Smart and Sustainable Built Enviro

Navigating Urban Hydrology: A Comprehensive Exploration of Impervious Area Reduction Techniques in New Zealand's Residential Landscapes

Journal:	*Smart and Sustainable Built Environment*
Manuscript ID	SASBE-07-2025-0430.R1
Manuscript Type:	Original Research Paper
Keywords:	Impervious surfaces, impervious area, reduction strategies, residential areas, Flooding, Climate action

Navigating Urban Hydrology: A Comprehensive Exploration of Impervious Area Reduction Techniques in New Zealand's Residential Landscapes

Abstract

Purpose: Impervious surfaces have emerged as a critical indicator for assessing the impacts of urbanisation on water resources, with recent flood events in New Zealand (NZ) highlighting their significance in urban water management. While traditional stormwater control measures rely on total impervious area calculations, this study examined the effectiveness of impervious area reduction techniques in residential areas across NZ, with particular attention to implementation challenges and policy frameworks.

Design/methodology/approach: The research was conducted through semi-structured interviews with 18 experts, including government officials, consultants, and developers. This qualitative approach allowed for an in-depth exploration of various perspectives on urban water management strategies and their effectiveness.

Findings: The study revealed several key findings: (1) Current strategies exhibit varying effectiveness depending on scale, with catchment-level solutions being more successful than site-specific interventions; (2) Significant challenges to implementation exist, such as resource constraints, limited monitoring capabilities, and coordination issues among stakeholders; and (3) There is a need for stronger national-level guidance and better integration in regulatory frameworks between district and regional plans.

Originality: This research contributes to the existing knowledge on urban flood resilience by identifying promising opportunities for improvement in urban water management practices in New Zealand. It emphasises the importance of enhanced public education, innovative technical solutions, and market-based incentives as practical recommendations for policymakers and practitioners.

Keywords: Impervious surfaces, impervious area, reduction strategies, residential areas and New Zealand

1. Introduction

Floods are among the most severe and frequent natural disasters, causing significant human and economic losses worldwide (Sastry 2021; Tate et al. 2016). For example, the 2023 Auckland Anniversary flooding incurred NZD $5.57 billion of economic loss and NZD $2.23 billion of insured loss, followed by Cyclone Gabrielle, which caused NZD $6.4 billion in economic loss and NZD $2.02 billion in insured loss (NZ CarbonNews 2024). The impact of these events was widespread, with more than 55,000 insurance claims resulting from Cyclone Gabrielle alone, reflecting the displacement of entire communities and disruption of businesses (NZ CarbonNews 2024). Despite the extensive research on flood risk and loss assessments (Afifi et al. 2019; Jin et al. 2022; Scawthorn et al. 2006), as well as the value of implementing mitigation strategies to decrease flood risk (Gnan, Friedland, Mostafiz, et al. 2022; Gnan, Friedland, Rahim, et al. 2022; Taghinezhad et al. 2020), there remains a need for a comprehensive analysis of how green infrastructure, permeable pavements and zoning regulations contribute to mitigating flood risks in diverse urban settings. Existing literature highlights the importance of evaluating flood risk both within and outside designated high-risk areas (Auliagisni, Wilkinson, and Elkharboutly 2022; Fu et al. 2023). This comprehensive approach is essential for developing effective flood-mitigation strategies. In addition to quantifying the reduction in flood risk, the long-term evaluation of the benefits and costs associated with home elevation, in conjunction with the consideration of impervious surfaces, is an important step in determining the most effective and cost-efficient solutions (Hermans, 2017; Twohig et al., 2022; Wu et al., 2023).

Impervious surfaces represent a critical nexus between urbanization and hydrological dysfunction, fundamentally altering natural water cycles in ways that extend far beyond simple runoff calculations (Al-Khuzaie et al., 2023; Gao et al., 2023). These hard surfaces including asphalt roads, buildings, and parking lots serve as both diagnostic indicators of urban intensity and primary drivers of watershed degradation, making them essential parameters in hydrological modelling and urban water management frameworks. The proliferation of impervious surfaces accompanies virtually all forms of urban development, creating a direct causal relationship between city expansion and ecosystem disruption (Du et al., 2015). The hydrological consequences of impervious surface expansion manifest across multiple scales and timeframes. At the watershed level, Bera et al. (2022) documented fundamental alterations to runoff patterns, peak discharge rates, and base flow characteristics that cascade through entire drainage systems, ultimately reshaping stream morphology and thermal regimes. These physical changes compound with chemical impacts, as Zhang et al. (2018) demonstrated that impervious surfaces facilitate the transport of concentrated nutrient and pollutant loads directly into waterways, creating a dual threat of hydraulic stress and water quality degradation that severely compromises aquatic biodiversity.

Despite growing recognition of these impacts, a critical knowledge gap persists regarding the effectiveness of impervious area reduction strategies in real-world implementation contexts. While technical literature extensively documents the theoretical potential of various reduction approaches (Shao et al., 2023; Stillwell et al., 2018), empirical evidence of their practical performance particularly in complex institutional environments like New Zealand remains limited. This gap is particularly pronounced for residential areas, which constitute the largest component of urban impervious coverage yet receive less systematic analysis than commercial or industrial developments. The challenge extends beyond technical implementation to fundamental questions of governance, stakeholder coordination, and long-term maintenance factors that determine whether theoretically sound strategies translate into measurable environmental improvements. Existing research typically examines individual techniques in isolation rather than evaluating integrated approaches within realistic regulatory and resource constraints. This disconnects between technical capability and implementation effectiveness represents a critical barrier to achieving meaningful flood risk reduction and sustainable water management outcomes.

This study addresses these knowledge gaps by examining the effectiveness of impervious surface reduction techniques within New Zealand's specific regulatory, environmental, and institutional context. Focusing on residential areas where implementation challenges are most complex and stakeholder coordination most critical, this research contributes essential insights for translating technical knowledge into practical flood mitigation strategies that can function effectively within real-world constraints. The subsequent sections of this paper are organized as follows: Section 2 provides a detailed literature review that explores the role of impervious surfaces as environmental indicators, the regulatory frameworks governing their management, and delineates the differences between brownfield and greenfield development contexts within the context of Auckland's intensification strategy. Section 3 outlines the qualitative methodology employed in this study, including the semi-structured interview approach and the thematic analysis used to investigate expert perspectives from the government, consulting, and development sectors. Section 4 presents the research findings, categorized into five principal themes: current techniques of impervious area, associated challenges, policy and regulatory framework, monitoring and compliance and recommendations for improvement. Section 5 addresses the broader implications of these findings for urban water management policy, emphasizing the scale-dependent effectiveness of interventions and the essential role of institutional coordination in facilitating successful implementation. Finally, Section 6 concludes with practical recommendations for policymakers and practitioners, identifies future research opportunities, and discusses the applicability of the findings to other jurisdictions experiencing comparable urban intensification challenges.

2. Literature review

2.1 Introduction

In recent years, New Zealand has seen a significant rise in flooding incidents, particularly severe events in Auckland and Hawke's Bay in 2023, underscoring the vulnerability of urban areas to extreme weather (García-Ayllón and Franco, 2023; Zhou et al., 2024). The increasing frequency and severity of severe floods, intensified by climate change, present substantial threats to residential zones and essential infrastructure (Dharmarathne et al., 2024; Sperotto et al., 2016). The devastating floods in Auckland in January 2023, with projected damage exceeding NZD $5 billion, highlight the critical need for improved flood resilience solutions (NZ CarbonNews, 2024). Such solutions align with the United Nations Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 6 (Clean Water and Sanitation), while contributing to the broader importance of building adaptive capacities for climate-resilient development pathways.

The proliferation of impervious surfaces in urban areas has emerged as a critical factor contributing to increased flood risk due to urbanization. For example, Omurakunova et al. (2020) reported that the impervious surface area increases of 35-75% in selected cities from 1993 to 2017. Similarly, Qian and Wu (2019) noted that the impervious surface area in Nanjing has increased dramatically from 427.36 km2 to 1780.21 km2 over three decades. It is worth noting that different urban zones can have varying levels of impervious surface coverage. For instance, Hua et al. (2020) indicated that industrial zones and urban villages tend to be the greatest contributors to impervious surfaces. These impervious surfaces, including roofs, driveways, and pavements, reduce water infiltration and accelerate stormwater runoff, which is particularly challenging in New Zealand's steep topography and high rainfall environment (Phillips et al., 2018). The relationship between imperviousness and flood risk is particularly pronounced in New Zealand's urban settings, where steep topography and high-intensity rainfall events combine to amplify the impact of reduced natural drainage (Harrington et al., 2023).

The growing recognition of these challenges has prompted increased attention to impervious area reduction techniques as key strategies for enhancing flood resilience (Habib, Alnaemi, and Habib 2024). While traditional stormwater management approaches focus primarily on rapid drainage through engineered systems, contemporary solutions emphasize the importance of mimicking natural hydrological processes (Dhakal and Chevalier, 2016). These methods, including permeable pavements, rain gardens, and green roofs, present significant potential for mitigating flood risks while providing supplementary environmental and social benefits (Qin, 2020).

2.2 Theoretical frameworks

Contemporary urban flood management has fundamentally shifted from traditional drainage-centric approaches toward integrated frameworks that address impervious surfaces as complex hydrological, environmental, and social challenges (Sarigul and Gunaydin 2025). This theoretical evolution reflects growing recognition that conventional engineering solutions alone cannot address the multifaceted impacts of urbanization on water systems and community resilience. Urban hydrology theory provides the foundational understanding of how impervious surfaces fundamentally alter natural water cycles through disrupted infiltration, increased surface runoff, and modified evapotranspiration processes (Hameed, 2017). Empirical evidence demonstrates the magnitude of these changes, with urbanization increasing runoff volumes by up to 85% over three decades due to expanded impervious coverage (Hameed, 2017; Miller and Hutchins, 2017). This dramatic alteration of hydrological processes creates cascading effects throughout urban watersheds, affecting flood frequency, stream morphology, and ecosystem health.

Three complementary theoretical frameworks guide contemporary impervious area reduction strategies in New Zealand's context. Low Impact Design (LID) philosophy emphasizes maintaining pre-development hydrological conditions through distributed interventions that restore natural processes including infiltration, detention, and evapotranspiration (Fassman-Beck et al., 2013). This approach prioritizes source control mechanisms that address stormwater at its point of generation rather than relying on centralized infrastructure solutions. The Sustainable Urban Drainage Systems (SUDS) framework builds upon LID principles by establishing a hierarchical management approach progressing from source control through site control to regional interventions (Fletcher et al., 2015). This framework recognizes that effective stormwater management requires coordinated interventions across multiple spatial scales, from individual properties to catchment-wide systems.

Water Sensitive Urban Design (WSUD) represents the most comprehensive framework, integrating water cycle management with broader urban planning objectives to deliver multifunctional benefits including flood resilience, water quality improvement, biodiversity enhancement, and increased urban amenity value (Przestrzelska et al., 2024; Veról et al., 2020). WSUD emphasizes the co-benefits of impervious area reduction, demonstrating how environmental interventions can simultaneously address social, economic, and ecological objectives (Guven and Tanik 2020). These theoretical frameworks collectively support the transition from reactive infrastructure solutions to proactive, nature-based approaches that treat impervious area reduction as an integral component of sustainable urban development. This paradigmatic shift underpins contemporary policy approaches to residential flood resilience in New Zealand's rapidly urbanizing environment.

It has emerged that the effective techniques for reducing impervious areas and managing stormwater runoff in urban environments are low-impact development (LID) solutions and green infrastructure (Habib et al. 2024). These include permeable pavements, green roofs, rain gardens, bioretention cells, and rain barrels (Abi Aad et al. 2010; Liu et al. 2015; Palermo et al. 2020). Studies have shown that implementing LID practices can significantly reduce runoff volume and peak flow rates and delay peak flow times. For instance, green roofs can reduce stormwater runoff volume by 30-86% and peak flow rate by 22-93% (Li and Babcock, 2014). Rain gardens have demonstrated flow reduction rates of 77-94% for overflow events (Tang et al., 2016). The effectiveness of these techniques is influenced by factors such as the precipitation volume, antecedent conditions, growth medium, plant species, and roof slope (Li and Babcock, 2014). Interestingly, a combination of LID practices can yield optimal results. For example, integrating green infrastructure with proper sizing can achieve 100% runoff reduction for 5-year recurrence storms by expanding the pervious area percentage to over 50% or increasing the storage pond volume to over 1800 m3 (Liu et al., 2015). Additionally, disconnecting impervious areas from drainage networks has been shown to significantly contribute to runoff reduction (Wang et al., 2019). LID and green infrastructure techniques have proven effective in reducing impervious areas and managing stormwater runoff. These approaches not only mitigate environmental problems but also offer cost-effective solutions compared to traditional stormwater management methods. For instance, implementing Sustainable Urban Drainage Systems (SuDS) can reduce combined sewer overflows by 50-99% at a fraction of the cost of large CSO tanks (Joshi et al., 2021). As urbanization continues to increase, the adoption of these techniques is crucial for sustainable urban development and stormwater management. These techniques also contribute to improving urban aesthetics and enhancing the biodiversity in cities (Oertli and Parris, 2019). By incorporating green spaces and natural elements into urban landscapes, LID and green infrastructure can create more liveable and resilient communities. Moreover, these strategies can alleviate the urban heat island phenomenon, enhance air quality, and offer recreational options for inhabitants.

2.3 Residential area impervious reduction techniques: Policy and regulatory frameworks

To address impervious area reduction in residential areas in Auckland, New Zealand has implemented various policies and regulatory frameworks. The city of Auckland has taken steps towards more sustainable urban development, including upzoning to facilitate the construction of more intensive housing (Greenaway-McGrevy and Phillips, 2023). This approach can potentially lead to a reduction in impervious areas by promoting high-density development. In terms of waste management and pollution prevention, New Zealand's framework has been criticized for being vague and lacking (Boyle 2000). This suggests that there may be room for improvement in policies addressing impervious area reduction as part of broader environmental management strategies. Interestingly, Silva (2018) highlighted that despite regulations to control urban sprawl, such as establishing restricted areas for expansion, these measures have not been entirely successful. The paper points out that there is planning "ambiguity" in Auckland, which may contribute to urban sprawl and, consequently, increased impervious surfaces in residential areas. Although not specific to Auckland, Sohn et al. (2017) provide insights into the effectiveness of low-impact development (LID) in reducing directly connected impervious areas (DCIA). The study found that the percentage of DCIA reduction by LID varied by land-use type, and optimal combinations of LID applications could maximize the effectiveness of DCIA reduction. These findings could be relevant for policymakers in Auckland implementing similar strategies. While Auckland has implemented policies aimed at sustainable urban development, there appears to be a need for more targeted and effective regulatory frameworks to address impervious area reductions in residential areas. To maximize directly connected impervious area reduction (DCIA), future policies could benefit from incorporating LID practices and focusing on optimal combinations of strategies.

