050 Sea-Level Rise and 100-Year Return Period

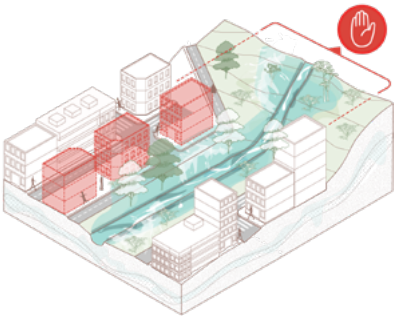
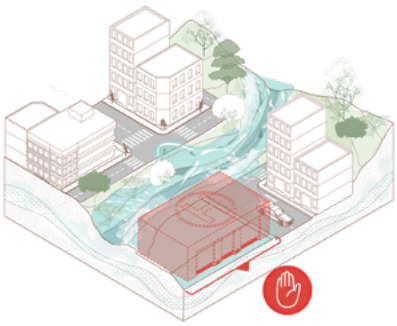


Source: Antunes, Rocha, and Catita 2019.

Coastal cities, especially those located in cyclone-prone regions, need robust coastal flood protection infrastructure like seawalls, levees, and elevated structures. Additionally, they should consider the retreat and relocation of critical infrastructure and vulnerable communities from high-risk areas. Zoning and land-use regulations should establish restrictions and conditions for new developments along the shoreline. Finally, cities must promote the restoration and conservation of ecosystems that act as natural barriers, sustainable drainage, and efficient dewatering systems. Tables 5.6 to 5.8 summarize examples of RCP measures to reduce flash, pluvial, riverine, and coastal flood hazards and risks to achieve more livable and resilient cities.

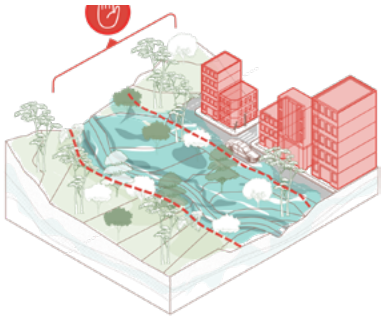
Table 5.6: Examples of "Restrict" Measures for Flood-risk-informed Urban Planning

Restrict: Applies when hazard and risk levels are unacceptably high and cannot be reduced to acceptable levels through feasible, cost-effective measures.

Undeveloped zones – Hazard-based planning		
Restrict development in life-threatening and high-impact flood hazard areas.	Avoid new developments and the construction of critical infrastructure when flood hazard cannot be reduced to acceptable levels.	Restrict development in coastal zones when risk cannot be reduced to acceptable levels, accounting for current and projected sea-level rise and coastal erosion.
		
Avoid construction of inadequate infrastructure and obstruction of natural channels that could lead to infrastructure failure and/or a dam-break phenomenon.	Restrict or control densification in low-lying areas when risk cannot be reduced to acceptable levels and human lives are at stake.	Restrict urbanization along high-velocity drainage pathways.
		

Undeveloped zones – Hazard-based planning

Restrict encroachment on buffer zones and occupation of key ecosystems in flood-prone areas.



Restrict development in key coastal protection ecosystems to preserve natural flood buffers.



Protect swamps and natural groundwater recharge zones to preserve infiltration and avoid major land alteration and soil sealing.



Developed zones – Risk-based planning

Resettle communities and relocate critical infrastructure when flood risks cannot be reduced to acceptable levels and human lives are at stake.



Restrict uncontrolled stormwater discharge into flash-flood-prone rivers and channels.



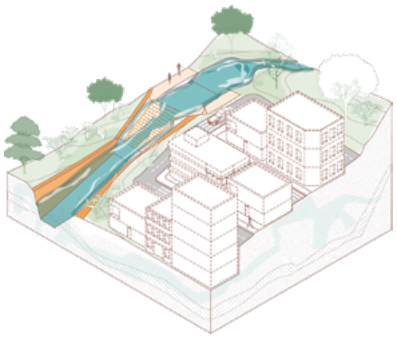
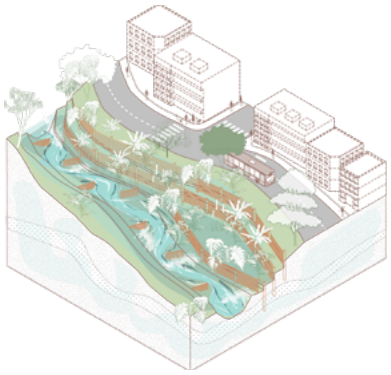
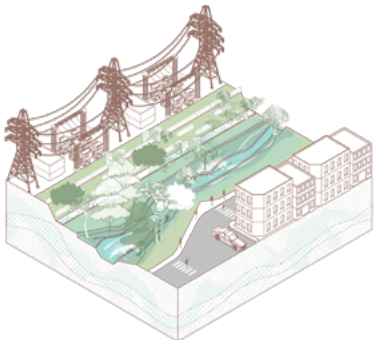
Resettle communities and critical infrastructure when coastal risks cannot be reduced to acceptable levels and human lives are at stake.



Source: Original for this publication.

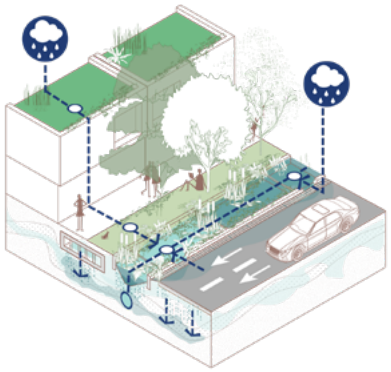
Table 5.7: Examples of "Condition" Measures for Flood-risk-informed Urban Planning

Condition: Applies where hazards or risks are relevant but can potentially be reduced to acceptable levels through appropriate planning, design, and construction practices.

Hazard-based planning – Undeveloped zones		
Condition new developments on the implementation of flood-protection and hazard-reduction measures such as flood-mitigation infrastructure, flow deflectors, and channel modifications.	Allow new developments with upstream and river-channel green and gray infrastructure to control water flow and reduce flood hazard to acceptable levels.	Design and build new structures with flood-protection and flood-proofing (wet and/or dry) features, following appropriate standards to minimize potential flood damage.
		
Condition densification on the design and construction of infrastructure with appropriate setbacks and resilience standards to prevent increase of flood risks downstream.	Allow new development only if measures to reduce risk to acceptable levels (for example seawalls, levees, and elevation) are implemented.	Allow critical infrastructure in high-risk zones only when no viable alternative location exists, and strictly contingent on the implementation of robust flood-protection and risk-reduction measures to ensure safety, functionality, and resilience.
		

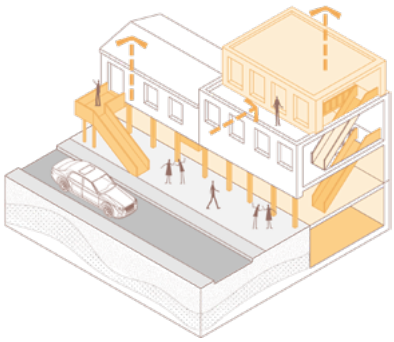
Hazard-based planning – Undeveloped zones

Implement sustainable drainage systems (SUDS) and appropriate stormwater management systems.

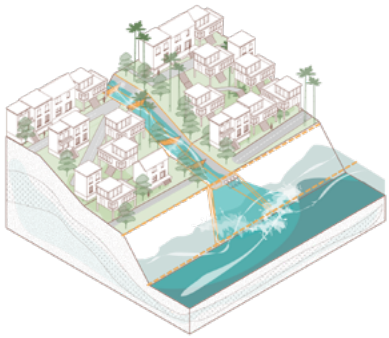


Risk-based planning – Developed zones

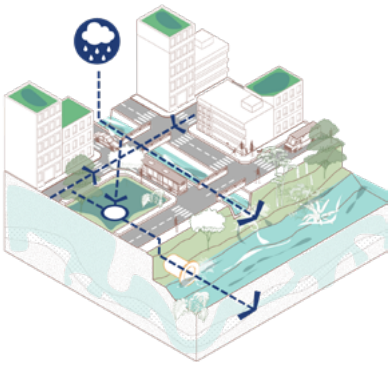
Retrofit existing buildings and infrastructure to ensure compliance with appropriate building standards.



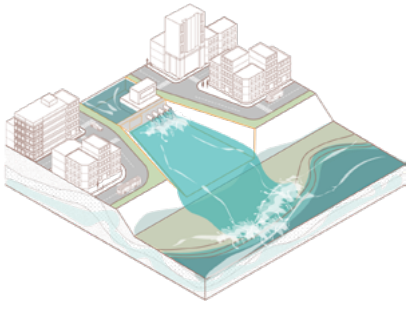
Undertake informal settlement upgrading only if measures to reduce flood risk to acceptable levels are implemented.



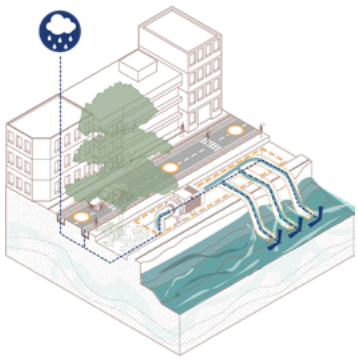
Design and upscale drainage infrastructure to meet current and future demand and improve stormwater systems to prevent overflow into buildings and underground spaces.



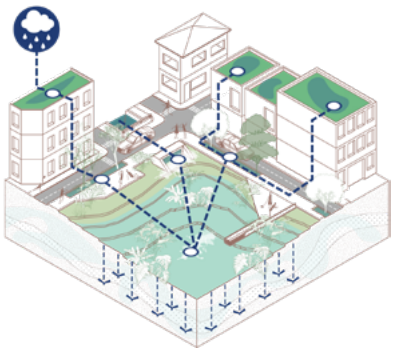
Incorporate dewatering systems to manage excess water in flood-prone areas.



Ensure appropriate dewatering and drainage system design and maintenance to handle increased runoff volume.



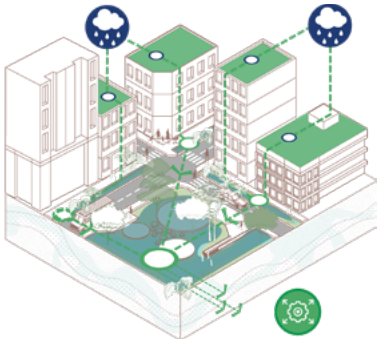
Implement flow-control measures such as retention ponds in critical areas to manage water flow and reduce flood risks in urban spaces.

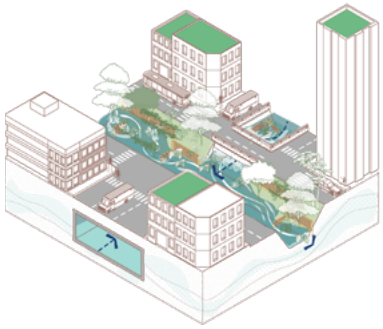
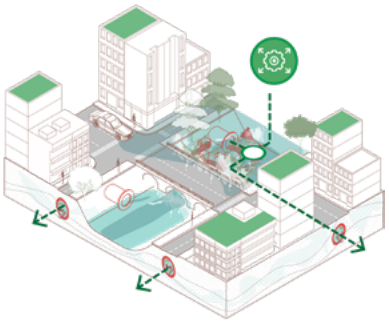
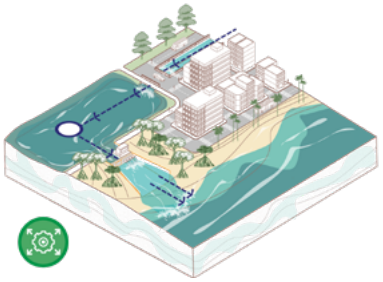


Source: Original for this publication.

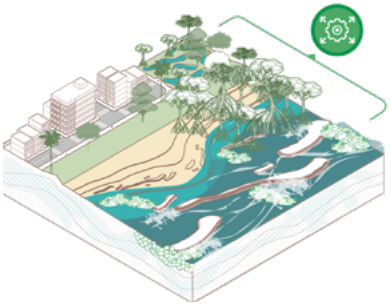
Table 5.8: Examples of "Promote" Measures for Flood-risk-informed Urban Planning

Promote: Applies to actions that complement the restriction and conditioning measures to incentivize an appropriate use of natural resources.

Infiltration and runoff reduction		
Promote nature-based solutions (NBS) focused on reforestation and preservation of natural vegetation to slow down water flow and improve infiltration.	Implement sustainable drainage systems (SUDS) to increase infiltration, capture, and slowly release stormwater to reduce runoff.	Include NBS such as rain gardens along roads and in public spaces to capture and slowly release stormwater.
		

Urban drainage systems		
Require high resilience standards in all drainage and urban infrastructure, accounting for climate change projections and anticipated urban growth.	Implement Zero Waste programs to prevent blockages in drainage systems.	Design appropriate drainage systems and maintenance strategies in coastal areas.
		

Natural buffer protection to reduce flood risk

Encourage natural buffer protection, such as wetlands, forests, and floodplains.	Promote conservation and restoration of natural coastal barriers
	

Source: Original for this publication.

Chapter 6

Geohazards

In urban settings, geohazards arise from a combination of natural geological processes and human activity, posing risks to life, infrastructure, and the environment. There are three categories of geohazard: seismogenic, volcanogenic—which result from Earth's internal geophysical processes—and shallow geohazards that arise from near-surface processes, such as landslides, sinkholes, and erosion (UNDRR 2020). These shallow geohazards can also be triggered or intensified by other geological processes, such as earthquakes and volcanic eruptions, or by hydrometeorological hazards like intense rainfall, storms, or rapid snowmelt, further compounding their risks in urban environments.

This chapter explores the major categories of geohazards and their implications for urban planning. It begins with mass movements, such as landslides, mudflows, and rockfalls, which are increasingly driven by deforestation, unplanned development, and climate change. It then examines seismic hazards, including earthquakes and their secondary effects like liquefaction and tsunamis, emphasizing the importance of integrating comprehensive risk assessments into planning and infrastructure development. The chapter also analyzes volcanic hazards and shows how they can disrupt urban settlements. Through case studies and best practices, the chapter provides insights into how cities can anticipate, adapt to, and mitigate geohazard risks, ensuring safer and more resilient urban development.

The effective management of geohazards requires a multidisciplinary approach that integrates hazard and risk information, spatial planning, engineering solutions, and nonstructural measures. Understanding the characteristics, triggers, and aggravating factors of each type of geohazard is fundamental to designing strategies that minimize exposure and mitigate potential losses.

6.1 Shallow Geohazards: Mass Movements

Mass movements, also known as slope failures, encompass a variety of phenomena, including landslides, falls, and flows, and represent a significant socio-natural hazard that poses serious risks to life and infrastructure in both rural and urban environments. These hazards are primarily driven by gravitational forces and can be triggered by natural or human-induced factors, including intense rainfall, earthquakes, volcanic activity, deforestation, slope modifications, natural drainage system alterations, and inadequate water management, or a combination of these elements.

Between 1903 and 2023, mass movements have resulted in more than 73,000 fatalities worldwide and affected more than 15 million people (Froude and Petley 2018), and over the 2004–2016 timeframe, overall losses were estimated at US$20 billion annually (Sim, Lee, and Wong 2022). Moreover, the damage and losses caused by slope failures are severely underestimated due to their classification as secondary hazards, because their impacts are often attributed to the primary event, such as an earthquakes, cyclones, or heavy rainfall (Kirschbaum, Stanley, and Zhou 2015; Nadim 2017; Petley 2012; Sim, Lee, and Wong 2022).

With slope failure risks increasing as a consequence of climate change and human activity, these hazards have become a growing concern for cities, especially those developing in hilly or unstable terrain. Urbanization exacerbates the risks by causing deforestation, altering natural landscapes and drainage systems, and increasing pressure on already vulnerable slopes. Furthermore, mass movements are highly unpredictable and often occur with little to no warning, making them an extremely dangerous hazard. While some provide early signs of instability, others can strike suddenly, leaving little time for preparedness or evacuation.

Recent research by Johnston et al. (2021) found that urban areas can be up to 10 times more susceptible to precipitation-triggered landslides compared to rural regions. This heightened vulnerability is linked to human-induced alterations such as vegetation loss and modifications to topography, which destabilize slopes and increase the likelihood of landslides. As urban populations continue to grow and climate change intensifies shifts in precipitation patterns while increasing the frequency and severity of extreme weather events, the need for proactive landslide mitigation in urban planning becomes more urgent than ever.

Risk-informed urban planning must integrate mass movement risk considerations by ensuring that land-use decisions, zoning regulations, and infrastructure development are carefully considered and properly managed. This includes stabilizing slopes, preserving the natural landscape, and avoiding slope modifications that could exacerbate instability.

Studying mass movement types and their characteristics—speed, volume, runout distance, and triggers—allows engineers to design effective solutions. It also enables planners to enforce land-use and development measures that reduce risk and boost community resilience. Inadequate consideration of slope stability can lead to unsafe developments and increased hazards for existing developments, resulting in risk to life and

increased damage and losses. A risk-informed planning approach should integrate hazard mapping, slope stabilization measures, zoning regulations, EWS, and preparedness measures. The following sections provide a detailed analysis of some of the most common types of mass movements, their characteristics, triggers, aggravating factors, and urban planning implications.

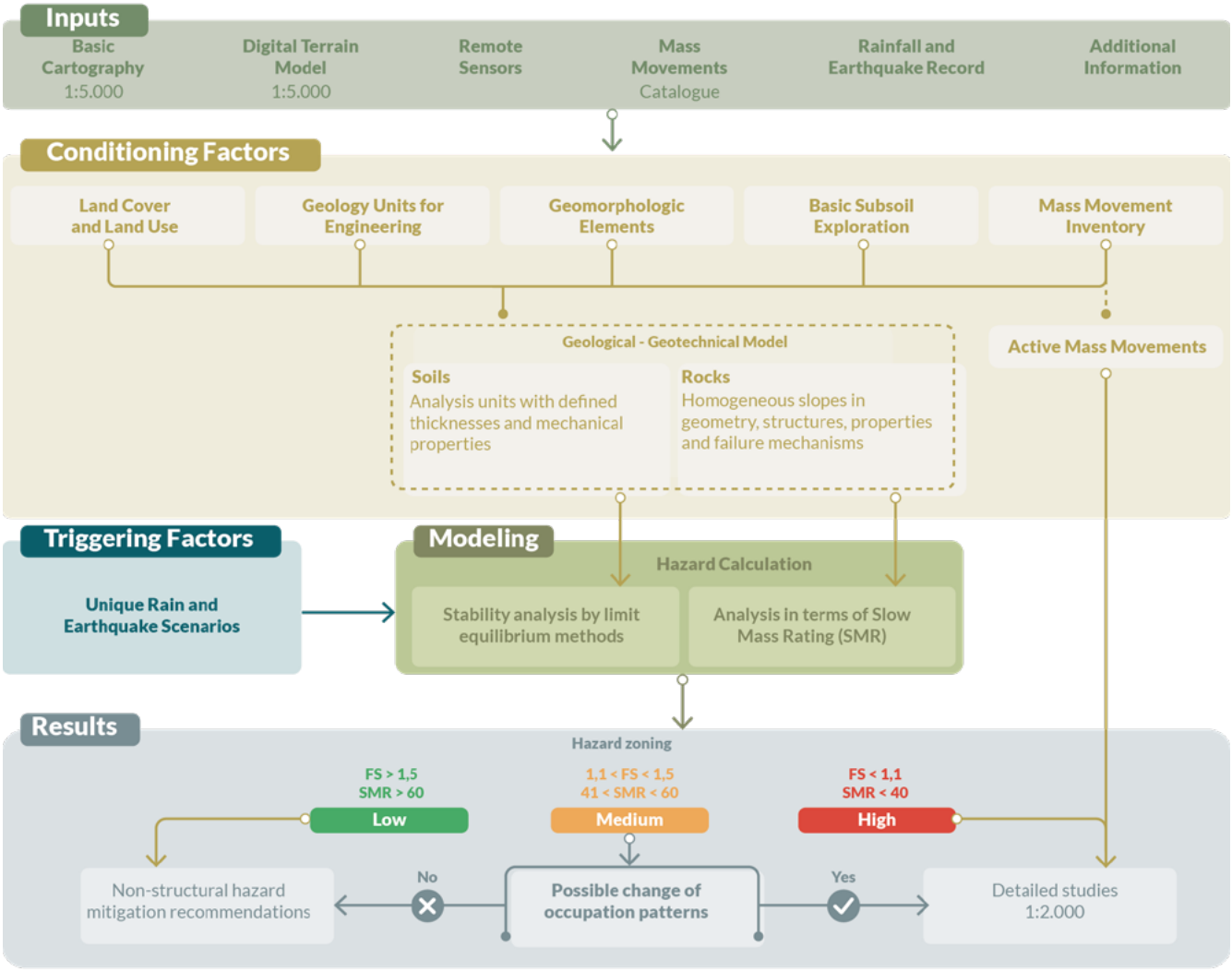
Assessment and mapping methodologies vary based on available data, scale, and assessment objectives, ranging from susceptibility assessments to hazard and risk evaluations. Susceptibility maps indicate areas where slope failures are likely to occur based on terrain characteristics such as slope gradient, geology, soil type, and land cover. They do not account for triggering factors like rainfall or earthquakes, but provide a baseline assessment of unstable areas. Hazard maps go further by incorporating potential triggers such as rainfall, earthquakes, or human activities to estimate the probability and magnitude of future landslides. The most comprehensive risk maps integrate hazard data with exposure and vulnerability assessments, highlighting the potential effects on people, infrastructure, and economic assets. Mapping techniques range from regional assessments using remote sensing and GIS-based models to detailed, site-specific evaluations requiring field investigations and geotechnical analysis.

While susceptibility mapping identifies areas prone to slope failure, it does not determine which areas may be impacted by displaced material. This gap poses significant challenges for urban planning and risk management as it limits the ability to assess exposure, implement zoning regulations, and design effective mitigation measures. To address this, scale-appropriate analyses are essential. Susceptibility mapping is typically conducted at 1:5,000 scale for homogeneous area delineation, while detailed characterization of specific events and runout zones may require a 1:1,000 scale or finer.

