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Linking Monitoring Investment to Operational Resilience through Response Capacity: A Conceptual Framework for Coastal Water Infrastructure

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ABSTRACT

Coastal water infrastructure faces interconnected pressures from hydrological hazards, waste accumulation, and fragmented governance, making investment decisions critical to environmental sustainability and operational resilience. This study aims to synthesize relationships among infrastructure stress, monitoring technology, and organizational response to develop a conceptual framework for green economy risk management. A systematic literature review examines 85 studies published between 2021 and 2025, identified through Scopus, Web of Science, ScienceDirect, and IEEE Xplore, using thematic synthesis and interpretation of the system dynamics outputs reported in the study. The reported findings indicate that drainage deficits and increasing waste generation undermine environmental carrying capacity, whereas IoT-enabled monitoring and improved model efficiency support water quality, irrigation stability, and environmental performance. Qualitative material identifies coordination gaps between waste management and drainage maintenance as barriers to timely intervention. Together, these findings inform a framework linking monitoring investment to operational resilience through response capacity, emphasizing the organizational ability to translate information into coordinated maintenance and corrective action. The framework supports managerial consideration of monitoring allocation, preventive maintenance, and service continuity. Its potential contributions align with Sustainable Development Goal 6 through improved water management, Goal 9 through resilient infrastructure and innovation, Goal 11 through disaster risk reduction, and Goal 13 through climate adaptation. The study concludes that monitoring investment should be evaluated alongside response capacity and infrastructure conditions when planning coastal resilience interventions; these SDG contributions represent prospective implications rather than measured achievements.

ABSTRAK

Infrastruktur air wilayah pesisir menghadapi tekanan yang saling berkaitan akibat bahaya hidrologis, akumulasi sampah, dan tata kelola yang terfragmentasi, sehingga keputusan investasi menjadi penting bagi keberlanjutan lingkungan dan ketahanan operasional. Penelitian ini bertujuan menyintesis hubungan antara tekanan infrastruktur, teknologi pemantauan, dan respons organisasi guna mengembangkan kerangka konseptual manajemen risiko ekonomi hijau. Tinjauan literatur sistematis ini mengkaji 85 studi yang diterbitkan pada 2021–2025 dan diidentifikasi melalui Scopus, Web of Science, ScienceDirect, serta IEEE Xplore, menggunakan sintesis tematik dan interpretasi keluaran dinamika sistem yang dilaporkan dalam penelitian. Temuan yang dilaporkan menunjukkan bahwa defisit drainase dan peningkatan timbulan sampah melemahkan daya dukung lingkungan, sedangkan pemantauan berbasis Internet of Things (IoT) dan peningkatan efisiensi model mendukung kualitas air, stabilitas irigasi, serta kinerja lingkungan. Materi kualitatif mengidentifikasi kesenjangan koordinasi antara pengelolaan sampah dan pemeliharaan drainase sebagai hambatan intervensi tepat waktu. Temuan tersebut menjadi dasar kerangka yang menghubungkan investasi pemantauan dengan ketahanan operasional melalui kapasitas respons, dengan menekankan kemampuan organisasi menerjemahkan informasi menjadi tindakan pemeliharaan dan perbaikan yang terkoordinasi. Kerangka ini mendukung pertimbangan manajerial mengenai alokasi pemantauan, pemeliharaan preventif, dan keberlanjutan layanan. Kontribusi potensialnya berkaitan dengan Tujuan Pembangunan Berkelanjutan (SDG) 6, 9, 11, dan 13 melalui pengelolaan air, infrastruktur tangguh, pengurangan risiko bencana, serta adaptasi iklim. Penelitian menyimpulkan bahwa investasi pemantauan perlu dievaluasi bersama kapasitas respons dan kondisi infrastruktur; kontribusi SDG tersebut merupakan implikasi prospektif, bukan capaian yang telah diukur.

Kata kunci: Investasi pemantauan; Ketahanan operasional; Kapasitas respons; Infrastruktur air pesisir; Manajemen risiko ekonomi hijau; Dinamika sistem.

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1. INTRODUCTION

Water infrastructure resilience is a management concern because hydrological disturbances affect environmental quality, service reliability, and the economic activities dependent on functioning networks (Maiolo et al., 2020; Quaranta et al., 2022). Evidence from drainage control and infrastructure sustainability assessments shows that operational performance must be considered alongside investment requirements and environmental consequences, rather than evaluated through hydraulic capacity alone (Maiolo et al., 2020; Mohammadifardi et al., 2022). Flood vulnerability also varies across population groups and neighborhoods, making aggregate infrastructure improvements an incomplete indicator of equitable protection (Englund et al., 2023; de Macedo et al., 2025). Meanwhile, the transformation of water utilities into interconnected technological and organizational systems increases the importance of understanding how information, physical assets, and managerial action interact (Bhandari et al., 2023; Zhang et al., 2022). These developments establish a broader rationale for examining coastal water infrastructure through an integrated green economy perspective that connects resource protection with continuity of essential services (Quaranta et al., 2022; de Macedo et al., 2025). Within this context, investment in monitoring merits attention as one component of resilience management whose value depends on the operating conditions and response mechanisms surrounding its implementation (van der Werf et al., 2021; Bhandari et al., 2023).

The central problem is that detecting infrastructure stress does not, by itself, resolve the physical and organizational conditions through which disruption develops, particularly when monitoring uncertainty and implementation constraints persist (Zhang et al., 2022; Bhandari et al., 2023). Maiolo et al. (2020) demonstrate that control configurations and gate placement influence drainage performance, while Schmitt et al. (2020) show that control retrofits can produce different outcomes across rainfall conditions. Together, these findings challenge the assumption that additional digital capability will consistently yield greater protection without considering network characteristics and intervention design (Maiolo et al., 2020; Schmitt et al., 2020). Economic challenges include comparing competing investments, recognizing environmental benefits, and avoiding conclusions that transfer screening estimates directly into local operating decisions (Quaranta et al., 2022; Mohammadifardi et al., 2022). Organizational challenges concern legacy information systems, workforce capabilities, data management, and the coordination required to translate interconnected information into decisions (Bhandari et al., 2023; Englund et al., 2023). For coastal infrastructure management, these challenges motivate examination of drainage stress, waste generation, irrigation stability, and environmental quality as connected management concerns, with response capacity treated as the organizing link between monitoring investment and operational action (Sun et al., 2024; de Macedo et al., 2025).

Research on digital drainage performance has developed complementary approaches whose boundaries help define the present investigation (Maiolo et al., 2020; van der Werf et al., 2021). Maiolo et al. (2020) model distributed control of a real drainage network, linking improved hydraulic performance to strategically located gates; the comparison with van der Werf et al. (2021) indicates that implementation benefits also require an appropriate baseline. Schmitt et al. (2020) simulate seven detention basins and identify event-dependent limitations, cautioning against interpreting control installation as uniformly beneficial across storm magnitudes (Schmitt et al., 2020; Maiolo et al., 2020). Van der Werf et al. (2021) introduce realized potential indicators using an Eindhoven case, improving comparison of control strategies, although hydraulic benchmarking does not alone establish organizational readiness or investment affordability (van der Werf et al., 2021; Bhandari et al., 2023). Zhang et al. (2022) examine uncertain monitoring signals through reinforcement-learning simulations, addressing algorithmic robustness rather than measuring institutional response arrangements (Zhang et al., 2022; Bhandari et al., 2023). These four studies therefore provide technical evidence, but transferring their implications into coastal managerial decisions requires distinguishing control effectiveness, monitoring reliability, and the capacity to implement corrective action (Schmitt et al., 2020; Zhang et al., 2022).

Research on economic appraisal, vulnerability, and systemic sustainability extends the technical literature while introducing different analytical boundaries (Quaranta et al., 2022; Englund et al., 2023). Quaranta et al. (2022) compare overflow management costs and benefits across Europe, providing economic evidence whose screening scale requires contextualization before local application (Quaranta et al., 2022; de Macedo et al., 2025). Mohammadifardi et al. (2022) combine system dynamics and lifecycle assessment for wastewater asset decisions, integrating economic and environmental outcomes, although their application does not answer the coastal monitoring-response question (Mohammadifardi et al., 2022; Bhandari et al., 2023). Englund et al. (2023) develop a participatory Swedish vulnerability index, revealing distributional differences while explicitly identifying data gaps and transferability questions (Englund et al., 2023; de Macedo et al., 2025). Sun et al. (2024) integrate water, population, agriculture, ecology, and economic dynamics in Golmud, offering a systemic assessment whose inland setting differs from coastal operational conditions (Sun et al., 2024; Bhandari et al., 2023). Building on these contributions, the present study's novelty is an integrative synthesis that positions response capacity between monitoring investment and operational resilience while retaining infrastructure, environmental, and green economy relationships as its substantive foundation (Bhandari et al., 2023; Mohammadifardi et al., 2022).