2.4 Residential area impervious reduction techniques: implementation challenges, barriers and opportunities

The implementation of impervious area reduction techniques in residential areas in Auckland, New Zealand, encounters numerous challenges, barriers, and opportunities. The city's urban growth management strategy, focused on "liveability" and a "quality compact city," has led to the development of high-density housing typologies within existing suburban areas (Allen, 2015). This approach presents challenges and opportunities for reducing impervious areas. While high-density housing may increase impervious surfaces, it also provides opportunities for innovative stormwater management solutions. One significant barrier is the tension between local government planning practices, which emphasize urban sustainability and housing intensification, and central government housing policies that prioritize land supply and housing affordability (Murphy, 2016). This conflict can hinder the implementation of green infrastructure and impervious area reduction techniques, as the focus may shift towards rapid housing development rather than sustainable urban design. Despite these challenges, there are opportunities to implement impervious area-reduction techniques in Auckland. The city's engagement with neo-liberalism has resulted in the revalorization of inner-city areas, which could potentially include green infrastructure initiatives (Murphy, 2008). Additionally, the growing concern over air quality and pollutants in urban areas (Boamponsem et al., 2024) may drive support for green infrastructure solutions that can help mitigate these issues while reducing impervious surfaces. Policymakers and urban planners must address implementation barriers by examining the trade-offs residents encounter in selecting housing typologies and their valuation of urban amenities (Allen, 2015). It is essential that techniques for reducing impervious areas correspond with residents' preferences and enhance overall neighbourhood satisfaction.

2.5 Brownfield vs. Greenfield Development: Impervious Area Management in Auckland's Intensification Context

Auckland's urban intensification occurs through two distinct mechanisms that present fundamentally different challenges for managing impervious areas. Brownfield redevelopment involves demolishing existing housing and constructing higher-density developments on previously developed sites, while greenfield development represents original construction on undeveloped land (Zapata-Diomedi et al. 2019). These contexts create substantially different opportunities and constraints for implementing impervious area reduction strategies. Brownfield redevelopment in Auckland presents unique impervious area challenges despite offering broader urban sustainability benefits (Jayawardena 2024). While brownfield projects generally deliver economic viability and enhanced walkability compared to greenfield alternatives (Zapata-Diomedi et al. 2019), the specific context of impervious surface management reveals significant constraints. Existing infrastructure, property boundaries, and underground utilities limit opportunities for implementing comprehensive stormwater management systems. The demolition-reconstruction process often results in maximized site coverage to achieve economic viability, potentially increasing impervious coverage beyond original levels despite regulatory limits (Aernouts, Maranghi, and Ryckewaert 2020).

Contemporary scholarship emphasizes that cost-effectiveness comparisons between development approaches must incorporate environmental outcomes, including stormwater management performance (De Sousa 2004). However, Auckland's experience suggests that achieving impervious area reduction targets in brownfield contexts requires innovative space-efficient solutions rather than traditional extensive green infrastructure approaches. The "often-central location" advantage of brownfield sites (Lin et al. 2019) creates opportunities for strategic catchment-scale interventions, but individual site constraints necessitate alternative implementation strategies. Greenfield development contexts in Auckland offer greater flexibility for integrating comprehensive impervious area reduction strategies from project inception. Unlike brownfield sites where "toxic contaminants from prior work on the land" may constrain intervention options (Hou et al. 2023), greenfield developments enable systematic water-sensitive urban design implementation. However, market pressures and density requirements under Auckland's planning framework can compromise impervious area objectives even when physical constraints are minimal.

The regulatory framework struggles to differentiate effectively between these contexts. Auckland's Unitary Plan applies relatively uniform impervious area limits across different development types, potentially failing to account for the distinct constraints and opportunities each context presents (Council 2013). Recent research suggests that jurisdictions require "standardized evaluation criteria specifically calibrated to local environmental, economic, and cultural contexts" (Burinskienė et al. 2017) that recognize these fundamental differences. Advanced decision support systems incorporating geospatial analysis could enhance planning responses to these differential contexts (Hammond et al. 2021). For Auckland's intensification strategy, this suggests developing context-specific impervious area management approaches that recognize brownfield constraints while maximizing greenfield opportunities, rather than applying uniform solutions across fundamentally different development environments.

3. Methods

This qualitative study is grounded in constructivist epistemology, which recognizes that knowledge emerges through the interaction between researchers and participants, emphasizing the socially constructed nature of understanding (Creswell, 2009). This philosophical foundation acknowledges that research participants' experiences and interpretations of impervious area reduction strategies are shaped by their professional contexts, institutional environments, and lived experiences within New Zealand's urban water management sector. The research design employed an interpretive framework that prioritizes understanding how experts make sense of implementation challenges, policy constraints, and technical effectiveness within their specific organizational and regulatory contexts. This approach recognizes that flood mitigation strategies operate within complex socio-technical systems where success depends not only on engineering performance but also on institutional capacity, stakeholder coordination, and community acceptance.

Semi-structured interviews served as the primary data collection method, enabling exploration of participants' experiences while maintaining sufficient flexibility to pursue emergent themes and unexpected insights. Interview participants were selected based on their direct involvement in impervious area reduction implementation across government agencies, consulting firms, and development organizations, ensuring diverse perspectives on both policy development and practical implementation challenges.The interview process was designed to facilitate reflective discourse through informal settings and extended duration (over one hour), allowing participants to articulate complex relationships between technical, institutional, and political factors that influence strategy effectiveness. All interviews were recorded, transcribed, and subjected to content analysis. Following a thorough examination of the interview transcripts, the researchers identified recurring themes derived from shared ideas and perspectives with coding based on the participants' responses. This study received approval from the XXX University of Technology Ethics Committee (AUTEC) under reference number 24/70. The approval covered the recruitment process, participant information and consent procedures, data collection through interviews, and data management protocols. There were no specific conditions attached beyond compliance with AUTEC’s standard requirements for confidentiality, voluntary participation, and secure data storage.

The interview transcripts were subjected to a detailed review to guarantee the accuracy and coherence of the respondents' statements, thus enabling data triangulation and source validation.

Qualitative data obtained from participants were examined using ATLAS.ti 9 software, which aided in the organization, interpretation, and evaluation of the textual material. After an initial exploration of the data, the researchers applied the open coding function of ATLAS.ti 9 to identify pivotal words, phrases, and relevant keywords related to the topic at hand. The number of interviews was deliberately constrained until a saturation point was reached. For a detailed overview of the participants, see Table 1, the demographics of the participants. This thorough qualitative methodology allowed researchers to develop a deep understanding of the effectiveness of impervious area reduction techniques in residential settings, drawing insights directly from the experiences and perspectives of informed stakeholders.

The participants selected for this study held high-ranking positions within their respective organizations, with over ten years of tenure, and possessed higher educational backgrounds, indicating their substantial knowledge and extensive experience within the NZ construction industry (see Table 1, Demography of Participants). The qualitative data analysis process was conducted systematically to gain a deep understanding of participants' meanings and experiences, following the guidelines outlined by Creswell (2009) and explained in Figure 1. The qualitative data analysis began by identifying key phrases and expressions from participant interviews that examine the effectiveness of impervious area reduction techniques in residential areas of NZ. These phrases, including direct participant quotations, guided the systematic categorization of data during the initial analysis phase. Given time constraints and the researcher's bilingual expertise, both manual and electronic coding methods were employed using Microsoft Word and ATLAS.ti 9, ensuring comprehensive analysis while maintaining efficiency (Basit, 2003). Following Creswell's (2009) framework, the analysis proceeded through five systematic stages. First (Stage 1), raw interview transcripts were organized into folders for structured analysis. Second (Stage 2), multiple readings of each transcript and accompanying field notes facilitated a deep understanding of participants' awareness and comprehension regarding the effectiveness of impervious area reduction techniques in residential areas of NZ. Third (Stage 3), the Cut-and-Paste method (Stewart et al., 2007) was employed to identify significant text segments relevant to the research questions for transcript analysis. Fourth, using ATLAS.ti 9, color-coded symbols distinguished between themes and networks within the text, with key words, phrases, sentences, and paragraphs systematically identified and categorized. In stage 4, major thematic classifications emerged from preliminary readings, with relevant transcript passages highlighted and organized according to each identified theme. This systematic approach enabled a comprehensive understanding of participants' meanings and experiences while maintaining analytical rigour throughout the coding process.

Table 1*: Demography of Participants (Source: Authors' own work)*

Figure 1. *Qualitative Analysis Framework and Procedures (Source: Authors' own work)*

An inductive approach ensured no data was pre-coded, allowing concepts to emerge naturally from participants' expressions within their contextual performance. Researchers closely examined participant language to identify key concepts related to effectiveness of impervious area reduction techniques in residential areas of NZ. In stage 5, identified elements were analysed and organized into primary themes based on their correlations with impervious area reduction techniques in residential areas of NZ. The researcher reviewed all interview transcripts to identify essential phrases and statements explaining categories that became the key variables of the preliminary research model. Following complete coding, materials were systematically categorized using coded transcripts, gathering all items relevant to each key subject for final interpretive analysis. This process, facilitated by Microsoft Word and ATLAS.ti 9, generated multiple distinct codes. Due to resource constraints and to eliminate inter-coder bias, all interview data was thematically analysed and coded by the researcher, who had conducted all interviews and possessed comprehensive understanding of emerging themes.

4. Results and Discussions

This section presents the research findings derived from qualitative interviews. The results are organized into five principal thematic categories that emerged from the analysis: (1) current techniques of impervious area, (2) challenges and barriers to effective implementation, (3) policy and regulatory framework considerations, (4) monitoring and compliance mechanisms, and (5) evidence-based recommendations for improvement. Each theme is examined in detail, with findings presented alongside relevant discussion and interpretation in relation to the existing literature and research objectives.

4.1 Current techniques of impervious area

The growing awareness of the intricacy of urban water systems is reflected in the development of impervious area management. As noted by P-1, the field has progressed from ad-hoc approaches to more structured frameworks, incorporating water-sensitive urban design (WSUD) principles with sophisticated spatial prioritization strategies (Wu et al., 2023). This evolution is particularly evident in the regulatory landscape. As P-9 explained, "The Auckland Unitary Plan sets specific restrictions limiting impervious areas to 60-70% of total site area in new developments, but the practical implementation of these controls faces significant hurdles." This participant further noted that "*insufficient funding for compliance monitoring undermines the effectiveness of existing regulations, making it difficult to ensure adherence to impervious surface limits*." The implementation of reduction techniques has resulted in significant advancements in both theory and practice. Green infrastructure components including swales, wetlands, and green roofs have emerged as fundamental elements of modern urban water management. Recent research by Al-Khuzaie et al. (2023) demonstrated the practical success of these approaches in flood reduction, whereas P-3's findings highlight the effectiveness of comprehensive solutions incorporating living roofs, rain gardens, and permeable paving options.

However, the transition from theoretical models to practical implementation has revealed important challenges. Twohig et al. (2022) identify a notable implementation gap, where real-world results often fall short of theoretical projections. This disparity is particularly pronounced in brownfield developments, where spatial constraints and existing infrastructure present significant challenges to integrating green infrastructure solutions. P-6 further emphasizes the complex balance required between housing yield priorities and impervious area requirements, stating: "*The unitary plan's maximum impervious area requirements must balance against housing yield priorities, particularly in urban areas. While greenfield developments offer more opportunities for implementation, brownfield developments present significant challenges, especially for integrating green infrastructure within small lots in established residential areas.*" This participant elaborated on the practical constraints, noting that "*the adoption of pervious paving, rainwater reuse tanks, and green roofs remain limited, and bioretention systems are particularly challenging to implement in brownfield developments due to space constraints and existing infrastructure*."

Despite these challenges, innovative solutions have continued to emerge. P-14 describes the development of comprehensive frameworks, "*Our approach relies on planning rules and consent requirements where property owners must obtain resource consent when exceeding permitted impervious area thresholds, ensuring proper assessment and management of stormwater impacts*." This participant further detailed how "*the strategy aligns with broader Council policies focused on climate change adaptation*" and extends beyond individual properties to include "*public spaces like roads, promoting green space and permeable landscaping to enhance stormwater absorption and mitigate urban heat island effects*." These approaches are complemented by sophisticated green infrastructure solutions, as outlined by P-15, which integrate traditional water knowledge with modern techniques (Asad et al., 2022). Developer-led initiatives, as described by P-16, demonstrate the potential of combining semi-pervious solutions with Low Impact Design principles, achieving measurable success in reducing post-development water flows to 80% of pre-development levels.

Quantifiable evidence supports the effectiveness of these reduction techniques. Research indicates that green roof implementations can reduce stormwater runoff volume by 30-86% (Li and Babcock, 2014), whereas rain gardens achieve flow reduction rates of 77-94% for overflow events (Tang et al., 2016). More significantly, integrated approaches that combine multiple techniques have demonstrated the potential for complete runoff reduction under certain conditions (Liu et al., 2015). These solutions are often more cost-effective than traditional approaches, with Sustainable Urban Drainage Systems (SuDS) reducing combined sewer overflows by 50-99% at lower costs than conventional solutions (Joshi et al., 2021). This field has continued to evolve with technological advancements. Wang (2021) and Puttinaovarat and Horkaew (2020) highlight the potential of AI-enabled monitoring systems and machine learning in flood forecasting, though resource constraints currently limit widespread implementation. P-11 described how catchment management works in New Zealand…. "*Most catchments operate without specific management plans, instead relying on district and regional plan policies and rules*." The participant explained that "*larger councils like Christchurch and Auckland have more capacity for catchment-wide approaches*" compared to smaller councils with limited resources.

