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ASSESSING DAVAO CITY'S URBAN ROAD NETWORK VULNERABILITY: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

This study systematically reviews and synthesizes existing literature on the vulnerability of Davao City's road network to flooding and related environmental hazards. Urban flooding, driven by climate change and rapid urbanization, poses significant risks to road infrastructure, with potential disruptions to mobility, economic activity, and emergency responses. The review employs the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework to identify, screen, and evaluate relevant studies. Key factors influencing road infrastructure vulnerability, including urbanization, topography, climate change, and environmental data, are explored through a GIS-based approach. Additionally, the study assesses resilience strategies employed in similar urban settings to mitigate flooding risks. Findings from the review offer insights into the complexities urban road networks face and propose best practices for enhancing resilience in flood-prone areas like Davao City.

Keywords: Urban flooding, road network vulnerability, Davao City, climate change, urbanization, GIS-based analysis, resilience strategies, infrastructure adaptation, flood risk management, systematic review

1. INTRODUCTION

Urban flooding has emerged as a pressing global issue, with cities increasingly grappling with the impacts of climate change and rapid urbanization. Infrastructure vulnerabilities are becoming more pronounced as populations and urban landscapes evolve, particularly evident in cities where road networks—essential for transportation and economic stability—are at risk. According to the World Bank (2021), cities in developing countries face heightened vulnerability to flooding due to inadequate infrastructure, insufficient drainage systems, and limited disaster preparedness measures. Davao City, one of the fastest-growing urban centers in the Philippines, compounded by the increasing frequency and intensity of flooding, has not kept pace with population growth (World Bank, 2021). However, the vulnerability of Davao City's road infrastructure is not limited to flooding alone but extends to other environmental stressors such as landslides, earthquakes, and extreme weather events, which are becoming more frequent due to climate change. Assessing the vulnerability of road networks to environmental risks is crucial for disaster preparedness and resilience planning. Road closures due to natural disasters like flooding can severely impact mobility, economic activity, and emergency responses, disrupting access to essential services and affecting daily life. This study seeks to systematically evaluate the vulnerability of Davao City's road network by systematically reviewing the literature on the use of Geographic Information Systems (GIS) in vulnerability assessments, addressing various environmental stressors that affect road networks. The review will analyze existing research employing GIS-based spatial analysis, overlay and buffer techniques, and risk assessment models. It will focus on various factors influencing road infrastructure vulnerability and resilience, including but not limited to flooding, topographical features, land use patterns, and the effects of climate change. By synthesizing findings from diverse studies, this review will provide a broader understanding of the complexities urban road networks face, particularly in regions like Davao City, which are vulnerable to multiple environmental challenges. This systematic review will utilize the PICO framework (Population, Intervention, Comparison, and Outcome) to ensure the research focuses on urban road networks (Population), vulnerability assessments (Intervention), geographic and topographic variability (Comparison), and resilience strategies (Outcome) (Huang et al., 2006). Additionally, the study will be guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure a rigorous and transparent review process, including literature selection, screening, and synthesis (Page et al., 2021). Through this systematic review, the study aims to synthesize findings from previous research to provide valuable insights into the risks faced by road networks in urban areas. It will also identify best practices, methodologies, and strategies for enhancing road network resilience in Davao City based on existing knowledge from similar urban settings. Accordingly, this study's key research questions (KRQs) are: RQ1.) What are the factors influencing the vulnerability of road infrastructure in urban settings, particularly in flood-prone areas like Davao City? RQ2.) How do historical environmental data, urbanization trends, and topographic features contribute to the vulnerability of road networks in cities like Davao? RQ3.) What resilience strategies and methodologies have been proposed or implemented in similar urban settings to mitigate the impact of environmental risks on road infrastructure?

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2. METHODOLOGY

Design. This study systematically reviews and synthesizes existing literature to assess the vulnerabilities of Davao City's road network to flooding and other related hazards. The study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines to ensure that the review process is transparent and rigorous (Page et al., 2021; Shamseer et al., 2015). PRISMA provides a clear framework that helps explain why the review was done, the methodology used, and what was found. This process includes four key stages: Identification, Screening, Eligibility, and Inclusion, each of which is critical to ensuring the quality and relevance of the studies included in the review.

In the Identification phase, we used the PICO framework (Population, Intervention, Comparison, Outcome) to develop relevant keywords for searching studies across various databases and search engines. PICO allowed us to focus on studies that address urban road networks, vulnerability assessments, GIS-based spatial analysis, resilience strategies, and flood risk mitigation in urban flood-prone areas. The keywords derived from this framework were used to gather a broad pool of studies across various sources without restricting the study location or database at this stage. This approach ensured that the initial search captured a comprehensive range of studies related to the topic. At this point, studies were considered based on their relevance to the research questions rather than their specific database or source.

After 1839 studies were identified, the Screening phase involved removing duplicates and evaluating the remaining studies based on their titles and abstracts. This step was crucial to ensure the studies were directly relevant to the key research questions. After the removal of duplications, 709 studies were left. The studies were screened for their relevance to at least one of the following aspects: (1) factors influencing the vulnerability of road infrastructure in urban flood-prone areas, (2) contributions of environmental data, urbanization trends, or topographic features to road network vulnerability, and (3) resilience strategies to mitigate the impact of environmental risks on road infrastructure. This process helped ensure that only studies directly aligned with the review's objectives were considered for further evaluation (Liberati et al., 2009). This step left the researcher with 591 studies. For the record, no existing systematic literature reviews have been conducted yet following the researcher's objectives.

In the Eligibility phase, studies were evaluated based on four key criteria. First, studies needed to provide either empirical data or conceptual frameworks, offering empirical evidence (quantitative or qualitative) or theoretical insights into urban infrastructure resilience or vulnerability. This ensured that only studies with robust, credible findings contributed to the review (Dixon et al., 2020). Second, the study must be published within the last 10–15 years, ensuring that the findings are relevant to current urbanization trends and climate change challenges (Srinivasan et al., 2019). Third, the study had to focus on regions with characteristics similar to Davao City or other urban flood-prone areas, such as tropical climates and high urbanization. This geographical relevance was crucial to ensuring that the findings could be directly applied to the context of Davao (Ezzati et al., 2020). Lastly, the study had to employ reliable methodologies, such as GIS-based analysis, vulnerability mapping, or multi-criteria decision-making models, ensuring that the methodologies were sound and replicable (Sadiq et al., 2021). After going through the eligibility criteria screening, the researcher was left with 99 studies.

The Inclusion phase was the final step, where studies that met all eligibility criteria were included in the review. Only studies with available full texts published in peer-reviewed journals were considered for inclusion, ensuring that the studies were of high academic quality (Higgins & Thomas, 2021). The researcher is left with 36 studies. The researcher conducted an organized, systematic, and comprehensive search on five (5) online databases: Scopus, Google Scholar (search engine), JSTOR, Semantic Scholar, and WorldCat. Scopus, Google Scholar (search engine), JSTOR, Semantic Scholar, and WorldCat are well-established, reliable platforms for accessing academic literature.

Table 1. Distribution of Studies in Peer-Reviewed Journals and Databases

Source	number
Scopus	4
JSTOR	1
Google Scholar	36
Semantic Scholar	36
WorldCat	28

These databases primarily index peer-reviewed journals, conference proceedings, books, and other scholarly materials. They are widely recognized in academic and research communities for providing access to high-quality, credible content. Studies that did not meet these criteria, such as those without accessible full texts or those found in non-peer-reviewed sources, were excluded. This step ensures that only high-quality, credible studies inform the findings of this review. Out of the 36 studies

that passed the eligibility criteria, four (4) can be found in Scopus, one (1) in JSTOR, and 28 can be found in WorldCat. All of these studies can be found in Semantic Scholar and Google Scholar (see Appendix 1).

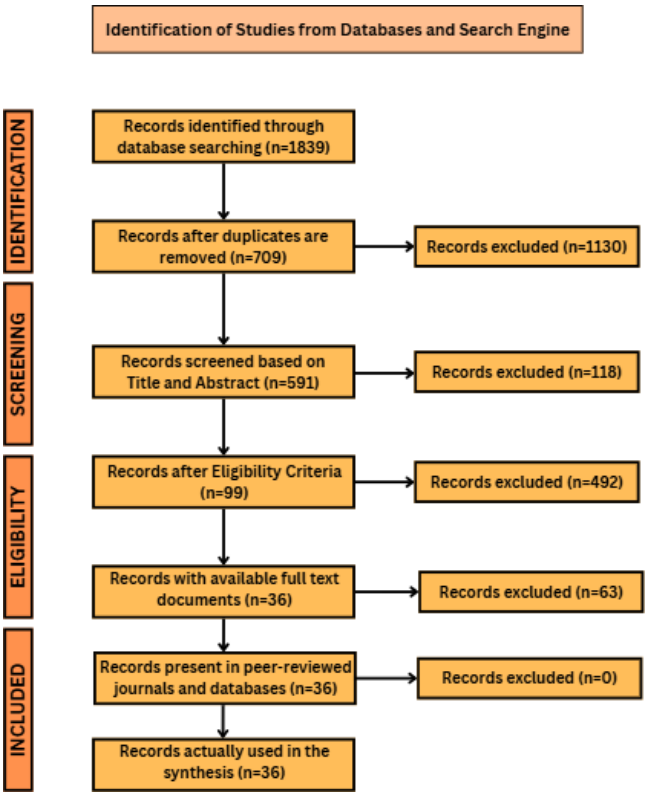

Figure 1. Contextualized PRISMA Model Used in the Study

By following these systematic and rigorous processes, this study ensures that only the most relevant, recent, and methodologically sound literature contributes to synthesizing best practices for enhancing road network resilience in flood-prone urban areas like Davao City. This approach, underpinned by established systematic review methods, provides a clear framework for addressing the research questions and generating actionable insights.