Additionally, limited expertise and competing development priorities often prevent investment in local risk evaluations. As a result, urban expansion continues in hazardous areas, increasing exposure and limiting effective risk reduction. Strengthening municipal capacity, improving data availability, and integrating multihazard assessments all play an essential role in enhancing urban resilience.

Figure 6.1 illustrates the methodology for landslide hazard zoning at 1:5,000 scale (Servicio Geológico Colombiano 2016). Notably, the same guide recommends using a more detailed 1:2,000 scale methodology for in-depth risk studies. This finer scale provides more precise, site-specific information to support land-use planning and risk management decisions.

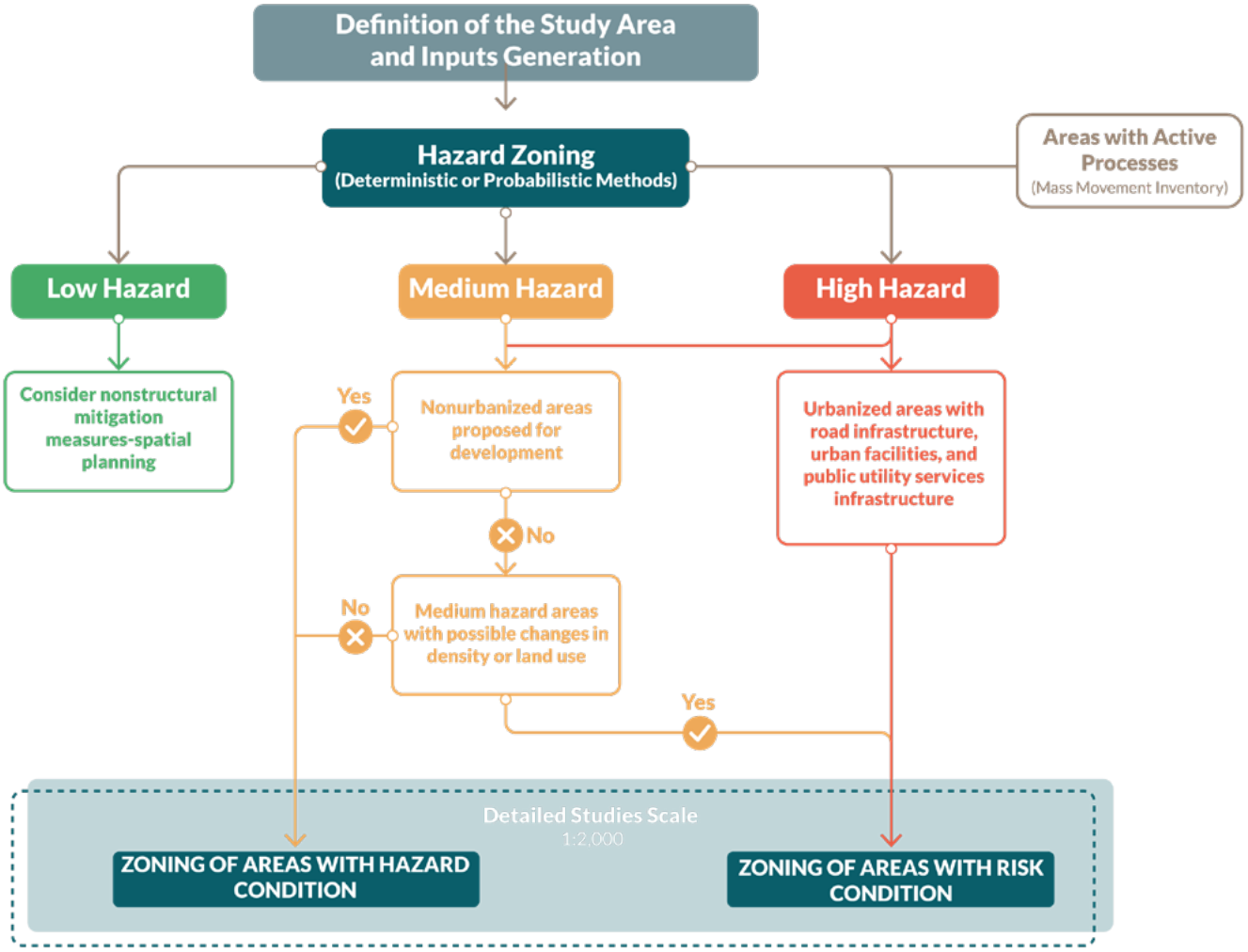
Figure 6.1: Example Process for Mass Movement Hazard Zoning



Source: Edited and translated from Servicio Geológico Colombiano 2016, 35.
Note: FS = Factor of Safety.

Building on the hazard analysis in figure 6.1, figure 6.2 illustrates a decision-making framework that integrates hazard assessments into spatial planning. The framework distinguishes between hazard conditions in undeveloped areas and risk conditions in already urbanized zones, and establishes when more risk-informed and resilient development will require more detailed studies. Urban planning and expansion should be guided by hazard and risk zoning to avoid increasing hazards or worsening exposure.

Figure 6.2: Example Process for Mass Movement Hazard for Risk-informed Urban Planning



Source: Redrawn and translated from Servicio Geológico Colombiano 2016, 21.

Landslides – Rotational and Translational Landslides

Landslides are among the most common and destructive forms of mass movement, involving the downslope displacement of soil, rock, or debris. They vary in type and scale, with two of the most significant categories being rotational landslides and translational landslides.

Rotational landslides, occur along curved failure surfaces, where the displaced material rotates backward as it moves downslope, forming head scarps and depressions. Common in uniform soil formations, they are often triggered by excessive water infiltration, seismic activity, or excavation at the slope's base. Though they tend to move slower, they can displace large volumes of material.

Translational landslides, on the other hand, involve the movement of earth or rock along a relatively flat surface, such as a fault, bedding plane, or weak soil layer. These slides can travel long distances and

accelerate rapidly when triggered by heavy rainfall, seismic shaking, or human activities (Highland and Bobrowsky 2008).

Landslides are one of the most destructive hazards, often striking with little to no warning. They can be triggered by persistent and intense precipitation, groundwater fluctuations, seismic activity, or excavation at the slope's base (photo 6.1).

Photo 6.1: Rainfall-Triggered Landslide in the Municipality of Alausi, Ecuador, 2023.



Source: © Chamaski / Shutterstock.

Aggravating factors include deforestation, poor land management, and infrastructure development near or on unstable slopes, leading to toe undercutting (where the base of the slope is removed or weakened, reducing overall stability) and increased loads at the top of the hills. Impacts range from disruption of transportation and lifeline infrastructure and structural collapses to loss of life and displacement of communities, with potential secondary consequences such as terrain deformation or damming of river channels and induced flooding (table 6.1).

Table 6.1: A Summary of the Characteristics and Impacts of Landslides

Characteristics and Impacts
Landslides involve the movement of large masses of earth, rock, or debris down a slope. They can cause extensive damage to buildings, infrastructure, and roads, often resulting in significant economic losses and potential fatalities. Landslides can also disrupt essential services like water and power supply.

Triggers

Landslides are triggered by heavy rainfall, earthquakes, volcanic eruptions, or human activities such as excavation, cuts or alterations on slopes. Slope saturation from excessive water weakens the stability of the ground, leading to landslides.

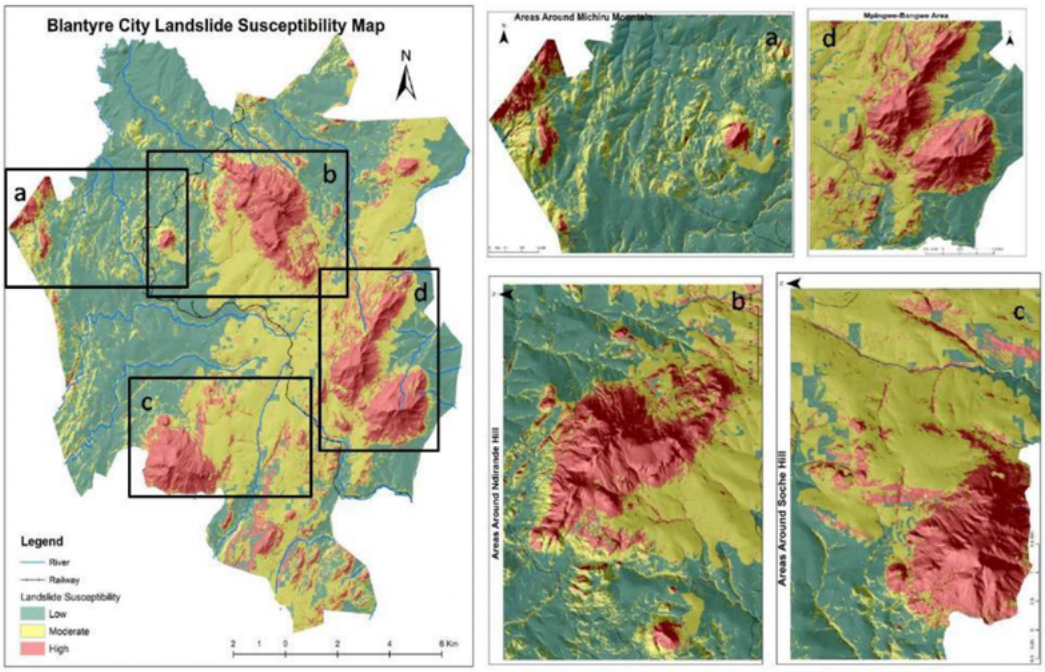
Aggravating factors

- Steep terrain, intense and prolonged rainfall, natural erosion, and certain soil types—such as loose, sandy, or clay-rich soils that can become unstable when wet—as well as the absence of vegetation to stabilize slopes, all contribute to landslide susceptibility.
- Deforestation
- Construction activities
- Poor land-management practices and excavation or alterations of natural slopes might disrupt stability.

Hazard and risk zoning

Landslide hazard and risk zoning classify areas based on terrain stability, triggering factors, and potential impacts, guiding land-use planning and mitigation efforts. Susceptibility maps (figure 6.1.1) highlight areas prone to slope failures based on geological, topographical, and soil characteristics, while hazard maps incorporate natural and human-induced triggers to estimate landslide probability and intensity. Risk maps provide a more comprehensive assessment by integrating exposure and vulnerability data.

Figure 6.1.1: Example of a Landslide Susceptibility Map for Blantyre City, Malawi



Source: NIRAS 2023.

Landslide risk must be integrated into zoning and infrastructure development strategies, considering detailed geotechnical assessments where necessary. Engineering interventions, such as retaining walls, soil nailing, and deep drainage systems, can be employed to enhance stability, while urban expansion should be guided by zoning regulations and land-use policies that restrict or condition development in landslide-prone areas.

6.1.2 Fluid-Driven Mass Movements: Mudflows, Mudslides, Debris Flows, and Lahars

Fluid-driven mass movements are among the most destructive and life-threatening slope failures, posing severe risks due to their rapid velocity, high-impact forces, and potential for widespread damage. Fluid-driven mass movements are high-mobility slope failures characterized by the rapid downslope transport of saturated soil, sediment, and debris under high pore water pressure, where water in the pore spaces between soil particles reduces internal strength. Mudflows and mudslides involve fine-grained material mobilized by excessive rainfall or groundwater fluctuations, while debris flows (photo 6.2) incorporate a mix of coarse-grained material, including rock fragments and organic debris, often initiated by sudden hydrological surges.

Photo 6.2: Debris Flow in Soche Mountain, Blantyre City, Malawi, during Tropical Cyclone Freddy, 2023



Source: © World Bank.

Lahars, specific to volcanic environments, are composed of volcanic ash and debris mobilized by pyroclastic activity, rapid glacial melt, or intense precipitation. These phenomena exhibit high velocity and impact forces, causing severe structural damage, sediment deposition, and hydrological system alterations. Triggers include intense or prolonged rainfall, glacial melting, seismic activity, and volcanic eruptions, with aggravating factors such as deforestation, inadequate drainage management, and urban encroachment on alluvial fans increasing susceptibility.

Fluid-driven mass movements like mudslides and debris flows are prevalent in urban regions, especially those with steep terrains, affected by intense rainfall. A study analyzing global rainfall-triggered mass movements in postfire settings found that mudslides were the most frequently identified type, accounting for 25 percent of all classified events (Culler et al. 2023). Furthermore, urbanization exacerbates these hazards by increasing surface runoff due to impervious surfaces, leading to higher peak flows, which can trigger debris flows or mudflows (table 6.2).

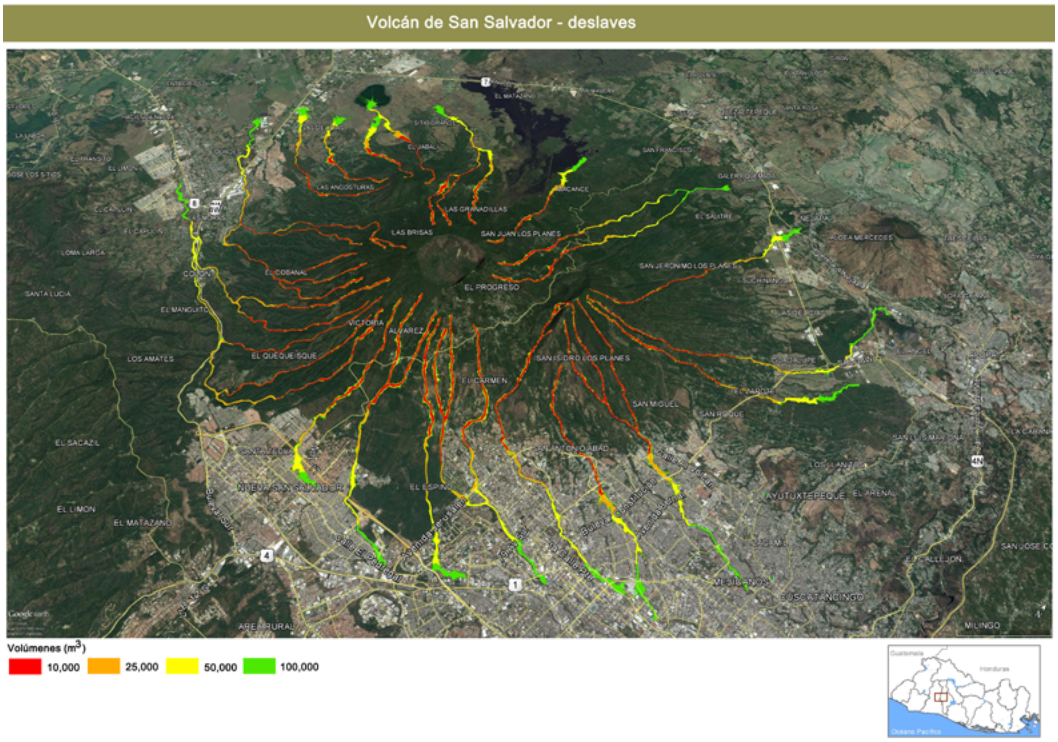
Table 6.2: A Summary of the Characteristics and Impacts of Fluid-Driven Mass Movements

Characteristics and Impacts
Debris flows and mudflows are fast-moving mixtures of water, soil, rocks, and organic material that flow down slopes. They can be highly destructive, burying structures, blocking roads, and causing fatalities. The rapid movement and volume of material involved make these flows particularly dangerous in mountainous and hilly regions. These fast-moving flows and their rapid onset pose a serious risk to life as they offer little to no warning.
Triggers
Debris and mud flows are typically triggered by intense rainfall, rapid snowmelt, volcanic activity, or the sudden release of water from natural or artificial sources, such as dam breaks. Lahars, specific to volcanic environments, are mobilized by pyroclastic activity, rapid glacial melt or intense rainfall, or a combination of these triggers.
Aggravating factors
• Steep slopes, loose or unstable soil, heavy rainfall, and the presence of channels that direct flow paths can exacerbate debris and mud flows. • Wildfires that remove vegetation also make slopes more susceptible to these flows. • Urban development altering natural water flow patterns, deforestation, poor land management, and inadequate drainage systems increase susceptibility to debris and mud flows.

Hazard and risk zoning

Hazard and risk zoning for lahars, mudslides, and debris flows involves delineating areas based on flow paths, historical events, topographic susceptibility, and hydrometeorological triggers (figure 6.2.1). High-hazard zones include channels, alluvial fans, and steep slopes with past activity, potential runout areas, and secondary deposition zones.

Figure 6.2.1: Example of a Lahar and Mudslide Hazard Map for San Salvador Volcano, El Salvador



Source: Kattan et al. 2017.

Effective urban planning must incorporate hydrological and geomorphological modeling to delineate flow paths and deposition zones, restricting development in hazard-prone areas. Mitigation measures include the construction of dams, debris basins, and channelized flow paths to dissipate energy and contain debris transport.

However, due to the destructive potential of fluid driven mass movements, exposure should be avoided. While rainfall-intensity thresholds and real-time monitoring systems can support early warning and evacuation in high-risk areas, the rapid onset, high velocity, and destructive potential of fluid-driven mass movements often make timely warnings and evacuations challenging, if not unfeasible.

Rockfalls

Rockfalls and toppling failures are hazardous slope processes driven by the gravitational detachment of rock masses from steep slopes or cliffs, posing risks to infrastructure and human safety. Natural susceptibility factors and triggers include mechanical weathering, freeze-thaw cycles, seismic shaking, and differential thermal expansion, which progressively weaken rock masses. Preexisting rock discontinuities exacerbate instability, while groundwater seepage weakens rock joints, increasing the likelihood of detachment. Anthropogenic activities, such as blasting, excavation, and slope undercutting, can further destabilize steep slopes.

Rockfall hazard assessments integrate geotechnical analysis, probabilistic modeling, and high-resolution spatial data to evaluate detachment likelihood and potential impacts (table 6.3). They require topographic and geological data, including slope geometry, rock mass characteristics, and triggering factors such as seismic activity and weathering. Trajectory simulations play a crucial role in predicting runout distances, assessing how detached rock masses travel downslope based on terrain features, energy dissipation, and impact dynamics (Lari, Frattini, and Crosta 2014; Zhan et al. 2022).

Table 6.3: A Summary of the Characteristics and Impacts of Rockfalls

Characteristics and Impacts

Rockfalls involve the sudden detachment and rapid descent of rocks from steep slopes or cliffs. These events can cause severe damage to infrastructure, roads, and buildings, posing significant risks to human safety. The impact is typically localized but can be catastrophic, especially in areas with high population density or critical infrastructure.

Triggers

Rockfalls are triggered by natural factors, such as heavy rainfall, earthquakes, freeze-thaw cycles, or erosion that destabilize rock formations. Human activities like construction or mining can also trigger rockfalls by altering the stability of slopes.

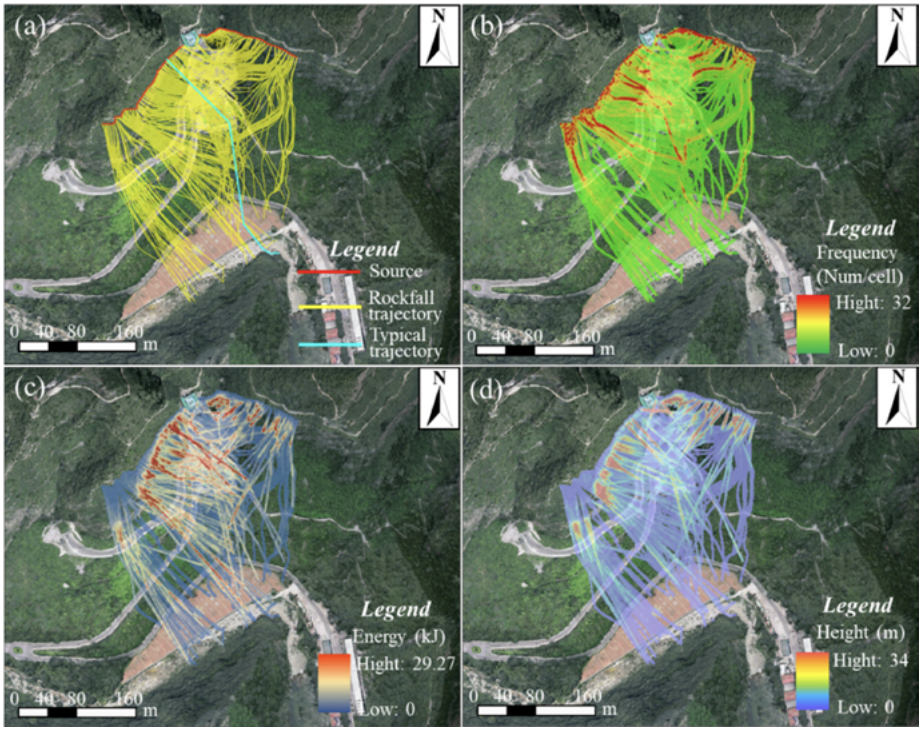
Aggravating factors

- Weathering of rock surfaces, the steepness of slopes, and lack of vegetation can increase the susceptibility to rock falls. The presence of loose, unconsolidated soils or interlayering of loose soils and rocks can also increase the risk of rockfalls when they do not provide adequate support to overlying rocks.
- Deforestation, cuts, and construction work, mining, and vibrations from traffic can destabilize slopes and increase the frequency of rockfalls.

Hazard and risk zoning

Rockfall hazard and risk zoning involves identifying areas prone to rock detachment, trajectory, and impact based on slope gradient, geological conditions, weathering processes, and seismic or hydrometeorological triggers (figure 6.3.1). High-hazard zones include steep cliffs, escarpments, and areas with frequent rockfall activity.

Figure 6.3.1: Example of Rockfall Hazard Assessment – Spatial Distribution of Disaster-Causing Factors in the Scenic Spot of Sky City, China



Source: Zhan et al. 2022.
Note: (a) rockfall trajectory; (b) rockfall frequency; (c) rockfall kinematic energy; (d) rockfall bounce height.

Urban planning in rockfall-prone areas must integrate geomechanical assessments using rockfall trajectory modeling and analysis of kinematic stability analysis to identify high-risk zones. Engineering solutions include rockfall barriers, catchment ditches, and draped wire mesh systems to intercept falling debris. Slope stabilization techniques such as rock bolting, shotcrete application, and controlled blasting can reduce detachment risks. Transportation corridors in mountainous regions should be designed with protective infrastructure, and automated monitoring systems can provide early warnings of potential rockfalls, enabling timely mitigation interventions.