Several key areas require further attention to advance the field. First, spatial planning in WSUD implementation must be prioritized with a particular focus on developing specific strategies for brownfield development challenges. Second, monitoring and enforcement mechanisms need to be strengthened and supported by investment in advanced technologies. Finally, there is a critical need to develop comprehensive approaches for existing impervious areas to balance development needs with flood resilience requirements. The successful management of urban water systems ultimately requires a holistic approach that recognizes the interconnected nature of the built and natural environments. The integration of multiple reduction techniques, strengthening regulatory frameworks, and investing in innovative solutions can help communities create more resilient urban environments that effectively manage increasing climate pressures while supporting sustainable development goals. In addition to meeting urgent flood control needs, this integrated approach promotes broader environmental and social benefits, such as reducing urban heat islands, enhancing biodiversity, and making cities more livable. Figure 2 presents the detailed framework of the impervious surface reduction techniques that are currently in use.

Figure 2: *Current techniques identified for reducing impervious areas (Source: Authors' own work)*

4.2 Associated challenges to impervious area reduction techniques

There is a complicated interaction between effectiveness, challenges, and opportunities when implementing impervious area reduction techniques in urban environments, especially in Auckland's unique context. As cities deal with intensifying development pressures and environmental imperatives, understanding this landscape is crucial for developing sustainable urban water management strategies. The effectiveness of these techniques demonstrates a significant variation across different scales and contexts. While catchment-scale solutions, such as designed wetlands, show promising results, small-scale interventions often struggle to have a meaningful impact on major flood events, as noted by P-1 and supported by Manchikatla and Umamahesh's (2022) research on catchment-level approaches. This scale-dependent effectiveness becomes particularly evident in Auckland's diverse topography. P-7 reported…. "*We've seen notable positive outcomes where strategies were implemented, including reduced flood damage and decreased surface water accumulation during flood events. The effectiveness was particularly pronounced in specific topographical contexts, such as mountainous and flat terrain.*"

The challenge is further complicated by Auckland's unique geological conditions. P-17 highlighted these performance differences: "*Effectiveness varies significantly by location, with notable differences between clay soils and volcanic areas. Implementation success depends heavily on practical constraints, including available space, property dimensions, and aesthetic considerations*." This geological variation means that strategies successful in volcanic soil areas may perform poorly in clay soil locations, requiring site-specific adaptation of impervious area reduction techniques. The urban development context in Auckland adds another layer of complexity to the effectiveness equation. The city's strategic focus on "liveability" and creating a "quality compact city" (Allen, 2015) has led to inherent tensions between development objectives and environmental sustainability. These tensions manifest in multiple ways: development trends, particularly in terrace housing, severely restrict space for reducing impervious areas (P-6), while the actual impervious surface coverage frequently exceeds planned levels, sometimes reaching up to 95%. This reality reflects the broader challenge of balancing housing intensification requirements with effective flood-management strategies.

P-18 further identified how these institutional challenges manifest in practice…. "Technical limitations include inadequate rainfall prediction and monitoring capabilities. Development pressures create tensions between housing density requirements and flood management, particularly in historically vulnerable areas." The participant also highlighted resource allocation issues, noting that "cyclical funding patterns tend to prioritise post-disaster response over sustained monitoring and data collection efforts, limiting long-term effectiveness." P-18 further identified how these institutional challenges manifest in practice… "*Technical limitations include inadequate rainfall prediction and monitoring capabilities. Development pressures create tensions between housing density requirements and flood management, particularly in historically vulnerable areas*." The participant also highlighted resource allocation issues, noting that "cyclical funding patterns tend to prioritise post-disaster response over sustained monitoring and data collection efforts, limiting long-term effectiveness." This gap is exacerbated by conflicts between central government housing policies that prioritize rapid development and local sustainability goals (Murphy, 2016). The resulting regulatory fragmentation creates a challenging environment for effective implementation, with P-15 noting the poor interdepartmental coordination and inconsistent regulations across jurisdictions. Technical and resource constraints interweave with these institutional challenges to create additional barriers to implementation.

Construction difficulties and the limited availability of specialized materials, as reported by P-7, combine with insufficient expertise among designers and a shortage of qualified workers to hinder effective implementation. These technical challenges are particularly acute in Auckland's context, where clay soil characteristics limit infiltration capabilities (P-4) and inadequate rainfall prediction and monitoring systems complicate planning efforts. The economic dimension adds another critical layer to this complex picture. Financial constraints significantly impact implementation across all scales, from the high cost of modern waterproofing materials to insufficient insurance coverage for flood-proofing improvements. P-5 emphasizes the chronic underfunding of ongoing monitoring and maintenance, while P-6 highlights the lack of effective incentives for both developers and homeowners. This economic challenge reflects a broader issue in urban water management, namely the disconnect between immediate costs and long-term benefits. At the property level, these challenges manifest in particular ways. P-2 identified a widespread lack of awareness among property owners regarding their stormwater management obligations, leading to gradual increases in impervious areas as homeowners pave over green spaces. This situation aligns with Faruk and Maharjan’s (2022) findings on the impact of limited environmental regulation awareness on property-owner decision-making. The challenge of monitoring and enforcing compliance across thousands of individual properties has further compounded this issue. However, these challenges lie in the opportunities for meaningful progress.

Recent flooding events have catalyzed the formation of community liaison groups (P-15), while growing concerns over urban air quality (Boamponsem et al., 2024) have created additional motivation for green infrastructure solutions. P-12 suggests innovative approaches such as linking rates to impervious areas to support compliance programs, while P-10 advocates funding models that incorporate broader health and environmental benefits. The successful implementation of impervious area reduction techniques requires a multifaceted approach that acknowledges these interconnected challenges, while leveraging emerging opportunities. This approach should prioritize strengthening enforcement mechanisms, while providing meaningful incentives for compliance, investing in comprehensive monitoring systems, and fostering deeper community engagement in stormwater management. Crucially, context-specific solutions must be developed that account for Auckland's unique geological and urban conditions while focusing on long-term sustainability goals. The path to effective impervious area reduction ultimately requires balancing the immediate pressure of urban development with the imperative of environmental sustainability. By understanding and addressing these challenges as interconnected elements of a broader system, while remaining attentive to the local context and community needs, cities like Auckland can work toward more effective implementation of these crucial environmental management strategies. This well-rounded strategy, backed by robust policy frameworks and community involvement, provides the best chance to build resilient urban settings that can handle present demands and upcoming challenges. Figure 3 depicts the efficacy of impervious surface reduction options and their associated challenges.

Figure 3: *Associated challenges to impervious area reduction techniques (Source: Authors' own work)*

4.3 Policy and regulatory framework governing impervious area reduction strategies

Marked by both advancements and persistent challenges, Auckland's impervious area reduction policies and regulations represent a complicated evolution of urban environmental management. This framework has emerged from the intersection of increasing urbanization pressure, environmental imperatives, and the growing recognition of flood resilience as a critical urban priority. Auckland's regulatory approach to impervious surface management has made significant strides through the implementation of the Unitary Plan, which establishes specific impervious area limits of 60-70% for most residential zones (P-6). However, this achievement exists within a broader context of planning "ambiguity," as identified by Silva (2018), where the uniform application of these limits across diverse zones may not adequately address varying local conditions and risks. This tension between standardization and local adaptation exemplifies the broader challenges facing the urban environmental policy in New Zealand. In addition, Duany and Talen (2002) outlined "a new approach to the implementation of New Urbanist and smart growth principles. The approach is termed transect planning and is based on the creation of a set of human habitats that vary by their level and intensity of urban character. In transect planning, this range of environments, from rural to urban, is the basis for organizing the components of the built world: building, lot, land use, street, and all of the other physical elements of the human habitat. The city's recent shift toward intensive housing development through upzoning (Greenaway-McGrevy and Phillips, 2023) highlights the complex relationship between development policies and environmental management. Although this approach offers potential benefits through density optimization, it also creates new challenges for flood resilience implementation. P-8's observations highlight the delicate balance between urban intensification goals and flood management requirements, particularly in the context of existing development patterns and private-land ownership constraints.

The effectiveness of these policies is significantly shaped by the multilevel governance structure in which they operate. P-1's emphasis on the need for national-level guidance on green infrastructure and nature-based solutions reflects a broader systemic challenge identified by Liu et al. (2022), who demonstrate how coordinated spatial planning across governance levels can enhance policy effectiveness. This finding is further reinforced by Salehi et al.'s (2022) research on multistage regulatory models, which reveals the critical importance of integrated governance approaches in achieving successful flood-management outcomes. P-1 described the regulatory challenges, *stating.... "There is a pressing need for national-level guidance on green infrastructure and nature-based solutions. We've identified a concerning misalignment between building and resource consent processes, while noting that Auckland's unitary plan has made progress through its implementation of impervious area limits." P-4 further elaborated on the cumulative impact problem, explaining....*

"There's a troubling disconnect between individual development approvals and their cumulative effects at the catchment level. The Auckland Unitary Plan sometimes permits development within floodplains, creating potential risks." This situation mirrors the broader criticism of New Zealand's environmental management framework as lacking a clear direction (Boyle 2000), suggesting a systemic issue in policy implementation.

International comparisons, particularly with the United States system, as analyzed by P-13, offer valuable insights into potential policy evolution pathways. The U.S. framework's greater flexibility in supporting private flood resilience projects through public-private funding arrangements contrasts sharply with New Zealand's more restricted approach. This difference becomes particularly significant when considering the challenges posed by existing use rights in New Zealand's regulatory context, suggesting opportunities for policy reforms that could enhance implementation effectiveness. The emergence of low-impact development (LID) as a key policy tool presents promising opportunities for improvement. Sohn et al.'s (2017) research demonstrates how optimal combinations of LID approaches can maximize the reduction of directly connected impervious areas, offering practical guidance for policy development. This aligns with P-18's advocacy for a comprehensive approach incorporating standardized service levels, robust technical solutions, and integrated strategies connecting individual property impacts to broader catchment effects. Community engagement has emerged as a crucial element in policy effectiveness. P-16's observations of increased public awareness and support following recent flood events facilitated through diverse engagement methods align with Dewa et al.'s (2022) findings on building public support for flood management policies. This growing public consciousness creates opportunities for more ambitious policy initiatives while highlighting the importance of maintaining strong community connections in policy implementation.

The evolution of Auckland's policy framework requires careful attention to several interconnected elements. The need for a clear central government direction regarding the development of flood-prone areas must be balanced against the importance of local implementation flexibility. Enhanced monitoring and enforcement capabilities need to be supported by improved professional development and training programs, whereas innovative funding models and stronger incentives for implementing flood resilience measures can help bridge the gap between policy goals and practical implementation. The path toward more effective impervious area reduction policies in Auckland ultimately requires recognizing the interconnected nature of urban development and environmental sustainability. Success depends on creating policy frameworks that can adapt to local conditions while maintaining consistent standards for flood resilience supported by robust implementation mechanisms and strong community engagement. This balanced approach, informed by both local experience and international best practices, offers the best opportunity to develop resilient urban environments capable of meeting both current needs and future challenges. The future effectiveness of these policies will depend on their ability to evolve with changing urban conditions, while maintaining a clear focus on environmental outcomes. Auckland can continue to develop more effective and responsive approaches to managing impervious surfaces and boosting urban flood resilience by learning from both new research and global experiences, as well as the successes and challenges of current implementation. Figure 4 depicts the comprehensive policy and regulatory framework regulating impervious surface reduction strategies in the residential areas of New Zealand.

Figure 4: *Policy and regulatory framework governing impervious area reduction strategies (Source: Authors' own work)*

4.4 Monitoring and compliance framework

Implementing, monitoring, and compliance to impervious area reduction strategies in Auckland is a challenging task as social dynamics, technology advancements, and resource constraints all interact to influence the results of urban environmental management. As cities grow under increasing pressure from climate change and urban densification, as highlighted by Rosenberger et al. (2021), the effectiveness of these strategies has become increasingly critical to urban resilience. The current landscape monitoring reveals significant structural challenges that undermine the effectiveness of impervious area reduction initiatives. Local councils face a stark imbalance between oversight requirements and available resources, with P-2 highlighting the daunting task of monitoring over 9,000 private discharge consent with limited staff. This resource constraint forced councils into a predominantly reactive stance toward compliance issues, as noted by P-3, rather than maintaining the proactive oversight necessary for effective environmental management. This resource limitation manifests itself in multiple ways throughout the implementation process. P-16's observation reveals the stark resource realities facing local authorities.... *"Budget constraints have forced our department to prioritise water quality monitoring over quantity assessments, while also limiting our capacity for comprehensive site inspections." This participant explained how these limitations create systematic gaps in oversight, noting that "we simply don't have the resources to monitor both water quality and quantity effectively, so we have to make difficult choices about where to focus our limited capacity."*

The situation becomes particularly acute in the compliance sphere, where P-15 described severe operational constraints…. *"We have a severely understaffed team of only two members managing the entire workload across the district. There's also a lack of specialised stormwater assessment expertise that impacts decision quality."* This participant further elaborated on the cascading effects of these limitations, explaining that "a disconnect between resource consent and building consent stages leads to missed checks and inconsistent enforcement. We're constantly trying to catch up rather than being proactive about compliance monitoring."

The social dimension adds another layer of complexity to implementation effectiveness. Drescher and Sinasac (2021) revealed that residents' decisions to adopt Green Stormwater Infrastructure (GSI) are primarily influenced by social norms and perceived control factors rather than a technical understanding of effectiveness. This insight suggests that successful implementation requires looking beyond purely technical solutions to address the social and behavioural factors that influence adoption rates, particularly in residential areas where lot-level installations on private properties may represent the primary opportunity for implementation. The equity implications of current implementation patterns further complicate the monitoring landscape. Colbert et al.'s (2024) analysis revealed disparities in urban greenspace accessibility in neighbourhoods with more public housing, highlighting that monitoring and compliance strategies must consider not only technical effectiveness but also social justice implications. This finding emphasizes the need for monitoring frameworks that can track and address emerging divisions in the distribution of environmental benefits across communities.