3. RESULTS AND DISCUSSION

Factors Influencing Vulnerability of Road Infrastructure in Urban Settings, Particularly in Flood-Prone Areas Like Davao City

The vulnerability of road infrastructure in urban flood-prone areas, such as Davao City, is influenced by a complex interaction of environmental, urbanization, and topographic factors, each supported by specific literature findings:

Urbanization and Land Use. The rapid and poorly managed urban expansion, particularly into flood-prone zones, significantly exacerbates the vulnerability of road infrastructure. “The urbanization of natural basins causes an alteration of their corresponding hydrological processes, leading to more rapid flooding and more severe consequences, including a lack of sustainable urban rainwater management systems” (Cacciuttolo et al., 2023). “Unregulated urbanization in flood-prone areas increases the risk of

flooding by reducing natural flood buffers like green spaces and wetlands” (Korah & Cobbinah, 2016). This reflects how urban expansion in Davao City, particularly into flood-prone areas, reduces the capacity of natural systems to manage floodwater, increasing infrastructure vulnerability. As noted by the World Bank (2021), cities in developing countries face heightened vulnerability to flooding due to inadequate infrastructure, insufficient drainage systems, and limited disaster preparedness measures.

Climate Change and Weather Extremes. One of the major contributors to the vulnerability of road infrastructure in flood-prone cities is climate change, which is expected to intensify rainfall patterns. “Urban growth and increased impervious surfaces exacerbate flooding risks, requiring innovative solutions such as permeable pavement and improved stormwater management to mitigate these risks” (Cacciuttolo et al., 2023). “The interaction between urbanization and climate change accelerates the frequency and severity of flood events in urban areas, with significant consequences for infrastructure and public services” (Sakib et al., 2023). These findings emphasize the growing challenge faced by cities like Davao, which must adapt to increasingly extreme weather events that stress existing infrastructure. According to the National Economic and Development Authority (NEDA, 2021), reports indicate that climate change is causing more frequent and intense rainfall events, amplifying the strain on urban infrastructure, particularly in cities like Davao.

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Topography and Drainage. Topography plays a pivotal role in determining the vulnerability of road infrastructure to flooding, particularly in areas with steep slopes or proximity to water bodies.

"The use of permeable interlocking concrete pavement (PICP) proves to be a sustainable and feasible alternative for reducing urban flooding and adapting to climate change by improving stormwater management" (Cacciuttolo et al., 2023). "In areas with poorly managed drainage systems, steep topographical features significantly increase the vulnerability of urban infrastructure to flooding and damage during extreme weather events" (Korah & Cobbinah, 2016). Such solutions are particularly relevant in cities like Davao, where steep topography and inadequate drainage systems significantly contribute to flooding and road damage during heavy rainfall events. Additionally, Davao City's diverse topography, which includes coastal and low-lying areas as well as mountainous regions, compounds the vulnerability of road networks to various environmental stressors.

Contribution of Historical Environmental Data, Urbanization Trends, and Topographic Features to Road Network Vulnerability in Cities Like Davao

The contribution of historical environmental data, urbanization trends, and topographic features to road network vulnerability in cities such as Davao can be summarized through specific findings from studies on climate projections, urban expansion, and geographic conditions:

Environmental Data and Climate Projections. "Urban flooding, exacerbated by climate change, directly affects users within residential, commercial, and industrial areas, demanding new solutions to adapt to the changing climate" (Cacciuttolo et al., 2023). This emphasizes the pressing need for innovative solutions that can mitigate the growing risks of urban flooding in Davao City. "Urbanization and changes in land cover are significantly altering hydrological processes, resulting in more rapid runoff and greater flood risks for urban infrastructure" (Gnecco et al., 2024).

Urbanization Trends. "Sustainable urban drainage systems (SUDS), including permeable pavements, are key to managing the increased stormwater runoff caused by urbanization and climate change" (Cacciuttolo et al., 2023). This particularly applies to Davao, where rapid urbanization has led to the loss of natural drainage systems, exacerbating flood risks. "As urbanization continues, it is critical to incorporate resilient infrastructure solutions, such as green spaces and SUDS, to reduce flooding risks"

(Rezvani et al., 2024). This is a key consideration for Davao, where urban growth has significantly reduced natural flood buffers.

Topography and Drainage Systems. As evidenced in Davao (Cabrera & Han Soo Lee, 2019), topographic features such as elevation and proximity to water bodies influence flood risks.

"The improper management of land and water resources has significantly contributed to high erosion rates, deforestation, and urban flooding, exacerbating the challenges posed by climate change" (Luo, 2023). This highlights how poor management of urban growth and land use in Davao City has led to greater flood risks, further stressing the importance of integrated flood management strategies.

Socioeconomic Impacts of Road Vulnerability in Davao City

While this study focuses on technical and environmental factors, it is essential to acknowledge the socioeconomic consequences of compromised road infrastructure. In many urban areas, flooding disrupts mobility, economic activities, and access to essential services, leading to significant social and economic costs.

"The exceedance of stormwater management capacity in cities due to the growth and waterproofing of soils causes urban flooding, directly affecting users within residential, commercial, and industrial areas" (Cacciuttolo et al., 2023). This situation applies to Davao, where flood disruptions affect both daily commuting and local businesses, making road resilience essential for economic stability. "The lack of resilient infrastructure and flood management systems undermines economic activity, especially in urban centers vulnerable to climate change" (Molina et al., 2022).

Community Engagement and Resilience Building in Urban Flood Management

Effective flood resilience strategies also involve community engagement and local knowledge integration. "Resilience focuses on designing for the unpredictable, while sustainability emphasizes responsive designs that are efficient and optimized for future conditions" (Luo, 2023).

In Davao City, involving communities in resilience-building activities, such as disaster preparedness workshops, local flood mapping, and early warning systems, could enhance public awareness and readiness. "Implementing stormwater management systems not only reduces flooding risks but also offers significant ecosystem benefits, such as CO2 capture and improved urban green spaces" (Cacciuttolo et al., 2023). "Resilient communities are better equipped to recover from disasters and adapt to the impacts of climate change" (Miyamoto et al., 2022).

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Resilience Strategies and Methodologies to Mitigate Environmental Risks on Road Infrastructure in Similar Urban Settings

To address the growing vulnerability of road infrastructure in flood-prone urban areas, including Davao City, various resilience strategies have been proposed and successfully implemented in similar settings. These strategies focus on engineering solutions, urban planning, and community-based initiatives.

Green Infrastructure. The importance of green infrastructure in enhancing urban resilience to flooding has been widely acknowledged. "The application of new technologies in urban infrastructure, such as permeable paving systems, offers an innovative approach to mitigating climate change impacts and improving urban drainage" (Cacciuttolo et al., 2023). Implementing these technologies in Davao could provide a sustainable way to reduce urban flooding while also benefiting the city's green spaces.

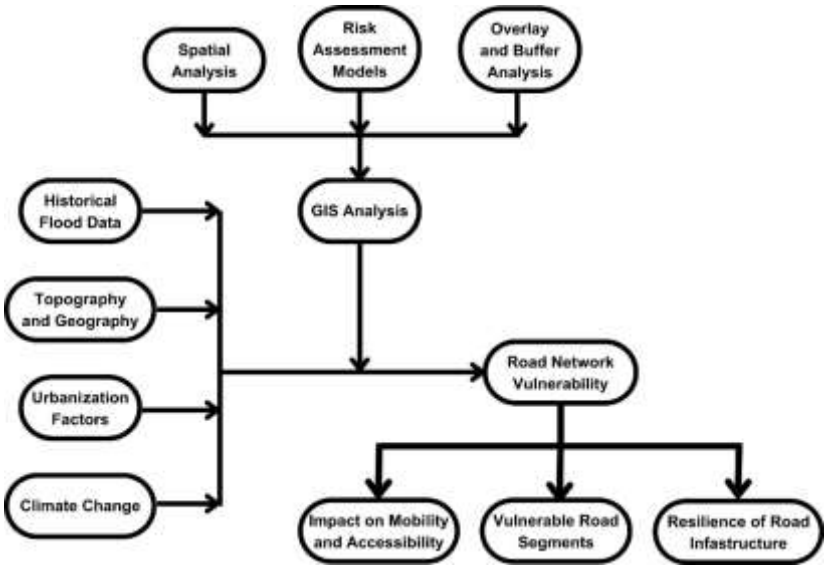
"Green infrastructure, including vegetation and permeable materials, reduces surface runoff and improves water quality" (Karabakan & Yelda, 2021).

Urban Planning and Risk Management. Proactive urban planning and flood risk management strategies are essential for reducing the vulnerability of road infrastructure. "Sustainable urban drainage systems (SUDS), including permeable pavements, are key to managing the increased stormwater runoff caused by urbanization and climate change" (Cacciuttolo et al., 2023). In Davao, these solutions could help reduce flooding, especially in newly developed urban areas. "Coordinated planning efforts, involving local communities and stakeholders, are essential for building resilience to flood risks" (Miyamoto et al., 2022).

Engineering and Infrastructure Adaptation. Engineering solutions also play a crucial role in strengthening infrastructure resilience. "Resilience in socio-ecological systems is synonymous with a region that is ecologically, economically, and socially sustainable" (Luo, 2023). For Davao, engineering interventions, such as reinforcing road surfaces and upgrading drainage systems, can significantly enhance the resilience of road networks against flood risks.

Proactive vs. Reactive Strategies. "Resilience focuses on designing for the unpredictable, while sustainability focuses on responsive designs" (Luo, 2023). Davao City could benefit from adopting a proactive approach, particularly in strengthening flood defense measures such as flood barriers, improved drainage, and better urban planning to anticipate future flood risks.

4. STUDY FRAMEWORK



5. CONCLUSION

The vulnerability of road infrastructure in flood-prone urban settings like Davao City is influenced by a combination of environmental factors, urbanization trends, and topographic features. Historical environmental data and climate projections, alongside urban expansion and inadequate drainage systems, are key contributors to flood risk. In response, green infrastructure, urban planning strategies, and engineering solutions have proven effective in mitigating risks and enhancing resilience. The findings from cities like Kumasi, Dhaka, and Bangladesh clearly show the importance of integrated, proactive resilience strategies that combine urban planning, community engagement, and infrastructure improvements to safeguard road networks from the growing threats of flooding and climate change. Additionally, addressing the socioeconomic impacts and integrating community knowledge into resilience planning can further strengthen flood resilience in Davao City.