The remaining research gap concerns the articulation of connections across existing approaches, rather than an absence of integrated water management research (Mohammadifardi et al., 2022; Sun et al., 2024). Bhandari et al. (2023) review cyber-physical-human water systems and identify challenges in representing interconnections and evolving risks, making their contribution a direct foundation for integrative analysis (Bhandari et al., 2023; Zhang et al., 2022). De Macedo et al. (2025) connect flood causes, consequences, and protective barriers through Bowtie analysis and the Sendai Framework, strengthening risk communication without making every organizational feedback a calibrated dynamic relationship (de Macedo et al., 2025; Sun et al., 2024). Comparing these contributions with hydraulic benchmarking and economic screening reveals different units of analysis, time horizons, and outcome definitions that complicate their translation into a managerial explanation (van der Werf et al., 2021; Quaranta et al., 2022). The present study addresses this interface by examining how monitoring information, infrastructure stress, and coordinated response can be interpreted together within green economy risk management, without assuming that evidence from one setting establishes universal effects. Its distinction is therefore the synthesis question and explicit response pathway, not a claim to technological invention (Bhandari et al., 2023; Englund et al., 2023).

The study retains General Systems Theory as its theoretical orientation, with complex adaptive systems, resilience, and ecological economics providing complementary interpretations of interconnected infrastructure management (Bhandari et al., 2023; Mohammadifardi et al., 2022). Through a systems lens, changes in physical assets, information flows, and organizational decisions are interpreted relationally, consistent with evidence that water utility evolution involves interacting technological, social, economic, and operational factors (Bhandari et al., 2023; Sun et al., 2024). The complex adaptive systems perspective directs attention to changing interdependencies and context-sensitive outcomes, illustrated by the performance responses observed across control configurations and rainfall conditions (Maiolo et al., 2020; Schmitt et al., 2020). Resilience provides an interpretive focus on the maintenance of service under disturbance, while vulnerability evidence emphasizes that the distribution of protection matters alongside network performance (Englund et al., 2023; de Macedo et al., 2025). Ecological economics informs consideration of environmental conditions and economic consequences together, supported by appraisals that evaluate environmental benefits and infrastructure costs within the same decision setting. These perspectives guide the synthesis; they do not replace evidence or establish the empirical causal strength of relationships between monitoring, response, and coastal resilience within this study (Quaranta et al., 2022; Mohammadifardi et al., 2022).

The conceptual vocabulary comprises water infrastructure dynamics, coastal disaster mitigation, system dynamics, green economy risk management, monitoring investment, response capacity, and operational resilience (Bhandari et al., 2023; de Macedo et al., 2025). Water infrastructure dynamics concerns changing interactions among drainage, irrigation, waste pressures, and environmental conditions, interpreted within resource–society–economy relationships examined in water assessments (Sun et al., 2024; Mohammadifardi et al., 2022). Coastal disaster mitigation provides the application context for preventive and corrective interventions, while system dynamics supplies feedback and temporal interaction rather than a guarantee of predictive validity (de Macedo et al., 2025; Sun et al., 2024). Monitoring investment denotes the allocation of resources to acquiring condition information, whose relevance depends on measurement quality, system limitations, and the decisions that information can support (Zhang et al., 2022; van der Werf et al., 2021). Response capacity denotes the ability to translate information into action, connecting technological interdependence with practical risk management responsibilities (Bhandari et al., 2023; de Macedo et al., 2025). Operational resilience and green economy risk management organize the intended outcomes around service continuity and environmentally informed economic decisions, without treating hydraulic improvement as equivalent to demonstrated financial or social benefits (Quaranta et al., 2022; Englund et al., 2023).

The study is important because the same monitoring technology may support different managerial outcomes depending on physical constraints, investment priorities, and the arrangements through which intervention occurs (Schmitt et al., 2020; Bhandari et al., 2023). Its interest lies in explaining this conditional relationship while keeping water quality, irrigation stability, drainage pressures, and environmental carrying capacity within a connected management discussion (Sun et al., 2024; Mohammadifardi et al., 2022). Such integration can help distinguish a need for additional information from a need for maintenance, coordinated responsibility, or a different intervention package, rather than presuming that technology acquisition resolves every source of vulnerability (Zhang et al., 2022; de Macedo et al., 2025). The prospective sustainability contribution spans SDG 6 through water quality and integrated water management, and SDG 9 through reliable infrastructure and innovation, linking environmental protection with infrastructure decision-making (Quaranta et al., 2022; Mohammadifardi et al., 2022). It also concerns SDG 11 through disaster resilience and attention to vulnerable populations, and SDG 13 through adaptation-oriented flood risk management. These links identify intended application pathways, not measured SDG achievements, and require contextual evaluation before being interpreted as demonstrated benefits of the proposed framework (Englund et al., 2023; de Macedo et al., 2025).

Accordingly, the study aims to synthesize literature on system dynamics in water infrastructure risk management and develop a conceptual framework linking monitoring investment to operational resilience through response capacity, informed by technical and socio-organizational evidence (Maiolo et al., 2020; Bhandari et al., 2023). Its systematic literature review focuses on the interactions of drainage loads, irrigation stability, waste generation, and environmental

quality, retaining green economy risk management as the integrative decision perspective (Sun et al., 2024; Mohammadifardi et al., 2022). More specifically, it examines how infrastructure pressures relate to environmental and economic consequences, interprets the role of monitoring and model efficiency, and clarifies the organizational response pathway relevant to preventive maintenance and service continuity (Zhang et al., 2022; Quaranta et al., 2022). The intended scientific contribution is a structured explanation connecting previously differentiated technical, ecological, economic, and governance concerns; the managerial contribution is a framework for interpreting monitoring and maintenance priorities under context-dependent constraints (Bhandari et al., 2023; de Macedo et al., 2025). These objectives guide synthesis rather than presuppose mediation, investment returns, or universal applicability, recognizing contextually comparable baselines and locally differentiated vulnerability when translating literature into coastal infrastructure decisions (van der Werf et al., 2021; Englund et al., 2023).

2. RESEARCH METHODS

This study employs a systematic literature review to examine relationships among water infrastructure dynamics, coastal disaster mitigation, and green economy risk management. The review combines qualitative interpretation with descriptive consideration of quantitative findings, retaining the distinction between evidence extracted from publications and conceptual relationships developed through synthesis. This distinction is important when integrating heterogeneous technical, environmental, and managerial research without assuming that different measurements are directly comparable (Campbell et al., 2020; Bhandari et al., 2023). The methodological sequence comprises research design, literature collection, eligibility assessment, extraction, analysis, framework development, and assessment of evidential limitations, as explained in the following subsections.

2.1 Research Design

The research design integrates thematic literature synthesis with secondary examination of system dynamics applications. Its analytical focus is the interaction between infrastructure pressures, environmental conditions, technological interventions, and economic resilience, consistent with integrated approaches to water infrastructure assessment (Mohammadifardi et al., 2022; Sun et al., 2024). The conceptual framework is the intended research output; an operational software product or independently validated forecasting model is not established through literature synthesis alone. The review therefore distinguishes conceptual integration from empirical model verification when interpreting its contribution (Bhandari et al., 2023; Zhang et al., 2022). Figure 1 presents the methodological sequence guiding literature collection and synthesis.

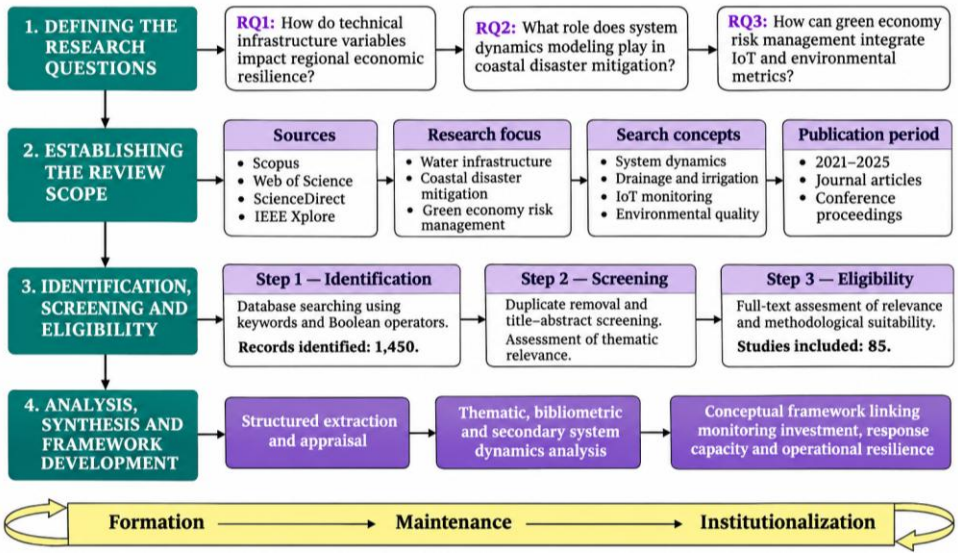


Figure 1. Literature Review and Conceptual Framework Development Process

Figure 1 illustrates the progression from defining the review questions to constructing the conceptual framework. Identification, screening, and eligibility assessment represent distinct decisions and should not be interpreted as interchangeable stages. The diagram retains the reported identification and inclusion totals without assigning unavailable numerical values to intermediate exclusions. Extraction precedes synthesis so that relationships can be interpreted against study characteristics rather than detached from their evidential context. Such separation supports transparent reporting but does not independently establish completeness, reproducibility, or absence of selection bias (Page et al., 2021; Rethlefsen et al., 2021). The following subsection specifies the literature sources and collection boundaries.