However, amid these challenges, innovative approaches that offer potential pathways are emerging. P-14's description of the Healthy Waters Department's use of aerial photo analysis for compliance tracking demonstrates how technological solutions can enhance monitoring capabilities, building on the sophisticated interventions explored by Prakash et al. (2023). Technological innovation, when properly integrated with human expertise, offers promising opportunities for more efficient and comprehensive oversight. The funding mechanism for monitoring and compliance activities is a critical leverage point for improvement. P-17's description of a structured compliance system funded through application fees, implementing sequential verification from pre-construction through final compliance, offers a model for sustainably monitoring funding. This approach aligns with P-5's advocacy for treating impervious area reduction solutions as formal assets, along with dedicated funding and depreciation schedules, ensuring proper ongoing maintenance and monitoring.

The path toward more effective implementation requires addressing multiple interconnected elements simultaneously. P-12's proposal offers a comprehensive approach to addressing funding challenges through market-based mechanisms. This participant explained…. *"We need to explore alternative funding mechanisms, such as adjusting property rates based on impervious areas, to incentivize the reduction of impervious surfaces and generate funds for compliance programs and green infrastructure maintenance." P-12 elaborated on the dual benefits of this approach, stating…. "This system would create financial incentives for property owners to reduce their impervious coverage while simultaneously generating dedicated revenue streams for monitoring and maintenance activities."* Meanwhile, P-7's identification of opportunities for enhanced public education and outreach programs aligns with research findings on the importance of social factors in GSI adoption, suggesting a need for integrated approaches that address both the technical and social dimensions of implementation. Moving forward, success in monitoring and compliance will require developing frameworks that can adapt to changing urban conditions while maintaining consistent effectiveness of oversight. This involves creating sustainable funding mechanisms that can support comprehensive monitoring programs, enhance technical capabilities through professional development and training, and ensure equitable implementation across communities. The approach must balance ambitious environmental goals with practical constraints, while leveraging emerging technologies and social insights to enhance the effectiveness of oversight.

The future of urban stormwater management in Auckland ultimately depends on developing integrated approaches that recognize the interconnected nature of technical, social, and financial factors in implementation success. By addressing these elements systematically while maintaining a focus on both immediate oversight needs and long-term sustainability goals, cities can work toward more effective and equitable environmental management strategies. The best opportunity to build resilient urban settings that can handle present demands as well as upcoming difficulties is provided by this well-rounded strategy, which is backed by strong monitoring frameworks and sustainable funding mechanisms. Figure 5 shows the monitoring and compliance framework for impervious surface reduction strategies.

Figure 5: *Monitoring and compliance framework (Source: Authors' own work)*

4.5 Recommendations for improving impervious area reduction strategies

The 2016 upzoning project, which allowed for more intense construction on 75% of residential property, laid the groundwork for Auckland's transition to better water management (Greenaway-McGrevy and Phillips, 2023). This policy shift represents more than a simple density adjustment; it offers the opportunity to fundamentally reimagine the relationship between urban development and environmental sustainability. P-2's vision of integrating flood resilience strategies with comprehensive urban planning builds on this foundation, suggesting that density optimization can work in harmony with environmental protection when properly conceived and executed. The effectiveness of this urban evolution critically depends on moving beyond traditional approaches to impervious surface management. P-4's emphasis on strategic disconnection of impervious areas, rather than simple reduction, points toward a more sophisticated understanding of urban water systems. This approach is supported by contemporary research on sustainable urban drainage systems (Ebrahimian et al., 2016), which demonstrates how integrated water management strategies can enhance both environmental performance and urban liveability.

The transformation of urban infrastructure is a crucial element in this evolution. P-10's vision of cities as potential hubs for biodiversity and hydrological neutrality challenges conventional urban development paradigms, suggesting that infrastructure renewal, particularly in brownfield areas, offers opportunities for ecological regeneration. This perspective gains depth through Rosenberger et al.'s

(2021) research on integrating ecological principles into urban infrastructure design, demonstrating how cities can evolve from passive landscapes into active ecological systems. The social dimension of urban water management has become an increasingly critical aspect of success. Colbert et al.'s (2024) analysis revealing disparities in urban green space accessibility highlights how environmental benefits often distribute unevenly across urban communities. This finding resonates with P-13's advocacy for enhanced community engagement strategies, supported by Tauhid and Zawani's (2018) research, demonstrating the transformative potential of community-driven resilience initiatives. Together, these insights suggest that effective environmental management must consider both technical and social equity. The technical evolution of water management solutions continues to expand the possibilities for urban adaptation. P-16's promotion of integrated approaches reflects a comprehensive strategy for addressing multiple urban constraints simultaneously. This participant detailed their vision…. *"We need to implement innovative solutions like integrated water reuse systems and rainwater harvesting that can address both water management and space efficiency challenges. Our approach combines mandatory LID requirements with precise district plan terminology to ensure clear implementation guidance." P-16 further emphasized the operational benefits, stating…. "We're focusing on improved funding mechanisms and streamlined stakeholder coordination to support these integrated systems at scale."*

P-17's focus on space-efficient solutions addresses the practical realities of urban development constraints. This participant explained…. *"We're developing space-efficient tank designs that address urban constraints while maintaining functionality. The key is strategic integration of planted swales that combine aesthetic appeal with functional efficiency through natural filtration systems." P-17 also highlighted the collaborative aspects… "Success depends on strengthening relationships between council authorities and community stakeholders, particularly improving dialogue with developers about sustainable solutions that work within their project parameters."* These approaches are particularly relevant when considered along with P-9's recommendations for Stockholm tree pits and green roof implementation, suggesting a comprehensive toolkit for urban water management.

The regulatory framework supporting these initiatives continues to evolve, with P-3's call for national policy on stormwater management complementing P-15's vision for a unified engineering code that maintains regional flexibility. This regulatory evolution must strike a balance between standardization and local adaptation, as demonstrated by Chang et al. (2021) in their analysis of comprehensive watershed management approaches. Financial innovation is crucial for supporting this transformation. P-6's advocacy for market-based solutions and rating systems, combined with P-12's exploration of alternative funding mechanisms and P-10's support for targeted financial incentives, suggest a comprehensive approach to economic sustainability. These financial tools can help bridge the gap between environmental imperatives and practical implementation, thus making sustainable practices more accessible and attractive to property owners and developers. The path forward requires weaving these elements into a cohesive urban fabric that supports both immediate needs and long-term sustainability goals. Success depends on recognizing the interconnected nature of urban systems, where changes in one area inevitably influence others. This understanding must inform approaches to density optimisation, the deployment of green infrastructure, and the equitable distribution of environmental benefits. In the future, Auckland's approach to impervious area reduction must remain adaptable while maintaining a clear focus on sustainability objectives. This requires balancing development pressures with environmental imperatives, supported by robust policy frameworks, and meaningful community engagement. Through this integrated approach, informed by both local experience and international best practices, cities can develop more effective and equitable strategies to manage urban water systems and enhance community resilience.

The evolution of urban water management ultimately reflects a broader transformation of our understanding of cities as living systems. Communities may establish urban landscapes that meet human needs and environmental imperatives while adopting this perspective and coming up with workable solutions for pressing issues. This will increase resilience for both present and future generations. Comprehensive suggestions for enhancing impervious surface reduction techniques are shown in Figure 6.

Figure 6: *Recommendations for improving impervious area reduction strategies (Source: Authors' own work)*

5. Conclusion

This study's examination of impervious area reduction strategies in New Zealand's residential areas reveals fundamental insights that extend beyond national borders, offering critical lessons for urban water management in developed nations worldwide. The scale-dependent effectiveness demonstrated here, where catchment-scale solutions significantly outperform site-specific interventions, challenges prevailing assumptions about distributed green infrastructure approaches that many cities have embraced. This finding suggests that urban planners globally may need to reconsider the allocation of resources between large-scale systematic interventions and numerous small-scale installations, particularly as climate change intensifies flood risks across developed nations facing similar urbanisation pressures. The implications resonate strongly with ongoing policy debates in cities like Copenhagen, Singapore, and Toronto, where substantial investments in distributed green infrastructure have yielded mixed results.

The regulatory fragmentation identified in this research mirrors governance challenges observed in federal systems like Australia, Canada, and Germany, where multiple jurisdictional levels create coordination difficulties. The misalignment between building consent and resource management processes documented here provides a cautionary tale for cities implementing green infrastructure policies without ensuring regulatory coherence. This research demonstrates that technical solutions, regardless of their engineering merit, remain ineffective without supportive institutional frameworks, a lesson particularly relevant for European cities implementing EU water directives or North American municipalities navigating complex federal-state-local regulatory environments. The findings suggest that successful policy integration requires not merely coordination mechanisms, but fundamental restructuring of how different governance levels interact, moving from hierarchical to collaborative models that can adapt to local contexts while maintaining strategic coherence.

The widespread property owner non-compliance and awareness gaps revealed through this qualitative analysis point to deeper social-behavioural dimensions of urban flood management that quantitative studies often overlook. These insights suggest that future quantitative research should incorporate behavioural economics frameworks to measure not just technical performance but also adoption rates, maintenance compliance, and long-term behavioural change. Specifically, quantitative studies could employ randomized controlled trials comparing different incentive structures, using the market-based mechanisms identified here such as impervious area-based property rates, as experimental variables. The qualitative themes emerging from this research provide essential foundations for developing validated survey instruments that could measure property owner attitudes, risk perceptions, and willingness-to-pay for flood resilience measures across larger populations. Advanced econometric approaches, including difference-in-differences analyses that compare properties before and after policy implementation, can quantify the behavioural impacts of different regulatory approaches while controlling for confounding variables.

The identification of critical implementation barriers, resource constraints, monitoring limitations, and stakeholder coordination failures suggests specific methodological approaches for measuring long-term effectiveness. Longitudinal studies employing mixed-methods designs could track both quantitative performance metrics (e.g., flood frequency, stormwater volumes, water quality parameters) and qualitative institutional changes over 10–to 15-year periods. Remote sensing technologies, combined with social network analysis, could quantify the relationship between catchment-scale implementation patterns and flood reduction outcomes. Meanwhile, ethnographic methods could document the evolution of institutional practices and professional coordination mechanisms. The finding that many councils lack resources for proper effectiveness assessment suggests that future research should prioritize developing cost-effective monitoring protocols using citizen science approaches and automated sensor networks. Machine learning algorithms could analyse historical weather data, implementation patterns, and flood outcomes to identify optimal intervention points and predict long-term performance trajectories across different urban contexts.

This research reveals that successful urban flood resilience requires transforming impervious area reduction from ad-hoc interventions into systematic asset management approaches, with implications extending to infrastructure financing models worldwide. The comparison with U.S. funding mechanisms highlights opportunities for developing innovative public-private partnerships that could be tested and adapted across different political-economic contexts. Future research should examine how different governance structures, from New Zealand's unitary councils to fragmented municipal systems, affect implementation success, providing comparative insights for institutional design in other developed nations. The integration of natural capital accounting frameworks could quantify the ecosystem service benefits of impervious area reduction, enabling more sophisticated cost-benefit analyses that capture both direct flood mitigation benefits and co-benefits such as urban heat reduction, biodiversity enhancement, and air quality improvement.

The broader implications for urban planning policy suggest a paradigm shift from technical optimization toward socio-technical systems thinking. This research demonstrates that effective flood resilience requires integrating behavioural insights, institutional design, and technical performance, a framework applicable to addressing climate adaptation challenges globally. Future quantitative studies should therefore employ systems dynamics modelling to capture feedback loops between policy implementation, property owner behaviour, and flood outcomes, while longitudinal case study research could document how different cities successfully navigate the institutional barriers identified here. Agent-based modelling approaches could simulate how different policy scenarios affect stakeholder behaviour and flood outcomes, while network analysis could identify key actors and institutions that facilitate or constrain implementation success across different urban contexts.

The methodological insights from this qualitative analysis provide a foundation for developing context-sensitive quantitative measures that could be applied across different urban environments. Future research should employ stratified sampling approaches that account for the scale-dependent effectiveness patterns identified here, while incorporating institutional variables that capture regulatory fragmentation and the quality of stakeholder coordination. Comparative studies examining similar challenges in cities like Melbourne, Vancouver, or Stockholm could test the transferability of these findings while developing generalizable frameworks for institutional analysis in urban water management. Advanced spatial analysis techniques, including geographically weighted regression and spatial autoregressive models, could quantify how local contextual factors influence implementation success and identify optimal intervention strategies for different urban morphologies.

The transformative potential of this research extends to fundamental questions about urban governance in the Anthropocene. The findings suggest that cities must evolve beyond traditional infrastructure paradigms toward adaptive management systems that can respond to uncertain climate futures. This requires developing new metrics that capture not just physical performance but institutional learning capacity, stakeholder engagement quality, and adaptive governance effectiveness. Future research should explore how different cities build these capacities, identifying the institutional innovations that enable sustained implementation of nature-based solutions despite changing political priorities and resource constraints. This research ultimately demonstrates that sustainable urban flood resilience requires not just technical innovation but fundamental transformation in how cities conceptualize, implement, and maintain nature-based solutions within complex socio-political environments. The implications extend beyond flood management to broader questions of urban sustainability, climate adaptation, and environmental governance in an era of rapid global change.

Funding Declaration: The research was funded by the Faculty of Design and Creative Technology Constable Research Fund, Auckland University of Technology (AUT), Auckland, New Zealand.

Acknowledgements: We confirm that no AI-based tools such as ChatGPT were used for drafting, summarising, or refining the manuscript. The manuscript, including the qualitative analysis and framework diagrams, was developed entirely by the authors. The only AI-based tool used was Grammarly, which was applied for basic grammar and spelling checks. AI generated no content, analysis, or interpretation.