Mainstreaming landslide risk management into urban planning is essential for reducing both future and existing risks while fostering resilient development. Integrating disaster risk considerations into planning

processes ensures that urbanization processes do not exacerbate hazards but instead contribute to safer and more resilient cities. Hong Kong provides a compelling example of how this can be achieved (box 6.1). The territory developed a multitiered, risk-based approach to slope safety, including corrective, prospective risk reduction and preparedness measures.

Hong Kong's Slope Safety System demonstrates how landslide risk can be seamlessly integrated into urban planning and urban management. This approach emphasizes the need to balance urban expansion with risk reduction, ensuring sustainable growth while maintaining acceptable safety standards. By implementing a multitiered strategy, the system has not only halted the rise in landslide-related fatalities linked to urbanization, but has also mitigated preexisting and residual risks, reinforcing long-term resilience.

Box 6.1:

Hong Kong's Multitiered Risk-based Approach to Slope Safety

Hong Kong's dense urban landscape is built on steep and geologically complex terrain, with around 63 percent of its 1,100 km² land area featuring slopes steeper than 15° and 30 percent exceeding 30°, making landslides a critical urban risk. Rapid population growth and urban expansion heightened risks by increasing the number of man-made slopes and concentrating developments near both artificial and natural hillsides. Slope failures caused over 400 fatalities between 1940 and 1976, with major disasters like the 1972 Po Shan Road landslide (67 deaths) and the 1972 and 1976 Sau Mau Ping landslides (71 and 18 deaths, respectively) underscoring the urgent need for a comprehensive, systematic approach to slope management and safety (Ho et al. 2015). To address this, Hong Kong developed one of the world's most advanced landslide risk management systems, integrating geotechnical engineering, land-use planning, and real-time monitoring to ensure urban resilience.

The Slope Safety System: A Three-Pronged Approach

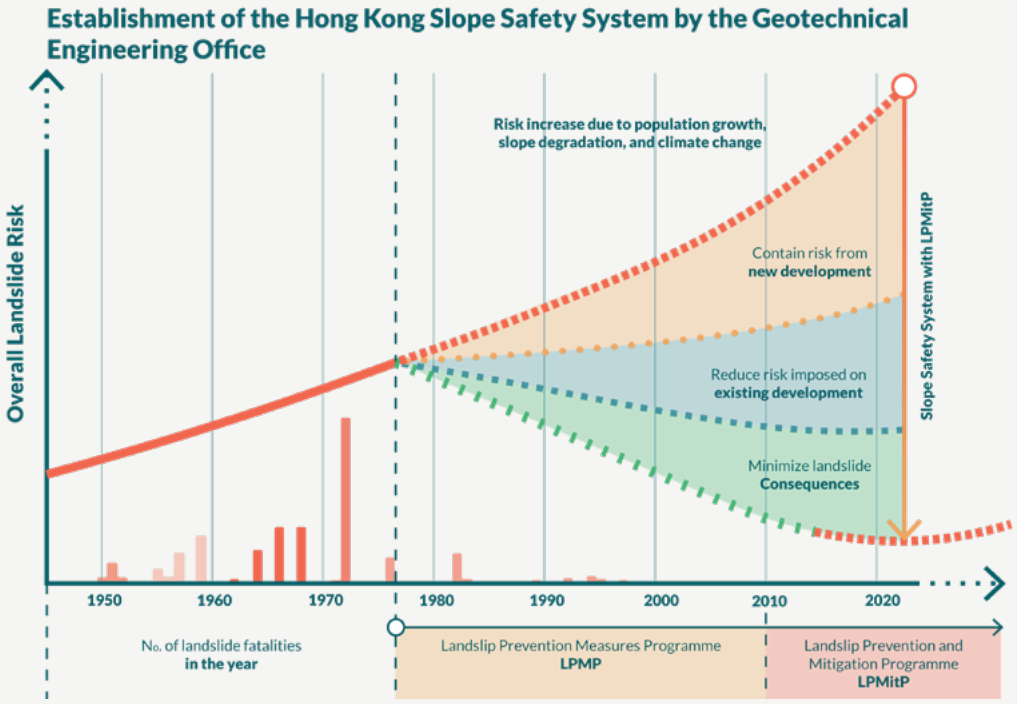
The Slope Safety System manages landslide risk through three core strategies: contain risk from new development, reduce risk imposed on existing development, and minimize landslide consequences. This system has been fundamental in protecting the city's rapidly expanding urban areas and critical infrastructure (CEDD 2024a; Ho et al. 2015). It has effectively curbed the rapid upward trend in landslide fatalities and mitigated existing risks by managing slopes and minimizing the impact of landslides on lives and property (figure B6.1.1).

Containing Risk from New Development

To prevent landslide risks from escalating amid urban expansion, the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) has played a critical role by enforcing stringent geotechnical controls across Hong Kong. This comprehensive regime ensures that all new slopes and geotechnical works, whether public or private, meet rigorous safety standards.

The GEO also collaborates with town planners, land administrators, and project departments to incorporate landslide risk mitigation into land-use planning and development proposals from the earliest stages. For challenging terrains, the GEO may impose special geotechnical conditions in lease agreements, recommend alternative development approaches, or even advise against development. Administrative measures introduced in the early 2000s further regulate developments near natural hillsides by adopting criteria to assess and mitigate natural hazards. Moreover, the GEO's systematic landslide investigation program continues to advance knowledge, identify high-risk areas, and improve safety standards. As a result, despite the addition of over 20,000 new slopes since 1977, the upward trend in landslide risk has been effectively halted (Ho et al. 2015).

Figure B6.1.1: Impact of Landslide Risk Reduction Strategies in Hong Kong



Source: Redrawn from CEDD 2024a.

Reducing Risk Imposed on Existing Development

In 1977, following a series of severe landslide disasters in the 1970s, Hong Kong launched the Landslip Preventive Measures Programme (LPMP) to systematically upgrade and stabilize substandard man-made slopes. Building on its success, the more comprehensive Landslip Prevention and Mitigation Programme (LPMitP) was introduced in 2010, expanding efforts to address natural hillside hazards alongside man-made slopes. As of September 2024, the GEO had invested approximately US$29.5 billion in landslip prevention and mitigation, upgrading around 6,780 government slopes, completing studies for 6,562 private slopes, and implementing mitigation measures for 480 natural hillside catchments (CEDD 2024a).

LPMitP employs a risk-based priority ranking system to identify and address high-risk slopes and natural hillside catchments, especially those adjacent to densely populated urban areas. The risk-based methodology integrates both qualitative and quantitative approaches to assess landslide likelihood and consequences and prioritize interventions (CEDD 2024b; Ho et al. 2015).

Through extensive engineering works, such as slope reinforcements, drainage improvements, and the construction of retaining structures, the program significantly reduced landslide risks and improved geotechnical safety. Environmental integration is promoted by implementing landscape treatments for upgraded man-made slopes and hillside mitigation measures, preserving existing trees, using vegetation cover where possible, and minimizing the visual impact of hard surfaces, supported by technical guidelines and ongoing research to enhance eco-friendly and cost-effective greening techniques (CEDD 2024b).

Minimizing Landslide Consequences

As a key component of Hong Kong's Slope Safety System, minimizing landslide consequences involves a multifaceted approach integrating advanced technology, emergency response, and community preparedness. The territory has developed a sophisticated early warning system that leverages remote sensing, rainfall thresholds, and real-time slope monitoring to predict potential landslides. The authorities are able to issue timely alerts and coordinate preemptive evacuations, thereby substantially reducing the number of casualties. Landslide emergency services ensure rapid response and recovery efforts. Additionally, public awareness campaigns and community preparedness initiatives help residents understand risks and take precautions, while guidelines are provided to private slope owners to strengthen their landslide resilience.

6.2 Earthquakes

Earthquakes and tsunamis are among the deadliest natural hazards, causing massive damage to infrastructure, significant loss of life, and substantial economic damage. While floods were the most frequent disasters worldwide, accounting for 44 percent of all reported events between 2000 and 2019, earthquakes and tsunamis were the deadliest form of disasters, responsible for 58 percent of total disaster-related deaths during the same period (CRED, UNDRR 2020).

Earthquakes result from the sudden release of elastic strain energy when stressed rock ruptures along preexisting faults. They occur primarily in tectonically active zones, such as subduction interfaces, or transform boundaries within the global "Ring of Fire"—a region that accounts for approximately 90 percent

of global seismic activity (National Geographic 2025). An earthquake's size is quantified by its magnitude—the energy released at the source—whereas the level of shaking at the surface is described by its intensity, an observational rating of the earthquake's effects on people and structures (for example, the Modified Mercalli intensity scale).

The devastating effects and impacts of earthquakes on both human life and economies have been evident in numerous recent disasters. The 2015 Nepal earthquakes caused over 8,790 casualties, and damage and losses were estimated at about US$7,065 billion, equivalent to one third of the country's GDP (Government of Nepal, National Planning Commission 2015). The 2011 Great East Japan Earthquake (GEJE) and Tsunami resulted in US$239 billion in economic losses, making it the costliest disaster event on record (CRED, UNDRR 2020). More recently, the 2023 earthquakes in Turkey and Syria resulted in over 56,683 deaths and US$42.9 billion in damages. Earthquakes and tsunamis consistently rank at the top of mega-disaster[9] and mass casualty events, as seen in the 2004 Indian Ocean tsunami (226,408 deaths) and the 2010 Haiti earthquake (222,570 deaths) (CRED, UNDRR 2020).

In seismically active regions, understanding seismic hazard and risk is fundamental to effective urban planning. Seismic hazard refers to the probability of occurrence of earthquake-induced ground shaking and related phenomena at a specific location over a defined time period. It is typically expressed in terms of ground motion parameters—such as peak ground acceleration (PGA) or spectral acceleration (SA)—with specified probability of exceedance over a given time horizon (for example, 10 percent in 50 years). Seismic hazard assessments integrate tectonic, geological, and geophysical factors to estimate the expected frequency and intensity of ground shaking, forming the basis for spatial planning, building codes, and structural design criteria.

Earthquakes may also trigger secondary hazards, including liquefaction, tsunamis, and landslides, which can pose additional risks to life and property. Local site conditions can amplify shaking intensity and damage potential. The following section provides technical guidance on amplification, liquefaction, and tsunami risks, while landslides and other shallow geohazards are addressed in section 6.1.

Microzonation studies play a critical role in risk-informed urban planning and engineering decisions by identifying areas with significant seismic amplification effects—typically due to soft soils, landfills, or complex topography—where varying seismic design loads and structural detailing requirements must be applied. These studies also assess liquefaction susceptibility, informing foundation design and ground improvement needs. In coastal regions, tsunami hazard layers may be integrated to delineate inundation zones and guide elevation requirements, land- use restrictions, and spatial planning for critical infrastructure.

Amplification due to Site Effects

The distribution of shaking is not uniform across urban areas, as local geological and topographic conditions can amplify seismic waves. Strong motion—the intense ground shaking produced by seismic waves—is influenced by factors such as earthquake magnitude, depth, the distance from the fault rupture, and the local conditions at the site (table 6.4). Local geological conditions can significantly alter seismic wave behavior, leading to amplification effects.

[9] Events that kill more than 100,000 people.

The correlation between site effects and earthquake damage is well-documented. In Mexico City, built atop ancient lakebed sediments, the 1985 Michoacán earthquake caused catastrophic damage due to significant amplification of seismic waves by the soft clay deposits (Abbiss 1989; Cruz-Atienza et al. 2016; Nikolaou et al. 2018). Similarly, during the 2005 Kashmir earthquake, 98 percent of the most severely damaged buildings were located in zones of topographically amplified seismic response (Khan et al. 2020). In the 2015 Gorkha earthquake in Nepal, local amplification and soil nonlinearity were responsible for the uneven damage pattern observed throughout the Kathmandu Valley (Gautam et al. 2016). In San Salvador, El Salvador, the 1986 and 2001 earthquakes caused severe damage, with studies showing that seismic amplification from low-velocity ash layers contributed to the collapse of structures whose natural periods matched those of the underlying deposits (Kattan et al. 2017; Kattan, Lopez, and Menjívar 2017; Faraone et al. 2023).

Site effects refer to the ways in which local geological and topographic conditions can amplify or modify seismic waves, leading to varying levels of ground shaking and potential damage. Soft, loose soils, including landfills, tend to amplify ground motion, while hard, dense soils and rock transmit seismic energy more efficiently. Site conditions act as natural filters, amplifying certain seismic wave frequencies while attenuating others. This frequency-dependent behavior has critical implications for structural response, as different building types resonate at different natural frequencies. Soils with low shear wave velocities tend to amplify lower-frequency waves, increasing the seismic demand on taller, more flexible structures. Moreover, when subjected to high-intensity ground shaking, nonlinear effects can result in a wide range of complex behavior, including liquefaction and changes in the resonance characteristics of soils.

To evaluate seismic amplification and ground response, site effect investigations employ a combination of field investigations, laboratory testing, numerical modeling, and historical earthquake analysis. Geotechnical surveys, geophysical methods, and laboratory mechanical and dynamic tests assess soil characteristics and behavior, while numerical models simulate site response under both linear and nonlinear conditions. Additionally, past earthquake records provide critical data for identifying high-risk areas and validating predictive models.

Table 6.4: A Summary of the Characteristics and Impacts of Earthquakes

Characteristics and Impacts
Ground shaking is the primary effect of earthquakes, with severity influenced by proximity to the hypocenter and local site conditions. Amplification due to site effects occurs when seismic waves pass through softer, less consolidated soils or materials, increasing the intensity of shaking compared to areas with bedrock. Amplification effects occur at particular frequencies or periods, depending on site conditions, which can result in resonance with specific building types, increasing the risk of structural failure. Near-fault effects, such as directivity pulses, can result in severe ground shaking with high velocities and accelerations, causing significant damage to buildings and infrastructure, particularly in areas directly above or near the fault line.

Triggers

Ground shaking is mainly triggered by earthquakes, which result from the sudden release of accumulated elastic strain energy when stressed rock ruptures. The level of shaking depends on the earthquake's magnitude, depth, and distance from the fault, as well as the site conditions.

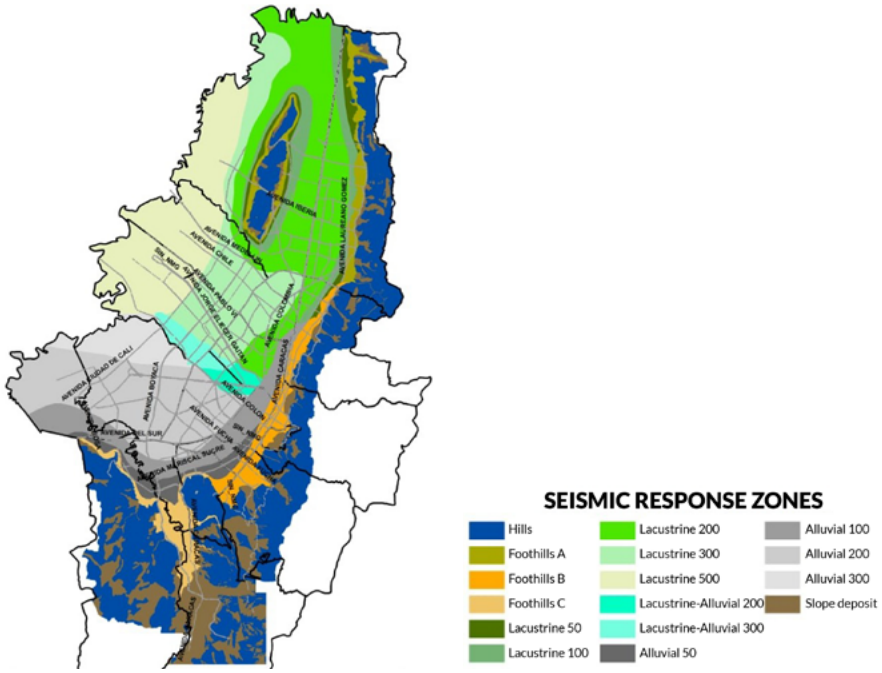
Aggravating factors

- Presence of soft soils, deep alluvial deposits, and the interlayering of dense rock and soft soils contribute to ground shaking amplification. Topographical features like ridges and valleys can also influence shaking intensity.
- Construction on reclaimed land and failure to enforce building codes that account for local site conditions exacerbate the impacts of amplified ground shaking.

Hazard and risk zoning

Hazard and risk zoning involve classifying areas based on seismic hazard levels and potential impacts, using both regional and site-specific analyses. Seismic macrozonation defines broad hazard zones by modeling tectonic sources, seismicity parameters, and ground motion prediction equations to estimate ground shaking for various return periods. Microzonation refines this by incorporating local soil and geological conditions—such as shear-wave velocity and site geometry—to assess ground motion amplification. Amplification factors for short (Fa) and long (Fv) periods are commonly used to adjust seismic design spectra in building codes (figure 6.4.1). Risk zoning further integrates exposure and vulnerability data to quantify expected impacts.

Figure 6.4.1: Seismic Microzonation in Bogota, Colombia



Source: Instituto Distrital de Gestión de Riesgos y Cambio Climático, Bogotá.

Liquefaction

Liquefaction is a soil failure phenomenon that occurs when water-saturated, loose granular soils lose their structural integrity in response to ground shaking. It can be a major cause of damage during earthquakes (table 6.5). During a seismic event, cyclic loading causes the pressure in pore water between soil particles to increase, reducing the effective stress and transforming the soil into a fluid-like state, leading to severe ground instability, and causing structures to tilt, sink, or collapse. Reclaimed land, riverbeds, and coastal plains with unconsolidated sediments are particularly prone to liquefaction effects. The consequences of liquefaction include foundation failures, damage to underground utilities, and disruption to transportation networks, severely impacting urban resilience.

Liquefaction risk poses a significant challenge for urban planners as it is often a localized and hidden hazard that can vary greatly over short distances. Susceptibility mapping and numerical modeling can help identify areas prone to liquefaction; however, detailed assessments may be necessary to confirm liquefaction potential, particularly in areas with high susceptibility or historical evidence of liquefaction (see example in figure 2.7).

While seismic risk is typically considered independent of climate change, it can influence secondary seismic hazards such as liquefaction. Climate change amplifies liquefaction risk, particularly in coastal areas. Sea-level rise elevates groundwater tables, reducing the thickness of nonliquefiable layers and increasing ground failure potential during earthquakes. In low-lying zones, even minor sea-level increases can heighten liquefaction susceptibility. Intensified rainfall accelerates aquifer recharge, while reduced precipitation and groundwater overextraction can cause land subsidence, impacting liquefaction dynamics.

Table 6.5: A Summary of the Characteristics and Impacts of Liquefaction

Characteristics and Impacts
Liquefaction occurs when saturated, loose, granular soils lose their strength and behave like a liquid during intense shaking. This phenomenon can cause buildings and infrastructure to tilt or collapse, leading to significant structural damage. Liquefaction can also cause severe ground deformation, lead to rupture of underground pipelines and disrupt utilities.
Triggers
Liquefaction is triggered by strong ground shaking during an earthquake in areas with loose, water-saturated soils, such as riverbeds, reclaimed land, and coastal zones.

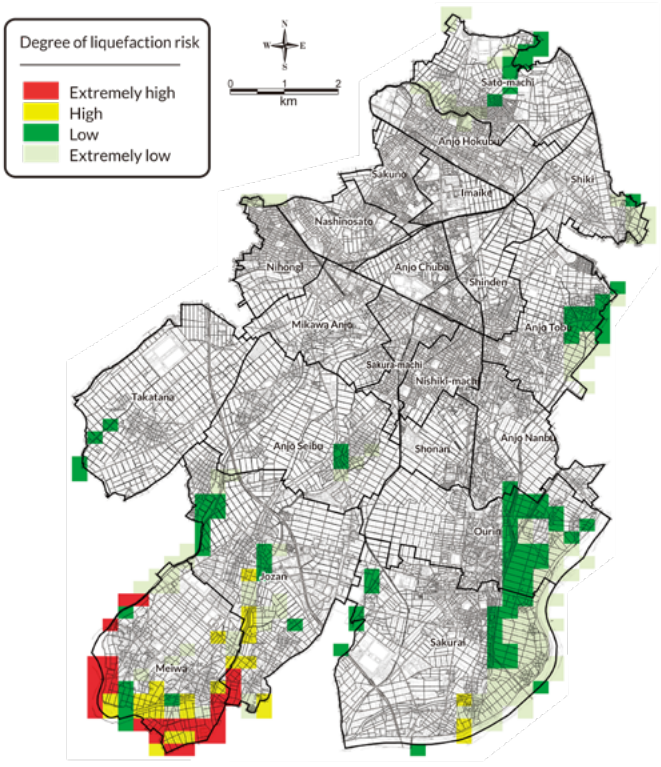
Aggravating factors

- Areas with high groundwater tables, loose sandy soils, and sediment deposits are susceptible to liquefaction.
- Climate change, through sea-level rise and changing precipitation patterns, can elevate groundwater levels and increase the risk of liquefaction and ground failure.
- Construction on poorly compacted or reclaimed land and lack of soil stabilization measures exacerbate liquefaction risks.

Hazard and risk zoning

Liquefaction hazard and risk zoning assess areas susceptible to ground failure during seismic events due to water-saturated, loose soils losing strength. Hazard zoning identifies locations prone to liquefaction by integrating information on soil composition, groundwater levels, and seismic hazard data. Geophysical methods are sometimes utilized as a cost-effective, nondestructive alternative, particularly in regions where extensive soil exploration is limited. Susceptibility mapping and numerical modeling provide an initial assessment, but detailed investigations are often required for accuracy (figure 6.5.1).

Figure 6.5.1: Example of Liquefaction Risk Map of Anjo City, Japan



Source: World Bank 2016.