2.2 Literature Sources and Data Collection

Literature collection covers Scopus, Web of Science, ScienceDirect, and IEEE Xplore, targeting peer-reviewed journal articles and conference proceedings published between 2021 and 2025. Search concepts encompass water resource infrastructure, coastal disaster mitigation, system dynamics, risk management, and sustainable green economies. Using multiple sources accommodates disciplinary differences in coverage, although naming databases alone does not establish search completeness (Gusenbauer & Haddaway, 2020; Rethlefsen et al., 2021). The reported identification total is 1,450 records. Database-specific search dates, executable Boolean expressions, and individual retrieval totals are not specified here; consequently, exact replication requires the corresponding search records. Eligibility assessment follows the collection stage.

2.3 Eligibility Assessment and Study Selection

Selection proceeds through duplicate removal, title and abstract screening, and examination of full-text relevance, resulting in the reported inclusion of 85 studies. The substantive boundaries concern water infrastructure, disaster risk, environmental conditions, and systemic relationships relevant to economic sustainability. Publications outside the designated period or lacking the stated thematic and analytical relevance fall outside these boundaries. Selection transparency requires distinguishing identification records from eligible reports and included studies, while explaining exclusion decisions rather than relying on general descriptions of rigor (Page et al., 2021; Rethlefsen et al., 2021). The selected publications provide the documentary material for the extraction instrument described next.

2.4 Research Instruments and Extraction Fields

The research instrument is a structured literature extraction and appraisal matrix rather than a questionnaire administered to human respondents. Its content can be organized into seven field groups: author information, publication year, geographical focus, methodological design, principal variables, statistical or simulation findings, and study limitations. These groups retain the documented extraction content without assigning an unsupported number of questionnaire items. Explicit extraction categories help preserve the relationship between findings, methodological characteristics, and interpretation, particularly when quantitative results are synthesized narratively (Campbell et al., 2020; Page et al., 2021). The completed study records constitute the units examined within the geographical scope discussed below.

2.5 Units of Analysis and Geographical Scope

The units of analysis are the 85 included publications and their reported infrastructure relationships, findings, and modeling approaches. Their geographical coverage concerns river basins, coastal zones, and urban–rural settings, with attention to developing and emerging economies. This documentary scope does not constitute a single fieldwork location or a human participant population. Geographical illustrations identify settings requiring contextual interpretation rather than independently demonstrating sampling or data collection procedures. Distinguishing spatial context from the analytical sample is important because infrastructure behavior and management conditions vary between locations (Bhandari et al., 2023; Sun et al., 2024). These contextual differences inform the analytical alignment presented next.

2.6 Data Analysis and Synthesis

Analysis combines descriptive bibliometric mapping, thematic coding, and secondary interpretation of system dynamics applications, using NVivo and VOSviewer as the reported analytical tools. The thematic focus includes drainage loads, irrigation stability, water quality, waste generation, environmental carrying capacity, and technological interventions. Quantitative aggregation concerns reported findings and must remain distinguishable from a statistical meta-analysis requiring comparable effect estimates and an explicit pooling model (Campbell et al., 2020; Zhang et al., 2022). Interpretation also considers how study design and context constrain managerial conclusions (Bhandari et al., 2023; Mohammadifardi et al., 2022). Preserves the three substantive research questions while distinguishing their analytical purposes. RQ1 connects technical variables with economic consequences; RQ2 examines how feedback representations contribute to disaster risk interpretation; RQ3 integrates technological and environmental considerations within management frameworks. The indicators organize extraction and comparison rather than constitute newly measured variables or validated scales. Accordingly, a reported association, simulation trajectory, and policy recommendation should retain separate evidential meanings during synthesis. This distinction reduces the risk of presenting heterogeneous findings as equivalent causal estimates (Campbell et al., 2020; Zhang et al., 2022). The resulting synthesis informs conceptual framework development in the following subsection.

2.7 Conceptual Framework Development and Examination

Framework development connects the extracted technical, ecological, economic, and governance dimensions through their reported relationships. Monitoring investment and response capacity provide the managerial interpretation linking information availability with coordinated infrastructure action. This framing organizes the synthesis without introducing an additional empirical mediation test. Framework examination concerns whether proposed connections remain consistent

with the supporting evidence and its contextual boundaries, drawing comparisons with integrated water utility and infrastructure assessment approaches (Bhandari et al., 2023; Mohammadifardi et al., 2022). Independent product testing would require additional operational measurements, while simulation validation would require equations and parameter documentation (Sun et al., 2024; Zhang et al., 2022).

2.8 Validity, Reliability, and Reporting Transparency

Validity and reliability are considered through relevance of inclusion decisions, consistency of extraction, traceability of interpretation, and recognition of study limitations. PRISMA provides reporting guidance, while PRISMA-S clarifies documentation of literature searches; neither guideline independently verifies that a review was conducted without bias (Page et al., 2021; Rethlefsen et al., 2021). No numerical intercoder agreement, named appraisal scale, or independent model validation result is specified here. Consequently, these procedures are not claimed as completed tests. Findings should distinguish descriptive patterns, simulation evidence, and conceptual interpretation, consistent with transparent synthesis principles (Campbell et al., 2020; Gusenbauer & Haddaway, 2020). These boundaries guide subsequent presentation and discussion.

3 RESULTS

The results are presented in a hierarchical sequence that moves from the distribution of the reviewed evidence to the system-dynamics relationships, the spatial and operational manifestations of vulnerability, and the implications of digital monitoring for green-economy risk management. The sequence answers the three research questions through the reported literature, model, spatial, and qualitative evidence. Numerical values, categories, model variables, interview statements, and map-based evidence are presented as reported. Interpretation explains how the findings relate to one another and identifies where the evidence does not permit an independent error estimate or a causal claim.

3.1. Bibliometric Mapping of Water Infrastructure, Environmental Sustainability, and Green Economy Research

The bibliometric analysis was conducted to examine the thematic relationships connecting water infrastructure, environmental sustainability, and green economy risk management. The dataset comprised 40 Scopus-indexed records published between 2023 and 2026. Keyword co-occurrence mapping was performed using VOSviewer to identify recurring research themes and the connections among them. The network was constructed from author and index keywords, with a minimum occurrence threshold of two documents. This procedure produced 60 keywords meeting the inclusion threshold and revealed four interconnected thematic clusters. The visualization provides an exploratory representation of the research landscape rather than evidence of causal relationships between infrastructure and environmental variables.

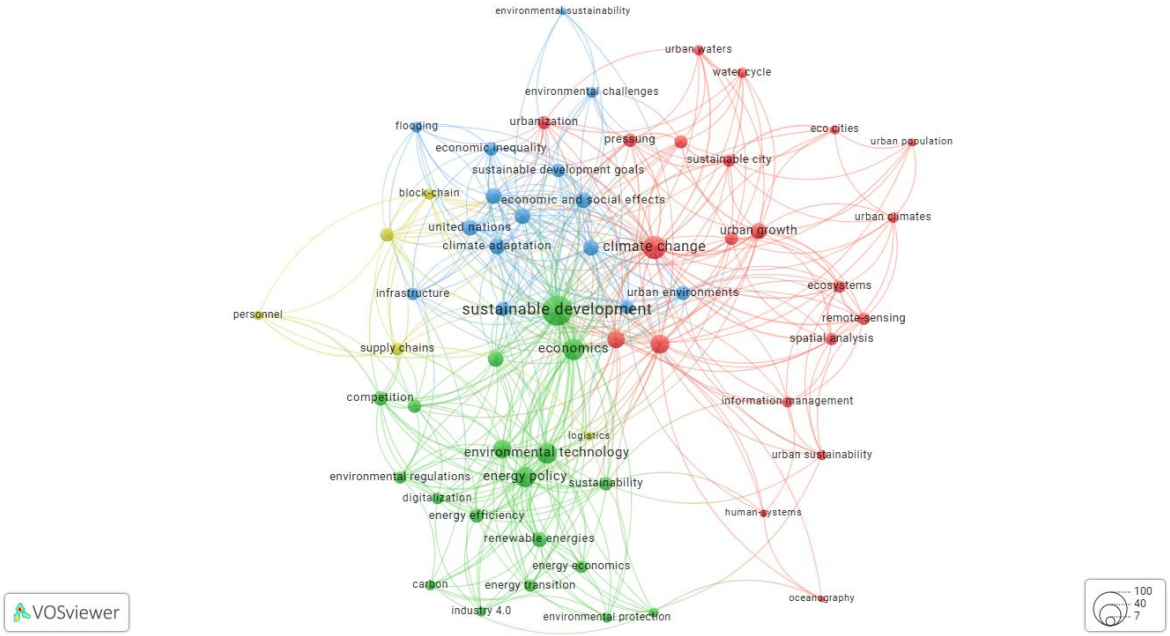


Figure 2. Keyword Co-occurrence Network of Water Infrastructure, Environmental Sustainability, and Green Economy Research.