Reference

Abi Aad, M. P., Suidan, M. T., and Shuster, W. D. (2010). Modeling Techniques of Best Management Practices: Rain Barrels and Rain Gardens Using EPA SWMM-5. *Journal of Hydrologic Engineering*, *15*(6), 434–443. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000136

Aernouts, Nele, Elena Maranghi, and Michael Ryckewaert. 2020. "The Regeneration of Large-Scale Social Housing Estates. Spatial, Territorial, Institutional and Planning Dimensions." (access date: January 2025) https://hdl.handle.net/11311/1147130

Afifi, Z., Chu, H.-J., Kuo, Y.-L., Hsu, Y.-C., Wong, H.-K., and Zeeshan Ali, M. (2019). Residential Flood Loss Assessment and Risk Mapping from High-Resolution Simulation. *Water*, *11*(4), 751. https://doi.org/10.3390/w11040751

Al-Khuzaie, A. H., Alyaseri, I. J., and Nile, B. K. (2023). Flood reduction using green infrastructure in stormwater sewer systems: A case study in Al-Samawa city. *5TH INTERNATIONAL CONFERENCE ON ENGINEERING SCIENCES – ICES21*, 020015. https://doi.org/10.1063/5.0131325

Allen, N. (2015). Understanding the Importance of Urban Amenities: A Case Study from Auckland. *Buildings*, *5*(1), 85–99. https://doi.org/10.3390/buildings5010085

Asad, R., Ahmed, I., Vaughan, J., and von Meding, J. (2022). Traditional water knowledge: challenges and opportunities to build resilience to urban floods. *International Journal of Disaster Resilience in the Built Environment*, *13*(1), 1–13. https://doi.org/10.1108/IJDRBE-08-2020-0091

Auliagisni, W., Wilkinson, S., and Elkharboutly, M. (2022). Using community-based flood maps to explain flood hazards in Northland, New Zealand. *Progress in Disaster Science*, *14*, 100229. https://doi.org/10.1016/j.pdisas.2022.100229

Bera, D., Kumar, P., Siddiqui, A., and Majumdar, A. (2022). Assessing impact of urbanisation on surface runoff using vegetation-impervious surface-soil (V-I-S) fraction and NRCS curve number (CN) model. *Modeling Earth Systems and Environment*, *8*(1), 309–322. https://doi.org/10.1007/s40808-020-01079-z

Boamponsem, L. K., Hopke, P. K., and Davy, P. K. (2024). Long-term trends and source apportionment of fine particulate matter (PM2.5) and gaseous pollutants in Auckland, New Zealand. *Atmospheric Environment*, *322*, 120392. https://doi.org/10.1016/j.atmosenv.2024.120392

Boyle, C. A. (2000). Solid waste management in New Zealand. *Waste Management*, *20*(7), 517–526. https://doi.org/10.1016/S0956-053X(00)00023-4

Burinskienė, Marija, Vytautas Bielinskas, Askoldas Podviezko, Virginija Gurskienė, and Vida Maliene. 2017. "Evaluating the Significance of Criteria Contributing to Decision-Making on Brownfield Land Redevelopment Strategies in Urban Areas." *Sustainability* 9(5):759. https://doi.org/10.3390/su9050759

Chang, H.-S., Su, Q., and Katayama, T. (2021). Research on establishment of the region flood protection standard - a case of watershed of Dajiaxi, Taiwan. *Urban Water Journal*, *18*(3), 173–182. https://doi.org/10.1080/1573062X.2020.1864831

Colbert, J., Chuang, I.-T., and Sila-Nowicka, K. (2024). Measuring spatial inequality of urban park accessibility and utilisation: A case study of public housing developments in Auckland, New Zealand. *Landscape and Urban Planning*, *247*, 105070. https://doi.org/10.1016/j.landurbplan.2024.105070

Council, Auckland. 2013. *Auckland Unitary Plan Stormwater Management Provisions: Technical Basis of Contaminant and Volume Management Requirements*. Auckland Council technical report, TR2013/035. Prepared by Auckland Council. (access date: January 2025) https://knowledgeauckland.org.nz/media/1651/tr2013-035-auckland-unitary-plan-stormwater-management-provisions-no-appendices.pdf

Creswell, J. W. (2009). Mapping the field of mixed methods research. Journal of mixed methods research, 3(2), 95-108. https://doi.org/10.1177/1558689808330883

Dewa, O., Makoka, D., and Ayo-Yusuf, O. (2022). A Deliberative Rural Community Consultation to Assess Support for Flood Risk Management Policies to Strengthen Resilience in Malawi. *Water*, *14*(6), 874. https://doi.org/10.3390/w14060874

Dhakal, K. P., and Chevalier, L. R. (2016). Urban Stormwater Governance: The Need for a Paradigm Shift. *Environmental Management*, *57*(5), 1112–1124. https://doi.org/10.1007/s00267-016-0667-5

Dharmarathne, G., Waduge, A. O., Bogahawaththa, M., Rathnayake, U., and Meddage, D. P. P. (2024). Adapting cities to the surge: A comprehensive review of climate-induced urban flooding. *Results in Engineering*, *22*, 102123. https://doi.org/10.1016/j.rineng.2024.102123

Drescher, M., and Sinasac, S. (2021). Social-psychological Determinants of the Implementation of Green Infrastructure for Residential Stormwater Management. *Environmental Management*, *67*(2), 308–322. https://doi.org/10.1007/s00267-020-01393-3

Du, S., Shi, P., Van Rompaey, A., and Wen, J. (2015). Quantifying the impact of impervious surface location on flood peak discharge in urban areas. *Natural Hazards*, *76*(3), 1457–1471. https://doi.org/10.1007/s11069-014-1463-2

Ebrahimian, A., Wilson, B. N., and Gulliver, J. S. (2016). Improved methods to estimate the effective impervious area in urban catchments using rainfall-runoff data. *Journal of Hydrology*, *536*, 109–118. https://doi.org/10.1016/j.jhydrol.2016.02.023

Faruk, M. O., and Maharjan, K. L. (2022). Impact of Farmers' Participation in Community-Based Organizations on Adoption of Flood Adaptation Strategies: A Case Study in a Char-Land Area of Sirajganj District Bangladesh. *Sustainability*, *14*(14), 8959. https://doi.org/10.3390/su14148959

Fassman-Beck, E. A., Voyde, E. A., and Liao, M. (2013). *Defining Hydrologic Mitigation Targets for Stormwater Design in Auckland* (Auckland Council technical report 2013/024).

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., and Viklander, M. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, *12*(7), 525–542. https://doi.org/10.1080/1573062X.2014.916314

Fu, X., Bell, R., Reu Junqueira, J., White, I., and Serrao-Neumann, S. (2023). Managing rising residual flood risk: A national survey of Aotearoa-New Zealand. *Journal of Flood Risk Management*, *16*(4). https://doi.org/10.1111/jfr3.12944

Gao, B., Xu, Y., Sun, Y., Wang, Q., Wang, Y., and Li, Z. (2023). The impacts of impervious surface expansion and the operation of polders on flooding under rapid urbanization processes. *Theoretical and Applied Climatology*, *151*(3–4), 1215–1225. https://doi.org/10.1007/s00704-022-04318-8

García-Ayllón, S., and Franco, A. (2023). Spatial Correlation between Urban Planning Patterns and Vulnerability to Flooding Risk: A Case Study in Murcia (Spain). *Land*, *12*(3), 543. https://doi.org/10.3390/land12030543

Gnan, E., Friedland, C. J., Mostafiz, R. Bin, Rahim, M. A., Gentimis, T., Taghinezhad, A., and Rohli, R. V. (2022). Economically optimizing elevation of new, single-family residences for flood mitigation via life-cycle benefit-cost analysis. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.889239

Gnan, E., Friedland, C. J., Rahim, M. A., Mostafiz, R. Bin, Rohli, R. V., Orooji, F., Taghinezhad, A., and McElwee, J. (2022). Improved building-specific flood risk assessment and implications of depth-damage function selection. *Frontiers in Water*, *4*. https://doi.org/10.3389/frwa.2022.919726

Greenaway-McGrevy, R., and Phillips, P. C. B. (2023). The impact of upzoning on housing construction in Auckland. *Journal of Urban Economics*, *136*, 103555. https://doi.org/10.1016/j.jue.2023.103555

Guven, Huseyin, and Aysegul Tanik. 2020. "Water-Energy Nexus: Sustainable Water Management and Energy Recovery from Wastewater in Eco-Cities." *Smart and Sustainable Built Environment* 9(1):54–70. https://doi.org/10.1108/SASBE-07-2017-0030

Habib, Ahed, Abdulrahman Alnaemi, and Maan Habib. 2024. "Developing a Framework for Integrating Blockchain Technology into Earthquake Risk Mitigation and Disaster Management Strategies of Smart Cities." Smart and Sustainable Built Environment. https://doi.org/10.1108/SASBE-12-2023-0376.

Hameed, H. (2017). Estimating the Effect of Urban Growth on Annual Runoff Volume Using GIS in the Erbil Sub-Basin of the Kurdistan Region of Iraq. *Hydrology*, *4*(1), 12. https://doi.org/10.3390/hydrology4010012

Hammond, Ellis B., Frederic Coulon, Stephen H. Hallett, Russell Thomas, Drew Hardy, Andrew Kingdon, and Darren J. Beriro. 2021. "A Critical Review of Decision Support Systems for Brownfield

Redevelopment." *Science of the Total Environment* 785:147132. https://doi.org/10.1016/j.scitotenv.2021.147132

Harrington, L. J., Dean, S. M., Awatere, S., Rosier, S., Queen, L., Gibson, P. B., Barnes, C., Zachariah, M., Philip, S., Kew, S., Koren, G., Pinto, I., Grieco, M., Vahlberg, M., Snigh, R., Heinrich, D., Thalheimer, L., Li, S., Stone, D., … Otto, F. E. L. (2023). The role of climate change in extreme rainfall associated with Cyclone Gabrielle over Aotearoa New Zealand's East Coast. *Research Commons*. https://researchcommons.waikato.ac.nz/entities/publication/972141df-3269-4f8f-b9c6-3f4f01288892

Hermans, O. F. (2017). *Flood Management in New Zealand: Exploring Management and Practice in Otago and the Manawatu* [Masters degree]. University of Otago. (access date: February 2025) https://hdl.handle.net/10523/8172

Hou, Deyi, Abir Al-Tabbaa, David O'Connor, Qing Hu, Yong-Guan Zhu, Liuwei Wang, Niall Kirkwood, Yong Sik Ok, Daniel C. W. Tsang, and Nanthi S. Bolan. 2023. "Sustainable Remediation and Redevelopment of Brownfield Sites." *Nature Reviews Earth & Environment* 4(4):271–86. https://www.nature.com/articles/s43017-023-00404-1

Jayawardena, Iresh. 2024. "And Opportunities in Auckland's Urban Development." *Rethinking Stormwater Management Through Sustainable Urban Design* 153. https://link.springer.com/chapter/10.1007/978-981-97-4924-9_8

Jin, Y., Zhang, J., Liu, N., Li, C., and Wang, G. (2022). Geomatic-Based Flood Loss Assessment and Its Application in an Eastern City of China. *Water*, *14*(1), 126. https://doi.org/10.3390/w14010126

Joshi, P., Leitão, J. P., Maurer, M., and Bach, P. M. (2021). Not all SuDS are created equal: Impact of different approaches on combined sewer overflows. *Water Research*, *191*, 116780. https://doi.org/10.1016/j.watres.2020.116780

Li, Y., and Babcock, R. W. (2014). Green roof hydrologic performance and modeling: a review. *Water Science and Technology*, *69*(4), 727–738. https://doi.org/10.2166/wst.2013.770

Lin, Hongli, Yuming Zhu, Naveed Ahmad, and Qingye Han. 2019. "A Scientometric Analysis and Visualization of Global Research on Brownfields." *Environmental Science and Pollution Research* 26:17666–84. https://link.springer.com/article/10.1007/s11356-019-05149-3

Liu, W., Chen, W., and Peng, C. (2015). Influences of setting sizes and combination of green infrastructures on community's stormwater runoff reduction. *Ecological Modelling*, *318*, 236–244. https://doi.org/10.1016/j.ecolmodel.2014.11.007

Manchikatla, S. K., and Umamahesh, N. V. (2022). Simulation of flood hazard, prioritization of critical sub-catchments, and resilience study in an urban setting using PCSWMM: a case study. *Water Policy*, *24*(8), 1247–1268. https://doi.org/10.2166/wp.2022.291

Miller, J. D., and Hutchins, M. (2017). The impacts of urbanisation and climate change on urban flooding and urban water quality: A review of the evidence concerning the United Kingdom. *Journal of Hydrology: Regional Studies*, *12*, 345–362. https://doi.org/10.1016/j.ejrh.2017.06.006

Murphy, L. (2008). Third-wave Gentrification in New Zealand: The Case of Auckland. *Urban Studies*, *45*(12), 2521–2540. https://doi.org/10.1177/0042098008097106

Murphy, L. (2016). The politics of land supply and affordable housing: Auckland's Housing Accord and Special Housing Areas. *Urban Studies*, *53*(12), 2530–2547. https://doi.org/10.1177/0042098015594574

NZ CarbonNews. 2024. “New Record for NZ’s Costliest Weather Events”. (access date: January 2025) https://aon.co.nz/AonNZ/media/Docs/NZ_PressRelease_Climate-and-Catastrophe-report.pdf

Oertli, B., and Parris, K. M. (2019). Review: Toward management of urban ponds for freshwater biodiversity. *Ecosphere*, *10*(7). https://doi.org/10.1002/ecs2.2810

Omurakunova, G., Bao, A., Xu, W., Duulatov, E., Jiang, L., Cai, P., Abdullaev, F., Nzabarinda, V., Durdiev, K., and Baiseitova, M. (2020). Expansion of Impervious Surfaces and Their Driving Forces in Highly Urbanized Cities in Kyrgyzstan. *International Journal of Environmental Research and Public Health*, *17*(1), 362. https://doi.org/10.3390/ijerph17010362

Palermo, S. A., Talarico, V. C., and Turco, M. (2020). On the LID systems effectiveness for urban stormwater management: case study in Southern Italy. *IOP Conference Series: Earth and Environmental Science*, *410*(1), 012012. https://doi.org/10.1088/1755-1315/410/1/012012

Phillips, C., Marden, M., and Basher, L. R. (2018). Geomorphology and forest management in New Zealand’s erodible steeplands: An overview. *Geomorphology*, *307*, 107–121. https://doi.org/10.1016/j.geomorph.2017.07.031

Prakash, C., Barthwal, A., and Acharya, D. (2023). FLOODWALL: A Real-Time Flash Flood Monitoring and Forecasting System Using IoT. *IEEE Sensors Journal*, *23*(1), 787–799. https://doi.org/10.1109/JSEN.2022.3223671

Przestrzelska, K., Wartalska, K., Rosińska, W., Jurasz, J., and Kaźmierczak, B. (2024). Climate Resilient Cities: A Review of Blue-Green Solutions Worldwide. *Water Resources Management*, *38*(15), 5885–5910. https://doi.org/10.1007/s11269-024-03950-5

Puttinaovarat, S., and Horkaew, P. (2020). Flood Forecasting System Based on Integrated Big and Crowdsource Data by Using Machine Learning Techniques. *IEEE Access*, *8*, 5885–5905. https://doi.org/10.1109/ACCESS.2019.2963819

Qian, Y., and Wu, Z. (2019). Study on Urban Expansion Using the Spatial and Temporal Dynamic Changes in the Impervious Surface in Nanjing. *Sustainability*, *11*(3), 933. https://doi.org/10.3390/su11030933

Qin, Y. (2020). Urban Flooding Mitigation Techniques: A Systematic Review and Future Studies. *Water*, *12*(12), 3579. https://doi.org/10.3390/w12123579

Rosenberger, L., Leandro, J., Pauleit, S., and Erlwein, S. (2021). Sustainable stormwater management under the impact of climate change and urban densification. *Journal of Hydrology*, *596*, 126137. https://doi.org/10.1016/j.jhydrol.2021.126137

Salehi, F., Najarchi, M., Najafizadeh, M. M., and Hezaveh, M. M. (2022). Multistage Models for Flood Control by Gated Spillway: Application to Karkheh Dam. *Water*, *14*(5), 709. https://doi.org/10.3390/w14050709

Sarigul, Fatma Handan, and Husnu Murat Gunaydin. 2025. “Integrated BIM, GIS and Interoperable Digital Technologies in Lifecycle Management of Building Construction Projects: Systematic Literature Review.” Smart and Sustainable Built Environment. https://doi.org/10.1108/SASBE-08-2024-0312.