Tsunamis

Tsunamis are large, powerful sea waves generated by underwater seismic events, landslides, or volcanic activity. Unlike normal ocean waves, tsunamis travel at high speeds across vast distances with minimal energy loss. As they approach shallow coastal waters, their speed decreases while wave height increases dramatically, leading to coastal inundation and potential devastation. Their characteristics depend on multiple factors, including the earthquake's magnitude, the depth of the seafloor displacement, and the coastal topography. Tsunamis exhibit complex interactions with coastal geomorphology, including wave amplification in bays, estuaries, and narrow inlets. They can generate successive waves, often causing prolonged and repeated flooding.

Throughout history, tsunamis have caused extensive and widespread devastation, with several notable events standing out due to their catastrophic impacts (table 6.6). The 2004 Indian Ocean tsunami, triggered by a magnitude 9.1 earthquake off Sumatra, claimed over 227,000 lives across 14 countries, making it the deadliest tsunami in recorded history (CRED and UNDRR 2020). In 2010 and 2011, the Maule Earthquake in Chile (magnitude 8.8) and the GEJE (magnitude 9.0) triggered devastating tsunamis that traveled across the Pacific. The 2010 tsunami affected 12 million people in 900 cities and towns (Siembieda et al. 2012), while the 2011 GEJE tsunami killed nearly 20,000 people (International Recovery Platform n.d.). Volcanic eruptions can also generate large tsunamis, as seen in the 1883 Krakatoa eruption, which washed away 165 coastal villages across Java and Sumatra, killing around 36,000 people (GeoNet n.d.).

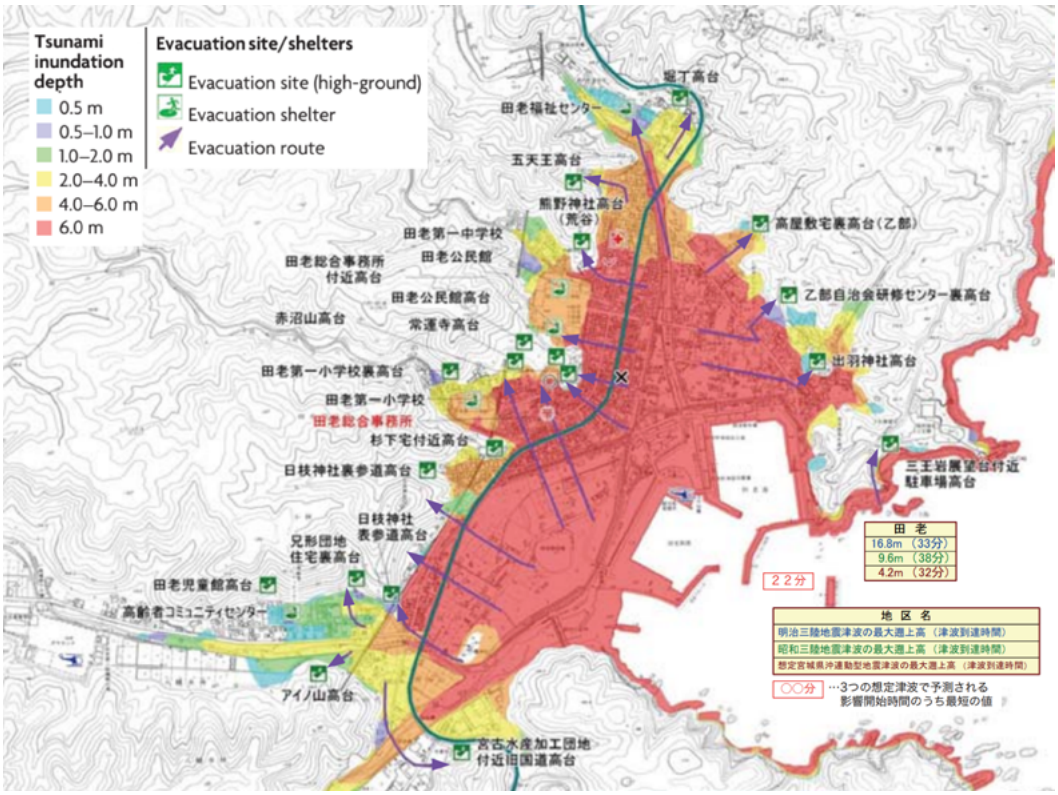
Table 6.6: A Summary of the Characteristics and Impacts of Tsunamis

Characteristics and Impacts
Tsunamis are large ocean waves generated by undersea earthquakes, landslides, or volcanic eruptions. Tsunami waves can travel vast distances and inundate coastal areas, causing widespread destruction in proximal and distal regions.
Triggers
Tsunamis are primarily triggered by subduction zone earthquakes, mostly reverse faulting, that displace large volumes of water. Other triggers include submarine landslides and volcanic eruptions that cause abrupt displacement of water.
Aggravating factors
• Coastal topography, such as shallow bays and estuaries, can amplify tsunami wave heights and increase inundation areas. • High population density in coastal areas, inadequate coastal defenses, destruction of natural barriers, and poorly planned development in tsunami-prone zones increase the vulnerability of communities to tsunami impacts.

Hazard and risk zoning

Tsunami hazard and risk zoning delineates areas based on inundation potential, wave height, flow velocity, and arrival time, integrating factors such as bathymetry, coastal topography, historical tsunami and seismic events, and seismic hazard. Numerical models are typically used for simulating tsunami generation, propagation, and inundation to assess hazard levels and support risk-based planning. They estimate wave formation based on seismic source parameters (for example, fault rupture, magnitude and depth); model wave travel across ocean basins, considering bathymetry and seabed geometry; and predict coastal inundation using high-resolution topographic data (figure 6.6.1). Probabilistic tsunami hazard assessments integrate multiple earthquake scenarios and their associated probabilities to quantify tsunami hazard and risk, accounting for uncertainties in seismic source characteristics, wave propagation, and coastal inundation.

Figure 6.6.1: Example of a Tsunami Hazard Map – Miyako City, Iwate Prefecture, Japan



Source: World Bank 2014.

Integrating seismic hazard considerations into urban planning is essential for minimizing earthquake impacts and enhancing the safety and resilience of cities. In contrast to floods and landslides—which often require strict land-use restrictions and conditions—earthquake risk is primarily managed through the

application and enforcement of seismic building codes. However, in areas with known fault lines, liquefaction susceptibility, high-risk tsunami zones, or other geotechnical hazards, land-use and zoning regulations may also be necessary to limit exposure and guide safer development.

Effective planning in seismically active regions relies on comprehensive hazard and risk assessments. On the urban scale, seismic microzonation studies are a vital tool for land-use regulations and building standards. Site-specific characteristics must be carefully assessed as they can significantly influence how seismic forces interact with the built environment. In urbanized areas, seismic risk assessments provide a broader perspective by quantifying the potential economic and societal impacts of earthquakes, including damage to infrastructure, disruption of economic activity, and risks to human lives. By understanding seismic risks, governments and planners can prioritize investments in risk reduction measures and emergency preparedness, and support resilient development policies (box 6.2).

In seismic regions, urban resilience is underpinned not only by structural safety but by the sustained functionality of critical services. The interconnected nature of urban systems, where the failure of one component can cascade across sectors, needs to be considered. Resilient infrastructure—particularly lifelines such as water supply, power, transport, and communications—is critical for maintaining essential functions, enabling effective emergency response, and minimizing recovery time and socioeconomic losses. Therefore, risk-informed planning must integrate performance-based design, interdependency analysis, and investment in robust, redundant systems to ensure continuity of essential services. To encourage seismic resilience further, urban planners can provide incentives for retrofitting vulnerable structures, designate safe public spaces, and establish well-defined evacuation routes in high-risk areas.

Effective tsunami risk management in urban areas requires a combination of structural and nonstructural measures. Structural defenses, such as sea walls, levees, and tsunami-resistant infrastructure, provide direct protection against waves. Nonstructural measures, including EWS, evacuation planning, and land-use zoning, help mitigate impacts by reducing exposure to tsunami hazards. Restricting high-density construction in tsunami-prone areas and enforcing elevation-based zoning can significantly reduce human and economic losses. Public education and preparedness programs are essential to ensure timely and effective evacuations when warnings are issued.

Seismic risk can be effectively managed through comprehensive strategies, and Japan's experience provides a model for best practices worldwide. Its complex tectonic setting has produced more than 100 earthquakes over magnitude 7 in the past century, including the catastrophic 1995 Kobe Earthquake and the 2011 GEJE and Tsunami. In response, Japan has invested in advancing seismic risk knowledge and translating lessons from past disasters into laws, regulations, and strategic investments. Japan's multilayered approach to seismic risk management integrates adaptive planning, scalable infrastructure resilience, land-use controls, strict building codes, disaster preparedness, and recovery planning. Box 6.2 highlights key lessons from Japan in integrating seismic risk management into urban planning.

Box 6.2:

Integrating Seismic Risk Management into Urban Planning. Lessons from Japan

Japan's urban planning framework has evolved significantly in response to lessons learned from major earthquakes. The Great East Japan Earthquake (GEJE) of 2011 underscored the need for comprehensive risk-informed planning, particularly in areas prone to liquefaction, tsunami impact, and cascading failures in critical infrastructure.

Multilayered Approach to Urban Planning: Land-use Regulations, Infrastructure Adaptation, Strategic Relocation, and Evacuation Preparedness

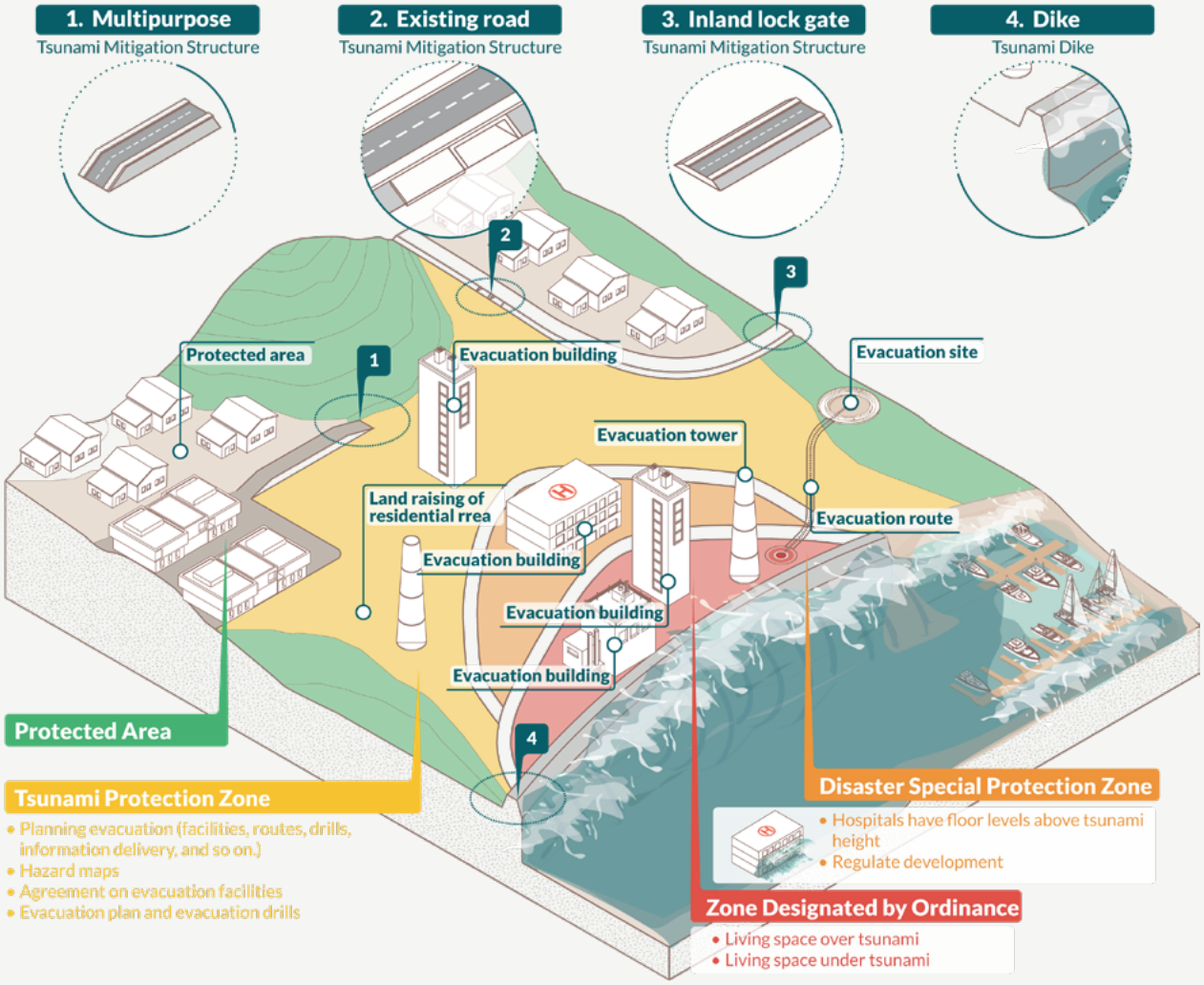
The integration of seismic risk information into land-use planning has been reinforced by lessons from past disasters. Following the 1995 Great Hanshin-Awaji Earthquake (Kobe earthquake), extensive damage was attributed to liquefaction in reclaimed land areas such as Port Island and Rokko Island. This led to revised land-use policies and the implementation of soil stabilization measures. A magnitude 7.2 event struck the Hyogo Prefecture, Osaka, and Kyoto. Kobe, one of Japan's major cities, experienced significant damage, with 6,437 fatalities and 104,906 houses destroyed (Yanase 2018). Kobe's post-1995 earthquake housing recovery leveraged risk-informed urban planning, integrating preexisting zoning, land readjustment, and urban renewal strategies. Urban growth boundaries defined the Disaster Restoration Zone, subdivided into Black (redevelopment), Gray (concentrated restoration), and White (minimal regulation) Zones, ensuring targeted interventions in rebuilding efforts (Preuss 1999).

Similarly, the GEJE disaster reinforced the importance of proactive land-use regulations and strategic relocation to minimize human and economic losses. Communities that had relocated to higher ground after previous tsunamis—such as Yoshihama Village—remained largely unharmed, while those in low-lying, unregulated areas suffered devastating losses. However, implementing relocation policies can be socially and economically complex, particularly in coastal communities where industries such as fishing and tourism are tied to the shoreline.

The GEJE triggered a tsunami of unprecedented strength, which breached sea walls and other protective structures and highlighted both the effectiveness and limitations of structural disaster prevention measures, such as tsunami breakwaters and dikes. While these structures reduced some of the damage, they failed to withstand the full force of the tsunami (Koshimura and Shuto 2015; Takemoto et al. 2021). Recognizing these challenges, Japan has adopted a multilayered approach to land-use planning, integrating relocation, infrastructure adaptation, and evacuation preparedness. Relying on one or two interventions proved to be insufficient, as disasters often exceed forecasted impacts (Ranghieri and Ishiwatari 2014).

The Act on Building Communities Resilient to Tsunami, enacted in 2011, categorizes risk-prone areas into yellow, orange, and red zones, each with corresponding measures (figure B6.2.1) (Ranghieri and Ishiwatari 2014).

Figure B6.2.1: Building Communities Resilient to Tsunami



Source: Redrawn from Rangheri and Ishiwatari 2014

- **Yellow zones** are areas where residents face a significant risk of fatality during a tsunami. These zones require comprehensive evacuation measures, including designated shelters, hazard maps, and regular evacuation drills to enhance preparedness.
- **Orange zones** are areas where the risk of fatality is even higher. Critical infrastructure, such as hospitals and emergency facilities, must be housed in tsunami-resistant structures to ensure functionality during and after a disaster.

- **Red zones** are areas where evacuation is not feasible due to extreme tsunami risk. In these zones, all buildings, including residences, must be tsunami-resilient, either through elevated, multistory designs that provide safe refuge or through mandatory relocation to safer ground.

The Ministry of Land, Infrastructure, Transport and Tourism formulated basic guidelines on tsunami countermeasures for prefectures and municipal governments. To support implementation, local governments provide incentives for private sector participation, including tax reductions and construction bonuses for buildings that incorporate designated evacuation spaces. Moreover, Japan has strengthened urban planning enforcement mechanisms, ensuring that disaster risk is systematically integrated into land-use policies, building codes, and emergency response planning. Regular inspections of critical facilities by fire departments and disaster management agencies have become standard practice, reinforcing accountability and preparedness (Ranghieri and Ishiwatari 2014).

Land Reclamation

The 2011 GEJE once again demonstrated the influence of land reclamation and soil modification in liquefaction-induced risks. The earthquake caused extensive liquefaction in the coastal area of Tokyo Bay and the lower banks of the Tone River in the North Kanto region. Areas with artificially modified soils, such as reclaimed land from old rivers, back swamps, valleys, or sites with backfilled soil after gravel, were mostly affected (Kuwata and Iejiri 2014).

Buildings constructed on reclaimed land, particularly those without deep foundation systems, suffered significant structural impacts. Japan's building codes covered countermeasures for liquefaction in reinforced concrete and other buildings, but not for detached wooden houses, which are common in residential areas. In response, the Ministry of Land, Infrastructure, Transport and Tourism introduced technical guidelines to mitigate liquefaction risks, and several local governments have since developed liquefaction risk maps to inform urban planning and encourage property owners to implement countermeasures (Takemoto et al. 2021).

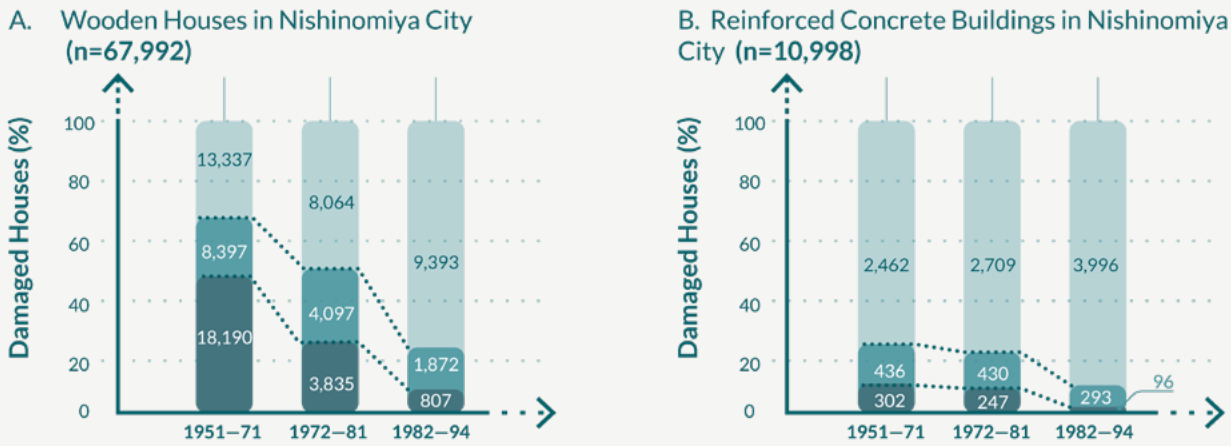
Building Codes and Building Regulations

Japan's building regulations are considered among the most advanced in the world, evolving in response to major earthquakes. The Building Standard Law of Japan, first enacted in 1950, has undergone several revisions to incorporate new engineering insights and seismic risk assessments. The 1981 revision introduced the New Seismic Design Code, emphasizing ductility and base isolation techniques to enhance earthquake resistance. Strict enforcement of these codes significantly reduced earthquake-related structural damage during the 2011 GEJE (figure B6.2.2), with most losses attributed to the ensuing tsunami.

The 1995 Kobe Earthquake underscored the vulnerability of older structures. The event led to extensive damage, with 97 percent of collapsed buildings constructed before 1981. In response, the

Act for Promoting Seismic Retrofitting of Existing Buildings was enacted. Under the Act, national and local governments offer subsidies, tax reductions, and low-interest loans to incentivize structural assessments and retrofitting (Ranghieri and Ishiwatari 2014).

Figure B6.2.2: Damage to Building Structures in the Great Hanshin-Awaji Earthquake by Period of Construction



Source: Redrawn from Moullier and Sakoda 2018.

Transport infrastructure has also been reinforced to withstand seismic forces. After Kobe 1995, highway and railway companies led major retrofitting campaigns, strengthening bridges, viaducts, and elevated structures. By 2011, the East Japan Railway Company had reinforced over 17,000 bridge piers, and 490 bridges in the Tohoku region had undergone seismic retrofitting, preventing widespread collapses during the GEJE (Ranghieri and Ishiwatari 2014). While the central government prioritized certain buildings and set target seismic resistance rates for them, local governments also set their own targets. Table B6.2.1 shows the target rates and actual rates for Yokohama city.

Table B6.2.1: Seismic Resistance Rates in Yokohama City – Target versus Actual

Type of building	Seismic resistance rate Target rate	End of FY 2015 Actual rate	End of FY 2020 Target rate
Houses	90%	89%	95%
Private buildings (hospitals, hotels, department stores, and so on.)	90%	89%	95%
Public buildings (government offices, schools, hospitals, fire stations, polices stations, etc.)	100%	99%	100%

Source: Redrawn from Moullier and Sakoda 2018.

Disaster Preparedness and Continuity of Operations in Urban Planning

Ensuring continuity of operations is a critical component of Japan's disaster preparedness strategy, recognizing that disruptions to essential services, transportation networks, and economic activities can have far-reaching consequences. The impact of the GEJE extended far beyond the area directly affected by the event, as supply- chain disruptions triggered by the disaster spread through the globe's networked production system, and the entire manufacturing sector in Japan and some industries abroad were forced to suspend production. A total of 656 private companies went bankrupt within a year, with 88 percent located outside the Tohoku region, failing due to supply chain disruptions rather than direct damage (Ranghieri and Ishiwatari 2014). While Japan's advanced disaster risk management (DRM) system mitigated some of the impacts, the scale of the disaster reinforced the need for resilient infrastructure, robust contingency planning, and adaptive urban policies to sustain operations during and after catastrophic events.

Resilient Infrastructure and Redundant Systems

Japan designs infrastructure to "fail gracefully," recognizing residual risk and ensuring lifelines—such as transportation, energy, and communication—continue functioning even under extreme conditions. Reinforced roads, elevated railways, and decentralized power grids minimize disruptions, while redundant water, fuel, and telecommunication systems support rapid recovery. Hospitals, emergency centers, and government buildings are built to the highest seismic standards, with backup power, autonomous water supplies, and emergency stockpiles to sustain operations when primary systems fail (Ranghieri and Ishiwatari 2014).