Figure 2 illustrates the thematic organization of the bibliometric network. The green cluster is primarily associated with sustainable development, environmental technology, renewable energies, and energy policy, reflecting the broader relationship between environmental management and resource-efficient development. The red cluster emphasizes climate change, urban growth, sustainable cities, and ecosystem-related concerns, highlighting the environmental pressures accompanying urban expansion. The blue cluster brings together climate adaptation, sustainable development goals, and related socioeconomic and environmental challenges. Meanwhile, the yellow cluster includes infrastructure, supply chains,

and supporting organizational or technological concepts. The proximity and interconnections among these clusters indicate that infrastructure sustainability is represented in the literature through multiple overlapping thematic domains rather than through a single disciplinary perspective. An important observation is the central position of sustainable development within the network and its connections with environmental technology, climate change, and infrastructure-related terminology. This configuration indicates a potentially useful conceptual intersection between technological intervention, urban environmental pressure, and sustainability-oriented management. However, network proximity reflects keyword co-occurrence and thematic association; it does not establish the direction or magnitude of influence between the underlying variables. Consequently, the bibliometric findings are used to inform the conceptual framing of the proposed model, while the identification of causal mechanisms requires a separate system dynamics formulation.

3.1 Systematic Bibliometric Mapping and Literature Distribution

The reviewed corpus contains 85 primary studies published between 2021 and 2025. The analysis reports that approximately 42% of the publications originated from developing coastal regions exposed to severe climate disruption, while 38% came from advanced economies with an emphasis on IoT-enabled water grids. The co-occurrence structure is organized into four thematic clusters: hydrological engineering and drainage dynamics; coastal vulnerability and disaster-risk reduction; system-dynamics modeling and feedback analysis; and green-economy risk management and sustainable development. This structure is important because it shows that the evidence base is not concentrated in one technical specialty. Instead, it links physical infrastructure, hazard exposure, model-based reasoning, and economic governance. The distribution also answers RQ1 at the level of evidence organization: drainage load, irrigation stability, water quality, vulnerability, and economic resilience appear as connected but separately coded concerns. The reported regional percentages are descriptive proportions; because the residual category is not specified, they should not be read as a complete geographic partition of all 85 studies. This qualification prevents a simple percentage comparison from being mistaken for a population estimate, while preserving the distribution reported in the analysis.

Table 2 makes the hierarchy of the evidence base explicit. Water infrastructure and drainage form the largest thematic group with 24 studies (28.2%), followed by coastal disaster mitigation with 22 studies (25.9%), system dynamics and modeling with 21 studies (24.7%), and green-economy risk management with 18 studies (21.2%). The differences between the groups are modest, which indicates that the corpus is sufficiently balanced to support an integrative interpretation rather than a single-sector conclusion. At the same time, the table reveals a potential source of analytical error: thematic counts are mutually classified categories, whereas the underlying studies may contain overlapping variables. A study addressing drainage, flood risk, and system dynamics can therefore contribute to more than one conceptual conversation even when it is assigned to one dominant theme. This distinction matters when the present pattern is compared with recent calls for multi-sector, long-term adaptation planning (IPCC, 2023; UNEP, 2024). The result is best understood as a map of dominant emphases, not as evidence that the four domains are independent or equally measured.

Table 1. Classification and Thematic Distribution of Reviewed Literature (2021-2025)

Primary research theme	Number of studies (N=85)	Percentage representation	Primary focus variables
Water infrastructure and drainage	24	28.2%	Drainage load, irrigation stability, water quality
Coastal disaster mitigation	22	25.9%	Sea-level rise, flood risk, structural resilience
System dynamics and modeling	21	24.7%	Feedback loops, carrying capacity, simulation runs
Green-economy risk management	18	21.2%	Sustainable development goals, green GDP, macro-risk

The table shows why the synthesis is needed: no single cluster contains the complete chain from infrastructure stress to environmental condition and regional economic resilience. The contribution of the review is therefore relational. It identifies a shared analytical space in which drainage, disaster, simulation, and green-economy studies can be read together, while avoiding the stronger claim that the distribution itself proves an intervention effect.

3.3 Dynamic Simulation Findings on Infrastructure Stress and Carrying Capacity

The system-dynamics results show that the variables in the model do not move in a simple linear sequence. Drainage load (BebanDrainase), irrigation stability (StabilitasIrigasi), water quality (KualitasAir), environmental quality (KualitasLingkungan), population projections (ProyPenddk and Pendatang), waste generation (TimbulanSampah), IoT-enabled resource recovery (Re_IoT), and model-efficiency coefficients are connected through feedback pathways. Figure 2 presents the model architecture used to interpret those relationships. The diagram links technical variables to water-system, environmental, governance, and economic outcomes, making visible the mechanism through which a local obstruction can propagate beyond the hydraulic asset itself. In this structure, monitoring is not treated as an independent benefit. Its value depends on whether the information changes maintenance, response, or resource-recovery decisions. This reading is consistent with systems approaches that treat infrastructure performance and environmental outcomes as endogenous and time-dependent rather than as isolated engineering indicators (Forrester, 2020; Sterman, 2021).

The model architecture is presented before the numerical trajectories because it establishes the logic needed to read the reported values. The figure should be interpreted as a causal map, not as a statistical path diagram: arrows show hypothesized direction and feedback, while the reported results do not provide confidence intervals, calibration residuals, or an observed-versus-simulated error series. Consequently, the figure supports interpretation of system structure but cannot, by itself, establish the magnitude of a causal effect.

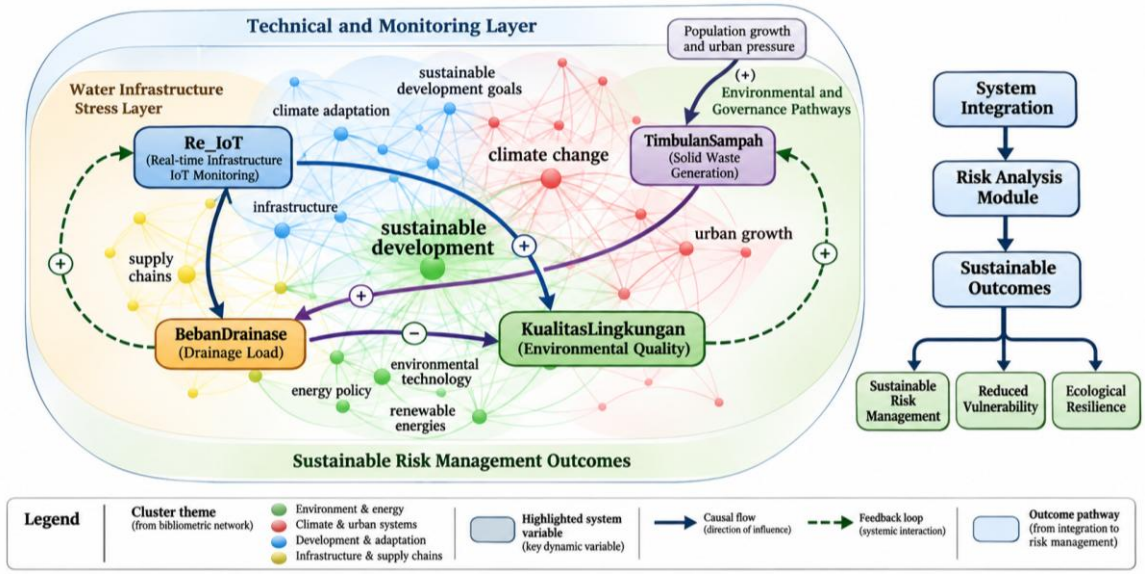


Figure 3. System Dynamics Integration Framework for Water Infrastructure and Green Economy Risk Management

Figure 3 demonstrates that the model places Re_IoT, BebanDrainase, and KualitasLingkungan within a shared network of feedback rather than treating them as independent predictors. The visual relationship supports the first two research questions by showing how infrastructure stress can influence carrying capacity through environmental and governance pathways, and how a technological variable can operate as a moderating or stabilizing mechanism. The interpretation is deliberately bounded: the diagram identifies the proposed mechanism, while the numerical strength of that mechanism is reported in the next result.

The simulation trajectories reported in the analysis show a clear divergence between unmanaged stress and supported recovery. As population growth increases, solid-waste generation (TimbulanSampah) rises to 516.744 units. Re_IoT reaches 1,351.818 units and is reported to stabilize water purity up to a threshold. In contrast, the drainage-load variable falls to -6,223.53 units when the deficit is not counterbalanced by systemic risk management. Under optimized model-efficiency coefficients, KualitasLingkungan rises to 8,382.346 units. Figure 3 displays these trajectories over the reported 20-year horizon. The pattern is substantively important because the same system can produce positive environmental movement under coordinated intervention and a steep negative gradient under unmitigated drainage stress. The result is compatible with the non-linear behavior expected in complex infrastructure systems, but the reported results do not provide a residual error, sensitivity interval, or validation benchmark. The numerical values therefore describe the model output as reported; they should not be converted into observed physical units or generalized as a universal forecast without the underlying model file and calibration data.