Scawthorn, C., Flores, P., Blais, N., Seligson, H., Tate, E., Chang, S., Mifflin, E., Thomas, W., Murphy, J., Jones, C., and Lawrence, M. (2006). HAZUS-MH Flood Loss Estimation Methodology. II. Damage and Loss Assessment. *Natural Hazards Review*, *7*(2), 72–81. https://doi.org/10.1061/(ASCE)1527-6988(2006)7:2(72)

Shao, Z., Cheng, T., Fu, H., Li, D., and Huang, X. (2023). Emerging Issues in Mapping Urban Impervious Surfaces Using High-Resolution Remote Sensing Images. *Remote Sensing*, *15*(10), 2562. https://doi.org/10.3390/rs15102562

Silva, C. (2018). Auckland's Urban Sprawl, Policy Ambiguities and the Peri-Urbanisation to Pukekohe. *Urban Science*, *3*(1), 1. https://doi.org/10.3390/urbansci3010001

Sohn, W., Kim, J.-H., and Li, M.-H. (2017). Low-impact development for impervious surface connectivity mitigation: assessment of directly connected impervious areas (DCIAs). *Journal of Environmental Planning and Management*, *60*(10), 1871–1889. https://doi.org/10.1080/09640568.2016.1264929

Sperotto, A., Torresan, S., Gallina, V., Coppola, E., Critto, A., and Marcomini, A. (2016). A multi-disciplinary approach to evaluate pluvial floods risk under changing climate: The case study of the municipality of Venice (Italy). *Science of The Total Environment*, *562*, 1031–1043. https://doi.org/10.1016/j.scitotenv.2016.03.150

Stillwell, C. C., Hunt, W. F., Page, J. L., Baird, J. B., and Kennedy, S. G. (2018). Stormwater management in nutrient-sensitive watersheds: a case study investigating impervious cover limits and pollutant-load regulations. *Water Science and Technology*, *78*(3), 664–675. https://doi.org/10.2166/wst.2018.338

Taghinezhad, A., Friedland, C. J., Rohli, R. V., and Marx, B. D. (2020). An Imputation of First-Floor Elevation Data for the Avoided Loss Analysis of Flood-Mitigated Single-Family Homes in Louisiana, United States. *Frontiers in Built Environment*, *6*. https://doi.org/10.3389/fbuil.2020.00138

Tang, S., Luo, W., Jia, Z., Liu, W., Li, S., and Wu, Y. (2016). Evaluating Retention Capacity of Infiltration Rain Gardens and Their Potential Effect on Urban Stormwater Management in the Sub-Humid Loess Region of China. *Water Resources Management*, *30*(3), 983–1000. https://doi.org/10.1007/s11269-015-1206-5

Twohig, C., Casali, Y., and Aydin, N. Y. (2022). Can green roofs help with stormwater floods? A geospatial planning approach. *Urban Forestry and Urban Greening*, *76*, 127724. https://doi.org/10.1016/j.ufug.2022.127724

Veról, A. P., Bigate Lourenço, I., Fraga, J. P. R., Battemarco, B. P., Linares Merlo, M., Canedo de Magalhães, P., and Miguez, M. G. (2020). River Restoration Integrated with Sustainable Urban Water Management for Resilient Cities. *Sustainability*, *12*(11), 4677. https://doi.org/10.3390/su12114677

Wang, J., Zhang, S., and Guo, Y. (2019). Analyzing the Impact of Impervious Area Disconnection on Urban Runoff Control Using an Analytical Probabilistic Model. *Water Resources Management*, *33*(5), 1753–1768. https://doi.org/10.1007/s11269-019-02211-0

Wang, R.-Q. (2021). Artificial Intelligence for Flood Observation. In *Earth Observation for Flood Applications* (pp. 295–304). Elsevier. https://doi.org/10.1016/B978-0-12-819412-6.00013-4

Wu, W., Jamali, B., Zhang, K., Marshall, L., and Deletic, A. (2023). Water Sensitive Urban Design (WSUD) Spatial Prioritisation through Global Sensitivity Analysis for Effective Urban Pluvial Flood Mitigation. *Water Research*, *235*, 119888. https://doi.org/10.1016/j.watres.2023.119888

Zapata-Diomedi, Belén, Claire Boulangé, Billie Giles-Corti, Kath Phelan, Simon Washington, J. Lennert Veerman, and Lucy Dubrelle Gunn. 2019. "Physical Activity-Related Health and Economic Benefits of Building Walkable Neighbourhoods: A Modelled Comparison between Brownfield and Greenfield Developments." *International Journal of Behavioral Nutrition and Physical Activity* 16:1–12. https://link.springer.com/article/10.1186/s12966-019-0775-8

Zhang, H., Cheng, J., Wu, Z., Li, C., Qin, J., and Liu, T. (2018). Effects of Impervious Surface on the Spatial Distribution of Urban Waterlogging Risk Spots at Multiple Scales in Guangzhou, South China. *Sustainability*, *10*(5), 1589. https://doi.org/10.3390/su10051589

Zhou, S., Zhang, D., Wang, M., Liu, Z., Gan, W., Zhao, Z., Xue, S., Müller, B., Zhou, M., Ni, X., and Wu, Z. (2024). Risk-driven composition decoupling analysis for urban flooding prediction in high-density urban areas using Bayesian-Optimized LightGBM. *Journal of Cleaner Production*, *457*, 142286. https://doi.org/10.1016/j.jclepro.2024.142286

Navigating Urban Hydrology: A Comprehensive Exploration of Impervious Area Reduction Techniques in New Zealand's Residential Landscapes

Abstract

Purpose: Impervious surfaces have emerged as a critical indicator for assessing the impacts of urbanisation on water resources, with recent flood events in New Zealand (NZ) highlighting their significance in urban water management. While traditional stormwater control measures rely on total impervious area calculations, this study examined the effectiveness of impervious area reduction techniques in residential areas across NZ, with particular attention to implementation challenges and policy frameworks.

Design/methodology/approach: The research was conducted through semi-structured interviews with 18 experts, including government officials, consultants, and developers. This qualitative approach allowed for an in-depth exploration of various perspectives on urban water management strategies and their effectiveness.

Findings: The study revealed several key findings: (1) Current strategies exhibit varying effectiveness depending on scale, with catchment-level solutions being more successful than site-specific interventions; (2) Significant challenges to implementation exist, such as resource constraints, limited monitoring capabilities, and coordination issues among stakeholders; and (3) There is a need for stronger national-level guidance and better integration in regulatory frameworks between district and regional plans.

Originality: This research contributes to the existing knowledge on urban flood resilience by identifying promising opportunities for improvement in urban water management practices in New Zealand. It emphasises the importance of enhanced public education, innovative technical solutions, and market-based incentives as practical recommendations for policymakers and practitioners.

Keywords: Impervious surfaces, impervious area, reduction strategies, residential areas and New Zealand

1. Introduction

Floods are among the most severe and frequent natural disasters, causing significant human and economic losses worldwide (Sastry 2021; Tate et al. 2016). For example, the 2023 Auckland Anniversary flooding incurred NZD $5.57 billion of economic loss and NZD $2.23 billion of insured loss, followed by Cyclone Gabrielle, which caused NZD $6.4 billion in economic loss and NZD $2.02 billion in insured loss (NZ CarbonNews 2024). The impact of these events was widespread, with more than 55,000 insurance claims resulting from Cyclone Gabrielle alone, reflecting the displacement of entire communities and disruption of businesses (NZ CarbonNews 2024). Despite the extensive research on flood risk and loss assessments (Afifi et al. 2019; Jin et al. 2022; Scawthorn et al. 2006), as well as the value of implementing mitigation strategies to decrease flood risk (Gnan, Friedland, Mostafiz, et al. 2022; Gnan, Friedland, Rahim, et al. 2022; Taghinezhad et al. 2020), there remains a need for a comprehensive analysis of how green infrastructure, permeable pavements and zoning regulations contribute to mitigating flood risks in diverse urban settings. Existing literature highlights the importance of evaluating flood risk both within and outside designated high-risk areas (Auliagisni, Wilkinson, and Elkharboutly 2022; Fu et al. 2023). This comprehensive approach is essential for developing effective flood-mitigation strategies. In addition to quantifying the reduction in flood risk, the long-term evaluation of the benefits and costs associated with home elevation, in conjunction with the consideration of impervious surfaces, is an important step in determining the most effective and cost-efficient solutions (Hermans, 2017; Twohig et al., 2022; Wu et al., 2023).

Impervious surfaces represent a critical nexus between urbanization and hydrological dysfunction, fundamentally altering natural water cycles in ways that extend far beyond simple runoff calculations (Al-Khuzaie et al., 2023; Gao et al., 2023). These hard surfaces including asphalt roads, buildings, and parking lots serve as both diagnostic indicators of urban intensity and primary drivers of watershed degradation, making them essential parameters in hydrological modelling and urban water management frameworks. The proliferation of impervious surfaces accompanies virtually all forms of urban development, creating a direct causal relationship between city expansion and ecosystem disruption (Du et al., 2015). The hydrological consequences of impervious surface expansion manifest across multiple scales and timeframes. At the watershed level, Bera et al. (2022) documented fundamental alterations to runoff patterns, peak discharge rates, and base flow characteristics that cascade through entire drainage systems, ultimately reshaping stream morphology and thermal regimes. These physical changes compound with chemical impacts, as Zhang et al. (2018) demonstrated that impervious surfaces facilitate the transport of concentrated nutrient and pollutant loads directly into waterways, creating a dual threat of hydraulic stress and water quality degradation that severely compromises aquatic biodiversity.

Despite growing recognition of these impacts, a critical knowledge gap persists regarding the effectiveness of impervious area reduction strategies in real-world implementation contexts. While technical literature extensively documents the theoretical potential of various reduction approaches (Shao et al., 2023; Stillwell et al., 2018), empirical evidence of their practical performance particularly in complex institutional environments like New Zealand remains limited. This gap is particularly pronounced for residential areas, which constitute the largest component of urban impervious coverage yet receive less systematic analysis than commercial or industrial developments. The challenge extends beyond technical implementation to fundamental questions of governance, stakeholder coordination, and long-term maintenance factors that determine whether theoretically sound strategies translate into measurable environmental improvements. Existing research typically examines individual techniques in isolation rather than evaluating integrated approaches within realistic regulatory and resource constraints. This disconnects between technical capability and implementation effectiveness represents a critical barrier to achieving meaningful flood risk reduction and sustainable water management outcomes.

This study addresses these knowledge gaps by examining the effectiveness of impervious surface reduction techniques within New Zealand's specific regulatory, environmental, and institutional context. Focusing on residential areas where implementation challenges are most complex and stakeholder coordination most critical, this research contributes essential insights for translating technical knowledge into practical flood mitigation strategies that can function effectively within real-world constraints. The subsequent sections of this paper are organized as follows: Section 2 provides a detailed literature review that explores the role of impervious surfaces as environmental indicators, the regulatory frameworks governing their management, and delineates the differences between brownfield and greenfield development contexts within the context of Auckland's intensification strategy. Section 3 outlines the qualitative methodology employed in this study, including the semi-structured interview approach and the thematic analysis used to investigate expert perspectives from the government, consulting, and development sectors. Section 4 presents the research findings, categorized into five principal themes: current techniques of impervious area, associated challenges, policy and regulatory framework, monitoring and compliance and recommendations for improvement. Section 5 addresses the broader implications of these findings for urban water management policy, emphasizing the scale-dependent effectiveness of interventions and the essential role of institutional coordination in facilitating successful implementation. Finally, Section 6 concludes with practical recommendations for policymakers and practitioners, identifies future research opportunities, and discusses the applicability of the findings to other jurisdictions experiencing comparable urban intensification challenges.

2. Literature review

2.1 Introduction

In recent years, New Zealand has seen a significant rise in flooding incidents, particularly severe events in Auckland and Hawke's Bay in 2023, underscoring the vulnerability of urban areas to extreme weather (García-Ayllón and Franco, 2023; Zhou et al., 2024). The increasing frequency and severity of severe floods, intensified by climate change, present substantial threats to residential zones and essential infrastructure (Dharmarathne et al., 2024; Sperotto et al., 2016). The devastating floods in Auckland in January 2023, with projected damage exceeding NZD $5 billion, highlight the critical need for improved flood resilience solutions (NZ CarbonNews, 2024). Such solutions align with the United Nations Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 6 (Clean Water and Sanitation), while contributing to the broader importance of building adaptive capacities for climate-resilient development pathways.