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Appendix

Appendix 1. List of Studies/Research retained after PRISMA.

Title	Author	Year of Publication	Research Design	Participants/Respondents / Related Sources	Variables Observed	Brief Description	Findings
A Probabilistic Approach to the Evaluation of Seismic Resilience in Road Asset Management	V. Nicolosi, M. Augeri, M. D'Apuzzo, A. Evangelisti, D. Santilli	2022	Quantitative, Stochastic Modeling, Probabilistic Risk Analysis	Data from the 2016 earthquakes in central Italy; seismic hazard data; recovery cost data from road and bridge repairs.	Seismic hazard (PGA) Road network resilience Recovery costs Vulnerability of road infrastructure Economic damage from seismic events	The study introduces a probabilistic approach to evaluate the seismic resilience of road networks. It proposes a cost-based resilience indicator that incorporates both the disruption costs and the recovery costs following seismic events. The methodology utilizes data from the 2016 central Italy earthquakes, analyzing repair costs for damaged road sections and bridges. The evaluation method considers the vulnerability of infrastructure and its recovery capacity after seismic events, aiming to help road managers	The study developed a stochastic model for assessing seismic resilience based on the economic costs of repair and disruption. The model calculates the overall damage and recovery costs, providing a tool for road managers to evaluate the seismic resilience of road networks. The findings emphasize that the methodology can be adapted to different countries' economic conditions by adjusting cost parameters. The case study of central Italy demonstrated the practical application of this model, offering a framework to predict future repair costs and resilience efforts in the event of

						optimize resilience planning and retrofitting efforts.	earthquakes.
An analysis of the methodology for building the environmental potential of urban areas	ad Budziński, Paweł Jarosiewicz	2021	Qualitative, Literature Review, Conceptual Framework Development	Urban planners, environmental scientists, policy makers, climate change experts; United Nations (UN) reports, Intergovernmental Panel on Climate Change (IPCC) data, Polish Academy of Sciences studies, ecohydrology literature.	Urbanization rate Global warming effects (temperature rise, urban heat islands) Urban floods Heat stress-related mortality Urban adaptation potential Water management strategies Nature-based solutions (green roofs, rain gardens)	This study analyzes the current methods and strategies used to minimize the effects of climate change on urban areas and improve the quality of life for city residents. It explores the growing issue of urban heat islands, urban floods, and the need for holistic, nature- based solutions to mitigate these challenges. The research emphasizes the importance of using natural processes, such as the blue-green network concept, to address urban climate stress. The study also discusses the development of sustainable water management strategies in cities and how these methods	The findings highlight that cities, particularly in Poland, face significant climate-related challenges, such as increased heat stress and urban flooding, which have already led to thousands of deaths. The research suggests that current urban systems lack resilience to climate change and need urgent adaptation strategies. The study proposes the implementation of nature-based solutions, such as green roofs, rain gardens, and green bus stops, which can effectively reduce the urban heat island effect, decrease surface runoff, and improve the urban microclimate. These strategies are aligned with global climate

						align with global strategic documents from the UN, focusing on adapting to climate change through innovative urban management approaches.	adaptation goals and offer sustainable alternatives to traditional urban planning.
Analysis of transportation networks subject to natural hazards - Insights from a Colombian case	Juan E. Muriel-Villegas, K. C. Alvarez-Uribe, C. Rodriguez, J. G. Villegas	2016	Quantitative, Statistical Reliability Analysis, Network Vulnerability Modeling	State of Antioquia, Colombia; historical data from the 2010-2011 rainy season; road network data from the national road institute (INVIAS); traffic flow data from a 2014 OD survey.	Road network disruptions Road failure types (e.g., landslides, road sinking) Traffic flow Failure probability Network vulnerability	This study develops a framework to assess the connectivity reliability and vulnerability of inter-urban transportation networks, particularly focusing on road disruptions caused by natural hazards. Using data from the 2010-2011 rainy season in Antioquia, Colombia, the study models the impact of various failure types (such as landslides and road sinking) on road performance. The analysis integrates statistical reliability functions and uses the Zero-	The analysis reveals that Antioquia's road network has low reliability, with many roads showing significant failure rates during the rainy season. The most vulnerable links are identified as those with high failure probabilities and severe consequences in terms of traffic flow reduction. Roads like Medellín – Puerto Berrío and Medellín – Puerto Triunfo are identified as critical, with their failure leading to substantial disruptions. The study suggests that network managers focus on these critical

						Inflated Poisson distribution (ZIP) to model road closures. The study identifies critical road segments in Antioquia's primary network that are most vulnerable to disruptions.	links for improvement and better disaster preparedness, particularly during the rainy season.
Characterization of vulnerability of road networks to fluvial flooding using SIS network diffusion model	B. Abdulla, Amin Kiaghadi, H. Rifai, B. Birgisson	2020	Quantitative, SIS Network Diffusion Model, Hydraulic Simulation	Memorial Super Neighborhood, Houston, USA; Road network data; Flood depth data (Hurricane Harvey); USGS water surface elevation data; LiDAR data; OpenStreetMap data.	Flood depth Vehicle speed Road network functionality Network connectivity Betweenness centrality Degree centrality Closeness centrality Eigenvector centrality	This study models the vulnerability of road networks to fluvial flooding using a Susceptible-Impacted-Susceptible (SIS) diffusion model. It investigates how flooding spreads through a road network, affecting connectivity over time. The study uses hydraulic simulation data to calculate temporal flood depths at road nodes and applies these depths to determine the functional status of road sections. Centrality measures, such as betweenness and degree centrality, are used to evaluate the impact of flood-induced disruptions initiated from	The study found that the vulnerability of the road network varies significantly based on where the flooding originates. Disruptions starting from nodes with high centrality (especially betweenness centrality) lead to more significant connectivity loss. The network showed substantial connectivity loss when nodes with high betweenness centrality were affected, while disruptions from randomly selected nodes caused less severe impacts. The findings suggest that preserving key central nodes in the road network is crucial for maintaining connectivity during flooding events. The SIS diffusion model is shown to be effective for assessing the cascading impacts of flood disruptions on road networks and can guide flood management and

						different locations in the network. The Memorial Super Neighborhood in Houston is used as a case study to demonstrate the method.	infrastructure resilience planning.
Climate Adaptation Measures for Enhancing Urban Resilience	S. M. Rezvani, Nuno Marques de Almeida, Maria João Falcão	2023	Mixed (Systematic Review, MCDA-AHP Mapping, GIS-based Risk Assessment)	Portuguese municipalities; Netobra.com platform users; GIS data, socio-economic data from Instituto Nacional de Estatística (INE), Portugal; climate adaptation measures.	Climate adaptation measures Urban resilience Disaster risk hotspots Socio-economic indicators Physical infrastructure resilience Ecosystem restoration Water management strategies Health and social interventions	This study explores 50 climate adaptation measures aimed at enhancing urban resilience. The research categorizes these measures into five broad groups: physical infrastructure, ecosystem restoration, water management, policy and planning, and health and social measures. Using the Netobra.com platform, the study integrates these measures into a GIS-based system to identify disaster risk hotspots in Portuguese municipalities. The study emphasizes the importance of cross-sectoral integration of climate adaptation measures and provides a comprehensive framework for decision-making in urban	The study highlights that integrating climate adaptation measures into urban resilience strategies significantly improves decision-making. It finds that physical infrastructure measures (e.g., sea walls, flood barriers) and ecosystem restoration (e.g., reforestation, mangrove protection) offer substantial benefits for reducing climate change impacts. The research further underscores the importance of water management strategies, such as rainwater harvesting and efficient irrigation, alongside policy frameworks and health measures. The Netobra.com platform was shown to be a valuable tool in identifying high-risk areas and guiding resource distribution for effective climate adaptation. The findings demonstrate the need for a multifaceted approach to urban resilience, combining infrastructure improvements, ecosystem-based strategies, and policy

						resilience planning, leveraging multicriteria decision analysis (MCDA) and analytic hierarchy process (AHP) mapping techniques.	interventions.
Climate change in asset management of infrastructure: A riskbased methodology applied to disruption of traffic on road networks due to the flooding of tunnels	Elja Huibregtse, Oswaldo Morales Napoles, Laura Hellebrandt, D. Paprotny, Sten De Wit	2016	Quantitative, Risk-based Methodology, Probabilistic Modelling, Structured Expert Judgment	Delft, The Netherlands; Road authorities, TNO (Netherlands Organization for Applied Scientific Research); Climate data from KNMI; Traffic flow and tunnel capacity data.	Rainfall intensity Rain duration Tunnel drainage capacity Probability of flooding Travel time delays Risk management measures	This study presents a risk-based methodology to evaluate the impact of climate change, specifically extreme rainfall, on the flooding of tunnels and the subsequent disruption to road networks. The methodology incorporates both failure probability and consequences, with a focus on the additional travel time caused by tunnel flooding. Using a joint probability function (copula) for rainfall intensity and duration, and applying structured expert judgment, the study assesses how climate change could affect tunnel performance and the resilience of the surrounding road network. The method includes	The findings show that the consequences of tunnel flooding are significantly different for highways compared to regional roads, with travel time delays increasing by a factor of 25 on highways. The risk-based approach allows for the assessment of when intervention is required to avoid unacceptable levels of service. The study demonstrates how the probability of failure (tunnel flooding) and its consequences (increased travel time) can be combined to evaluate the system's resilience. The results suggest that interventions for regional roads can be postponed significantly (until 2140), whereas highway systems require earlier intervention (by 2020). The paper emphasizes the need for adaptive management to continuously adjust to evolving climate data and infrastructure resilience.

						simulations of different scenarios, with the results used to inform risk management strategies and decision-making.	