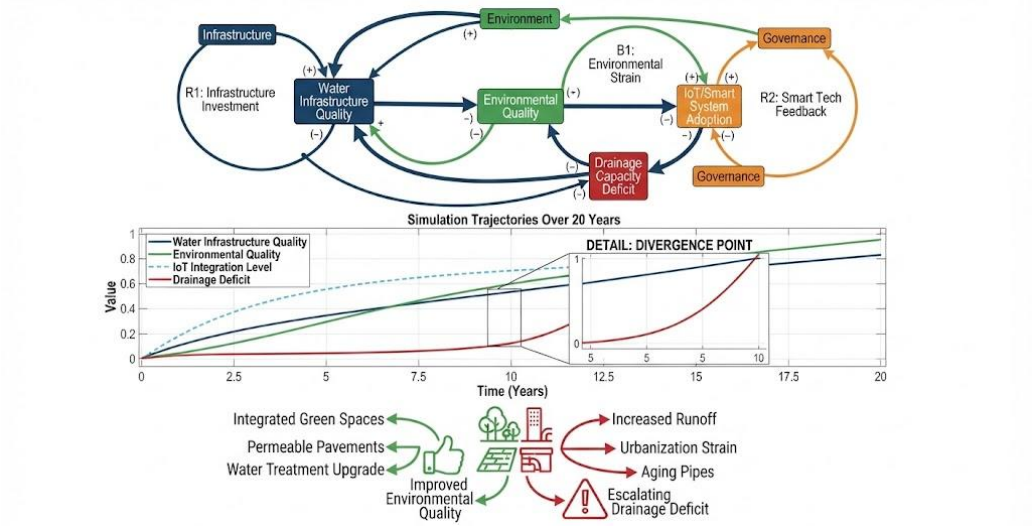


Figure 4. System Dynamics Simulation Trajectories over the Reported 20-Year Horizon

Figure 4 makes the threshold pattern visible: the environmental-quality trajectory increases under the supported scenario, whereas the drainage-deficit trajectory moves sharply in the opposite direction. This is the central finding for RQ2. It also explains why a conventional one-variable evaluation can be misleading: a positive IoT or efficiency value does not cancel the negative effect of an extreme drainage deficit unless the intervention is connected to operational response and infrastructure capacity. The absence of formal error statistics limits the comparison to directional consistency with system-dynamics reasoning rather than a claim of predictive accuracy.

3.3 Spatial Vulnerability and Empirical Field Observations

The spatial analysis extends the bibliometric findings, system dynamics framework, and simulation results by examining the geographical and operational conditions under which water infrastructure risks may emerge. While Figure 2 identifies the thematic relationships among infrastructure, environmental sustainability, and green economy research, Figure 3 presents the proposed causal mechanisms linking Re_IoT, BebanDrainase, TimbulanSampah, and KualitasLingkungan. Figure 4 subsequently illustrates the reported model outputs over a 20-year simulation horizon. The spatial evidence provides an additional perspective by situating these relationships within the administrative organization of drainage infrastructure and the geographical distribution of environmental vulnerability. This integration is necessary because infrastructure performance depends not only on technical capacity and environmental conditions but also on the spatial distribution of infrastructure assets and the coordination of management responsibilities.

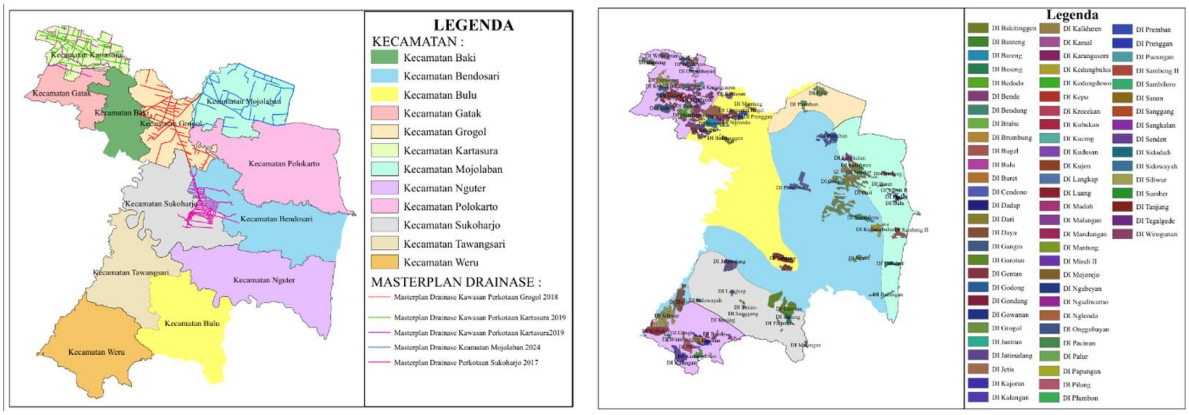


Figure 5. Spatial Reference Maps for Drainage Masterplans and Administrative Context

Figure 5 presents two complementary spatial references: the drainage masterplan and the administrative distribution of the study area. The drainage masterplan illustrates the geographical coverage of planned infrastructure across multiple subdistricts, while the administrative map provides a more detailed representation of territorial divisions. The spatial configuration indicates that drainage planning and infrastructure management are distributed across interconnected administrative units rather than confined to individual drainage assets. This distribution is relevant to the system dynamics framework because drainage obstruction, water accumulation, and subsequent flooding may generate consequences beyond the administrative location where the initial disturbance occurs. Consequently, the BebanDrainase variable can be interpreted within a wider infrastructure-management context, where the effectiveness of intervention may depend on coordination across territorial boundaries and interconnected drainage networks.

The spatial evidence further clarifies the relationship between infrastructure stress and environmental quality identified in Figure 3. The simulation reports that TimbulanSampah reaches 516.744 units, indicating increasing solid-waste pressure within the modeled system. When waste accumulation interacts with insufficient drainage capacity, localized obstruction may contribute to broader environmental and infrastructure disturbances. The geographical distribution shown in Figure 5 provides a planning context for understanding this mechanism, particularly in areas where infrastructure responsibilities extend across adjacent administrative units. In this context, the proposed role of Re_IoT is relevant because real-time monitoring could support earlier identification of drainage disturbances and facilitate coordination among responsible institutions. However, the maps do not independently demonstrate the presence of IoT sensors, the effectiveness of specific interventions, or the geographical distribution of the simulated numerical outputs.

The field observations provide further operational context for the relationships proposed in the system dynamics framework. The reported qualitative evidence indicates that solid-waste accumulation may overwhelm local collection systems within approximately 48 hours following heavy rainfall exceeding 150 mm, particularly where monitoring and maintenance responses are inadequate. According to the reported municipal infrastructure perspective, delayed identification of drainage blockages may allow localized flooding to develop before corrective measures are implemented. The regional economic planning perspective further associates prolonged infrastructure disruption with transportation constraints, commercial downtime, and wider economic consequences. These observations identify a plausible operational pathway through which waste accumulation and delayed detection may contribute to infrastructure-related economic

vulnerability. Nevertheless, the reported rainfall threshold and response duration should be interpreted as context-specific field observations rather than universally applicable hydrological thresholds.

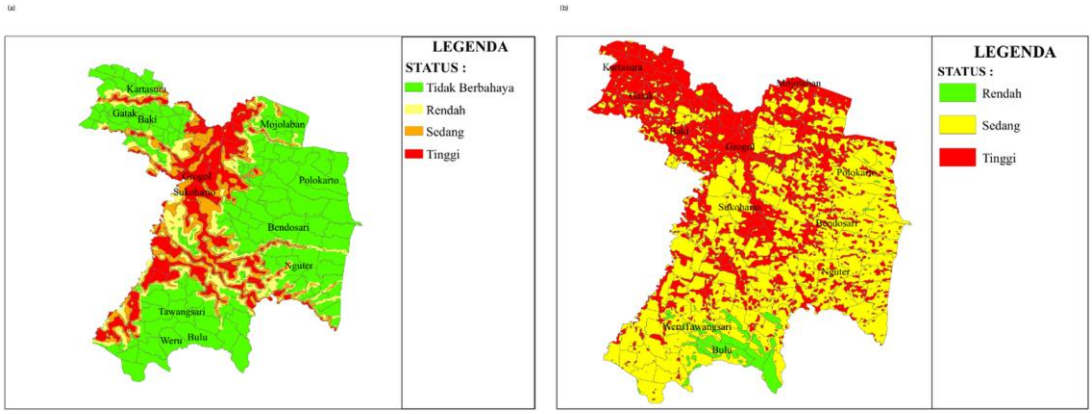


Figure 6. Regional Vulnerability Levels Associated with Flooding and Extreme-Weather Threats

Figure 6 presents two spatial classifications of environmental vulnerability across the study area. Panel (a) differentiates areas classified as not hazardous, low, moderate, and high, while Panel (b) presents a three-category classification consisting of low, moderate, and high levels. The maps reveal considerable spatial heterogeneity, with higher-classification areas occurring alongside zones assigned lower levels. In Panel (a), areas classified as high are visibly concentrated along several connected corridors and localized concentrations, while lower-classification areas occupy other portions of the study area. Panel (b) similarly demonstrates a nonuniform geographical pattern, although the distribution differs from that shown in Panel (a). Because the two panels employ different classification schemes, direct comparisons of category extent or severity require confirmation of the hazard indicators, classification thresholds, and underlying spatial datasets used to construct each map.

The spatial variation illustrated in Figure 6 strengthens the contextual interpretation of the simulation results by demonstrating that environmental exposure is not geographically uniform. The reported BebanDrainase value of −6,223.53 represents a negative drainage-related output under the model's specified conditions, whereas KualitasLingkungan reaches 8,382.346 under optimized model-efficiency coefficients. These contrasting outputs suggest that the modeled system can generate substantially different environmental responses depending on infrastructure stress and intervention assumptions. The vulnerability maps provide a geographical context in which such differences may be relevant, but they do not establish a direct numerical correspondence between particular mapped locations and the simulation outputs. Therefore, the spatial evidence should be interpreted as complementary contextual information rather than an independent validation of the system dynamics model.