The proliferation of impervious surfaces in urban areas has emerged as a critical factor contributing to increased flood risk due to urbanization. For example, Omurakunova et al. (2020) reported that the impervious surface area increases of 35-75% in selected cities from 1993 to 2017. Similarly, Qian and Wu (2019) noted that the impervious surface area in Nanjing has increased dramatically from 427.36 km2 to 1780.21 km2 over three decades. It is worth noting that different urban zones can have varying levels of impervious surface coverage. For instance, Hua et al. (2020) indicated that industrial zones and urban villages tend to be the greatest contributors to impervious surfaces. These impervious surfaces, including roofs, driveways, and pavements, reduce water infiltration and accelerate stormwater runoff, which is particularly challenging in New Zealand's steep topography and high rainfall environment (Phillips et al., 2018). The relationship between imperviousness and flood risk is particularly pronounced in New Zealand's urban settings, where steep topography and high-intensity rainfall events combine to amplify the impact of reduced natural drainage (Harrington et al., 2023).

The growing recognition of these challenges has prompted increased attention to impervious area reduction techniques as key strategies for enhancing flood resilience (Habib, Alnaemi, and Habib 2024). While traditional stormwater management approaches focus primarily on rapid drainage through engineered systems, contemporary solutions emphasize the importance of mimicking natural hydrological processes (Dhakal and Chevalier, 2016). These methods, including permeable pavements, rain gardens, and green roofs, present significant potential for mitigating flood risks while providing supplementary environmental and social benefits (Qin, 2020).

2.2 *Theoretical frameworks*

Contemporary urban flood management has fundamentally shifted from traditional drainage-centric approaches toward integrated frameworks that address impervious surfaces as complex hydrological, environmental, and social challenges (Sarigul and Gunaydin 2025). This theoretical evolution reflects growing recognition that conventional engineering solutions alone cannot address the multifaceted impacts of urbanization on water systems and community resilience. Urban hydrology theory provides the foundational understanding of how impervious surfaces fundamentally alter natural water cycles through disrupted infiltration, increased surface runoff, and modified evapotranspiration processes (Hameed, 2017). Empirical evidence demonstrates the magnitude of these changes, with urbanization increasing runoff volumes by up to 85% over three decades due to expanded impervious coverage (Hameed, 2017; Miller and Hutchins, 2017). This dramatic alteration of hydrological processes creates cascading effects throughout urban watersheds, affecting flood frequency, stream morphology, and ecosystem health.

Three complementary theoretical frameworks guide contemporary impervious area reduction strategies in New Zealand's context. Low Impact Design (LID) philosophy emphasizes maintaining pre-development hydrological conditions through distributed interventions that restore natural processes including infiltration, detention, and evapotranspiration (Fassman-Beck et al., 2013). This approach prioritizes source control mechanisms that address stormwater at its point of generation rather than relying on centralized infrastructure solutions. The Sustainable Urban Drainage Systems (SUDS) framework builds upon LID principles by establishing a hierarchical management approach progressing from source control through site control to regional interventions (Fletcher et al., 2015). This framework recognizes that effective stormwater management requires coordinated interventions across multiple spatial scales, from individual properties to catchment-wide systems.

Water Sensitive Urban Design (WSUD) represents the most comprehensive framework, integrating water cycle management with broader urban planning objectives to deliver multifunctional benefits including flood resilience, water quality improvement, biodiversity enhancement, and increased urban amenity value (Przestrzelska et al., 2024; Veról et al., 2020). WSUD emphasizes the co-benefits of impervious area reduction, demonstrating how environmental interventions can simultaneously address social, economic, and ecological objectives (Guven and Tanik 2020). These theoretical frameworks collectively support the transition from reactive infrastructure solutions to proactive, nature-based approaches that treat impervious area reduction as an integral component of sustainable urban development. This paradigmatic shift underpins contemporary policy approaches to residential flood resilience in New Zealand's rapidly urbanizing environment.

It has emerged that the effective techniques for reducing impervious areas and managing stormwater runoff in urban environments are low-impact development (LID) solutions and green infrastructure (Habib et al. 2024). These include permeable pavements, green roofs, rain gardens, bioretention cells, and rain barrels (Abi Aad et al. 2010; Liu et al. 2015; Palermo et al. 2020). Studies have shown that implementing LID practices can significantly reduce runoff volume and peak flow rates and delay peak flow times. For instance, green roofs can reduce stormwater runoff volume by 30-86% and peak flow rate by 22-93% (Li and Babcock, 2014). Rain gardens have demonstrated flow reduction rates of 77-94% for overflow events (Tang et al., 2016). The effectiveness of these techniques is influenced by factors such as the precipitation volume, antecedent conditions, growth medium, plant species, and roof slope (Li and Babcock, 2014). Interestingly, a combination of LID practices can yield optimal results. For example, integrating green infrastructure with proper sizing can achieve 100% runoff reduction for 5-year recurrence storms by expanding the pervious area percentage to over 50% or increasing the storage pond volume to over 1800 m3 (Liu et al., 2015). Additionally, disconnecting impervious areas from drainage networks has been shown to significantly contribute to runoff reduction (Wang et al., 2019). LID and green infrastructure techniques have proven effective in reducing impervious areas and managing stormwater runoff. These approaches not only mitigate environmental problems but also offer cost-effective solutions compared to traditional stormwater management methods. For instance, implementing Sustainable Urban Drainage Systems (SuDS) can reduce combined sewer overflows by 50-99% at a fraction of the cost of large CSO tanks (Joshi et al., 2021). As urbanization continues to increase, the adoption of these techniques is crucial for sustainable urban development and stormwater management. These techniques also contribute to improving urban aesthetics and enhancing the biodiversity in cities (Oertli and Parris, 2019). By incorporating green spaces and natural elements into urban landscapes, LID and green infrastructure can create more liveable and resilient communities. Moreover, these strategies can alleviate the urban heat island phenomenon, enhance air quality, and offer recreational options for inhabitants.

2.3 Residential area impervious reduction techniques: Policy and regulatory frameworks

To address impervious area reduction in residential areas in Auckland, New Zealand has implemented various policies and regulatory frameworks. The city of Auckland has taken steps towards more sustainable urban development, including upzoning to facilitate the construction of more intensive housing (Greenaway-McGrevy and Phillips, 2023). This approach can potentially lead to a reduction in impervious areas by promoting high-density development. In terms of waste management and pollution prevention, New Zealand's framework has been criticized for being vague and lacking (Boyle 2000). This suggests that there may be room for improvement in policies addressing impervious area reduction as part of broader environmental management strategies. Interestingly, Silva (2018) highlighted that despite regulations to control urban sprawl, such as establishing restricted areas for expansion, these measures have not been entirely successful. The paper points out that there is planning "ambiguity" in Auckland, which may contribute to urban sprawl and, consequently, increased impervious surfaces in residential areas. Although not specific to Auckland, Sohn et al. (2017) provide insights into the effectiveness of low-impact development (LID) in reducing directly connected impervious areas (DCIA). The study found that the percentage of DCIA reduction by LID varied by land-use type, and optimal combinations of LID applications could maximize the effectiveness of DCIA reduction. These findings could be relevant for policymakers in Auckland implementing similar strategies. While Auckland has implemented policies aimed at sustainable urban development, there appears to be a need for more targeted and effective regulatory frameworks to address impervious area reductions in residential areas. To maximize directly connected impervious area reduction (DCIA), future policies could benefit from incorporating LID practices and focusing on optimal combinations of strategies.

2.4 Residential area impervious reduction techniques: implementation challenges, barriers and opportunities

The implementation of impervious area reduction techniques in residential areas in Auckland, New Zealand, encounters numerous challenges, barriers, and opportunities. The city's urban growth management strategy, focused on "liveability" and a "quality compact city," has led to the development of high-density housing typologies within existing suburban areas (Allen, 2015). This approach presents challenges and opportunities for reducing impervious areas. While high-density housing may increase impervious surfaces, it also provides opportunities for innovative stormwater management solutions. One significant barrier is the tension between local government planning practices, which emphasize urban sustainability and housing intensification, and central government housing policies that prioritize land supply and housing affordability (Murphy, 2016). This conflict can hinder the implementation of green infrastructure and impervious area reduction techniques, as the focus may shift towards rapid housing development rather than sustainable urban design. Despite these challenges, there are opportunities to implement impervious area-reduction techniques in Auckland. The city's engagement with neo-liberalism has resulted in the revalorization of inner-city areas, which could potentially include green infrastructure initiatives (Murphy, 2008). Additionally, the growing concern over air quality and pollutants in urban areas (Boamponsem et al., 2024) may drive support for green infrastructure solutions that can help mitigate these issues while reducing impervious surfaces. Policymakers and urban planners must address implementation barriers by examining the trade-offs residents encounter in selecting housing typologies and their valuation of urban amenities (Allen, 2015). It is essential that techniques for reducing impervious areas correspond with residents' preferences and enhance overall neighbourhood satisfaction.

2.5 Brownfield vs. Greenfield Development: Impervious Area Management in Auckland's Intensification Context

Auckland's urban intensification occurs through two distinct mechanisms that present fundamentally different challenges for managing impervious areas. Brownfield redevelopment involves demolishing existing housing and constructing higher-density developments on previously developed sites, while greenfield development represents original construction on undeveloped land (Zapata-Diomedi et al. 2019). These contexts create substantially different opportunities and constraints for implementing impervious area reduction strategies. Brownfield redevelopment in Auckland presents unique impervious area challenges despite offering broader urban sustainability benefits (Jayawardena 2024). While brownfield projects generally deliver economic viability and enhanced walkability compared to greenfield alternatives (Zapata-Diomedi et al. 2019), the specific context of impervious surface management reveals significant constraints. Existing infrastructure, property boundaries, and underground utilities limit opportunities for implementing comprehensive stormwater management systems. The demolition-reconstruction process often results in maximized site coverage to achieve economic viability, potentially increasing impervious coverage beyond original levels despite regulatory limits (Aernouts, Maranghi, and Ryckewaert 2020).

Contemporary scholarship emphasizes that cost-effectiveness comparisons between development approaches must incorporate environmental outcomes, including stormwater management performance (De Sousa 2004). However, Auckland's experience suggests that achieving impervious area reduction targets in brownfield contexts requires innovative space-efficient solutions rather than traditional extensive green infrastructure approaches. The "often-central location" advantage of brownfield sites (Lin et al. 2019) creates opportunities for strategic catchment-scale interventions, but individual site constraints necessitate alternative implementation strategies. Greenfield development contexts in Auckland offer greater flexibility for integrating comprehensive impervious area reduction strategies from project inception. Unlike brownfield sites where "toxic contaminants from prior work on the land" may constrain intervention options (Hou et al. 2023), greenfield developments enable systematic water-sensitive urban design implementation. However, market pressures and density requirements under Auckland's planning framework can compromise impervious area objectives even when physical constraints are minimal.

The regulatory framework struggles to differentiate effectively between these contexts. Auckland's Unitary Plan applies relatively uniform impervious area limits across different development types, potentially failing to account for the distinct constraints and opportunities each context presents (Council 2013). Recent research suggests that jurisdictions require "standardized evaluation criteria specifically calibrated to local environmental, economic, and cultural contexts" (Burinskienė et al. 2017) that recognize these fundamental differences. Advanced decision support systems incorporating geospatial analysis could enhance planning responses to these differential contexts (Hammond et al. 2021). For Auckland's intensification strategy, this suggests developing context-specific impervious area management approaches that recognize brownfield constraints while maximizing greenfield opportunities, rather than applying uniform solutions across fundamentally different development environments.

3. Methods

This qualitative study is grounded in constructivist epistemology, which recognizes that knowledge emerges through the interaction between researchers and participants, emphasizing the socially constructed nature of understanding (Creswell, 2009). This philosophical foundation acknowledges that research participants' experiences and interpretations of impervious area reduction strategies are shaped by their professional contexts, institutional environments, and lived experiences within New Zealand's urban water management sector. The research design employed an interpretive framework that prioritizes understanding how experts make sense of implementation challenges, policy constraints, and technical effectiveness within their specific organizational and regulatory contexts. This approach recognizes that flood mitigation strategies operate within complex socio-technical systems where success depends not only on engineering performance but also on institutional capacity, stakeholder coordination, and community acceptance.

Semi-structured interviews served as the primary data collection method, enabling exploration of participants' experiences while maintaining sufficient flexibility to pursue emergent themes and unexpected insights. Interview participants were selected based on their direct involvement in impervious area reduction implementation across government agencies, consulting firms, and development organizations, ensuring diverse perspectives on both policy development and practical implementation challenges.The interview process was designed to facilitate reflective discourse through informal settings and extended duration (over one hour), allowing participants to articulate complex relationships between technical, institutional, and political factors that influence strategy effectiveness. All interviews were recorded, transcribed, and subjected to content analysis. Following a thorough examination of the interview transcripts, the researchers identified recurring themes derived from shared ideas and perspectives with coding based on the participants' responses. This study received approval from the XXX University of Technology Ethics Committee (AUTEC) under reference number 24/70. The approval covered the recruitment process, participant information and consent procedures, data collection through interviews, and data management protocols. There were no specific conditions attached beyond compliance with AUTEC's standard requirements for confidentiality, voluntary participation, and secure data storage.

The interview transcripts were subjected to a detailed review to guarantee the accuracy and coherence of the respondents' statements, thus enabling data triangulation and source validation.

Qualitative data obtained from participants were examined using ATLAS.ti 9 software, which aided in the organization, interpretation, and evaluation of the textual material. After an initial exploration of the data, the researchers applied the open coding function of ATLAS.ti 9 to identify pivotal words, phrases, and relevant keywords related to the topic at hand. The number of interviews was deliberately constrained until a saturation point was reached. For a detailed overview of the participants, see Table 1, the demographics of the participants. This thorough qualitative methodology allowed researchers to develop a deep understanding of the effectiveness of impervious area reduction techniques in residential settings, drawing insights directly from the experiences and perspectives of informed stakeholders.