Co-Design for Enhancing Flood Resilience in Davao City, Philippines	Mamoru Miyamoto, D. Kakinuma, T. Ushiyama, A. Rasmy, M. Yasukawa, D. Bacaltos, A. C. Sales, T. Koike, M. Kitsuregawa	2022	Mixed (Co-Design Methodology, Hydrological Modeling, E-Learning Workshops, Real-Time Flood Forecasting)	Davao City, Philippines; Local government units, community leaders, stakeholders, academia, civil society organizations (CSOs), and media; Participants in e- learning workshops; Flood risk data from hydrological models; Climate change impact data.	Flood risk Climate change impacts (tropical cyclones, rainfall, peak discharge) Inundation extent and depth Socioeconomic characteristics (demographic, geographic, economic features) Community-level disaster preparedness and literacy E-learning outcomes (Facilitator training, knowledge dissemination)	This study aims to enhance flood resilience in Davao City through a co-designed approach that integrates scientific knowledge with community participation. It developed the Online Synthesis System for Sustainability and Resilience (OSS-SR), a platform that supports real-time flood forecasting and climate change impact assessment. The methodology incorporates hydrological models for basin- and barangay-level flood simulations, and e-learning workshops for training Facilitators, who bridge the gap between the scientific community and local society. Facilitators play a crucial role in disseminating	The development of OSS-SR for Davao City enabled real-time flood forecasting and climate change impact assessment, showing that future flood risks (e.g., increased rainfall, peak discharge, inundation) are significantly higher than in the past. The study found that inundation areas could increase more than four times under future climate conditions. Two e-learning workshops successfully trained 30 Facilitators from diverse disciplines, who are now equipped to develop risk communication plans and work with local communities to improve disaster literacy. The deliverables produced from the workshops, including hazard maps and contingency plans, are set to be disseminated across various community groups. The study highlights the importance of co-designing solutions that integrate science with community engagement for

						knowledge on flood risk and climate change adaptation to the community.	enhancing flood resilience.
Evaluation of the Use of Permeable Interlocking Concrete Pavement in Chile: Urban Infrastructure Solution for Adaptation and Mitigation against Climate Change	Carlos Cacciuttolo, Felipe Garrido, Daniel Painenao, Andres Sotil	2023	Quantitative, Physical-Mathematical Modeling, Case Study	City of Temuco, La Araucanía region, Chile; Germán Becker Stadium parking lot; Pueblo Nuevo meteorological station; Permeable Design Pro Software; historical rainfall data from 1953–2020.	Rainfall intensity Water infiltration Stormwater storage capacity Drainage system performance Return period for storms Structural layer properties (thickness, porosity, permeability)	This study evaluates the feasibility of implementing permeable interlocking concrete pavement (PICP) as a sustainable drainage solution for urban flood mitigation in Temuco, Chile. Using physical-mathematical modeling, the research tests PICP performance under extreme rainfall conditions, simulating a 24-hour storm with a 100-year return period. The design incorporates smooth and corrugated drainage pipes, analyzing their impact on infiltration and storage. The study highlights PICP's potential for climate adaptation and urban sustainability, proposing its integration into urban infrastructure to address flooding and enhance green spaces.	The results show that PICP, paired with smooth drainage pipes, effectively manages extreme hydrological events, withstanding 140 mm of rainfall in 24 hours without saturation. The system's storage capacity and infiltration performance remained optimal, confirming its feasibility for urban application. Additionally, the design reduces flood risks, facilitates rainwater reuse for green space irrigation, and mitigates urban heat islands. Corrugated pipes, however, displayed lower efficiency, suggesting the need for smooth drainage systems in high-rainfall scenarios. The study concludes that PICP is a viable solution for climate change adaptation and sustainable urban development, contributing to reduced greenhouse gas emissions and improved quality of urban life.

Flood risk assessment for Davao Oriental in the Philippines using geographic information system-based multi-criteria analysis and the maximum entropy model	J. Cabrera, Han Soo Lee	2020	Mixed (GIS-based multi-criteria decision analysis (MCDA), Maximum Entropy model)	Davao Oriental, Mindanao, Philippines; Local government data; 70 field survey points; NCDC rainfall data; ASTER GDEM; population data from the Philippine Statistics Authority.	Rainfall Slope Elevation Drainage density Soil type Distance to main channel Population density	The study assesses flood-prone areas and flood risks due to pluvial flooding in Davao Oriental, Philippines, using GIS-based multi-criteria analysis (AHP) and the Maximum Entropy (Maxent) model. The analysis incorporates a variety of factors, including rainfall, slope, elevation, drainage density, soil type, and proximity to main channels. The methodology helps identify high-risk areas for flooding, considering both physical terrain and socio-economic factors like population density. The study utilizes historical flood data from field surveys to validate the models and refine flood risk maps.	The AHP model identifies 22% of the total area and approximately 30% of the population of Davao Oriental as being at high risk for pluvial flooding. The Maxent model, with an accuracy rate of 95.6%, shows that elevation, rainfall, and soil type are the most significant contributors to flood susceptibility. The findings emphasize the importance of integrating both AHP and Maxent approaches for comprehensive flood risk assessment, particularly in data-scarce regions. The models can be used to prioritize areas for more detailed studies and risk mitigation efforts.
Flood vulnerability and slum concentration mapping in the Indian city of Kolkata: A post-Amphan	Alokananda Banerjee Mukherjee, S. Bardhan	2021	Quantitative, Vulnerability Index Calculation, GIS Mapping	Kolkata, India; Slum population data (2009); Rainfall and flood data from the Kolkata Municipal Corporation	Flood Vulnerability Index (FVI) Water depth during flooding Duration of water logging Slum population concentration Drainage	This study focuses on assessing flood vulnerability in Kolkata, particularly after the super-cyclone Amphan in 2020. Using the Flood Vulnerability Index (FVI), the research maps areas of high vulnerability based on factors	The findings reveal that slum areas, particularly in boroughs VII and XV, are highly vulnerable to flooding due to poor drainage systems, increased urbanization, and loss of wetlands. These areas face prolonged water logging and are most affected by cyclonic storms like Amphan. The study suggests that slum-

analysis				(KMC), 2015-2020; Satellite imagery.	system efficiency	like water depth and the duration of flooding. The study also overlays these maps with the concentration of slum populations, which are located in poorly drained and low-lying areas, highlighting their increased exposure to flooding. The research emphasizes the link between urbanization, inadequate drainage, and climate change, which worsens the city's flood risks.	dwelling populations, who lack access to basic infrastructure and are concentrated in flood-prone areas, suffer disproportionately from flood-related hazards. The findings underscore the need for improved urban planning, enhanced drainage systems, and targeted disaster risk management strategies for these vulnerable populations.
Flood-Prone Area Assessment Using GIS-Based Multi-Criteria Analysis: A Case Study in Davao Oriental, Philippines	J. Cabrera, Han Soo Lee	2019	Quantitative, GIS-based Spatial Analysis, Multi-Criteria Decision Analysis (MCDA), Analytic Hierarchy Process (AHP)	Davao Oriental, Philippines; Local government data; National Climatic Data Center (NCDC); GIS data from ASTER GDEM, population census (2015); Rainfall data from Hinatuan and DOST-RXI stations.	Rainfall Slope Elevation Soil type Drainage density Distance to main channel Population density	This study uses GIS-based multi-criteria decision analysis (MCDA) to assess flood-prone areas in Davao Oriental, Philippines. The study integrates various flood-related indicators such as rainfall, slope, elevation, soil type, drainage density, and proximity to water channels. Using the Analytic Hierarchy Process (AHP), weights for each factor are assigned, and a flood hazard map is generated for the region. The study validates	The study finds that 95.99% of Davao Oriental is classified under low to moderate flood risk, while about 3.39% of the province, mainly in coastal areas, is at high to very high flood risk. The areas with the highest flood risks are primarily in the eastern coastal municipalities such as Boston, Cateel, and Baganga. The findings highlight the significance of rainfall and slope as the most important factors contributing to flood risks. AHP was found to be the most accurate method for generating flood hazard maps, with superior accuracy when compared to the WR and RW methods. The results underscore

						the results using field surveys from historical flood events and compares them to flood risk maps generated by other methods like Weight-by-Rank (WR) and Ratio Weighting (RW).	the need for immediate flood risk management strategies, particularly in high-risk areas, and call for enhancing local disaster preparedness and mitigation efforts.
Green Roads for Water: Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience	F. Steenbergen, Fatima Arroyo-Arroyo, K. Rao, Taye Alemayehu Hulluka, Kifle Woldearegay, Anastasia Deligianni	2021	Mixed (Guidelines-based, Cross-sectoral collaboration, Practical implementation)	Road agencies, agriculture, water management, disaster risk reduction, environmental and social specialists, local communities, NGOs in rural areas.	Road infrastructure resilience Water management Landscape impacts Community engagement Multi-sectoral collaboration Climate resilience	The guidelines promote an integrated approach to road development where roads are designed not only to function as transportation infrastructure but also as tools for water management and climate resilience. The core concept of "Green Roads for Water" aims to reverse the traditional conflict between roads and water, positioning roads to mitigate water-related issues such as erosion, flooding, and waterlogging while harvesting water for local use. The approach incorporates adaptive and proactive strategies to design roads that align with the landscape, optimize water use, and protect ecosystems and	The Green Roads for Water approach is shown to offer triple benefits: reducing road damage from water, improving the surrounding landscape, and managing water for community benefit. Adaptive strategies, which involve integrating basic water management practices into existing road designs, are more cost-effective and yield rapid returns. Proactive strategies, while more costly, have the potential for greater long-term environmental and economic impacts by rethinking road alignments and incorporating water management directly into the design. Successful examples from Ethiopia, Bangladesh, and Kenya demonstrate the substantial economic and environmental benefits of Green Roads, with benefits far outweighing initial investments. The guidelines emphasize the need for collaboration across sectors and community

						communities from climate change impacts.	engagement to ensure the success and scalability of Green Roads programs.