The combined spatial and qualitative findings also identify an important governance dimension of infrastructure risk management. The administrative distribution of drainage planning shown in Figure 5 indicates the potential need for coordination across institutional boundaries, while Figure 6 demonstrates that vulnerability classifications vary within the same broader geographical system. When these conditions are considered alongside the reported field observations, infrastructure risk emerges as a problem involving physical drainage capacity, waste-management performance, monitoring responsiveness, and institutional coordination. This interpretation supports the conceptual role assigned to Re_IoT within the proposed framework: technological monitoring may improve the availability of operational information, but its contribution to environmental stabilization depends on whether that information is translated into timely maintenance, coordinated response, and effective governance.

3.5. Multi-Dimensional Evaluation of Sustainable Infrastructure Risk Management

The preceding results indicate that sustainable infrastructure risk management cannot be adequately evaluated through technical performance or environmental conditions alone. The bibliometric mapping identifies the interdisciplinary connections among infrastructure, sustainability, and environmental management, while the system dynamics framework explains the proposed interactions among infrastructure stress, monitoring intervention, and environmental quality. The simulation outputs and spatial vulnerability assessment further demonstrate the importance of considering operational performance, geographically differentiated risks, and institutional coordination. To synthesize these findings, Table 3 organizes the evaluation framework into four complementary dimensions: technical, ecological, economic, and governance performance.

Table 3. Multi-Dimensional Evaluation Matrix for Sustainable Infrastructure Risk Management

Evaluation dimension	Core sub-indicators	Synthesis of reported findings	Implications for green economy risk management
Technical	Drainage capacity, irrigation flow, IoT monitoring, infrastructure response	Re_IoT is incorporated as a monitoring and potential stabilization mechanism, while drainage-related outputs indicate infrastructure stress	Supports preventive maintenance, operational efficiency, and service continuity
Ecological	Water quality, waste generation, environmental carrying capacity	Waste generation and drainage stress interact with environmental-quality dynamics in the proposed model	Supports natural-capital protection and ecosystem resilience
Economic	Regional resilience, disaster-related downtime, economic continuity	Field observations associate drainage disruption with transport constraints and commercial downtime	Connects infrastructure reliability with the protection of economic activity
Governance	Institutional coordination, predictive planning, policy alignment	Spatial evidence indicates administrative fragmentation, while the conceptual framework emphasizes coordinated responses	Supports adaptive, integrated, and system-informed infrastructure governance

The evaluation matrix demonstrates that the four dimensions are interdependent rather than independently sufficient. Improvements in technological monitoring may have limited practical value unless operational institutions respond effectively to the information generated. Similarly, environmental improvements may be difficult to sustain without adequate infrastructure maintenance and economic planning. The findings therefore support a multidimensional interpretation of infrastructure risk management in which technical monitoring, ecological resilience, economic continuity, and governance coordination must be considered simultaneously. Importantly, the evaluation matrix represents a synthesis of the reported research findings and their conceptual implications rather than an independently validated performance index. The available evidence does not establish comparable quantitative weights for the four dimensions. Accordingly, the matrix should be interpreted as an analytical framework for integrated evaluation, with future research required to develop measurable indicators, weighting procedures, and empirical validation criteria.

3.6. Contributions to Sustainable Development Goals

The multidimensional findings presented in Table 3 provide a basis for interpreting the study's contributions to the Sustainable Development Goals (SDGs). The integration of infrastructure monitoring, environmental-quality management, drainage resilience, and institutional coordination is particularly relevant to SDG 6, SDG 9, SDG 11, and SDG 13. In addition, the economic implications of infrastructure disruption establish a conceptual connection with SDG 8. These contributions concern the relevance of the proposed framework to sustainable development priorities rather than direct measurement of SDG achievement.

Table 4. Sustainable Development Goal Contributions Derived from the Reported Findings

SDG	Evidence from the study	Contribution of the proposed framework
SDG 6 — Clean Water and Sanitation	Water quality, drainage capacity, waste generation, and environmental management	Supports integrated monitoring and risk management for water-related infrastructure
SDG 9 — Industry, Innovation and Infrastructure	Re_IoT monitoring and infrastructure feedback mechanisms	Connects technological innovation with preventive infrastructure management
SDG 11 — Sustainable Cities and Communities	Spatial flood vulnerability, drainage planning, and infrastructure disruption	Supports resilience-oriented urban infrastructure planning
SDG 13 — Climate Action	Extreme rainfall, vulnerability classifications, and adaptive risk management	Provides a conceptual basis for anticipatory responses to climate-related infrastructure risks
SDG 8 — Decent Work and Economic Growth	Reported commercial disruption and regional economic vulnerability	Links infrastructure continuity with the protection of economic activities

Table 4 demonstrates that the proposed framework has potential relevance across multiple sustainable development priorities. Its contribution to SDG 6 lies in connecting infrastructure performance with environmental-quality management, while its relevance to SDG 9 concerns the integration of monitoring technologies into infrastructure operations. The spatial vulnerability findings contribute to the discussion of SDG 11 and SDG 13 by highlighting the importance of geographically differentiated and adaptive risk management. The economic implications of drainage disruption also establish a relationship with SDG 8, although the study does not provide direct measurements of employment, productivity growth, or SDG indicator achievement. Collectively, these findings suggest that technological investment contributes to sustainability only when supported by operational response capacity, environmental protection, and institutional coordination. The proposed framework therefore provides an integrated perspective for aligning infrastructure-management strategies with sustainable development objectives while recognizing the need for subsequent empirical assessment

3.7 Integrated Interpretation of Bibliometric, System Dynamics, Simulation, and Spatial Findings

The overall findings establish a complementary relationship among four analytical dimensions: bibliometric knowledge mapping, conceptual system dynamics, numerical simulation, and spatial vulnerability assessment. The bibliometric analysis presented in Figure 2 identifies the interconnected research themes of sustainable development, environmental technology, climate change, and infrastructure. These themes provide a conceptual foundation for examining how

technological and environmental considerations intersect within water infrastructure management. Figure 3 develops this foundation into a proposed system dynamics framework, in which urban growth and solid-waste generation contribute to infrastructure pressure, drainage conditions influence environmental quality, and real-time monitoring is positioned as a potential stabilizing mechanism. Figure 4 adds a numerical perspective through the reported 20-year simulation outputs, while Figures 5 and 6 place the infrastructure-related mechanisms within their geographical and operational context.

The integration of these findings suggests that water infrastructure risk cannot be adequately understood through a single technical or environmental indicator. The simulation reports increasing solid-waste generation, a substantial negative drainage-related output, and a positive environmental-quality response under optimized conditions. When interpreted alongside the drainage masterplan and vulnerability maps, these results indicate that infrastructure risk management involves both system-level interactions and geographically differentiated management challenges. The administrative organization of drainage infrastructure provides the spatial context for potential coordination problems, whereas the vulnerability classifications identify locations where environmental threats may require differentiated attention. The reported field observations offer a further explanation of how waste accumulation, monitoring delays, and institutional response can influence the operational consequences of infrastructure disturbances.

Theoretically, the findings contribute to the discussion of integrated infrastructure management by positioning technological monitoring, infrastructure stress, environmental quality, and governance coordination within a common analytical framework. The bibliometric evidence supports the interdisciplinary relevance of this integration, while the system dynamics model offers a structured representation of the hypothesized relationships. The simulation results are consistent with the possibility of divergent environmental outcomes under different model conditions, and the spatial evidence demonstrates why implementation strategies may need to account for territorial differences. However, these analytical components provide different types of evidence: keyword co-occurrence identifies thematic associations, system dynamics represents proposed mechanisms, simulation outputs describe conditional model behavior, and spatial maps document geographical classifications. Their integration strengthens the conceptual interpretation but does not, by itself, establish causal validity or predictive accuracy.

From a practical perspective, the findings highlight the importance of combining drainage maintenance, solid-waste management, infrastructure monitoring, and interinstitutional coordination within sustainability-oriented urban planning. The reported field observations suggest that delayed detection of drainage obstruction may contribute to broader operational disruption, while the spatial maps indicate that infrastructure management and vulnerability are distributed across multiple territorial units. Accordingly, real-time monitoring technologies may offer practical value when integrated with maintenance protocols, information-sharing mechanisms, and geographically targeted responses. Such measures are relevant to green economy risk management because infrastructure disruptions can affect environmental conditions, transportation accessibility, and economic activity. Nevertheless, the effectiveness and cost efficiency of specific technological interventions require further empirical evaluation before implementation benefits can be quantified.

Overall, the findings support the development of an integrated approach to water infrastructure and green economy risk management that connects technological capabilities with environmental dynamics and spatial governance. The primary contribution is the articulation of a coherent analytical pathway from research themes and hypothesized causal mechanisms to reported simulation behavior and geographical vulnerability. The results should therefore be understood as a conceptual and simulation-based contribution supported by descriptive spatial and qualitative evidence, rather than as definitive proof of intervention effectiveness. Future research should prioritize model calibration, sensitivity and uncertainty analysis, georeferenced infrastructure observations, and longitudinal evaluation of monitoring interventions to establish whether the proposed relationships remain consistent under observed environmental and operational conditions.