Business Continuity and Emergency Response

The government of Japan encourages public and private entities to develop business continuity plans (BCPs) to ensure that essential services resume quickly after a disaster. These plans include alternative operational sites, redundancies in supply chains, and emergency workforce protocols Eto sustain economic activities and public services. BCPs have proven highly effective, with 80–90 percent of medium and large enterprises that had them in place reporting that their plans facilitated recovery (Ranghieri and Ishiwatari 2014).

Early Warning Systems (EWS) and Disaster Preparedness

EWS and disaster preparedness proved their effectiveness in saving lives and protecting infrastructure and systems. Japan's ability to sustain operations and recover swiftly from disasters stems from continuous learning and adaptation. The Meiji-Sanriku Tsunami of 1896 claimed 40 percent of the affected population, while the GEJE reduced this to 4 percent (Ranghieri and Ishiwatari 2014), reflecting the impact of improved preparedness and resilient infrastructure.

During the GEJE, Japan's earthquake early detection system automatically halted 19 Shinkansen bullet trains, including two traveling at 270 km/h, preventing derailments and saving thousands of lives. Beyond transportation, early warnings help secure infrastructure, safeguard lifelines, and protect industries from cascading failures. Disaster preparedness also extends to education and evacuation drills, as seen in the "Kamaishi Miracle." In Kamaishi City, where the tsunami claimed 1,000 lives, only 5 out of 2,900 primary and junior high school students perished, a survival rate 20 times higher than the general public. Regular drills, hazard mapping, and DRM education proved critical in ensuring timely evacuation and reducing casualties (Ranghieri and Ishiwatari 2014).

6.3 Volcanic Processes

Urbanization in volcanic regions has significantly increased exposure to volcanic hazards. In 2015, over one billion people (14.3 percent of the global population) lived within 100 km of a Holocene volcano, with human concentrations in these areas outpacing global growth rates since 1975 (Freire et al. 2019). Southeast Asia and Central America together account for 40 percent of the exposed population, with Southeast Asia experiencing faster population growth in the proximal zone (within 10 km of volcanoes). Roughly 50 percent of people living within 100 km of a volcano reside in cities (Meredith et al. 2025). Bandung, Indonesia, ranks as the most exposed city overall, with eight million people within 30 km of 12 volcanoes. San Salvador, El Salvador, has the highest number of nearby volcanoes, sitting within 100 km of 23 volcanoes and positioned between the San Salvador Volcanic Complex and the Ilopango Caldera.

Volcanic activity is driven by multiple geological mechanisms, including the dynamic interactions between tectonic plates and intraplate volcanism. Most of the volcanic activity occurs along convergent plate boundaries, particularly subduction zones, where one tectonic plate descends beneath another. This process generates intense pressure and heat, melting the mantle and producing magma that can rise to form volcanic arcs. A prime example of convergent boundary volcanism is the Pacific Ring of Fire, which hosts the world's most active volcanoes (National Geographic 2025). Divergent boundaries, where tectonic plates move apart, account for a smaller proportion of global volcanic activity. While many of these volcanoes are submarine, some are terrestrial, such as those found along the East African Rift. The remaining volcanic activity is attributed to intraplate volcanism, often associated with mantle plumes or hotspots. The Hawaiian Islands are a well-known example of volcanism resulting from a mantle plume. Similarly, the Yellowstone Caldera has been linked to a mantle plume originating near the core-mantle boundary, extending upward to the Yellowstone hotspot (Yellowstone Volcano Observatory, USGS 2018).

It is important to note that volcanic risk knowledge is constrained by limited scientific knowledge of numerous volcanoes and the long timescales over which volcanic activity unfolds. A large number of these remain poorly understood due to sparse monitoring and a lack of detailed studies. Moreover, they can remain dormant for centuries and still be classified as active. These long repose periods, combined with data gaps, can obscure the true hazard potential. This highlights the need for conservative risk-informed urban planning in volcanic regions, even where no recent activity has been recorded.

For urban planning purposes, the focus will be on proximal hazards, as they present the highest risk to infrastructure and human settlements. Volcanic hazards can be categorized into those that impact vicinities close to a volcano (proximal) and those affecting areas tens to hundreds of kilometers away (distal). Proximal hazards include pyroclastic flows, lava flows, tephra fallout, volcanic gas emissions, and lahars. Pyroclastic flows, consisting of fast-moving flows of hot gas and volcanic material, are among the most destructive phenomena, capable of incinerating structures and causing mass casualties. Lava flows, while slower moving, can destroy infrastructure and completely alter landscapes.

Volcanoes are classified by their morphology and eruption style, ranging in frequency and hazard level, with cinder cones being the most common and calderas being the least common but most hazardous.

- **Shield volcanoes,** like Mauna Loa (Hawaii, United States), produce fluid lava flows that spread widely and cause widespread damage, but are generally nonexplosive and therefore pose lower risk to life.
- **Cinder cones** are the most numerous, forming from short-lived, explosive eruptions of pyroclastic material, like Cerro Negro (Nicaragua).
- **Stratovolcanoes,** or composite volcanoes, are common at subduction zones and feature steep, conical profiles formed by alternating explosive and effusive eruptions. Examples include Popocatépetl (Mexico), Merapi (Indonesia), and Fuego (Guatemala). Their hazard level varies depending on their characteristics but can be highly dangerous due to their explosive eruptions, pyroclastic flows, and lahars, which can rapidly impact surrounding areas.
- **Lava domes** frequently form within stratovolcanic complexes, developing as viscous magma piles up rather than flowing freely. These domes can collapse, triggering pyroclastic flows, as seen in Mount Unzen (Japan).
- **Calderas** form when a magma chamber collapses after a major eruption and are among the most hazardous volcanoes, with eruptions capable of altering the global climate. Notable examples include Yellowstone (United States), Ilopango (El Salvador), Toba (Indonesia), and Laguna del Maule (Chile).

Volcanic eruptions generate a complex interplay of simultaneous processes, creating complex hazard interactions that amplify their impact. These processes can be categorized into explosive, effusive, and secondary hazards, all of which can unfold in parallel. Explosive eruptions generate eruption columns, where fragmented magma, volcanic gases, and ash are ejected at high velocities. Volcanic bombs and tephra, expelled during the eruption, pose immediate threats to life and can cause structural damage to

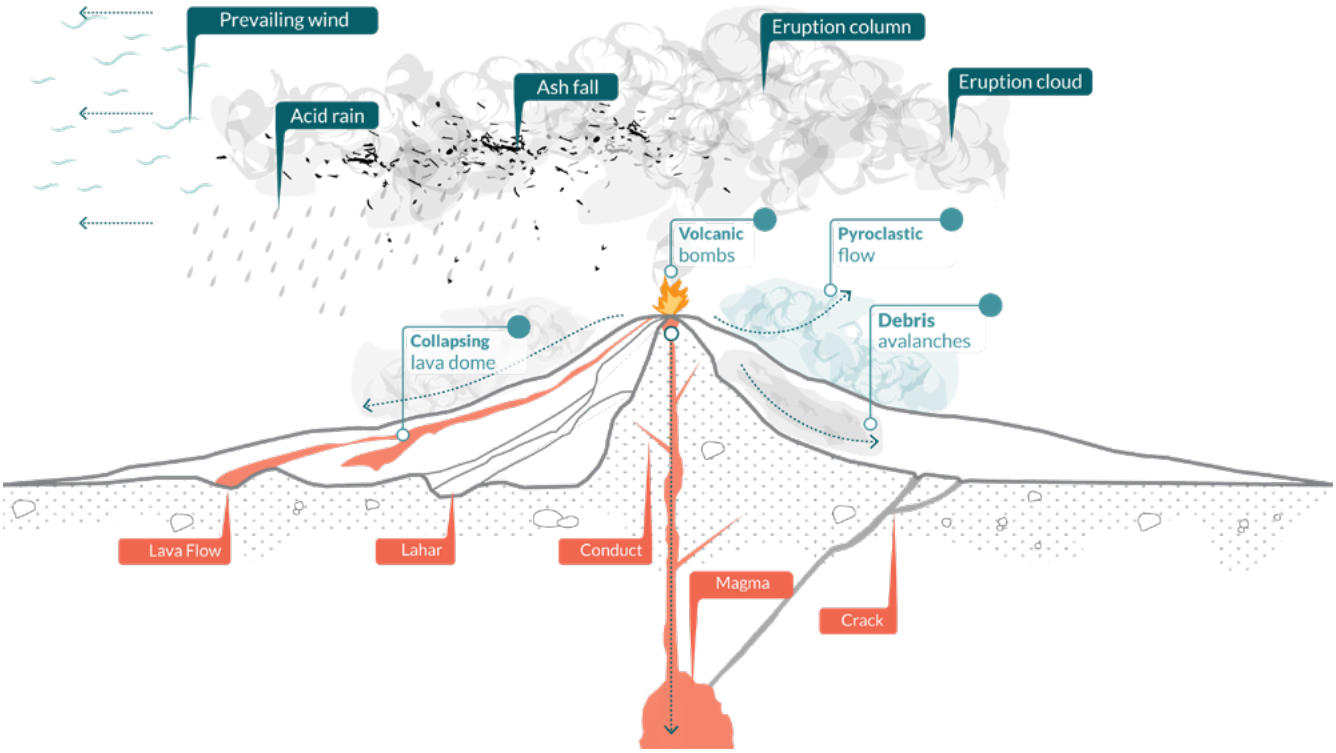
buildings and infrastructure near the source. Ashfall can collapse roofs, contaminate water supplies, and disrupt transportation and communication networks, while volcanic ash and gases contribute to respiratory illnesses and acid rain formation, affecting ecosystems and posing health risks. If ash plumes reach the stratosphere, they can disrupt aviation, reducing visibility, damaging jet engines, and leading to airspace closures to prevent flight hazards.

The Volcanic Explosivity Index (VEI) is used to classify eruptions based on their explosiveness. It is a logarithmic scale ranging from 0 (nonexplosive) to 8 (megacolossal). Developed by Newhall and Self in 1982, the VEI considers eruption volume, column height, and qualitative descriptions. Each increment represents a tenfold increase in explosivity. For example, VEI-4 eruptions eject close to 0.1 km^3 of material, like the 2021 eruption of La Soufrière on the island of St. Vincent in the Caribbean, while VEI-8 eruptions, such as Toba (~74,000 years ago), exceed 1,000 km^3 (U.S. Geological Survey 2021).

Pyroclastic density currents (PDCs) can travel hundreds of kilometers per hour, incinerating and burying everything in their path with superheated gas, ash, and debris, making them one of the most destructive volcanic hazards. The formation of PDCs is influenced by magma viscosity, volatile content, and conduit dynamics. PDCs encompass pyroclastic flows and pyroclastic surges. A pyroclastic flow is a high-density, fast-moving current of hot volcanic ash, gas, and rock debris that hugs the ground and moves downslope under gravity. In contrast, pyroclastic surges are less dense, more turbulent currents that can travel further and override obstacles due to their lower particle concentration. Dome collapse, explosive column collapse, or lateral blasts can all generate PDCs, with their runout distance controlled by topography and eruptive energy.

Effusive eruptions can cause widespread destruction as lava advances downslope, burying infrastructure, reshaping landscapes, and creating uninhabitable environments. Effusive processes involve the outpouring of low-viscosity magma, producing lava flows, lava lakes, and dome growth. The velocity of lava flow is determined by several key factors, including magma composition, temperature, eruption rate and volume, topography, and cooling rate. Lava moves faster on the steep slopes of stratovolcanoes, where gravity accelerates its descent, compared to the gentler slopes of shield volcanoes. Near the vent, where lava reaches peak temperatures and is under greater pressure, it flows more rapidly (U.S. National Park Service n.d.), with velocities up to 10 times higher (Kilburn 2000), before cooling and becoming more viscous. Figure 6.3 and table 6.7 show different volcanic processes, many of which can occur in parallel or cascading together.

Figure 6.3: An Illustration of Common Proximal Volcanic Hazards



Source: Original for this publication.

Table 6.7: A Summary of the Characteristics and Impacts of Volcanoes

Characteristics and Impacts
Proximal volcanic hazards are those that occur close to the volcano, typically within a few kilometers of the eruption site. These hazards include the following: **Pyroclastic density currents (PDCs)** are fast-moving currents of hot gas and volcanic matter that can reach speeds of up to 700 km/h. Flows can reach temperatures of up to 1,000°C (1,832°F), and their intense heat can ignite fires as they come into contact with flammable materials such as vegetation, buildings, and other structures. Pyroclastic density currents are extremely destructive due to their high temperature and velocity. They can be subdivided into pyroclastic flows and surges. Pyroclastic flows are high-density, fast-moving currents that move downslope under gravity. In contrast, pyroclastic surges are less dense, more turbulent currents that can travel further and override obstacles due to their lower particle concentration. **Volcanic bombs** are large, incandescent rocks ejected from a volcano during an explosive eruption. These bombs can travel several kilometers and cause significant damage upon impact due to their size and heat.

Lahars are mudflows or debris flows that occur when volcanic materials mix with water from rain, melted snow, or glaciers. Lahars can travel great distances and cause severe damage to infrastructure and loss of life. This hazard is addressed in detail in section in 6.1.2.

Lava flows are streams of molten rock that flow down the slopes of a volcano. Lava flows destroy everything in their path due to their high temperature and speed, particularly on steep slopes near the volcanic summit. While lava flows tend to decrease their speed with distance and slope reduction down the flanks, they remain highly destructive. The high temperatures of molten lava can ignite flammable materials in their path, such as vegetation and structures.

Tephra fallout (proximal) comprises fragments of volcanic rock and ash ejected into the air during an eruption. Large tephra can cause structural damage and collapse roofs, while fine ash can affect air quality and cause respiratory problems.

Volcanic gases are emissions of gases such as sulfur dioxide, carbon dioxide, and hydrogen sulfide. These gases can be toxic to humans and animals and can also contribute to acid rain and contaminate water sources.

Triggers

Proximal volcanic hazards are triggered by volcanic eruptions. Explosive eruptions, characterized by the rapid release of gas and magma, can trigger pyroclastic flows, tephra fallout, and the ejection of volcanic bombs. Effusive eruptions, where lava steadily flows out of the volcano, trigger lava flows. Lahars can be triggered by the melting of snow and ice during an eruption or by heavy rainfall mixing with volcanic debris.

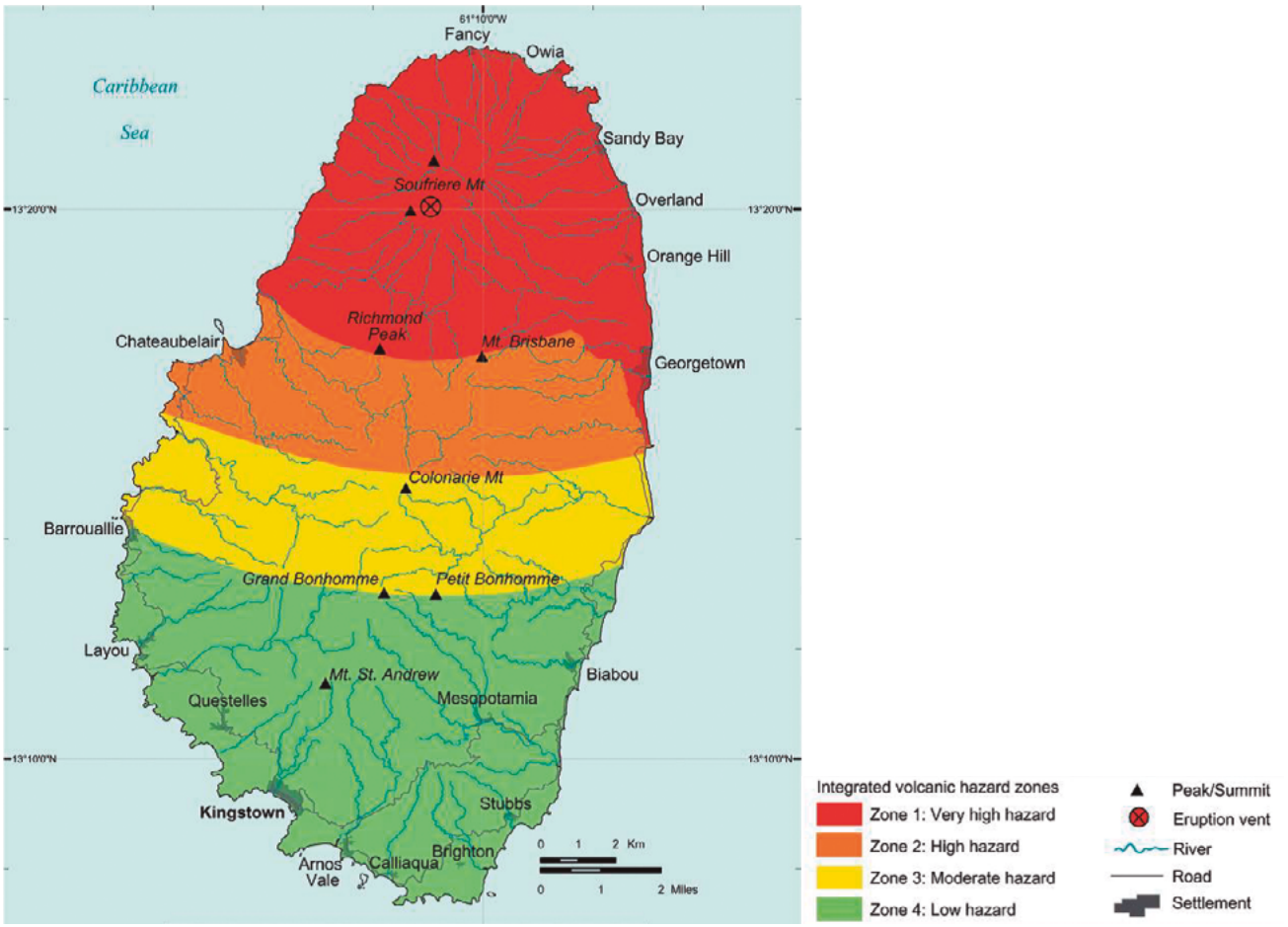
Aggravating factors

- Steep volcanic slopes can enhance the speed and reach of lava flows, pyroclastic flows, and currents.
- The presence of glaciers, snow, or water bodies like crater lakes can lead to increased explosiveness by generating phreatomagmatic activity. This interaction between magma and external water enhances pyroclastic activity and increases the likelihood of phenomena such as PDCs and lahars.
- Heavy rainfall can increase the likelihood and intensity of lahars.
- High population density heightens exposure within volcanic hazard zones. The fertility of volcanic soils drives demand for land.

Hazard and risk zoning

Volcanic hazard and risk zoning is a critical tool for land-use planning (figure 6.7.1). Hazard zoning delineates areas based on the expected intensity and frequency of volcanic hazards, such as pyroclastic flows, ashfall, and lava flows. This zoning is informed by geological mapping, historical eruption records, and numerical modeling of eruptive scenarios. Risk zoning integrates hazard assessments with exposure and vulnerability data, identifying areas where populations, infrastructure, and economic assets face the greatest risks. Zones are typically classified into high, moderate, and low hazard levels.

Figure 6.7.1: Example of Integrated Volcanic Hazard Zones in St. Vincent

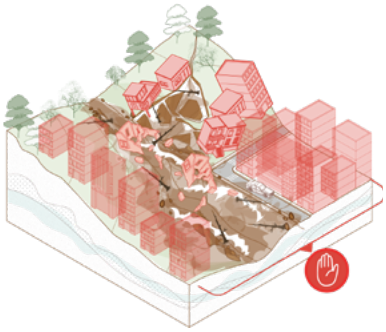


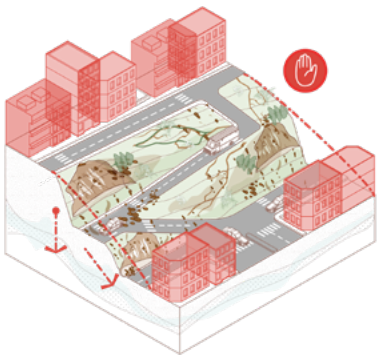
Source: The University of the West Indies Seismic Research Centre 2016.

In high-hazard zones, urban planning involves restrictions for permanent settlements and critical infrastructure. In urban settings, risk zoning can support preparedness and response planning, development and enforcement of building codes, and resettlement processes if necessary. Tables 6.8 to 6.10 show some examples of the Restrict, Condition, Promote (RCP) measures for geohazards.

Table 6.8: Examples of "Restrict" Measures for Geohazard Risk-informed Urban Planning

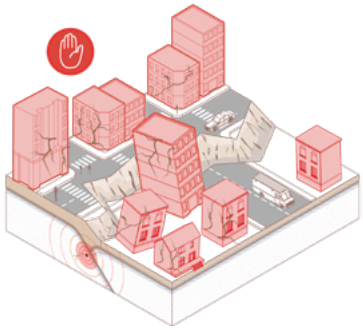
Restrict: Applies when hazard and risk levels are unacceptably high and cannot be reduced to acceptable levels through feasible, cost-effective measures.

Mass movements **Undeveloped zones – Hazard-based planning**		
Avoid development on steep, unstable slopes and areas of high landslide hazard.	Restrict development and enforce no-built zones in known debris and mud flow paths and high-risk zones.	Limit development near steep slopes and high-risk rockfall areas.
		

Mass movements **Developed zones – Risk-based planning**		
Resettle communities in built-up areas when landslide risk cannot be reduced to acceptable levels and human lives are at stake.	Limit slope alterations and land modifications that could heighten landslide risks and impact current or future developments.	Resettle communities in existing built-up areas when the high risk of debris flows and mudflows cannot be reduced to acceptable levels and human lives are at stake.
		

Strong motion and amplification

Apply appropriate setbacks near major active fault lines and enforce seismic design standards. Consider demolition of severely damaged structures or those that cannot feasibly be retrofitted to meet life safety or performance criteria.