Impact of Urbanization on Pluvial Flooding: Insights from a Fast Growing Megacity, Dhaka	Md. Shadman Sakib, Siam Alam, Shampa, S. Murshed, Ripan Kirtunia, S. Mondal, Ahmed Ishtiaque Amin Chowdhury	2023	Quantitative, Urban Drainage Modeling, Land Use and Land Cover (LULC) Change Analysis	Dhaka City, Bangladesh; Land Use and Land Cover (LULC) data (satellite imagery from 1973–2022); Hydrological and meteorological data; GIS-based modeling tools (ArcGIS, QGIS, PCSWMM); Local government and urban planning data; Remote sensing (Landsat, Sentinel-2); Bangladesh Meteorological Department.	Land use and land cover (LULC) change Impervious surfaces Vegetation and water bodies Built-up areas Rainfall intensity Drainage system performance Flood inundation areas Future urban growth scenarios	This study investigates the impact of rapid urbanization on pluvial flooding in Dhaka, Bangladesh, focusing on changes in Land Use and Land Cover (LULC) and their effects on urban drainage and flooding. It analyzes historical and projected LULC data over five decades (1973-2022) to identify trends in urban expansion, vegetation loss, and water body reduction. The study uses urban drainage modeling (PCSWMM) to simulate the effects of these LULC changes on flood risk, particularly focusing on the Goranchatbari catchment. Future projections for 2042 are made using a hybrid Cellular Automata- Artificial Neural Network (CA-ANN) model to predict urban growth and its implications on drainage and flooding.	The findings show a significant reduction in water bodies and green spaces within the Goranchatbari catchment, with an increase in built-up areas, particularly between 2003 and 2022. By 2042, settlement areas are projected to increase from 77.54% to 89.49%, leading to further depletion of natural drainage areas and exacerbating flood risks. The study predicts a 21.35% loss of retention pond area by 2042, which will further strain the city's ability to manage stormwater. The LULC changes are expected to severely disrupt the connectivity of critical drainage channels, such as the Baunia Khal and Diabari Khal, leading to drainage congestion in the northern regions of Dhaka. The study concludes that urbanization without adequate drainage and water management systems will worsen pluvial flooding, particularly in the low-lying and rapidly urbanizing areas of the city. The findings emphasize the need for integrated flood management strategies that account for future urban growth and LULC

							dynamics.
Impacts of Climate Change on Flood-Prone Areas in Davao Oriental, Philippines	J. Cabrera, Han-Yong Lee	2018	Quantitative, Spatial Flood Risk Assessment, Multi-Criteria Decision Analysis (MCDA), Climate Modeling	Davao Oriental, Philippines; Local government units; Climate projections from CMIP5 (RCP4.5, RCP8.5); GIS data (rainfall, elevation, soil type, drainage density, population density); Historical data from local rainfall stations (Hinatuan, DOST-RXI).	Flood risk Rainfall projections (CMIP5 RCP4.5, RCP8.5) Population density Soil type Slope Elevation Distance to main channel Drainage density	This study assesses the impact of climate change on flood risks in Davao Oriental, Philippines, under future climate scenarios (RCP4.5 and RCP8.5) for 2030, 2050, and 2100. The analysis integrates various spatial datasets, such as rainfall, slope, elevation, soil type, and population density, using Multi-Criteria Decision Analysis (MCDA) and the Analytic Hierarchy Process (AHP). The study aims to generate flood risk maps to identify flood-prone areas and their vulnerability, with a focus on future climate-induced risks. It incorporates the CMIP5 climate model for temperature and rainfall projections and uses GIS- based analysis to develop a comprehensive risk assessment.	The study finds that Davao Oriental is generally at low to moderate flood risk, with 95.91% of the province currently in these categories. However, future projections suggest a slight increase in the area at risk, with more regions facing moderate and high flood risks due to an increase in rainfall intensity. The municipalities along the riversides and coastal areas are identified as the most vulnerable, with Boston municipality showing the highest flood risk (very high category). The study emphasizes the need for immediate action to prepare for these risks, including community- based disaster management plans. The research highlights that rainfall intensity is projected to increase by approximately 69%, which will exacerbate the flood risks over time.
Juggling through Ghanaian urbanisation: flood hazard mapping of Kumasi	P. I. Korah, P. Cobbinah	2016	Mixed (Literature review, GIS- based spatial analysis, Multi-Criteria Analysis)	Secondary data, published documents from local and international organizations, GIS data, Kumasi Metropolitan Area (KMA)	lood hazard zones Urbanization Land use/cover change Emergency service accessibility Population concentration	The study investigates the flood hazard zones in Kumasi, Ghana, resulting from both natural (e.g., climate change, topography) and anthropogenic (e.g., urbanization) factors. Using Geographic Information Systems (GIS) and Multi-Criteria Analysis (MCA), the study maps flood-prone	The analysis reveals that Kumasi's flood hazard zones are largely influenced by the interaction of natural topography and rapid, unregulated urbanization. High-density residential areas located in flood-prone regions face greater risks due to the reduction in green spaces and poor waste management. Additionally, residents in high and moderate

						areas and assesses the accessibility to emergency services in flood-affected zones. Findings show that rapid urbanization, particularly haphazard development, increases the risk of flooding and limits access to emergency services for residents in high-risk areas.	hazard zones have limited access to emergency services, which further exacerbates the vulnerability of these communities during flooding events. The study highlights the urgent need for better urban planning and integrated flood risk management in Kumasi.
Mapping Urban Flood-Prone Areas' Spatial Structure and Their Tendencies of Change: A Network Study for Brazil's Porto Alegre Metropolitan Region	D. Altafini, Andrea da Costa Braga, Claúdio Ugalde	2023	Quantitative, Vulnerability Index Development, Composite Method	Nine coastal cities (Buenos Aires, Calcutta, Casablanca, Dhaka, Manila, Marseille, Osaka, Shanghai, Rotterdam); Climate data, socio-economic data, flood hazard data; Institutional reports.	Sea-level rise Storm surge Cyclone frequency River discharge Soil subsidence Coastal population Cultural heritage Shelters availability Awareness and preparedness Drainage infrastructure Flood hazard maps Institutional organizations	This study develops the Coastal City Flood Vulnerability Index (CCFVI) to assess the vulnerability of coastal cities to flooding. The CCFVI combines three components: hydro-geological, socio-economic, and politico-administrative vulnerability. The index uses indicators such as sea-level rise, storm surge, river discharge, and soil subsidence for the hydro- geological component; cultural heritage, population near the coast, and shelters for the socio-economic component; and flood protection measures, planning zones, and institutional capacity for the politico-administrative component. The CCFVI is applied to nine cities globally to compare their vulnerability under current conditions	The study reveals that Shanghai is the most vulnerable city overall, primarily due to exposure to hydro-geological factors like storm surge and sea-level rise, coupled with social vulnerability from high population density near the coastline. Dhaka and Manila are also highly vulnerable, while Casablanca and Marseille are less vulnerable. The results also show that climate change exacerbates vulnerabilities, particularly through increased coastal population growth and rising sea levels. The CCFVI model helps identify cities that need more detailed investigations and adaptation strategies. It provides a tool for decision-makers to prioritize actions for reducing flood risks in coastal cities.

						and in future climate change scenarios.	
Measuring Road Network Topology Vulnerability by Ricci Curvature	Lei Gao, Xingquan Liu, Yu Liu, Pu Wang, Min Deng, Qing Zhu, Haifeng Li	2018	Quantitative, Simulation-based Analysis, Experimental Design	Urban road network datasets from six cities (e.g., Beijing, NYC-Manhattan, Xi'an, Luoyang, Shenyang, Changchun)	Road network topology Ricci curvature Vulnerability under attack Network connectivity Road network evolution	This study presents a method for measuring the vulnerability of road networks using Ricci curvature, which captures the interaction between network nodes. The method is designed to identify key sections of a road network that are most vulnerable to disruptions, such as natural disasters or man-made attacks. The research includes simulation experiments involving random and targeted attacks to assess the vulnerability of different road network types (centripetal and centrifugal). It compares the Ricci curvature-based model with traditional betweenness centrality models.	The study finds that the Ricci curvature method provides a more localized and intrinsic measure of road network vulnerability compared to traditional node-based methods like betweenness centrality. Networks with negative Ricci curvature show higher vulnerability, particularly during targeted attacks. The results indicate that centrifugal road networks, such as those in NYC- Manhattan, exhibit higher robustness than centripetal networks like those in Beijing. The research also shows that road networks evolve over time, with their vulnerability characteristics remaining relatively stable despite changes in network size. The Ricci curvature model is found to be a more effective tool for identifying critical road sections and improving resilience planning.
Measuring the Green Infrastructure Resilience in Turkey	ıkan Berfin, Mert Yelda	2021	Mixed (GIS-based analysis, Multi-Criteria Decision Analysis, Expert Survey)	Edremit District, Van, Turkey; GIS data, local population data, air quality data, stormwater management data, expert survey	Green space accessibility Stormwater management Urban heat island effect Air quality Landscape connectivity Social vulnerability	This study assesses the resilience of green infrastructure in the Edremit district of Van, Turkey, through the Green Infrastructure Spatial Planning (GISP) model. The evaluation focuses on six resilience criteria: stormwater management, green space accessibility, urban heat island effect, air quality,	The study finds that areas with preserved green infrastructure, especially along the coastline, are more resilient, showing lower flood sensitivity and better air quality management. However, urbanized areas with higher construction density (Erdemkent, Erenkent, and Esentepe) exhibit vulnerabilities, such as higher urban heat island effects and inadequate green space

				responses (urban planners, architects, landscape architects, environmental engineers).		landscape connectivity, and social vulnerability. GIS and expert survey analyses are combined to assess these criteria's effectiveness in enhancing the district's resilience to climate change and urban pressures. The study highlights the importance of green infrastructure in urban resilience and emphasizes the need for policies that prioritize green spaces and sustainable urban practices.	access. Social vulnerability is also prominent in densely populated neighborhoods with limited green space access. The expert survey results underscore the importance of improving green space accessibility and stormwater management to enhance resilience. The study concludes that urban policies must consider local characteristics and integrate resilience strategies into urban planning to combat climate change impacts effectively.
Measuring urban road network vulnerability to extreme events: An application for urban floods	A. Morelli, Andre Luiz Barbosa Nunes da Cunha	2019	Quantitative, Network Analysis, Graph Theory	São Carlos, São Paulo, Brazil; traffic zones; OpenStreetMap data; Google Maps API; Origin/Destination (OD) matrix data (2007/2008).	Road network disruption Continuity Efficiency of alternative routes Travel distances Pedestrian vs. motorized vehicle movement	This study presents a method to measure urban road network resilience during extreme events, such as floods, by focusing on how disruptions in the network impact transportation. The method calculates two metrics: network continuity and the efficiency of alternative paths, using graph theory. The analysis is applied to São Carlos, Brazil, to assess the effects of different flooding scenarios. The study differentiates the impact of floods on pedestrians and motorized	The findings reveal that flooding significantly affects motorized vehicles and bicycles, especially in the southern regions of São Carlos, where most disruptions occur. Pedestrian movement shows less impact, as the trips tend to be shorter and more localized. The study finds that as flooding intensity increases, motorized vehicle routes become blocked, increasing travel distance and affecting efficiency, while pedestrian routes are less affected. This highlights the greater vulnerability of motorized transportation to urban flooding. The results suggest that cities with shorter pedestrian trips may be more resilient to such events.