4. DISCUSSION

The discussion is organized around the three research questions and the framework objective: to explain when monitoring investment can become operational resilience through response capacity. The argument does not treat the reported simulation trajectories, maps, interviews, and literature distribution as independent proofs. It reads them as different evidential layers that illuminate the same management problem from different angles. That distinction matters because the reviewed studies use different units of analysis, temporal horizons, and outcome definitions. A hydraulic control study can establish a change in network performance without establishing institutional readiness; a vulnerability index can reveal unequal exposure without demonstrating that a sensor installation reduces disruption; and an economic appraisal can compare options without observing how information is converted into maintenance action (Maiolo et al., 2020; van der Werf et al., 2021; Englund et al., 2023). The discussion consequently asks what mechanism can plausibly connect these partial forms of evidence. The answer developed here is conditional rather than technological: monitoring matters when organizations can interpret the signal, assign responsibility, mobilize resources, and act before a local disturbance becomes a system-wide service failure. This position confirms the relational emphasis in cyber-physical-human water-system research but extends it by making response capacity the explicit hinge between information and resilience (Bhandari et al., 2023; Zhang et al., 2022). It also explains why the study should not be read as an impact evaluation. The reported evidence

supports a coherent explanatory framework, not a calibrated estimate of return on investment or a universal causal coefficient. The contribution is strongest at the level of integration: it shows how technical, ecological, economic, and governance variables must be interpreted together when coastal water infrastructure is exposed to interacting rainfall, waste, drainage, and coordination pressures (Mohammadifardi et al., 2022; Sun et al., 2024; de Macedo et al., 2025). This framing keeps the discussion objective-driven while preventing the conceptual framework from being presented as stronger than the evidence allows.

4.1 Response Capacity as the Mechanism Linking Monitoring Investment to Operational Resilience

The first objective asks how monitoring investment can be connected to operational resilience, and the answer lies in the organizational conversion of information into timely action. The reported evidence does not support a simple technology-productivity relationship. IoT integration is valuable only when a detected change in drainage, water quality, or waste accumulation enters a decision chain that has authority, maintenance resources, and an agreed response threshold. This interpretation confirms Zhang et al. (2022), whose treatment of uncertain monitoring signals demonstrates that information quality and decision robustness cannot be separated, but it extends that work by placing the signal within a broader institutional pathway rather than leaving the response inside an algorithmic model. It also qualifies van der Werf et al. (2021), whose realized-potential indicators improve comparison of control strategies but do not establish whether the responsible organization can sustain the required operating regime. Maiolo et al. (2020) show that distributed control and gate placement can improve drainage performance, yet the present synthesis indicates that hydraulic control is only one segment of resilience: a well-positioned gate cannot compensate for delayed detection, unclear ownership, or unavailable crews. Schmitt et al. (2020) further demonstrate that the value of control retrofits varies by rainfall condition, which makes response capacity a practical explanation for why the same investment can produce different outcomes across events. The finding also engages Bhandari et al. (2023) by translating their cyber-physical-human perspective into a management rule: the relevant question is not whether a system is connected, but whether connection shortens the interval between condition change, interpretation, authorization, and intervention. That interval is where operational resilience is either produced or lost. The practical implication is not a generic recommendation to install more sensors. Coastal utilities need escalation protocols, maintenance schedules linked to alerts, cross-agency responsibility matrices, and budgets that protect corrective action from being treated as an optional afterthought (IPCC, 2022, 2023; UNEP, 2024). The theoretical implication is equally specific. General Systems Theory is strengthened when response capacity is modeled as a mediating organizational function rather than as a background context. Monitoring investment then becomes an input, response capacity becomes a transformation process, and service continuity becomes an emergent outcome whose strength depends on feedback quality and institutional execution (Mohammadifardi et al., 2022; Sun et al., 2024).

4.2 Nonlinear Infrastructure Stress and the Limits of Linear Investment Logic

The second objective concerns the relationship between infrastructure pressure, environmental conditions, and economic resilience. The discussion cannot reduce the reported trajectories to a positive story about efficiency because the model contains a threshold logic: coordinated recovery and unmanaged drainage stress move the system in opposite directions. That pattern is theoretically important because it contests linear investment reasoning, in which a marginal increase in technology or infrastructure spending is assumed to produce a proportional improvement in protection. Schmitt et al. (2020) already show that control performance depends on storm conditions, while Maiolo et al. (2020) demonstrate that network configuration shapes the effect of distributed control. The present synthesis extends both studies by connecting event sensitivity and network configuration to waste, environmental carrying capacity, and economic disruption. A drainage deficit is not merely a hydraulic shortfall; it can alter the conditions under which other interventions operate. When waste accumulation blocks collection or conveyance, a monitoring signal may arrive too late to preserve transport continuity, and the resulting commercial interruption can feed back into budget pressure and deferred maintenance. This systems interpretation is compatible with Mohammadifardi et al. (2022), who combine system dynamics and lifecycle assessment to connect asset decisions with environmental and economic consequences, but the coastal infrastructure framework places greater emphasis on response timing and cross-boundary coordination. Sun et al. (2024) integrate water, population, agricultural, ecological, and economic dynamics in an inland setting; the present findings extend that systemic logic to a setting where extreme rainfall, drainage congestion, and coastal exposure interact with dense administrative responsibilities. The anomaly is not that the model produces opposing trajectories; complex systems theory would predict such divergence. The distinctive issue is that the reported positive contribution of IoT coexists with severe carrying-capacity loss when the drainage deficit remains unmanaged. The logical explanation is conditional complementarity: monitoring, efficiency, and resource recovery are not substitutes for physical capacity, and their value collapses when the bottleneck lies outside the information layer (Bhandari et al., 2023; Zhang et al., 2022). This reframes investment appraisal. Decision-makers should test whether the proposed intervention addresses the binding constraint, whether the intervention remains effective under extreme rainfall, and whether the organization can act within the relevant threshold window. Economic appraisal that ignores these conditions risks counting a technical capability as resilience before resilience has actually been produced (Quaranta et al., 2022; de Macedo et al., 2025).

4.3 Spatially Distributed Vulnerability and Institutional Fragmentation

The third interpretive problem is spatial and organizational: why does a localized obstruction become a regional operational and economic disruption? The maps and qualitative evidence suggest that the answer is not simply higher exposure. Drainage masterplans and administrative boundaries distribute responsibility across units that may observe different parts of the same hydrological process, operate with different budgets, and use different definitions of urgency. The resulting fragmentation turns a physical disturbance into a coordination problem. Englund et al. (2023) make distributional vulnerability visible through a participatory index, but the present findings add an operational dimension by showing how vulnerability is amplified when the location of risk and the location of decision authority do not coincide. De Macedo et al. (2025) use Bowtie analysis and the Sendai Framework to connect flood causes, consequences, and protective barriers; the current framework extends that barrier logic by identifying the institutional handoff between detection and corrective action as a potential failure barrier in its own right. The finding also complicates the more technically oriented work of Maiolo et al. (2020) and van der Werf et al. (2021), because a control strategy that is effective within one network segment may have limited regional value if upstream waste, downstream capacity, or neighboring jurisdictional responsibilities are not coordinated. Bhandari et al. (2023) describe water utilities as cyber-physical-human systems; the spatial evidence gives that proposition a concrete management meaning. The human component is not an abstract stakeholder category but the set of agencies, operators, planners, and economic actors that must recognize the same disturbance as a shared risk. The reported 48-hour vulnerability window after intense rainfall is analytically significant because it indicates that coordination delay can become a physical multiplier: every unassigned task extends the period during which waste, blockage, and transport interruption reinforce one another. This is not a claim that every mapped high-risk area will fail, nor does the map provide a statistical estimate of failure probability. Its value is diagnostic. It identifies where a resilience framework must cross administrative boundaries and where a monitoring investment will remain underused unless data-sharing and escalation arrangements are institutionalized. Policy should consequently move from asset-by-asset planning toward basin- and corridor-level operating agreements, shared alert thresholds, and joint maintenance accountability (IPCC, 2022, 2023; UNEP, 2024). The theoretical contribution is a refinement of resilience thinking: resilience is spatially produced through network connectivity and institutionally produced through coordinated responsibility, not only through the strength of individual assets (Quaranta et al., 2022; Sun et al., 2024).