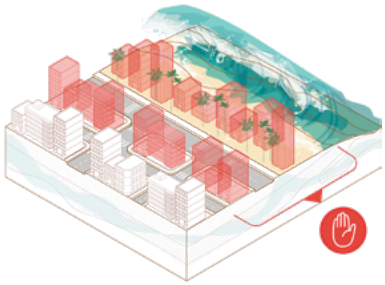


Limit structures with fundamental periods near the site's predominant period to avoid resonance effects and apply stringent design standards



Tsunamis

Restrict development and densification in high-risk tsunami inundation zones.

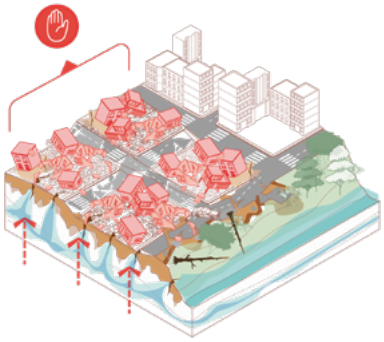


Liquefaction potential

Avoid development and critical infrastructure location in areas with high liquefaction potential.

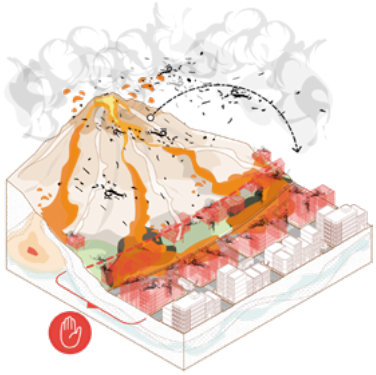


Restrict development and densification in uncompacted artificial fill zones.



Volcanic activity (proximal)

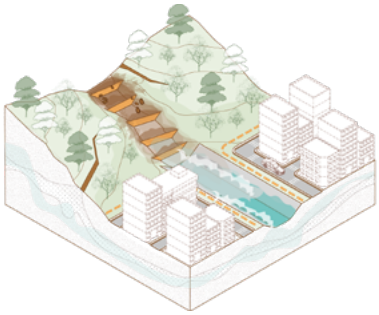
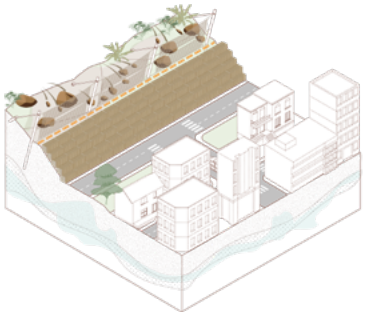
Restrict development and densification in areas susceptible to lava flows, pyroclastic flows, volcanic bombs, and immediate tephra fallout

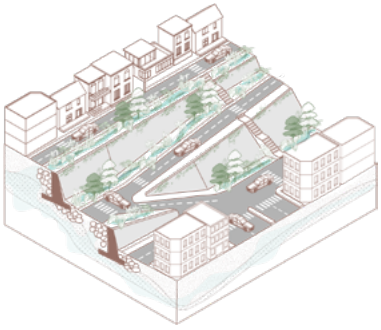
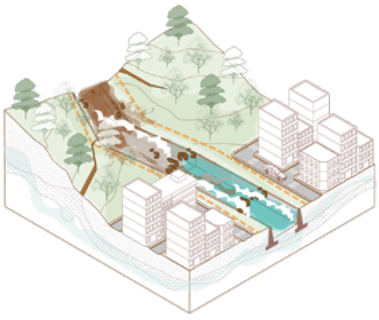
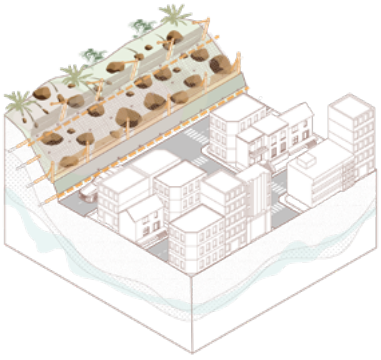


Source: Original for this publication.

Table 6.9: Examples of "Condition" Measures for Geohazard Risk-informed Urban Planning

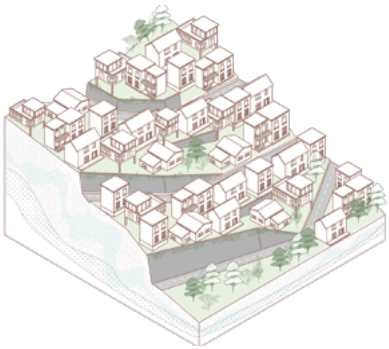
Condition: Applies where hazards or risks are relevant but can potentially be reduced to acceptable levels through appropriate planning, design, and construction practices.

Mass movement **Undeveloped zones – Hazard-based planning**		
Allow development in landslide-prone areas only if stabilization measures are implemented.	Allow development in areas prone to debris flows and mudflows only after reducing the risk to acceptable levels through measures like retention basins and barriers.	Allow development only if risk reduction measures, such as installing rockfall barriers, nets, or slope stabilization techniques, are implemented.
		

Mass movement **Developed zones – Risk-based planning**		
Implement risk reduction measures like retaining walls, slope stabilization, engineered structures, and improved drainage in built-up areas.	Implement risk reduction measures in built-up areas at risk from mudflows, mudslides, debris flows, and lahars.	Implement protective barriers, regular inspections, and structural reinforcements in built-up areas at risk from mass movements.
		

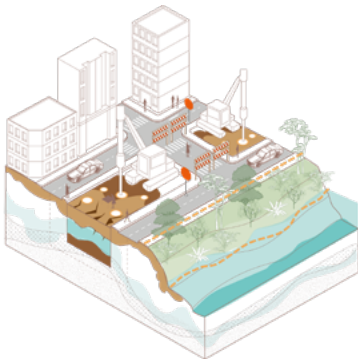
Mass movement
Developed zones – Risk-based planning

Undertake informal settlement upgrading only if measures are implemented to reduce risk of mass movement (landslides, rockfall, mudflows, mudslides, debris flows, and lahars) to acceptable levels.

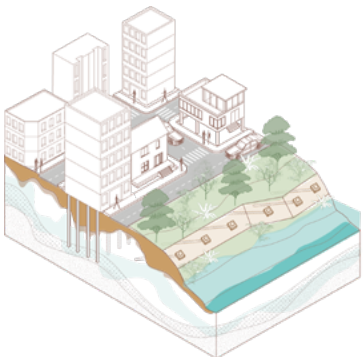


Liquefaction potential
Undeveloped and developed zones

Condition development on completion of detailed geotechnical studies and implementation of appropriate foundation systems and soil stabilization measures.

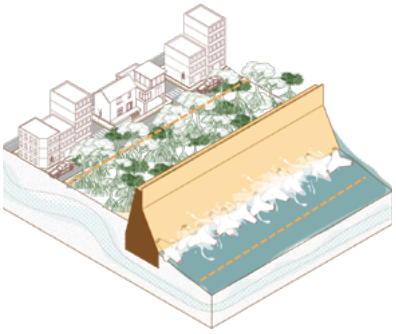


Condition approvals on setbacks from waterways, slopes, and land edges to reduce lateral spreading risks, or mandate deep foundation systems for stability in susceptible areas.



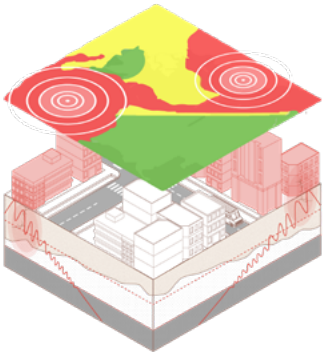
Tsunamis
(undeveloped zones)

Condition development on the implementation of protective measures, such as sea walls, natural barriers, and elevated structures.

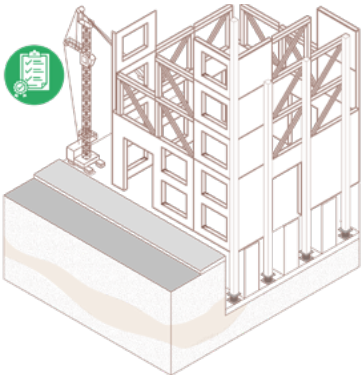


Strong motion and amplification –Undeveloped and developed zones

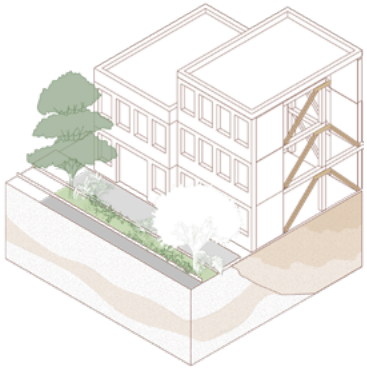
Condition development in areas prone to strong ground shaking on hazard assessments, site investigations, and compliance with earthquake-resistant design and construction standards.



Condition development for compliance with building codes to ensure that the designs can withstand the likely levels of shaking.

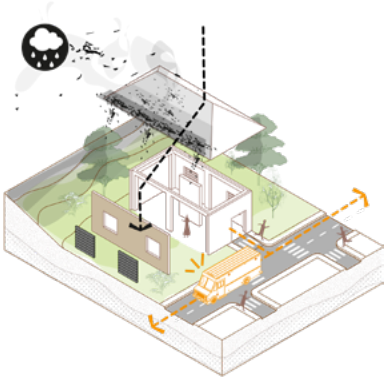


Retrofit vulnerable structures in built-up areas to meet life safety and performance criteria.



Volcanic activity (distal)

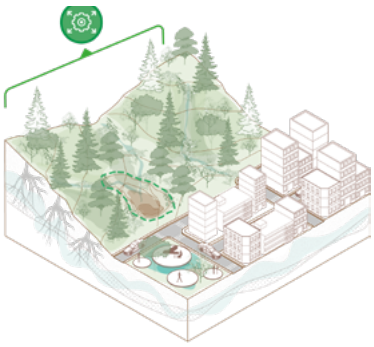
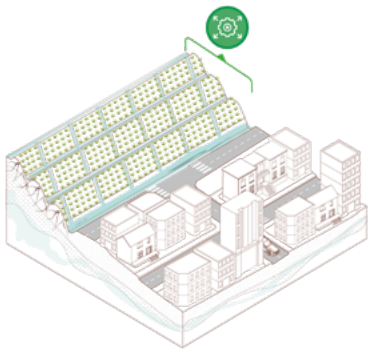
Include robust building codes to withstand ashfall in urban planning in moderate to low-risk zones.

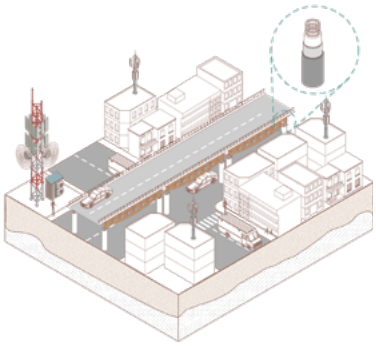
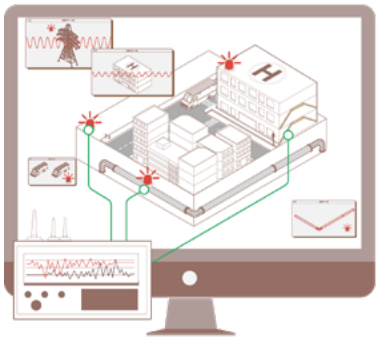
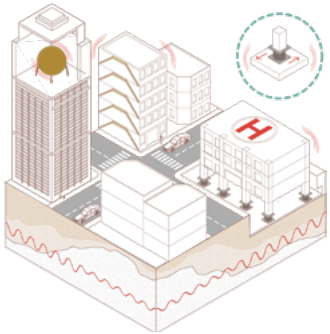


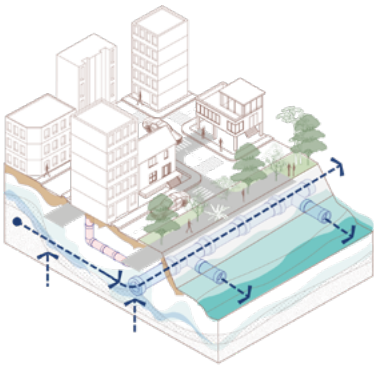
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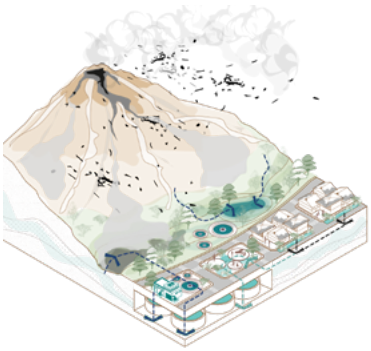
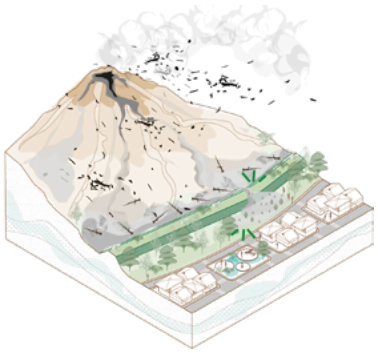
Table 6.10: Examples of "Promote" Measures for Geohazard Risk-informed Urban Planning

Promote: Applies to actions that complement the restriction and conditioning measures to incentivize an appropriate use of natural resources.

Mass movements		
Adopt nature-based solutions (NBS) focused on reforestation and afforestation to enhance slope stability to reduce runoff, rockfall, and flow risks.	Increase vegetation and green cover to stabilize slopes and act as barriers to reduce rockfall risks.	Improve drainage to reduce landslides and rockfall risks.
		

Strong motion and amplification		
Upgrade infrastructure to enhance resilience, including reinforcing and retrofitting bridges, utilities, and essential service lifelines.	Monitor critical facilities and lifelines regularly to ensure they meet seismic safety standards.	Encourage the use of advanced construction techniques such as base isolation and tuned mass dampers, which can help reduce the impact of amplified ground shaking frequencies.
		

Liquefaction potential		Tsunamis
Design utility networks with flexible materials and fail-safe systems to withstand ground deformation.	Design urban drainage, stormwater systems and groundwater extraction methods that account for liquefaction risks and prevent harmful water table fluctuations.	Promote protection and restoration of mangroves and coral reefs that can reduce tsunami force.
		

Volcanic activity	
Enhance redundancy in critical infrastructure and integrate water collection and filtration systems to minimize ash infiltration and ensure service continuity.	Implement NBS incorporating natural barriers like forests or artificial embankments to mitigate lahar and pyroclastic flow impacts.
	

Source: Original for this publication.

Chapter 7

Climatological Hazards

Climatological hazards stem from long-term atmospheric and environmental conditions, distinct from short-term meteorological events. As previously mentioned, for practical purposes, this handbook distinguishes between hydrometeorological and climatological hazards to better address their specific implications for risk-informed urban planning. These hazards, including extreme heat, prolonged droughts, and wildfires, are increasingly influenced by climate change, altering their frequency, intensity, and spatial distribution. Urban areas are particularly vulnerable due to land-use changes, heat retention from built environments, and UHI effects and increasing pressure on water resources. Addressing these hazards is closely aligned with the CCA agenda as effective urban planning and infrastructure decisions are critical to reducing long-term climate-related risks.

Unlike sudden-onset hazards, climatological hazards often develop gradually, leading to cumulative impacts on health, ecosystems, the economy, and the well-being of the urban population. The UHI effect exacerbates extreme heat, while land degradation and inefficient water management intensify drought conditions. Additionally, wildfires are becoming more frequent and severe, particularly in peri-urban areas where human settlements encroach on fire-prone landscapes.

This section focuses on three key climatological hazards: i) extreme heat, heat waves, and UHIs; ii) urban droughts; and iii) wildfires. Addressing these hazards requires integrating adaptive strategies into urban planning, including green infrastructure, sustainable water management, and climate-sensitive land-use regulations, to enhance resilience and sustainability in urban environments. While other hazards, such as extreme cold, are acknowledged and can be significant in high-latitude and mountainous regions, this handbook prioritizes the most prevalent and pressing hazards that require risk-informed planning interventions.

7.1 Extreme Heat, Heat Waves, and Urban Heat Islands

Extreme heat and heat waves are characterized by prolonged periods of excessively high temperatures, often coupled with high humidity. These conditions surpass the normal climate patterns of a region, leading to significant stress on human health, ecosystems, and infrastructure.

Extreme heat and heat waves represent significant urban hazards, exacerbated by the UHI effect, affecting millions annually with severe health and economic impacts. On average, extreme heat is responsible for 489,000 deaths worldwide annually, and the number is expected to increase as heat hazards continue to intensify due to climate change. Extreme heat and heat waves are expected to increase ill health and premature deaths further, reduce air quality, disrupt essential services, and increase the risk of food-borne, water-borne, and vector-borne diseases. Extreme heat and heat waves disproportionately affect vulnerable populations, including the elderly and those with preexisting health conditions, exacerbating social disparities. Cities face higher heat risks compared to rural areas as they are affected by the UHI effect. Nowadays, the most common manifestation of rising temperatures in densely built environments is the formation of a UHI, a phenomenon that amplifies the effects of warming temperatures from climate change.

Heat islands, often referred to as UHIs, are localized areas within a city or metropolitan area that experience significantly higher temperatures than their surrounding rural areas. This temperature differential is primarily caused by human activities and the built environment, as the result of factors such as the absorption and retention of heat by buildings, roads, and concrete surfaces (urban surfaces); the lack of vegetation and green spaces; increased energy use for cooling; and reduced natural ventilation due to tall buildings. This phenomenon not only increases energy consumption as residents seek to cool down but also escalates the risk of heat-related illnesses and mortality. The UHI effect makes urban areas hotspots for heat waves, which are expected to increase in frequency and intensity due to climate change.

City dwellers are affected by heat waves in uneven and diverse ways, mainly because of high temperatures hitting urban areas and poor air quality resulting from large fires in suburban and rural lands that increase carbon emissions. Because cities absorb more solar radiation than rural areas, and suburbs are increasingly affected by wildfires during hotter, drier seasons, heat resilience must become a core objective of master plans, through the integration of comprehensive urban heat management strategies.

Extreme heat events are relatively predictable and measurable (table 7.1). This means that cities can fine-tune their EWS and master plans to mitigate their effects on urban dwellers. Building on the identification of heat-prone areas through a combination of satellite mapping and ground sensors, urban plans must include guidelines for assessing, managing, monitoring, and coordinating actions to reduce the impact of heat waves in cities. Heat hazard and risk zoning are critical aspects of urban planning that involve identifying and categorizing areas within a city that are most susceptible to extreme heat and heat waves. This zoning enables targeted interventions to reduce heat exposure and vulnerability, particularly in densely populated or infrastructurally critical areas.

Table 7.1: A Summary of the Characteristics and Impacts of Extreme Heat

Characteristics and Impacts

Extreme heat and heat waves are prolonged periods of abnormally high temperatures that exceed regional norms and significantly impact human health, ecosystems, and infrastructure. These events are exacerbated in urban areas by the urban heat island (UHI) effect, where built environments absorb and retain heat, leading to higher localized temperatures. Impacts include increased mortality and morbidity rates due to heat-related illnesses such as heat stroke, dehydration, and cardiovascular stress. Vulnerable populations, including the elderly, children, and outdoor workers, are most at risk. Extreme heat disrupts systems by straining power grids (due to surging cooling demands), damaging crops and threatening food security, and reducing labor productivity, especially in heat-exposed industries. In urban settings, the intensified heat amplifies existing vulnerabilities, worsening living conditions, particularly in informal settlements with poor ventilation and limited green spaces. Additionally, extreme heat can trigger cascading hazards, such as flooding from rapid snowmelt or wildfires.

Triggers

Climate change is increasing the frequency, intensity, and duration of extreme heat and heat waves. Natural climatic variations, such as El Niño, serve as additional climatic stressors. On a meteorological scale, high-pressure systems can trap warm air in a region for extended periods, intensifying heat events. The UHI effect, where urban areas are significantly warmer than their rural surroundings due to human activities, further exacerbates the occurrence of extreme heat.

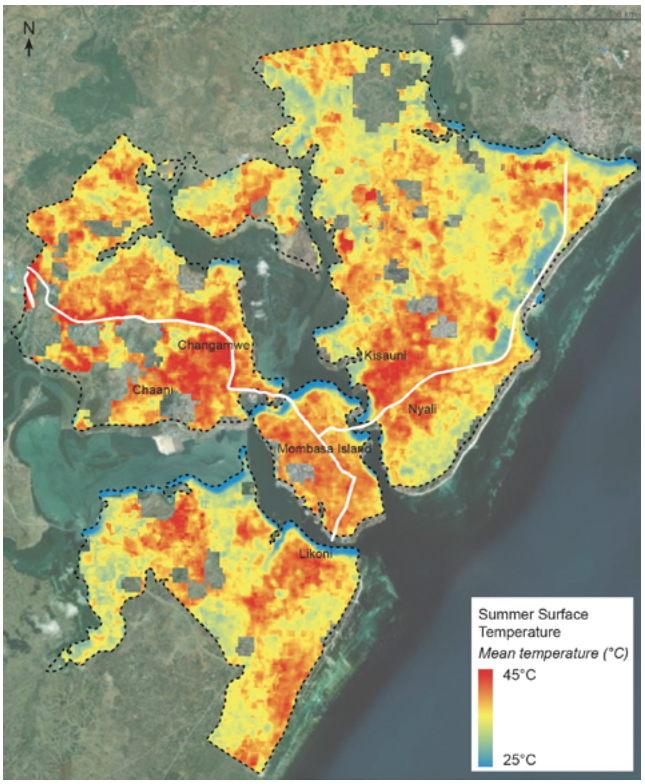
Aggravating factors

- Reduction of natural cooling elements, such as green spaces and water bodies, intensify heat impacts. Additionally, natural topographical features and limited natural ventilation can trap heat and exacerbate extreme heat events.
- Climate conditions, including droughts and reduced precipitation, diminish soil moisture and increase surface temperatures.
- People in coastal areas with high humidity also face a compounded heat burden, as the body's ability to cool through perspiration is reduced.
- Power outages or insufficient energy access limit cooling options, increasing health risks.
- Inefficient urban planning, lack of tree cover, and inconsistent use of heat-reflective infrastructure exacerbate heat retention and exposure.
- Informal settlements face greater extreme heat hazards due to dense, unplanned construction using heat-absorbing materials, lack of ventilation, and limited green spaces.
- Poor air quality can worsen the health impacts of extreme heat.