						vehicles, showing that pedestrians are less impacted due to shorter trips and more resilient network configurations.	
Methodology to Prioritize Climate Adaptation Measures in Urban Areas. Barcelona and Bristol Case Studies	Maria Guerrero-Hidalga, Martínez-Gomariz, B. Evans, J. Webber, Montserrat Termes-Rifé, B. Russo, L. Locatelli	2020	Mixed (Multi-criteria decision analysis (MCA), Cost-effectiveness analysis (CEA), Cost-benefit analysis (CBA), Stakeholder workshops)	Barcelona and Bristol case studies; Stakeholders from city councils, utilities (e.g., water, transport, waste management), urban planners, technical experts (engineers, economists, and natural scientists), and local communities.	Climate risks (pluvial flooding, CSO spills, fluvial flooding) Adaptation measures (green roofs, permeable paving, detention tanks, flood barriers) Economic damage (avoided damage, cost-benefit ratio) Social co-benefits (public health, job creation, social inclusion) Environmental co- benefits (air quality, biodiversity, water conservation)	This study develops a methodology to prioritize climate adaptation measures in urban areas, focusing on reducing extreme weather-related risks such as flooding and Combined Sewer Overflow (CSO) spills. The methodology is applied to two European cities, Barcelona and Bristol, using a multi-stage process that integrates technical, economic, and social evaluations. It begins with preliminary screening using cost- effectiveness and co-benefit scoring, followed by more detailed assessments such as economic damage reduction and risk modeling. Stakeholder engagement is integral to the process, ensuring that local knowledge and priorities are	The findings from the case studies show that nature- based solutions like Sustainable Urban Drainage Systems (SUDS) and structural measures (e.g., flood barriers) are highly prioritized for reducing flooding and CSO spill risks in both Barcelona and Bristol. In Barcelona, SUDS measures were the top-ranked for both pluvial flooding and CSO spills, due to their significant environmental and social co-benefits, despite higher initial costs. For Bristol, demountable flood protection barriers were preferred for both pluvial and fluvial flooding due to their cost-effectiveness and relatively low implementation costs. The detailed assessments revealed that the combination of SUDS and structural measures in targeted zones (e.g., Zone 5 in Barcelona) yielded the highest net benefits and risk reductions. The study highlights the importance of combining co-benefit analysis with technical assessments to ensure comprehensive and adaptive urban climate

						reflected in the decision-making. The methodology provides a framework for cities to identify and prioritize the most effective and feasible adaptation strategies under climate change scenarios.	resilience strategies.
Operating urban resilience strategies to face climate change and associated risks: some advances from theory to application in Canada and France	Heinzlef, B. Robert, Y. Hémond, D. Serre	2020	Mixed (Collaborative workshops, Spatial Decision Support Systems, Comparative analysis)	Urban and risk managers from Avignon (France) and Quebec (Canada); GIS departments; local government officials; infrastructure management teams; academic researchers.	Urban resilience Flood risk Critical infrastructures (CIs) Risk management strategies Vulnerability of urban areas Collaborative decision-making	This study examines two case studies from Avignon, France, and Quebec, Canada, focusing on integrating urban resilience into flood risk management strategies. The research investigates two approaches: a holistic resilience approach in Avignon and an organizational resilience approach in Quebec. Both regions face increasing flood risks due to climate change, and the study explores the use of spatial decision support systems and collaborative workshops to operationalize resilience. The workshops involved stakeholders discussing risk	The study found that although both regions have made progress in developing resilience tools, the practical application of these tools remains limited due to a lack of coordination and communication between stakeholders. In Avignon, there is a need for better integration of resilience strategies into urban planning, while in Quebec, the focus was on understanding the dependencies between critical infrastructures. The collaborative workshops helped improve understanding and foster a shared vision among stakeholders, though significant challenges remain in fully operationalizing resilience in risk management practices. The findings highlight the importance of continuous collaboration and adaptation to effectively address climate change

						management, resilience tools, and strategies to enhance local flood preparedness and response.	impacts.
Participatory Mapping for Enhancing Flood Risk Resilient and Sustainable Urban Drainage: A Collaborative Approach for the Genoa Case Study	I. Gnecco, F. Pirlone, I. Spadaro, Fabrizio Bruno, Maria Cristina Lobascio, Sabrina Sposito, M. Pezzagno, A. Palla	2024	Mixed (Participatory Mapping, Stakeholder Workshops, GIS-based Spatial Analysis)	Sampierdarena district, Genoa, Italy; Local stakeholders (government, urban planners, citizens, students); Various age groups (elementary, middle school, and high school students); Public surveys; Online GIS-based questionnaires; Site inspections.	Flood risk awareness Perceptions of flood risk and vulnerabilities Flood damage experiences Sustainable Urban Drainage Systems (SUDS) installation preferences Green spaces accessibility Stakeholder engagement in planning processes	This study applies a participatory mapping methodology to enhance urban flood resilience through the implementation of Sustainable Urban Drainage Systems (SUDS) in Genoa's Sampierdarena district. The research integrates community knowledge, technical assessments, and spatial data to guide the planning of SUDS as effective flood mitigation strategies. The methodology employs both top-down and bottom-up approaches, engaging various local stakeholders, including citizens and students, to identify flood-prone areas and design potential solutions. The participatory mapping process uses GIS tools to visualize local flood risks and integrate public input into the decision-making process for urban resilience.	The participatory process revealed that both general public and school-age participants shared a common understanding of the flood risks in the Sampierdarena district. The majority of participants identified critical areas prone to flooding, including commercial and residential zones with limited green space. The integration of community insights highlighted locations suitable for SUDS implementation, particularly in high-traffic areas and regions with dense infrastructure. The study emphasizes the value of including various stakeholders in the planning process, particularly through intergenerational participation, ensuring that both youth and adults contribute to urban resilience efforts. The findings underscore the importance of inclusive engagement in urban planning, promoting public awareness, and supporting the implementation of SUDS to mitigate flood risks in urban areas.

ripheral: Resilient Hydrological Infrastructures	Ulrik Ekman	2023	Mixed (Case Studies, Climate Adaptation Planning, Design Management, Interviews)	Six coastal cities: Copenhagen, Dragør, Birkholm (Denmark); Jakarta (Indonesia); Malé (Maldives); Tarawa (Kiribati); Government representatives, urban planners, engineers, local communities, policy experts.	Sea-level rise (SLR) Erosion Coastal protection (dikes, seawalls) Land reclamation Urbanization Water supply management Freshwater security Biodiversity Ecosystem services Socio-economic factors (population density, local economy)	This study investigates the potential for increased urban and environmental resilience in coastal cities facing sea-level rise (SLR). It includes case studies from both the Global North and South, analyzing urban responses to climate challenges like flooding, erosion, and loss of biodiversity. The research employs an open systems approach, focusing on adaptive strategies for hydrological infrastructures and emphasizing the role of the urban periphery in resilience planning. It critiques both central and peripheral approaches to urban resilience, examining how different cities are adjusting to SLR through mitigation (e.g., hard infrastructure like dikes) and adaptation (e.g., nature-based solutions, planned retreats).	The study finds that while cities like Copenhagen and Jakarta focus primarily on technological solutions like dikes and land reclamation, they face significant barriers related to social and ecological considerations. In contrast, smaller cities like Tarawa and Birkholm show potential for resilience in their peripheral, more flexible design approaches. The research highlights the importance of decentering human-centric designs to include more ecological, non-anthropocentric methods in urban planning. In Malé, the development of floating cities and land reclamation projects offers a partial solution but fails to fully address ecological resilience. The study concludes that greater resilience lies in transitioning from centralized, anthropocentric infrastructures to more flexible, regionally integrated systems that engage with local ecosystems and hydrological cycles.
Resilience and efficiency in transportation networks	A. Ganin, M. Kitsak, Dayton Marchese,	2017	Quantitative, Network Analysis, Traffic Simulation	40 major U.S. cities; U.S. Census Bureau data; OpenStreetMap data; traffic delay data from the Texas	Traffic delays Road network efficiency Resilience to road disruptions Link failure probability	This study explores the relationship between resilience and efficiency in urban transportation networks. The authors model traffic delays based on urban road networks, where	The study finds that urban areas with high efficiency under normal conditions (e.g., low traffic delays) are not necessarily the most resilient to disruptions. For instance, while cities like Los Angeles may suffer significant

	J. Keisler, T. Seager, I. Linkov			A&M Transportation Institute Urban Mobility Scorecard.	Commuter flow and road segment usage	intersections are nodes and road segments are links. Efficiency is calculated using annual delays per peak-period commuter, while resilience is assessed through changes in traffic delays resulting from random disruptions to road links. The study evaluates the performance of 40 major U.S. cities, quantifying both the normal traffic efficiency and the system's resilience to disruptions like road closures or accidents.	delays under normal conditions, their traffic systems are more resilient to disruptions. In contrast, cities such as San Francisco, despite having similar efficiency levels, experience substantial delays when 5% of road links are disrupted. The study suggests that cities need to invest in strategies that balance both efficiency and resilience to minimize the impact of disruptions on transportation systems.