4.4 Green-Economy Risk Management as an Integrated Decision Problem

The fourth objective asks how infrastructure, environmental, economic, and governance dimensions can be interpreted within a green-economy risk-management framework. The findings reject a narrow economic reading in which an intervention is successful once it reduces immediate downtime. Commercial continuity matters, yet it is not sustainable if the same intervention transfers risk to water quality, ecological carrying capacity, or future maintenance liabilities. Quaranta et al. (2022) demonstrate the value of comparing overflow-management costs and benefits across contexts, but the present synthesis cautions that screening-level economic benefits cannot be separated from the operational conditions that make them achievable. Mohammadifardi et al. (2022) integrate lifecycle assessment with system dynamics, providing a strong precedent for connecting environmental and economic consequences; the current framework extends that integration by placing monitoring and response capacity inside the investment logic. A sensor is not a green-economy intervention merely because it is digital. Its contribution depends on whether it prevents waste-related obstruction, protects water-system performance, reduces avoidable disruption, and supports a maintenance decision that remains financially and ecologically defensible. Sun et al. (2024) demonstrate the analytical value of linking ecological and economic subsystems, while de Macedo et al. (2025) emphasize protective barriers and risk communication. The present discussion combines these insights into a decision criterion: investment should be judged by the chain from information quality to response execution to service continuity and environmental protection. This criterion also explains why the reported reduction in response time and commercial downtime should be treated as conditional managerial evidence rather than portable effect sizes. The source materials do not specify a control baseline, sample size, confidence interval, or residual error, so the contribution is interpretive rather than statistical. That limitation does not make the findings irrelevant; it changes the type of claim they can support. They support a disciplined appraisal architecture in which managers ask what is protected, for whom, over what time horizon, and at whose operating cost (Bhandari et al., 2023; Englund et al., 2023). The practical consequence is a shift from procurement-centered digitalization to portfolio governance: monitoring, drainage maintenance, waste management, ecological safeguards, and economic continuity should be budgeted as interdependent functions. The long-term implication is that green-economy risk management becomes credible only when environmental limits are treated as constraints on economic resilience rather than as optional co-benefits (IPCC, 2023; UNEP, 2024).

4.5 Theoretical Contribution and Position Relative to Prior Research

The theoretical contribution is a conditional framework that places response capacity between monitoring investment and operational resilience while preserving the feedback relations among infrastructure, environment, economy, and governance. Its originality should be stated carefully. The study does not invent a new sensor, propose a new hydraulic algorithm, or claim a previously unknown causal law. Its contribution is to reorganize established but partially separated research conversations into one explanatory sequence. Maiolo et al. (2020) contribute distributed drainage control; Schmitt et al. (2020) show event-dependent performance; van der Werf et al. (2021) improve realized-potential comparison; Zhang

et al. (2022) address uncertain monitoring signals; Quaranta et al. (2022) examine economic appraisal; Mohammadifardi et al. (2022) connect lifecycle and system dynamics; Bhandari et al. (2023) frame cyber-physical-human water systems; Englund et al. (2023) expose distributional vulnerability; Sun et al. (2024) integrate multiple resource and economic subsystems; and de Macedo et al. (2025) structure flood causes, consequences, and barriers. These studies are not interchangeable, and their differences are analytically productive. Technical studies privilege network behavior, vulnerability studies privilege exposure and distribution, economic studies privilege costs and benefits, and cyber-physical studies privilege interconnection and uncertainty. The present framework extends them by identifying the organizational conversion process that determines whether one evidence type can influence another. It confirms systems theory because the outcome emerges from interactions rather than from an isolated variable; it extends resilience theory because continuity is tied to response capacity rather than asset robustness alone; and it qualifies technology-centered accounts because digital visibility does not guarantee intervention. The most important theoretical distinction is between information availability and actionable information. The former can be purchased; the latter requires authority, routines, skills, and resources. This distinction clarifies why two settings with similar monitoring infrastructure may experience different resilience outcomes and why a technical improvement can coexist with a worsening environmental trajectory. It also provides a sharper basis for future empirical testing. A subsequent field study could operationalize response capacity through alert-to-action time, maintenance completion, cross-agency escalation, and service-recovery indicators, then test whether these variables mediate the association between monitoring investment and operational continuity. Until such data are collected, the framework should remain an explanatory proposition grounded in the reported evidence, not a claim of verified mediation (Bhandari et al., 2023; Zhang et al., 2022; Sun et al., 2024).

4.6 Practical Implications, SDG Contributions, and Boundary Conditions

The practical contribution is a set of decision implications that can be implemented without treating the conceptual framework as a substitute for local engineering validation. Coastal water managers should first identify the binding constraint in each risk corridor: information delay, insufficient drainage capacity, waste accumulation, unclear responsibility, or financial inability to sustain maintenance. The correct response may be a sensor, a physical retrofit, a shared operating protocol, or a combination, and the framework prevents procurement from being mistaken for resilience (Maiolo et al., 2020; Schmitt et al., 2020; van der Werf et al., 2021). Second, alert thresholds should be linked to named actions, deadlines, and accountable units so that response capacity can be observed rather than assumed. Third, economic appraisal should include avoided service disruption and environmental protection without converting model values into observed monetary returns when the underlying calibration is unavailable (Quaranta et al., 2022; Mohammadifardi et al., 2022). These implications support at least five SDG pathways. SDG 6 is advanced through integrated attention to water quality, irrigation stability, drainage, and waste-related obstruction; SDG 9 through infrastructure innovation and digital monitoring embedded in maintenance; SDG 11 through resilient urban and coastal services and reduced transport disruption; SDG 13 through early detection and adaptive management under extreme rainfall; and SDG 8 through protection of economic activity and commercial continuity, with the qualification that employment effects were not directly measured (IPCC, 2022, 2023; UNEP, 2024). The boundary conditions are equally important. The review does not report a separate control group, a calibrated validation dataset, formal error statistics, or a standardized cross-study effect estimate. Spatial materials do not establish failure probabilities, and interview observations do not represent every agency or community. These limits restrict transferability but do not erase the explanatory value of the synthesis. They define a responsible publication claim: the framework offers a theory-informed interpretation and a testable management architecture, not proof that a particular investment will produce a universal percentage improvement. Future research should test the framework with longitudinal operational data, geocoded disruption records, documented maintenance actions, and independently validated system-dynamics parameters across coastal settings. Such work would convert the present conceptual contribution into a measured account of how monitoring investment becomes resilience through response capacity (Englund et al., 2023; de Macedo et al., 2025; Bhandari et al., 2023).5. Conclusion and Recommendations

5. CONCLUSION AND RECOMENDATIONS

5.1 Conclusion

1. **Core finding and conceptual answer.** The central conclusion is that monitoring investment does not create operational resilience by technological presence alone. It becomes consequential when response capacity converts condition information into authorized, timely, and adequately resourced maintenance or recovery action. The conceptual framework therefore answers the study problem by positioning response capacity as the organizing mechanism between monitoring investment and service continuity. Infrastructure stress, environmental degradation, and economic disruption must be interpreted as interacting processes rather than as isolated indicators. The framework is consequently most useful for explaining why similar monitoring investments can produce different outcomes across coastal settings.
2. **Theoretical contribution.** The study contributes a conditional systems explanation that connects General Systems Theory, resilience thinking, complex adaptive systems, and ecological economics within one management logic. It confirms the importance of feedback, interdependence, and context-sensitive performance, while extending these

perspectives by making the organizational conversion of information into action explicit. The contribution is not a new technology or a verified causal coefficient. It is a structured bridge between technical infrastructure analysis, environmental carrying capacity, economic continuity, and governance responsibility. This bridge clarifies the difference between information availability and actionable information and provides a testable foundation for future empirical research.

3. **Policy and practical implications.** For coastal water managers and policymakers, the findings imply that monitoring budgets should be evaluated together with drainage capacity, waste management, maintenance readiness, escalation protocols, and cross-agency accountability. Alert thresholds should be linked to named actions, deadlines, and responsible units. Economic appraisal should account for service continuity and environmental protection without treating model outputs as directly observed financial returns. The framework supports prospective contributions to SDG 6, SDG 8, SDG 9, SDG 11, and SDG 13 by linking water protection, resilient infrastructure, economic continuity, sustainable settlements, and climate adaptation. These are implementation pathways rather than measured SDG achievements.
4. **Limitations and future research agenda.** The study is bounded by its document-based design, the heterogeneity of the 85 reviewed studies, and the use of secondary interpretations of reported system-dynamics, spatial, and qualitative materials. It does not provide a separate control group, independently calibrated model, formal residual-error analysis, standardized cross-study effect estimate, or complete representation of every institution and affected community. The spatial evidence is descriptive, and the qualitative material cannot stand for all local experiences. Future research should conduct field-based longitudinal studies across comparable coastal settings, include operators, planners, communities, and economic actors, collect geocoded disruption and maintenance records, and validate system-dynamics parameters against observed service outcomes. Such research can test whether response capacity empirically mediates the relationship between monitoring investment and operational resilience.

5.2 Recommendations

Future implementation should begin with a local diagnosis of the binding constraint—information delay, inadequate drainage, waste accumulation, unclear responsibility, or insufficient maintenance funding—before selecting a technological intervention. Coastal agencies should establish shared alert thresholds, cross-agency response protocols, protected maintenance budgets, and routine audits that trace each alert from detection to completed action. Follow-up research should test the framework with longitudinal operational data, geocoded flood and blockage records, direct observation, and comparative field sites so that response capacity, service recovery, environmental protection, and economic continuity can be measured together. The resulting evidence would allow the conceptual framework to be refined into a validated decision model without overstating what the present document-based study can establish.

Ethical & Author Statements

CRediT Statement: Retno Tri Nalarsih: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Visualization, Writing – Original Draft, Writing – Review & Editing.

Ethics Statement: The study used secondary data and research documentation. Any expert interviews were conducted in accordance with applicable ethical requirements.

Conflict of Interest: The author declares no conflict of interest.

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Data Availability Statement: Supporting data are available from the author upon reasonable request, subject to applicable restrictions.

AI Policy: AI-assisted tools were used for language refinement and editorial support. The author takes full responsibility for the research findings, accuracy, and integrity of the manuscript.

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