Hazard and risk zoning

Urban heat hazard maps or hotspots can be produced by combining weather observations and satellite imagery to identify areas with elevated surface temperatures (figure 7.1.1). Key factors such as land use, vegetation cover, building density (and wind flow patterns), and infrastructure materials (like asphalt and concrete) that retain heat are mapped to determine areas prone to higher temperatures. These maps measure surface temperature, not ambient temperature, and help pinpoint hotter areas. They are often based on thermal imaging, utilizing remote sensing techniques. Importantly, they primarily represent urban heat susceptibility rather than the hazard itself, helping identify neighborhoods that are more vulnerable to extreme heat impacts due to their physical and environmental characteristics.

Figure 7.1.1: Example of Summer Surface Temperature Map for Mombasa, Kenya



Source: World Bank 2023f.

Urban planning must address heat hazards by mitigating the UHI effect through appropriate urban design, policies, and plans (box 7.1). Dense urbanization and high-rise buildings, especially in wind corridors, can block airflow, while the use of heat-absorbing materials and the reduction of green spaces exacerbate temperature rise. Solutions include reflective and permeable surfaces to lower heat retention, improved building codes to enhance insulation and energy efficiency, and the integration of green infrastructure, such as parks and urban forests. Additionally, heat action plans, cooling centers, and thermal mapping can

protect communities, particularly in vulnerable areas, from extreme heat events. To reduce the impact of this phenomenon, urban plans must incorporate measures such as those summarized in tables 7.1 to 7.3, in accordance with climatological hazards assessments.

Box 7.1:

Urban Cooling Solutions in Guangzhou, China

Extreme heat and heat waves, amplified in dense cities by the urban heat island (UHI) effect, are generating major disruptions in people's health, livability, and economic productivity (Roberts et al. 2023). As the planet is getting warmer, some cities such as **Guangzhou in China** are carrying out a series of urban cooling solutions to improve heat resilience, including the consolidation of the network of ecological corridors and the creation of six major ventilation corridors (photo B7.1.1). In addition to the environmental, health, and economic benefits, planning and implementing such solutions generates economic returns for cities. Studies suggest that a 20 percent increase in cool roofs and a 50 percent increase in cold pavements would yield returns ranging from US$6 to US$15.24 for each dollar invested (Estrada et al. 2017, 404).

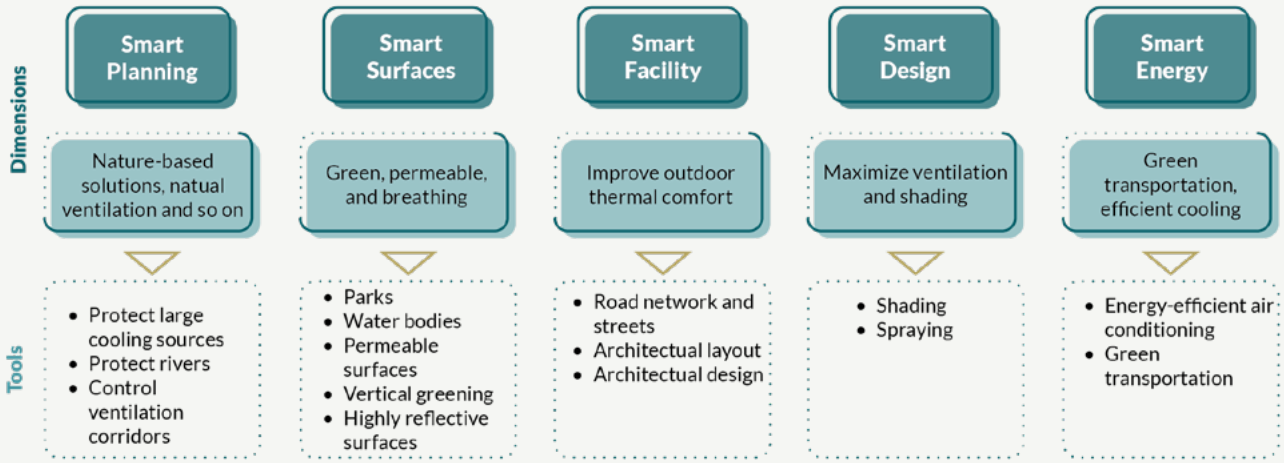
Photo B7.1.1: Aerial View, Guangzhou, 2025



Source: © lzf / Shutterstock.

In 2019, the World Bank launched the Sustainable Urban Cooling program, and Guangzhou was selected as the first pilot city. To mitigate the UHI effect, the Guangzhou Urban Planning and Design Survey Research Institute partnered with the World Bank in 2022 to develop the "Guidelines on Integrating Nature-based Cooling Solutions into Urban Planning and Design." Going beyond conventional air-conditioning-based approaches, these guidelines promote the use of reflective materials in buildings and public spaces to reduce heat absorption and develop strategies to increase natural ventilation, evapotranspiration, and shading to dissipate heat retention (World Bank 2022d). The five dimensions and 15 tools proposed as guidelines (figure B7.1.1) are the basis for the implementation of 40 different types of actions.

Figure B7.1.1. Dimensions and Tools of Urban Cooling Strategies in Guangzhou

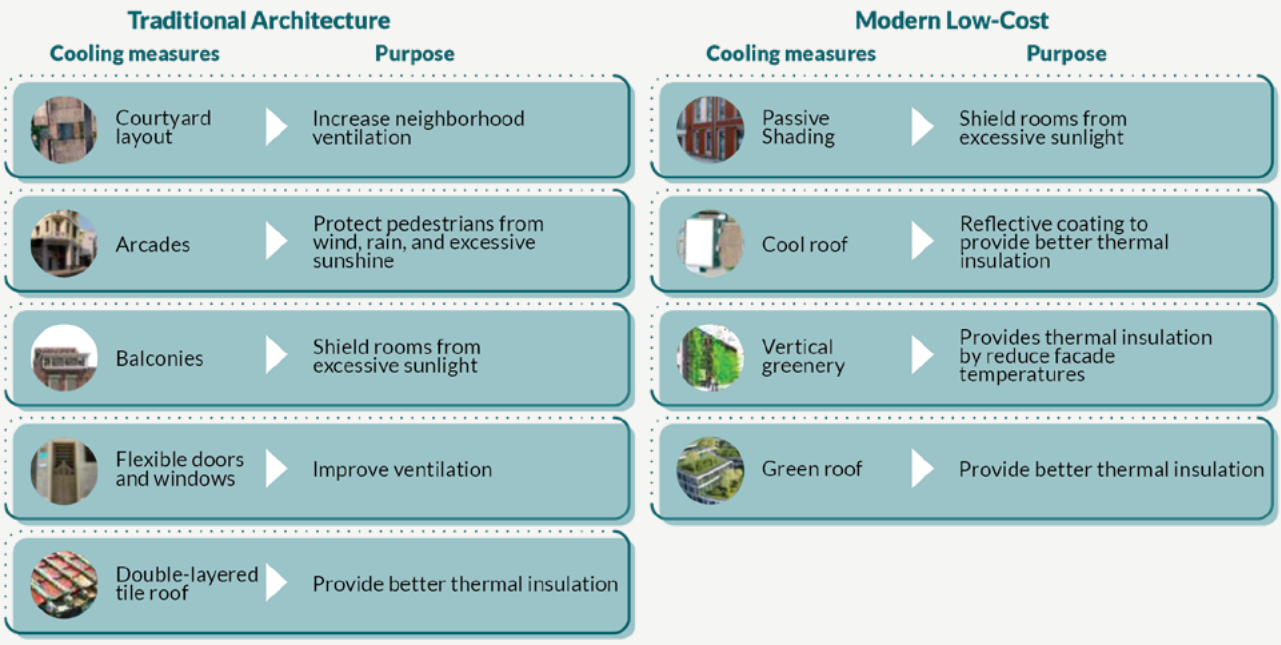


Source: Based on World Bank 2022d.

Cooling strategies are being tested at both city and neighborhood scales, addressing different urban contexts. For instance, in the historic neighborhood of Yongqing Fang, a preliminary microrenovation of three alleyways adjacent to Enning Road was led by Lab D+H between 2016 and 2017 with the financial support of Guangzhou Vanke Co. Ltd. This project included the reuse of local materials, the creation of small-scale public spaces and the implementation of innovative measures to enhance resilience to flooding caused by poorly functioning urban drainage. The urban design also contributed to reducing the UHI effect by including water gardens, new sidewalk vegetation, and roof gardens.

The second phase initiated in 2020 by the city with the support of the World Bank involved piloting cooling measures in the Jixiang section of Yongqing Fang. At the site level, the project focused on restoration and renovation, using land vacated by demolitions to create open spaces. To improve air flow, it also included changes to the street layout and reductions in the size of some buildings, replicating the cool alleys and patios of the traditional bamboo-tube house model. At the building level, the project combined traditional Lingnan regional architectural cooling methods and modern low-cost cooling measures (figure B7.1.2).

Figure B7.1.2. Building-Level Cooling Measures



Source: Based on World Bank 2022d.

At the landscape level, the project includes planting local trees to increase evapotranspiration and shaded areas as well as installing sprinkler facilities, solar-powered fans and water features, and fountains in public spaces (World Bank 2022d). This multilevel strategy, implemented at the neighborhood scale, becomes an opportunity for the city to move from planning to action by testing and scaling-up nature-based solutions (NBS) and passive cooling systems to increase heat resilience and mitigate the UHI effect. At the city scale, these actions contribute to the fulfillment of the Guangzhou 2035 Master Plan goals focused on promoting compact growth; protection of strategic ecosystems; consolidation of ecological corridors; reconnection of nature, society, and the city; and adaptation to climate change.

7.2 Urban Droughts

Droughts are becoming one of the most pressing challenges in the context of climate change and climate variability. Droughts are typically described as comprising four types: meteorological, hydrological, agricultural, and socioeconomic (Wilhite and Glantz 1985). Characterized by prolonged periods of significantly below-normal rainfall, droughts not only disrupt natural ecosystems but also affect human societies. Traditionally associated with agricultural losses in rural areas, drought is increasingly being recognized as a multifaceted hazard that can also cripple urban systems (table 7.2).

Urban drought can be considered a subtype of socioeconomic drought, representing a temporary water shortage condition in cities caused by either a sharp decrease in water supply or a sudden increase in water demand (Wang et al. 2020; Zhang et al. 2019). Urban centers, often densely populated and reliant on complex water infrastructure, are becoming more vulnerable to drought, particularly as climate change and rapid urbanization intensify water scarcity.

Growing populations are expected to result in an 80 percent increase in demand for water in urban areas by 2050, and the urban population is expanding faster than the cities' service provision capabilities. Climate change and urban population growth are putting increasing strain on existing, often inefficient, water infrastructure (Zaveri et al. 2021).

When urban water supply systems fail or face extreme pressures, the effects permeate all aspects of urban life, from public health and sanitation to economic productivity. This kind of drought can exacerbate existing inequalities, disproportionately affecting marginalized communities with limited access to alternative water sources. More frequent and intense droughts and insufficient and inequitable access to basic water services can undermine security, well-being, and development prospects, disproportionally affecting the urban poor (Hallegatte et al. 2017; Heymans et al. 2022; IPCC 2008; Zhang et al. 2019).

Although the terms "urban drought" and "water scarcity" are often used interchangeably, there are important differences. Urban drought specifically refers to short-term imbalances between water supply and demand in cities, whereas water scarcity encompasses all types of water shortages and can persist over a longer duration (Zhang et al. 2019). As cities continue to grow and climate change drives more extreme weather patterns and growing climate risks, integrating water resource management and urban drought risk into urban planning becomes critical for resilience building.

Table 7.2: Characteristics and Impacts of Droughts

Characteristics and Impacts
Urban drought, a subtype of socioeconomic drought, occurs when cities face temporary water shortages due to reduced water availability or increased demand. Densely populated urban areas, reliant on complex water infrastructure, are particularly vulnerable as climate change and rapid urbanization intensify water scarcity. Impacts include public health risks from inadequate water access, curtailed production, and disruptions to industries and services. Urban droughts often have cascading impacts and risks, such as unemployment and food insecurity; migration; economic, social, and political instability; and conflict. Droughts can also impact water quality and lead to waterborne diseases. People living in informal settlements or slums face disproportionate risks as these areas often lack reliable water supply systems, adequate sanitation, and effective water management.

Triggers

Droughts can result from natural climate variability or changes in atmospheric circulation patterns. Climate change is also a significant contributor, altering precipitation patterns and increasing the frequency and severity of droughts. Other triggers include El Niño and La Niña events, which can disrupt normal weather patterns, leading to prolonged dry spells in certain regions. Rapid urbanization contributes indirectly by straining existing water supply systems and increasing water demand, and mismanagement of water resources exacerbates baseline water scarcity.

Aggravating factors

- Deforestation and land degradation reduce the land's ability to retain water, worsening drought conditions.
- Climate change increases the frequency and intensity of droughts, higher temperatures, and heat waves, which accelerate water evaporation and raise water demand.
- Soil degradation and urban heat islands (UHIs) further increase water stress by reducing groundwater recharge rates and increasing evaporation in urban settings.
- Urbanization increases water demand, intensifying the strain on limited water resources.
- Poor water management practices, such as overextraction of groundwater and inefficient irrigation exacerbate water shortages.

Hazard and risk zoning

Urban droughts are an emerging hazard. Models often struggle with the complexities of urban microclimates and the dynamic nature of water demand. Urban drought risk assessments face significant challenges related to data availability, quality, and granularity. Many developing regions lack reliable monitoring systems, leading to gaps in understanding water resource trends and drought dynamics. Even in areas with adequate data collection infrastructure, datasets are often fragmented, with limited integration across sectors. Urban areas, in particular, require high-resolution data to account for the variability of water demand, microclimates, and population density. However, obtaining detailed spatial and temporal data, such as household-level water usage, groundwater recharge rates, and UHI effects, remains difficult. This lack of granularity hinders the development of accurate models that can predict urban drought patterns and impacts.

Methods are increasingly focusing on hybrid models that combine physical and social vulnerability assessments, incorporating both quantitative data (for example, hydrological models) and qualitative insights (for example, stakeholder surveys). Urban drought risk can then be assessed by evaluating drought hazard, considering surface water deficits and incorporating exposure (urban population) and vulnerability information (multivariate indicators such as water access, poverty, and government effectiveness).

City planners play a critical role in addressing urban drought by implementing strategies that promote water efficiency and reduce urban drought risk. Efficient water conservation and distribution systems must be prioritized to ensure equitable access to water, particularly for vulnerable groups disproportionately affected by urban droughts. This includes minimizing water wastage through effective regulation of water extraction, sustainable groundwater management, and the restoration of natural water systems to enhance recharge capacity and long-term availability.

Integrating water-sensitive urban design principles into urban planning can further mitigate drought risk. Expanding green infrastructure—such as urban parks, green roofs, and permeable surfaces—enhances groundwater recharge, reduces runoff, and moderates urban heat, thereby addressing compounding factors like the UHI effect. Zoning regulations should promote water-efficient building designs, mandating measures such as rainwater harvesting, gray water recycling, and the adoption of low-flow water fixtures.

Planners must also focus on informal settlements and underserved communities, where targeted interventions such as community water storage systems and improved sanitation infrastructure can improve the reliability of access to clean water during droughts. Investments in drought-resilient infrastructure, including stormwater harvesting systems, desalination plants, and smart water networks, are essential to meet increasing water demands. Data-driven approaches should underpin urban planning decisions. Advanced tools, including real-time analytics, hydrological models, and remote sensing technologies, allow planners to assess drought risks comprehensively, prioritize high-risk areas, and develop proactive strategies (box 7.2).

Box 7.2:

Evidential Learning in Urban Drought Management

Urban droughts have intensified globally over the past decade, driven by climate change, rapid urbanization, and water governance and urban planning that fail to account for emerging hazards. Australia's Millennium Drought (1997–2009) was one of the earliest large-scale events to highlight the vulnerability of urban water systems (Heberger 2012; van Dijk et al. 2013). São Paulo, Brazil, faced a severe water crisis in 2014–2015 as reservoirs fell to critical levels, while Chennai, India, experienced near-total depletion of its water supply in 2019 due to failed monsoons (photo B7.2.1). Cape Town, South Africa, came closest to complete urban water exhaustion during its 2018 "Day Zero" crisis, forcing extreme conservation measures (Joubert and Ziervogel 2019; Ziervogel 2019). More recently, in February 2022, the government of Nuevo León, Mexico, declared an emergency due to extreme drought conditions as two of the three dams supplying the Monterrey metropolitan area recorded historically low levels (Poder Ejecutivo del Estado de Nuevo León 2022). Montevideo, Uruguay, faced

an unprecedented crisis in 2023 that resulted in an emergency declaration (Poder Ejecutivo de Uruguay 2023). In Europe, Barcelona, Spain, has endured multiple severe droughts, including crises in 2008, 2022, and 2024, with the most recent emergency declared as reservoir levels fell below 16 percent (Cassidy 2024).

Photo B7.2.1: People filling their containers with drinking water from a municipal tanker in Kolkata, India, 2019



Source: © mr avijit ghosh / Shutterstock.

Cities must proactively invest in drought risk reduction and sustainable water management while strengthening their ability to anticipate, respond to, and adapt to prolonged water shortages. Long-term planning is essential to build resilience and ensure water security in the face of climate change and population growth. Sustainable urban design plays a key role in enhancing water availability and efficiency. Strategies such as rainwater harvesting, permeable surfaces, ecological corridors, and efficient water infrastructure help cities optimize water use, reduce runoff, and enhance groundwater recharge. Additionally, investments in integrated water management systems, water infrastructure, and green infrastructure are critical for maintaining reliable urban water sources while minimizing the impacts of drought and extreme heat.

Lessons from past events have demonstrated that improving drought resilience requires a comprehensive approach that integrates and balances demand-side and supply-side management strategies within urban planning frameworks.

On the supply side, diversification of water sources has proved to be critical for long-term resilience. Investments in desalination plants in places like Barcelona, California, and Melbourne have provided reliable alternative water supplies during prolonged droughts (World Meteorological Organization and Global Water Partnership 2017). Other measures include groundwater extraction, wastewater recycling, rainwater harvesting systems, and stormwater capture technologies.

Demand-side management has proven effective in many cities, especially in crisis situations, significantly reducing per capita consumption. Water conservation programs, such as public awareness campaigns, incentives for water-efficient appliances, and usage restrictions, have reduced per capita consumption in cities like Cape Town and Melbourne. For example, in Cape Town, strict water-use limits and public campaigns during the 2018 "Day Zero" crisis significantly curtailed consumption, avoiding a complete water supply collapse (Ziervogel 2019). Meanwhile, Australia's Millennium Drought saw a drastic reduction in water demand through community engagement and widespread adoption of water-saving technologies (Turner et al. 2016).

7.3 Wildfires

Traditionally associated with forested and rural landscapes, wildfires are increasingly encroaching into urban areas, particularly as climate change and land-use changes intensify fire risks. Wildfires, also referred to as vegetation or forest fires, are among the most devastating socio-natural hazards affecting ecosystems, economies, and human settlements. Recent evidence indicates that more than 75 percent of wildfires globally are caused by human activities, whether accidental, intentional, or due to negligence (WFP 2020).

The interplay between prolonged droughts, heat waves, and human activities has made wildfires more frequent, intense, and unpredictable. Climate change exacerbates these conditions, creating hotter, drier environments that increase the flammability of vegetation. Furthermore, rapid urbanization into fire-prone zones heightens exposure and vulnerability as cities face growing challenges in mitigating and responding to wildfire hazards.

The ramifications of wildfires in urban areas are extensive, encompassing loss of life, destruction of property, environmental degradation, health risks, and significant economic burdens. For example, the Lahaina Wildfire on Maui Island in Hawaii was ranked as one of the most costly disasters of 2023, with economic

losses amounting to US$5.5 billion (CRED 2024). The early 2025 Los Angeles wildfires resulted in the loss of 28 lives and the destruction of over 16,240 structures, property and capital losses estimated to be between US$95 billion and US$164 billion, and a 0.48 percent decline in Los Angeles county GDP amounting to US$4.6 billion (Li and Yu 2025). In Canada, wildfire smoke has placed a heavy strain on the health care system. In just one week during June 2023, health-related costs in Ontario alone—including premature deaths, increased hospital visits, and medical emergencies—were estimated at over US$1.2 billion (Sawyer, Stiebert, and Welburn 2023).

The Wildland-Urban Interface (WUI) presents significant challenges for wildfire risk management due to the proximity of flammable natural landscapes and densely populated urban or suburban communities. WUI refers to areas where human development and infrastructure meet or intermingle with fire-prone wildland vegetation (Radeloff et al. 2005). The WUI is particularly hazardous because it combines high ignition potential with limited access for emergency responders. Urban expansion, climate change, and prolonged droughts have intensified wildfire risks in these areas, making fires more frequent, severe, and difficult to control. Embers from wildfires can travel several kilometers, igniting homes, businesses, and infrastructure, often overwhelming firefighting resources (table 7.3).

Strategic land-use planning plays a key role in mitigating wildfire risks by directing development away from high-hazard zones and enforcing building codes that enhance structural resilience. Establishing fire hazard severity zones allows urban planners to implement risk-based zoning regulations, ensuring that new constructions incorporate fire-resistant materials, maintain defensible spaces, and adhere to strict safety standards. Additionally, integrating wildfire mitigation measures with urban infrastructure planning—such as expanding water supply networks, ensuring sustainable forest management practices, enhancing emergency response capacity, and improving evacuation routes—further strengthens urban resilience.