ROAD NETWORK ANALYSIS FOR RISK AND RESILIENCE ASSESSMENT FRAMEWORK OF ROAD INFRASTRUCTURE SYSTEMS	S. Ientile, Franzsika Schmidt, C. Chevalier, A. Orcesi, L. Adelaide, B. Nedjar	2020	Quantitative, Network Analysis, Probabilistic Modeling, Graph Theory	A2 Highway stretch, Guadalajara, Spain; OpenStreetMap (OSM) road network data; PANOPTIS project data; Road network performance metrics.	Travel time Network connectivity Road network topology Impactful edges Vulnerability index (EVI) Alternative routes	This study presents a methodology for assessing the resilience and vulnerability of road infrastructure (RI) systems using network analysis and graph theory. It aims to quantify the risk of road network failure due to natural hazards or road disruptions by evaluating the impact on travel time and network connectivity. Using data from OpenStreetMap, the road network is modeled as a graph, with nodes representing intersections and	The network analysis identified key edges whose failure significantly impacts the performance of the road network. The vulnerability index (EVI) varies depending on the specific set of origin-destination nodes considered. For some sets, essential edges were identified, where their failure led to complete disconnection of the network, highlighting their critical role in maintaining network functionality. The analysis also showed that alternative routes play a crucial role in mitigating the

						edges representing road segments. Vulnerability is assessed by eliminating "impactful edges" and recalculating travel times for different sets of origin-destination pairs. The results are used to calculate a vulnerability index (EVI), which measures the loss of serviceability of the road network.	impact of road failures, as networks with well-distributed alternative paths tend to exhibit lower vulnerability. The findings suggest that a detailed understanding of network structure and failure points can help improve resilience planning and inform decision-making for road infrastructure management.
Road Network Vulnerability Based on Diversion Routes to Reconnect Disrupted Road Segments	A. A. Redzuan, R. Zakaria, A. Anuar, E. Aminudin, Norbazlan Mohd Yusof	2022	Quantitative, Network Vulnerability Assessment, GIS-based Pathfinding, Diversion Route Evaluation	Malaysian Peninsular road network; GIS data; OSM road data; traffic data; Road Traffic Volume Malaysia (RTVM); Annual Average Daily Traffic (AADT) data.	Road segment length Diversion path distances (P1, P2) Ratio of diversion path to original segment (R1, R2) Independent route reliability (IR) Supporting vulnerability (SV) Traffic data (AADT, LOS, capacity)	This study develops a GIS-based method to assess the vulnerability of a road network by considering the disruption of road segments and the availability of diversion routes to maintain connectivity. The method calculates the first and second shortest diversion paths for each disrupted road segment, ensuring that the paths are internally disjointed (i.e., they do not intersect). A vulnerability index is proposed, considering both the diversion path reliability	The findings demonstrate that the majority of road segments in the Malaysian road network have viable diversion paths, but some segments, especially those in remote or mountainous regions, show high vulnerability due to the lack of alternative routes. The first diversion path (P1) is generally shorter and more reliable, while the second diversion path (P2) is longer and less reliable. The study identifies that segments with high Supporting Vulnerability (SV) are crucial in maintaining network resilience during disruptions. A high ratio of R1 or R2 indicates a

						(R) and the supporting vulnerability (SV) of segments that may become diversion routes for surrounding areas. The study applies this method to the Malaysian Peninsular road network, highlighting the most vulnerable road segments based on the diversion route calculations.	diversion path that is almost as reliable as the original route, while lower values suggest less reliable diversion paths that could cause substantial delays. The methodology helps prioritize vulnerable road segments, guiding transportation agencies to improve network resilience and plan for traffic management in case of disruptions.
Simplified Assessment of the Resilience Capacity of Urban Areas affected by Microtunneling Activities	J. A. Pineda, Sherley Catheryne Larrañaga	2022	Quantitative, Resilience Index Assessment, Multi-criteria evaluation	Bogotá, Colombia; Intersection at Av 68 x Av 1 Mayo; Geotechnical data; Local government reports; Traffic and socioeconomic data; Numerical simulations.	Surface displacement Building vulnerability Road deformation Lifelines (water, sewerage pipes) Traffic management capacity Economic activity impact Disaster risk management policies	This study presents a simplified methodology for evaluating the resilience of urban areas affected by microtunneling activities, specifically for the Bogotá metro project. The focus is on assessing the resilience of the area at two stages: before and after the disruptive event (microtunneling). The methodology incorporates four key components of resilience—robustness, redundancy, resourcefulness, and recovery—each evaluated through a multi-criteria approach. The study utilizes	The results show that the resilience index for the analyzed area of Bogotá, prior to the disruptive event, is high (0.75), with significant contributions from robustness and redundancy. After the event, the resilience index drops slightly to 0.71, indicating a slight loss of functionality but still maintaining an adequate level of resilience. The study found that while microtunneling caused surface displacements, these were within tolerable limits for most buildings and roads, though the sewerage systems faced more severe impacts. The traffic management and emergency response systems are considered robust,

						numerical simulations to model surface deformations and their impact on buildings, roads, and lifelines. The resilience index is calculated to guide decision-making for the sustainable implementation of trenchless technology in urban environments.	with good redundancy, ensuring minimal disruption to the community. The findings emphasize the need for further validation of the method across different scenarios to enhance resilience planning for urban infrastructure projects.
SRRI Methodology to Quantify the Seismic Resilience of Road Infrastructures	D. Forcellini	2022	Quantitative, Performance-based Earthquake Engineering (PBEE) methodology, Probabilistic modeling, Case study	Road network consisting of two interdependent infrastructures (bridges B1 and B2), typical California highway bridges, seismic hazard input from the PEER NGA database, repair cost ratio (RCR) and recovery time (RT) data, Caltrans Comparative Bridge Costs database.	Repair cost ratio (RCR) Repair time (RT) Peak ground acceleration (PGA) Prolongation of travel (PT) Connectivity losses (CL) Functionality ratio (ri) Infrastructure interdependencies	This study presents a new methodology to quantify the seismic resilience of road infrastructures, focusing on bridges within a network. Using the Performance-Based Earthquake Engineering (PBEE) methodology, it calculates direct and indirect losses from seismic events, including repair costs and travel delays. The study uses a case study comparing two road networks, each with different numbers of bridges, and analyzes the impact of seismic hazards like peak ground acceleration (PGA) on infrastructure functionality. Key	The results show that different configurations of road infrastructures exhibit varying levels of seismic resilience, especially under higher intensities of peak ground acceleration (PGA). For scenarios where infrastructure is partially open, such as Scenario 5 (where one infrastructure is partially opened), the resilience of the network improves, with lower losses compared to other scenarios. The study finds that bridges with rubber bearings (B2) perform better at higher seismic intensities (PGA > 0.68 g), whereas sliding isolators (B1) perform better at lower intensities. The study emphasizes the importance of considering infrastructure interdependencies and the impact of

						losses include prolongation of travel (PT) and connectivity losses (CL), with interdependencies between infrastructures considered in the assessment.	repair times and costs in enhancing resilience.
The cost of rapid and haphazard urbanization: lessons learned from the Freetown landslide disaster	Yi-fei Cui, Deqiang Cheng, C. Choi, W. Jin, Yu Lei, J. Kargel	2019	Quantitative, Remote Sensing Analysis	Freetown, Sierra Leone; 2017 Landslide disaster; 10 years of high-resolution satellite images.	Urbanization Rainfall Slope stability Land-use change Vegetation clearance	The study investigates the 2017 Freetown landslide disaster, which resulted in significant loss of life and property. The primary causes of the disaster were identified as rapid and poorly planned urbanization, steep slopes, deforestation, and heavy rainfall. The study uses satellite images over a 10-year period to analyze land-use changes and the impact of human activities on the environment, particularly the role of urban expansion in triggering and worsening landslides.	The findings reveal that urban expansion into hazard- prone areas, deforestation, and poor urban planning were key factors that exacerbated the effects of the heavy rainfall, leading to the devastating landslide. The study emphasizes the importance of better urban planning, land-use management, and risk mitigation strategies to reduce vulnerability to natural disasters in mountainous regions.
The demise of Angkor: Systemic vulnerability	D. Penny, C. Zachreson, Roland J. Fletcher, D. Lau, J.	2018	Quantitative, Systemic Vulnerability Modeling, Cascading	Angkor, Cambodia; Archaeological data of Angkor's water	Erosion Sedimentation Flood magnitude Topological damage (Q) Network flow distribution	This study analyzes the systemic vulnerability of the Angkor water distribution network, focusing on how climatic variations, particularly	The results show that Angkor's water distribution network was highly vulnerable to flooding, especially when flood magnitudes surpassed a critical threshold. Damage

of urban infrastructure to climatic variations	Lizier, N. Fischer, Damian H. Evans, C. Pottier, M. Prokopenko		Failure Analysis	distribution network; Remote sensing data; Historical climatic data (tree ring indices, flood data, etc.)	Water management infrastructure	extreme flooding, contributed to the failure of the infrastructure. The model simulates erosion and sedimentation dynamics within Angkor's water system to explore cascading failures in the network. The analysis identifies thresholds where floods cause substantial topological damage, leading to system instability. The model also investigates the spatial distribution of this damage across different sectors of the network.	occurred most significantly in the upstream regions, where the network first received water flow. The cascading failure mechanism, triggered by increased erosion and sedimentation, led to flow centralization in some channels, while other parts of the network were starved of water. The study concludes that extreme climatic events, like intense flooding in the 14th century, likely played a key role in the destabilization and eventual decline of Angkor's complex infrastructure. This finding underscores the importance of building resilience into urban infrastructure to cope with high- impact, low-frequency climatic events.
The Implementation of Resilience Engineering to Deal with Climate Change Impact	Luo Ching-Ruey (Edward)	2023	Quantitative, Risk and Resilience Assessment, Hazard Mitigation Framework	Public infrastructure in the context of climate change; Hazard data (meteorological, exposure, vulnerability); Risk assessment frameworks (ISO31000,	Hazard (natural and anthropogenic) Vulnerability (social, infrastructure, economic) Exposure (population, critical infrastructure) Resilience (robustness, redundancy, resourcefulness, rapidity) Adaptation	This study focuses on integrating resilience engineering into climate change adaptation and disaster risk reduction strategies for public infrastructure. It introduces a comprehensive risk assessment approach that combines hazard identification,	The research finds a direct negative correlation between risk severity and resilience, with lower resilience levels corresponding to higher disaster risks. Four adaptation strategies were identified based on resilience levels: retention for high resilience, transfer for high-medium resilience, mitigation for medium resilience,