Table 7.3: A Summary of the Characteristics and Impacts of Wildfires

Characteristics and Impacts
Wildfires affect forests and other vegetation types such as grasslands, shrublands, and other nonforest land cover. These uncontrolled fires spread rapidly across vegetation and forested areas, often encroaching on urban areas. They can cause extensive damage to property, infrastructure, and natural resources, leading to significant economic losses and environmental degradation. Wildfires pose severe risks to human life, cause poor air quality, and can result in long-term health issues due to smoke inhalation. They also disrupt power supplies, communication networks, and transportation, impacting entire communities.
Triggers
Wildfires can be triggered by natural phenomena such as lightning strikes and high temperatures, as well as human activities including unattended fires and faulty electrical lines. It has been estimated that more than 75 percent of wildfires globally are caused by human activity (WFP 2020).

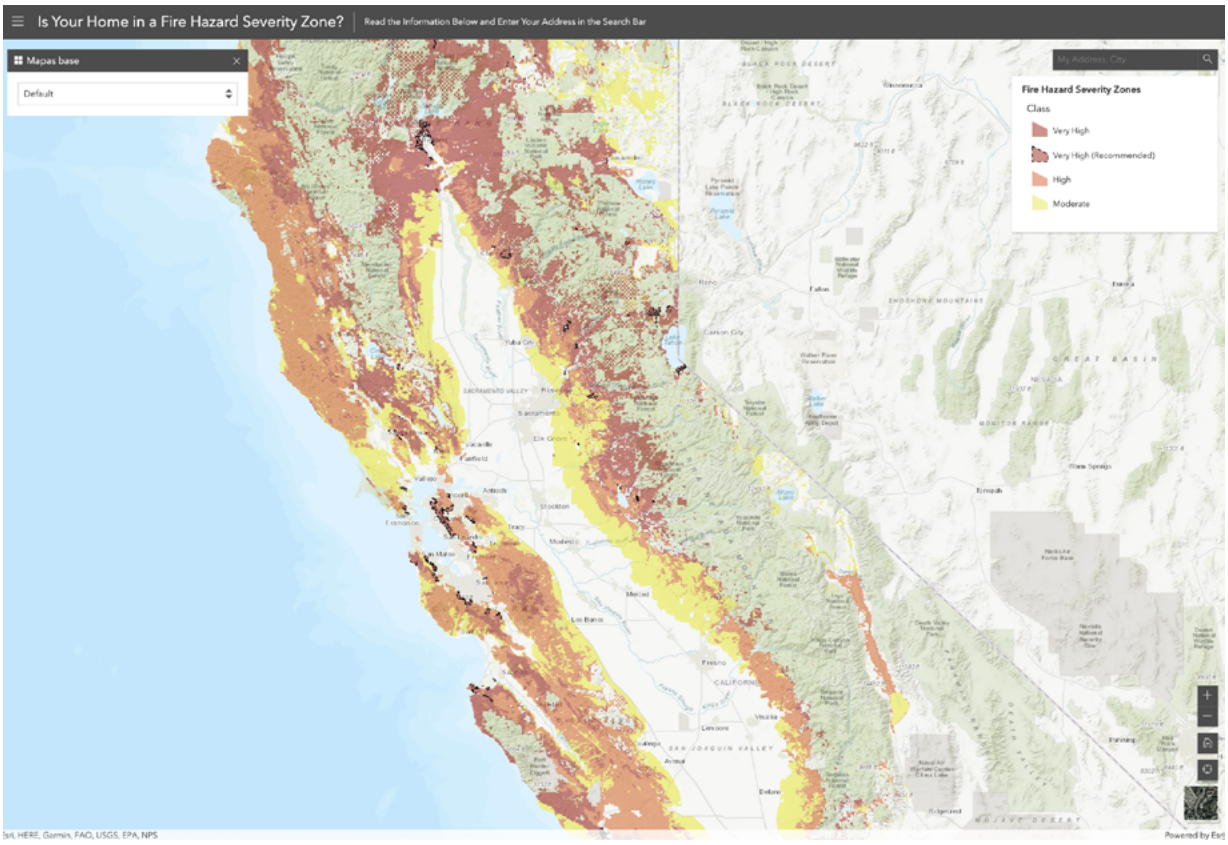
Aggravating factors

- Prolonged and extreme droughts, high temperatures and heat waves, low humidity, dry vegetation, and strong winds can aggravate wildfire risks and make wildfires more intense and difficult to control.
- Climate change contributes to the increased frequency and intensity of wildfires by creating hotter, drier conditions that make vegetation more flammable.
- Human actions such as deforestation, poor land management, urban expansion into wildfire-prone areas, and inadequate firebreaks heighten wildfire risk.

Hazard and risk zoning

Wildfire hazard and risk zoning involves systematically identifying and mapping areas with varying levels of wildfire risk by analyzing key factors such as vegetation type, topography, climate conditions, and historical fire occurrences (figure 7.3.1). In urban areas, integrating the Wildland-Urban Interface (WUI) into hazard assessments is essential. Advanced risk assessment tools, such as remote sensing and Geographic Information System (GIS), allow for dynamic mapping of WUI areas.

Figure 7.3.1: Example of Fire Hazard Severity Zones for California State

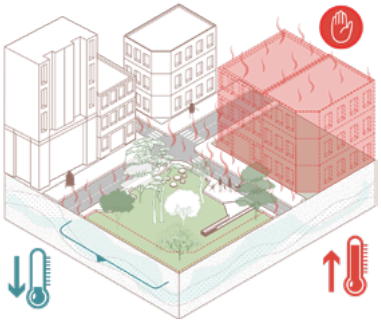
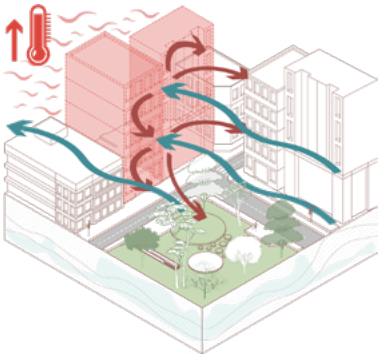
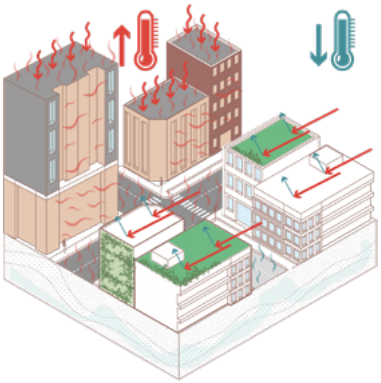


Source: ESRI, 2025.
https://www.arcgis.com/apps/Styler/index.html?appid=5e96315793d445419b6c96f89ce5d153

The Urban Fire Regulatory Assessment and Mitigation Evaluation Diagnostic (World Bank 2020) highlights the critical role of regulatory frameworks in reducing fire risks and strengthening urban resilience. The diagnosis emphasizes that a well-structured legal and administrative system is essential for defining clear roles and responsibilities among fire safety enforcement agencies, ensuring effective implementation and compliance with fire regulations. It also underscores the importance of integrating fire-resistant construction materials and design standards into building codes, along with mandatory maintenance protocols to sustain fire resilience over time. Moreover, the diagnosis highlights the need for enhanced local implementation strategies, including capacity-building initiatives for municipal authorities, resource allocation for regular inspections, and enforcement mechanisms to ensure compliance with fire safety regulations. Tables 7.4 to 7.6 show examples of the Restrict, Condition, and Promote (RCP) measures for these climatological hazards.

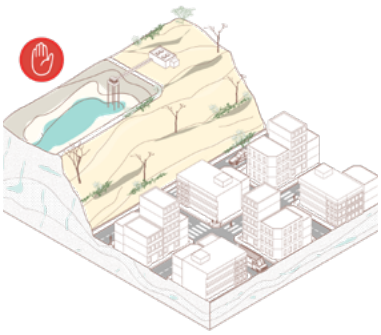
Table 7.4: Examples of "Restrict" Measures for Climatological Risk-informed Urban Planning

Restrict: Applies when hazard and risk levels are unacceptably high and cannot be reduced to acceptable levels through feasible, cost-effective measures.

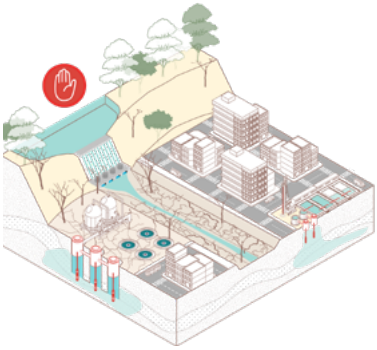
Extreme heat, heat waves, and urban heat islands		
Reduce depletion of green spaces in areas prone to heat hazards.	Prohibit densification along wind corridors.	Limit undue use of heat-absorbing materials.
		

Urban droughts

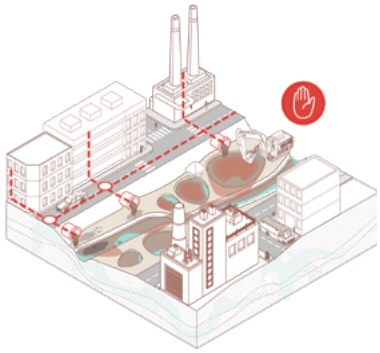
Restrict deforestation and large impervious surfaces in high-infiltration areas.



Restrict overextraction, unregulated well drilling, and excessive damming.



Restrict activities that trigger water pollution risks, such as mining, landfills, and untreated wastewater discharge near basins.



Wildfires

Restrict development in areas with high wildfire susceptibility.

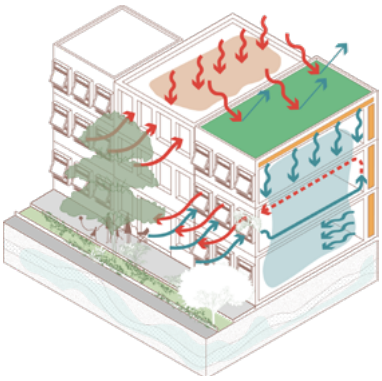
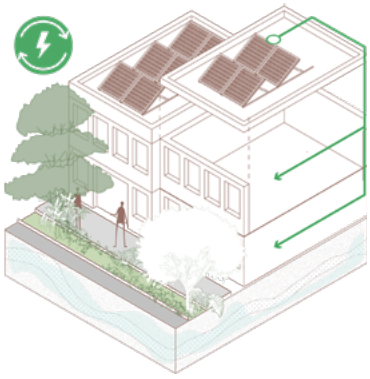


Source: Original for this publication.

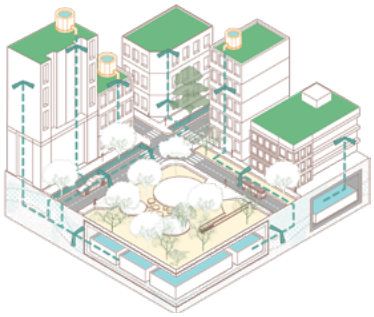
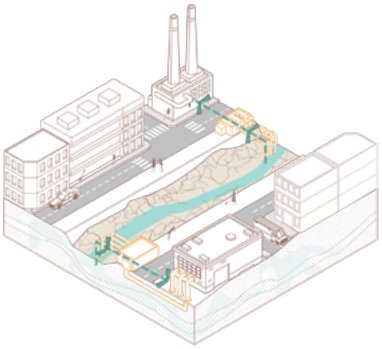
Table 7.5: Examples of "Condition" Measures for Climatological Risk-informed Urban Planning

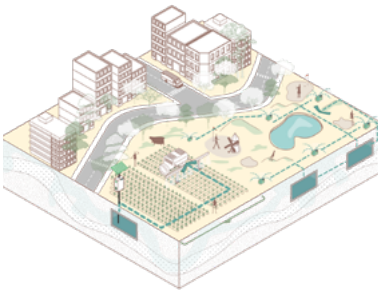
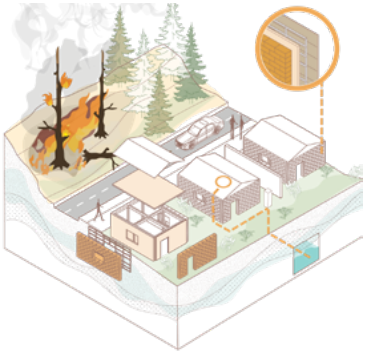
Condition: Applies where hazards or risks are relevant but can potentially be reduced to acceptable levels through appropriate planning, design, and construction practices.

Extreme heat, heat waves, and urban heat islands

Include reflective building materials and permeable surfaces in urban design.	Enhance building codes to promote insulation and ventilation for reducing indoor temperatures.	Use energy-efficient systems to prevent overloading of the power grid from cooling systems.
		

Urban droughts

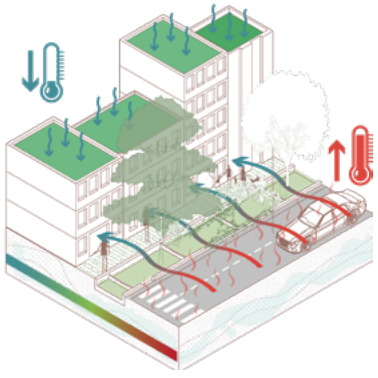
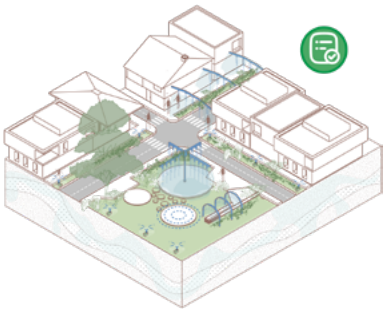
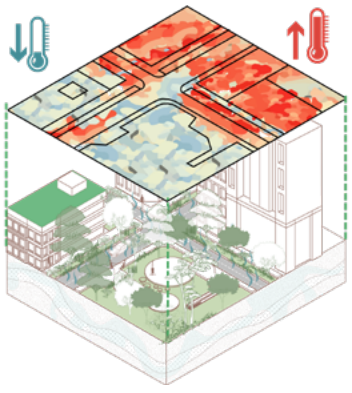
Implement efficient water conservation, capture and distribution systems, reduction of nonrevenue water, and assurance of water access to vulnerable groups in new developments.	Establish and enforce policies to monitor and control water extraction and prevent overexploitation.	Condition high-density urbanization and high-consumption industries to ensure sustainable water supply.
		

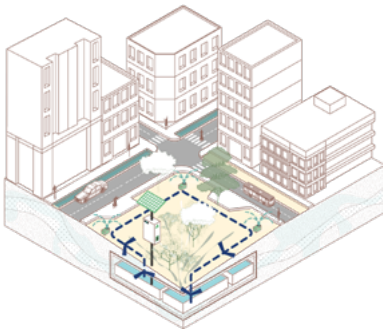
Wildfires		
Condition nonefficient irrigation agriculture and golf courses to ensure sustainable use of water.	Condition development on the implementation of risk reduction measures.	Retrofit existing buildings with fire-resistant materials and designs.
		

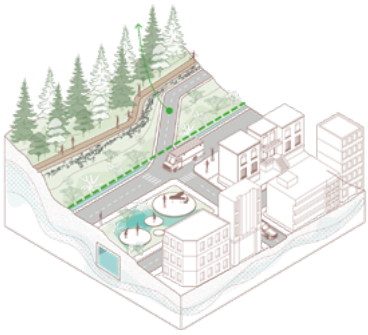
Source: Original for this publication.

Table 7.6: Examples of "Promote" Measures for Climatological Risk-informed Urban Planning

Promote: Applies to actions that complement the restriction and conditioning measures to incentivize an appropriate use of natural resources.

Urban cooling systems, heat action plans, and thermal mapping		
Promote sustainable drainage systems (SUDS) and nature-based solutions (NBS) to naturally cool urban areas and reduce energy consumption.	Develop heat action plans, including early warning systems (EWS) and access to urban cooling centers and systems, particularly in low-income areas.	Monitor land surface temperature and variations in land cover over time.
		

Water Use Optimization and Groundwater Protection		
Implement advanced technologies and practices to optimize water use and reduce waste.	Develop smart irrigation systems and promote water efficiency.	Formulate sustainable groundwater management plans that balance usage with natural recharge rates.
		

Green infrastructure, firefighting resources, firebreaks, and buffer zones		
Encourage NBS to reduce the buildup of flammable material.	Increase the capacity of existing firefighting resources, including access roads and water supplies.	Develop and maintain firebreaks and buffer zones to protect urban areas.
		

Source: Original for this publication.

While a hazard-specific perspective remains essential—since each hazard entails unique characteristics, triggers, and planning implications—it is equally important to recognize that many urban areas are exposed to multiple, interacting hazards that can lead to cascading, exponential impacts and systemic disruptions. In such contexts, planners should consider integrated measures that explicitly address multihazard interactions and deliver cobenefits. For example, resilient infrastructure can be designed to withstand both seismic and hydrometeorological shocks, while well-designed NBS can simultaneously reduce flood risk, mitigate urban heat, and restore degraded ecosystems. This integrated approach not only optimizes the use of resources but also enhances the overall effectiveness of risk reduction investments, contributing to more robust, adaptive, and sustainable urban systems.

Key Takeaways

As cities continue to expand and evolve, it becomes increasingly critical to integrate climate change adaptation (CCA) and disaster risk management (DRM) into urban planning processes. The complexities of urbanization, climate change, and disaster risk require a paradigm shift: one that enables cities to move beyond reactive measures to proactive, integrated, and sustainable planning approaches.

Hazards and risks in urban settings are multifaceted and cannot be attributed solely to natural phenomena. Urban plans must address the increasing challenges posed by the interaction of urbanization and climate and disaster risks. Recognizing that the interplay between urbanization and risk is not just a challenge but also an opportunity for transformation, this handbook has outlined the principles, goals, and operational frameworks necessary to achieve livable and resilient cities.

Through a structured and evidence-based approach, risk-informed urban planning enables cities not only to manage hazard exposure but also to act as catalysts for resilience and sustainability. The measures discussed demonstrate the multifaceted strategies that can be employed to reduce risk and enhance adaptive capacities. However, achieving true resilience requires more than policies and technical solutions: it demands a fundamental commitment from governments, urban planners, CRM and DRM experts, communities, and stakeholders at all levels.

- **Urbanization must be transformed into a driver of resilience:** Unplanned urbanization often intensifies hazards, social disparities, poverty, and exposure to various risks. By contrast, when urbanization is planned and risk-informed, it leads to the development of sound infrastructure, advanced communication systems, and effective emergency services, which enhance the city's resilience.
- **Risk-informed urban planning offers valuable, low-cost benefits for cities:** The main objective of risk-informed urban planning is to save lives and reduce climate- and disaster- related damage and losses. It also contributes to saving human and financial resources in postdisaster reconstruction and recovery processes. Estimates show that in low- and middle-income countries, every dollar invested in resilience yields a net benefit of US$4 as a result of a reduction in the disruptions and economic effects and impacts of disasters (Hallegatte et al. 2019).
- **Embedding climate, hazard, and risk information in urban plan formulation and implementation requires long-term vision, political will, and citizen engagement:** Promoting a new approach that considers climate change and hazard and disaster risk information as the basis for making spatial planning decisions requires a shared long-term vision and political will to ensure green and resilient growth, social inclusion, resilient built environments, and shared prosperity. Risk-informed planning processes must be participatory to foster citizen awareness and engagement.
- **Risk-informed urban plans must be flexible.** The process of integrating hazard and risk assessments into urban planning decisions is critical to ensuring that new developments are safely located and that

urbanized areas are resilient to potential disasters. When detailed hazard and risk assessments are not yet available, cities can base their plans on provincial- or municipal-scale assessments and gradually update regulations as new assessments are carried out.

- **Each city needs to strengthen its capacities, assess specific hazard and risk conditions, and develop customized risk-informed planning measures:** Although this handbook proposes an operational framework and a graphic catalog of measures to prevent and reduce disaster risk and climate-related shocks, each city is unique and must have the institutional, technical, and financial capacities to formulate and implement tailor-made risk-informed urban plans. Each hazard may require specific measures depending on the risks posed to life, infrastructure, and the economy, as well as the city's particular context. Moreover, hazards in urban settings can compound, creating complex interactions that must be carefully considered.

The call to action is clear: cities must integrate climate and risk considerations into all aspects of planning and decision-making. This means shifting from a mindset of short-term gains to one of long-term resilience, where urban growth is managed with foresight, inclusivity, and environmental consciousness. Policy makers must adopt and enforce regulatory frameworks that embed risk prevention and risk reduction into urban planning. Planners and practitioners must leverage data, innovation, and participatory processes to ensure that development aligns with resilience objectives. Communities must be actively engaged, empowered to contribute their knowledge and priorities, and included in decision-making processes that affect their future.

The road ahead is complex, but the benefits of proactive, risk-informed planning far outweigh the costs of inaction. With coordinated efforts, cities can not only withstand future shocks but also thrive in the face of uncertainty. By embedding resilience into urban planning today, we ensure that future generations inherit cities that are safe, sustainable, and equipped to meet the challenges of a changing world. The time to act is now. Risk-informed urban planning is not an option; it is a necessity for a resilient and livable future.

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Promoting livability and resilience through risk-informed urban planning enables cities to shift from reactive approaches focused on emergency response and postdisaster recovery to proactive, forward-looking strategies to reduce climate- and disaster-related impacts before they occur, minimizing human and economic losses. By embedding risk prevention and reduction into urban development processes, cities can anticipate hazards, minimize human and economic losses, and strengthen adaptive capacity, safeguarding people, ecosystems, infrastructure, livelihoods, and assets. This handbook proposes a fundamental paradigm shift, informed by lessons learned. It explores how risk is shaped by the dynamic interplay between urbanization, social systems, and the natural and built environments. It overturns the notion of cities as passive arenas of disaster and climate exposure. Instead, it recognizes urbanization itself as a key driver that can either increase or decrease risk. From this perspective, planning decisions become proactive expressions of evidence-based risk reduction. Thus integrating risk into planning is both a technical necessity and a governance imperative.

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The Global Facility for Disaster Reduction and Recovery (GFDRR) is a global partnership that helps low- and lower-middle-income countries better understand and reduce their vulnerabilities to natural hazards and adapt to climate change. GFDRR provides grant financing, technical assistance, training and knowledge sharing activities to mainstream disaster and climate risk management in national and regional policies, strategies, and investment plans. The Program Management Unit, located within the World Bank, manages grant resources to carry out GFDRR's mission.

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