				UNDRR guidelines).	strategies (retention, transfer, mitigation, avoidance)	vulnerability assessment, and exposure analysis to quantify resilience and guide adaptation efforts. The study provides a methodology for evaluating risks across five levels of severity, with corresponding resilience strategies: retention, transfer, mitigation, and avoidance. The framework is used to assess major infrastructure vulnerabilities in a climate change context and proposes tailored interventions for improving infrastructure resilience.	and avoidance for low-medium to low resilience. The study emphasizes that the risk assessment framework enables a structured approach for addressing disaster risks and enhancing resilience across public infrastructure systems. Key findings also include the importance of multi-agency collaboration in risk management and the necessity of adopting resilience metrics in planning for future climate impacts.
The Risk-Informed Asset-Centric (RIACT) Urban Resilience Enhancement Process: An Outline and Pilot- Case Demonstrator for Earthquake Risk Mitigation in Portuguese Municipalities	S. M. Rezvani, Maria João Falcão Silva, Nuno Marques de Almeida	2024	Mixed (Risk-Informed Asset-Centric (RIACT) decision-making process, GIS mapping, Entropy weighting algorithm)	Portuguese municipalities; Seismic hazard data (near- field and far-field earthquakes); Demographic and socioeconomic data (Instituto Nacional de Estatística, Portugal); GIS data for municipalities; Entropy weighting algorithm for data analysis.	Earthquake risk Population density Housing density Revenue per inhabitant Education rate Ageing ratio Exposure to seismic hazards Vulnerability indicators Resilience indicators	This study introduces the Risk-Informed Asset-Centric (RIACT) process to enhance urban resilience against seismic hazards in Portuguese municipalities. The RIACT framework incorporates GIS mapping to assess earthquake risks, vulnerability, and resilience of infrastructure and communities. The study evaluates seismic risk based on regional data, including population density, housing	The findings indicate significant regional variations in earthquake resilience across Portugal. Municipalities with higher revenue per inhabitant and better education levels demonstrated higher resilience scores, while areas with older populations or higher housing density were more vulnerable. The analysis identified key high-risk regions, such as the Azores, which are more susceptible to seismic impacts, and highlighted areas with strong resilience, such as municipalities with robust economic and social structures. The

						density, socioeconomic indicators, and asset exposure. A tailored entropy weighting algorithm is applied to assess these factors and calculate resilience scores for each municipality. The RIACT process helps prioritize disaster risk mitigation and preparedness measures tailored to specific municipalities.	study emphasizes the need for tailored resilience strategies based on localized risk profiles to enhance preparedness and recovery capabilities.
Towards Resilient Roads to Storm-Surge Flooding: Case Study of Bangladesh	Md. Shohel Reza Amin, U. Tamima, L. Amador	2020	Quantitative, Optimization, GIS-based analysis, Dynamic Linear Programming	Barguna district, Bangladesh; cyclone and storm surge data; pavement condition data; geophysical risk and vulnerability indices.	Geophysical risk zones Pavement condition (IRI, PSI) Community vulnerability Structural vulnerability Pavement maintenance and rehabilitation costs Storm surge impact	This study focuses on enhancing the resilience of road networks in Bangladesh's coastal areas, particularly in Barguna district, which is prone to cyclones and storm surges. The research proposes a method to estimate the geophysical risk and vulnerability (GEOPHRIV) of each road segment by integrating geophysical risk, community vulnerability, and infrastructure damage indices. The study optimizes the maintenance and rehabilitation (M&R) strategies using dynamic linear programming to allocate resources	The study demonstrates that the optimization of pavement M&R operations significantly improves the condition of roads in disaster-prone areas. The results indicate that an annual budget of approximately USD 3 million is required to maintain good road conditions and convert the most vulnerable roads into resilient perpetual pavements. Roads located in high and medium geophysical risk zones are prioritized for upgrades. The model shows a substantial reduction in the number of roads in poor and fair conditions within 20 years. This approach is crucial for ensuring road resilience and minimizing the economic and human losses caused by

						for converting vulnerable roads into resilient pavements, ensuring better performance during and after disasters like cyclones.	cyclones and storm surges.

Urban Planning for Climate Change: A Toolkit of Actions for an Integrated Strategy of Adaptation to Heavy Rains, River Floods, and Sea Level Rise	Mariano, Marsia Marino	2022	Mixed (Case Study Analysis, Ecosystem-based Approach (EbA), Toolkit Development)	Case studies from cities in Europe, USA, and other coastal regions; Best practices from global urban planning; Public sector authorities, municipalities, urban planners, and project stakeholders.	Climate risks (heavy rains, river floods, sea level rise) Ecosystem-based adaptation strategies Urban resilience Urban regeneration Nature-based solutions (NbS) Socioeconomic impacts (public health, local economy, community engagement)	This research focuses on developing a toolkit of adaptation actions aimed at enhancing urban resilience to climate change, specifically addressing heavy rains, river floods, and sea-level rise. The study conceptualizes three macro-strategies—“defence,” “adaptation,” and “relocation/de-anthropisation”—to categorize and analyze international best practices. A total of six best practices are critically assessed, focusing on their ecosystem-based approaches (EbA), such as restoring floodplains, constructing artificial hills, or creating nature-based solutions like green corridors and rainwater	The study identifies several effective strategies for mitigating climate change impacts on urban systems. Key findings include that the "defence" strategies, such as flood barriers and coastal protection, offer immediate protection but are most effective when combined with "adaptation" strategies like creating green infrastructure (e.g., wetlands, parks, and rainwater basins). "Relocation/de-anthropisation" strategies, although challenging, are vital for areas at extreme risk, such as low-lying coastal zones. The toolkit developed provides a comprehensive framework for policymakers to integrate climate-proofing actions into urban planning. The authors conclude that the toolkit is valuable for municipalities seeking to develop or update their climate adaptation plans in a holistic and

						catchment systems. The toolkit developed from these best practices is designed to be replicable in other urban contexts, particularly those vulnerable to climate-induced risks.	sustainable manner, with nature-based solutions playing a key role.
Urban Resilience Index for Critical Infrastructure: A Scenario-Based Approach to Disaster Risk Reduction in Road Networks	S. M. Rezvani, Maria João Falcão Silva, Nuno Marques de Almeida	2024	Mixed (Scenario-based approach, Stochastic simulation, Performance-based assessment)	Lisbon road network; Stakeholders (urban planners, civil engineers, infrastructure managers); GIS-based flood risk data, OpenStreetMap (OSM) data, historical flood records, municipal revenue data, machine learning models (Random Forest).	Road performance metrics Flood risk exposure Cost-benefit analysis Proactive resilience planning Reactive flood response Early warning systems Economic impact (maintenance, construction costs) Revenue per inhabitant (RMI)	This study assesses the resilience of Lisbon's road infrastructure to flood risks, proposing a four-stage methodology: avoidance, endurance, recovery, and adaptability. The approach integrates geospatial AI (GeoAI) models, stochastic simulations, and cost–benefit analysis to simulate various flood risk scenarios. It compares three resilience strategies—reactive flood response, proactive resilience planning, and early warning systems—evaluating the performance and cost implications for road networks. The research uses historical data, machine learning,	The results highlight that proactive resilience planning (Scenario 2) improves road network performance with a 7.6% increase over reactive strategies and a 3.5% increase over early warning systems. Scenario 2 proved to be the most cost-effective, with the lowest loss value in the loss and gain analysis, indicating substantial long- term benefits in flood mitigation. The study shows that early warning systems (Scenario 3) contribute to better resource allocation and reduced flood impacts, but the proactive strategy offers the highest resilience across all stages. These findings underscore the importance of pre-emptive infrastructure investment and risk management in reducing flood-related disruptions.

						and flood simulation to identify high-risk zones and assess the effectiveness of these strategies in mitigating flood impacts on road infrastructure.	
Urban Resilience to Flooding: Triangulation of Methods for Hazard Identification in Urban Areas	M. Almeida, M. Telhado, Morais, J. Barreiro, Ruth Lopes	2020	Mixed (Methodological Triangulation, Hydraulic Modeling, Collaborative Process)	Lisbon Municipality (CML); Energy Supply: Distribution System Operator (EDP D); Wastewater Systems: CML and ADTA; Water Supply: EPAL; Public Transport: CARRIS, METRO; Communications: MEO Altice, Vodafone, NOS.	Flood frequency Sewer network capacity Water depth in flooding events Hazard to pedestrians Hazard to vehicles Impact on urban services (mobility, waste, water cycle, electricity)	The paper discusses a methodology for identifying and mapping flood-related hazards in Lisbon, Portugal, using a triangulation-based approach. The methodology integrates historical data, hydraulic modeling (1D GIS and 1D/2D combined models), and a collaborative process involving multiple urban service stakeholders. It aims to assess flood-related hazards and the resilience of essential services, including mobility, wastewater systems, and waste collection, considering current and future climate scenarios. Results from the simulation are used to evaluate flood impacts and resilience, particularly in	The findings reveal that Lisbon's existing sewer network is already under stress in terms of flood risk, especially in high flood-prone areas like the downtown catchments. However, climate change scenarios exacerbate the situation, leading to higher sewer capacity use and increased flooding hazards. The introduction of green infrastructure (CAS1) and retention basins (CAS2) showed limited improvements, primarily affecting downstream areas. The most significant improvement was observed in the construction of a large interception tunnel (CAS3), which helped reduce flooding in the areas directly downstream of the tunnels. The study also highlighted that while flood risks are significant, current infrastructure and services can cope with the existing hazards, but future risks require adaptation strategies.

						key areas such as downtown Lisbon.	The methodology provides a valuable tool for urban planners and stakeholders to assess resilience and prioritize interventions for improving flood management in Lisbon.

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