The participants selected for this study held high-ranking positions within their respective organizations, with over ten years of tenure, and possessed higher educational backgrounds, indicating their substantial knowledge and extensive experience within the NZ construction industry (see Table 1, Demography of Participants). The qualitative data analysis process was conducted systematically to gain a deep understanding of participants' meanings and experiences, following the guidelines outlined by Creswell (2009) and explained in Figure 1. The qualitative data analysis began by identifying key phrases and expressions from participant interviews that examine the effectiveness of impervious area reduction techniques in residential areas of NZ. These phrases, including direct participant quotations, guided the systematic categorization of data during the initial analysis phase. Given time constraints and the researcher's bilingual expertise, both manual and electronic coding methods were employed using Microsoft Word and ATLAS.ti 9, ensuring comprehensive analysis while maintaining efficiency (Basit, 2003). Following Creswell's (2009) framework, the analysis proceeded through five systematic stages. First (Stage 1), raw interview transcripts were organized into folders for structured analysis. Second (Stage 2), multiple readings of each transcript and accompanying field notes facilitated a deep understanding of participants' awareness and comprehension regarding the effectiveness of impervious area reduction techniques in residential areas of NZ. Third (Stage 3), the Cut-and-Paste method (Stewart et al., 2007) was employed to identify significant text segments relevant to the research questions for transcript analysis. Fourth, using ATLAS.ti 9, color-coded symbols distinguished between themes and networks within the text, with key words, phrases, sentences, and paragraphs systematically identified and categorized. In stage 4, major thematic classifications emerged from preliminary readings, with relevant transcript passages highlighted and organized according to each identified theme. This systematic approach enabled a comprehensive understanding of participants' meanings and experiences while maintaining analytical rigour throughout the coding process.

***Table 1**: Demography of Participants (Source: Authors' own work)*

***Figure 1.** Qualitative Analysis Framework and Procedures (Source: Authors' own work)*

An inductive approach ensured no data was pre-coded, allowing concepts to emerge naturally from participants' expressions within their contextual performance. Researchers closely examined participant language to identify key concepts related to effectiveness of impervious area reduction techniques in residential areas of NZ. In stage 5, identified elements were analysed and organized into primary themes based on their correlations with impervious area reduction techniques in residential areas of NZ. The researcher reviewed all interview transcripts to identify essential phrases and statements explaining categories that became the key variables of the preliminary research model. Following complete coding, materials were systematically categorized using coded transcripts, gathering all items relevant to each key subject for final interpretive analysis. This process, facilitated by Microsoft Word and ATLAS.ti 9, generated multiple distinct codes. Due to resource constraints and to eliminate inter-coder bias, all interview data was thematically analysed and coded by the researcher, who had conducted all interviews and possessed comprehensive understanding of emerging themes.

4. Results and Discussions

This section presents the research findings derived from qualitative interviews. The results are organized into five principal thematic categories that emerged from the analysis: (1) current techniques of impervious area, (2) challenges and barriers to effective implementation, (3) policy and regulatory framework considerations, (4) monitoring and compliance mechanisms, and (5) evidence-based recommendations for improvement. Each theme is examined in detail, with findings presented alongside relevant discussion and interpretation in relation to the existing literature and research objectives.

4.1 Current techniques of impervious area

The growing awareness of the intricacy of urban water systems is reflected in the development of impervious area management. As noted by P-1, the field has progressed from ad-hoc approaches to more structured frameworks, incorporating water-sensitive urban design (WSUD) principles with sophisticated spatial prioritization strategies (Wu et al., 2023). This evolution is particularly evident in the regulatory landscape. As P-9 explained, "The Auckland Unitary Plan sets specific restrictions limiting impervious areas to 60-70% of total site area in new developments, but the practical implementation of these controls faces significant hurdles." This participant further noted that "*insufficient funding for compliance monitoring undermines the effectiveness of existing regulations, making it difficult to ensure adherence to impervious surface limits*." The implementation of reduction techniques has resulted in significant advancements in both theory and practice. Green infrastructure components including swales, wetlands, and green roofs have emerged as fundamental elements of modern urban water management. Recent research by Al-Khuzaie et al. (2023) demonstrated the practical success of these approaches in flood reduction, whereas P-3's findings highlight the effectiveness of comprehensive solutions incorporating living roofs, rain gardens, and permeable paving options.

However, the transition from theoretical models to practical implementation has revealed important challenges. Twohig et al. (2022) identify a notable implementation gap, where real-world results often fall short of theoretical projections. This disparity is particularly pronounced in brownfield developments, where spatial constraints and existing infrastructure present significant challenges to integrating green infrastructure solutions. P-6 further emphasizes the complex balance required between housing yield priorities and impervious area requirements, stating: "*The unitary plan's maximum impervious area requirements must balance against housing yield priorities, particularly in urban areas. While greenfield developments offer more opportunities for implementation, brownfield developments present significant challenges, especially for integrating green infrastructure within small lots in established residential areas.*" This participant elaborated on the practical constraints, noting that "*the adoption of pervious paving, rainwater reuse tanks, and green roofs remain limited, and bioretention systems are particularly challenging to implement in brownfield developments due to space constraints and existing infrastructure.*"

Despite these challenges, innovative solutions have continued to emerge. P-14 describes the development of comprehensive frameworks, "*Our approach relies on planning rules and consent requirements where property owners must obtain resource consent when exceeding permitted impervious area thresholds, ensuring proper assessment and management of stormwater impacts.*" This participant further detailed how "*the strategy aligns with broader Council policies focused on climate change adaptation*" and extends beyond individual properties to include "*public spaces like roads, promoting green space and permeable landscaping to enhance stormwater absorption and mitigate urban heat island effects.*" These approaches are complemented by sophisticated green infrastructure solutions, as outlined by P-15, which integrate traditional water knowledge with modern techniques (Asad et al., 2022). Developer-led initiatives, as described by P-16, demonstrate the potential of combining semi-pervious solutions with Low Impact Design principles, achieving measurable success in reducing post-development water flows to 80% of pre-development levels.

Quantifiable evidence supports the effectiveness of these reduction techniques. Research indicates that green roof implementations can reduce stormwater runoff volume by 30-86% (Li and Babcock, 2014), whereas rain gardens achieve flow reduction rates of 77-94% for overflow events (Tang et al., 2016). More significantly, integrated approaches that combine multiple techniques have demonstrated the potential for complete runoff reduction under certain conditions (Liu et al., 2015). These solutions are often more cost-effective than traditional approaches, with Sustainable Urban Drainage Systems (SuDS) reducing combined sewer overflows by 50-99% at lower costs than conventional solutions (Joshi et al., 2021). This field has continued to evolve with technological advancements. Wang (2021) and Puttinaovarat and Horkaew (2020) highlight the potential of AI-enabled monitoring systems and machine learning in flood forecasting, though resource constraints currently limit widespread implementation. P-11 described how catchment management works in New Zealand…. "*Most catchments operate without specific management plans, instead relying on district and regional plan policies and rules*." The participant explained that "*larger councils like Christchurch and Auckland have more capacity for catchment-wide approaches*" compared to smaller councils with limited resources.

Several key areas require further attention to advance the field. First, spatial planning in WSUD implementation must be prioritized with a particular focus on developing specific strategies for brownfield development challenges. Second, monitoring and enforcement mechanisms need to be strengthened and supported by investment in advanced technologies. Finally, there is a critical need to develop comprehensive approaches for existing impervious areas to balance development needs with flood resilience requirements. The successful management of urban water systems ultimately requires a holistic approach that recognizes the interconnected nature of the built and natural environments. The integration of multiple reduction techniques, strengthening regulatory frameworks, and investing in innovative solutions can help communities create more resilient urban environments that effectively manage increasing climate pressures while supporting sustainable development goals. In addition to meeting urgent flood control needs, this integrated approach promotes broader environmental and social benefits, such as reducing urban heat islands, enhancing biodiversity, and making cities more livable. Figure 2 presents the detailed framework of the impervious surface reduction techniques that are currently in use.

Figure 2: *Current techniques identified for reducing impervious areas (Source: Authors' own work)*

4.2 Associated challenges to impervious area reduction techniques

There is a complicated interaction between effectiveness, challenges, and opportunities when implementing impervious area reduction techniques in urban environments, especially in Auckland's unique context. As cities deal with intensifying development pressures and environmental imperatives, understanding this landscape is crucial for developing sustainable urban water management strategies. The effectiveness of these techniques demonstrates a significant variation across different scales and contexts. While catchment-scale solutions, such as designed wetlands, show promising results, small-scale interventions often struggle to have a meaningful impact on major flood events, as noted by P-1 and supported by Manchikatla and Umamahesh's (2022) research on catchment-level approaches. This scale-dependent effectiveness becomes particularly evident in Auckland's diverse topography. P-7 reported…. "*We've seen notable positive outcomes where strategies were implemented, including reduced flood damage and decreased surface water accumulation during flood events. The effectiveness was particularly pronounced in specific topographical contexts, such as mountainous and flat terrain.*"

The challenge is further complicated by Auckland's unique geological conditions. P-17 highlighted these performance differences: "*Effectiveness varies significantly by location, with notable differences between clay soils and volcanic areas. Implementation success depends heavily on practical constraints, including available space, property dimensions, and aesthetic considerations*." This geological variation means that strategies successful in volcanic soil areas may perform poorly in clay soil locations, requiring site-specific adaptation of impervious area reduction techniques. The urban development context in Auckland adds another layer of complexity to the effectiveness equation. The city's strategic focus on "liveability" and creating a "quality compact city" (Allen, 2015) has led to inherent tensions between development objectives and environmental sustainability. These tensions manifest in multiple ways: development trends, particularly in terrace housing, severely restrict space for reducing impervious areas (P-6), while the actual impervious surface coverage frequently exceeds planned levels, sometimes reaching up to 95%. This reality reflects the broader challenge of balancing housing intensification requirements with effective flood-management strategies.

P-18 further identified how these institutional challenges manifest in practice…. "Technical limitations include inadequate rainfall prediction and monitoring capabilities. Development pressures create tensions between housing density requirements and flood management, particularly in historically vulnerable areas." The participant also highlighted resource allocation issues, noting that "cyclical funding patterns tend to prioritise post-disaster response over sustained monitoring and data collection efforts, limiting long-term effectiveness." P-18 further identified how these institutional challenges manifest in practice… "*Technical limitations include inadequate rainfall prediction and monitoring capabilities. Development pressures create tensions between housing density requirements and flood management, particularly in historically vulnerable areas*." The participant also highlighted resource allocation issues, noting that "cyclical funding patterns tend to prioritise post-disaster response over sustained monitoring and data collection efforts, limiting long-term effectiveness." This gap is exacerbated by conflicts between central government housing policies that prioritize rapid development and local sustainability goals (Murphy, 2016). The resulting regulatory fragmentation creates a challenging environment for effective implementation, with P-15 noting the poor interdepartmental coordination and inconsistent regulations across jurisdictions. Technical and resource constraints interweave with these institutional challenges to create additional barriers to implementation.

Construction difficulties and the limited availability of specialized materials, as reported by P-7, combine with insufficient expertise among designers and a shortage of qualified workers to hinder effective implementation. These technical challenges are particularly acute in Auckland's context, where clay soil characteristics limit infiltration capabilities (P-4) and inadequate rainfall prediction and monitoring systems complicate planning efforts. The economic dimension adds another critical layer to this complex picture. Financial constraints significantly impact implementation across all scales, from the high cost of modern waterproofing materials to insufficient insurance coverage for flood-proofing improvements. P-5 emphasizes the chronic underfunding of ongoing monitoring and maintenance, while P-6 highlights the lack of effective incentives for both developers and homeowners. This economic challenge reflects a broader issue in urban water management, namely the disconnect between immediate costs and long-term benefits. At the property level, these challenges manifest in particular ways. P-2 identified a widespread lack of awareness among property owners regarding their stormwater management obligations, leading to gradual increases in impervious areas as homeowners pave over green spaces. This situation aligns with Faruk and Maharjan's (2022) findings on the impact of limited environmental regulation awareness on property-owner decision-making. The challenge of monitoring and enforcing compliance across thousands of individual properties has further compounded this issue. However, these challenges lie in the opportunities for meaningful progress.

Recent flooding events have catalyzed the formation of community liaison groups (P-15), while growing concerns over urban air quality (Boamponsem et al., 2024) have created additional motivation for green infrastructure solutions. P-12 suggests innovative approaches such as linking rates to impervious areas to support compliance programs, while P-10 advocates funding models that incorporate broader health and environmental benefits. The successful implementation of impervious area reduction techniques requires a multifaceted approach that acknowledges these interconnected challenges, while leveraging emerging opportunities. This approach should prioritize strengthening enforcement mechanisms, while providing meaningful incentives for compliance, investing in comprehensive monitoring systems, and fostering deeper community engagement in stormwater management. Crucially, context-specific solutions must be developed that account for Auckland's unique geological and urban conditions while focusing on long-term sustainability goals. The path to effective impervious area reduction ultimately requires balancing the immediate pressure of urban development with the imperative of environmental sustainability. By understanding and addressing these challenges as interconnected elements of a broader system, while remaining attentive to the local context and community needs, cities like Auckland can work toward more effective implementation of these crucial environmental management strategies. This well-rounded strategy, backed by robust policy frameworks and community involvement, provides the best chance to build resilient urban settings that can handle present demands and upcoming challenges. Figure 3 depicts the efficacy of impervious surface reduction options and their associated challenges.

***Figure 3:** Associated challenges to impervious area reduction techniques (Source: Authors' own work)*

4.3 Policy and regulatory framework governing impervious area reduction strategies

Marked by both advancements and persistent challenges, Auckland's impervious area reduction policies and regulations represent a complicated evolution of urban environmental management. This framework has emerged from the intersection of increasing urbanization pressure, environmental imperatives, and the growing recognition of flood resilience as a critical urban priority. Auckland's regulatory approach to impervious surface management has made significant strides through the implementation of the Unitary Plan, which establishes specific impervious area limits of 60-70% for most residential zones (P-6). However, this achievement exists within a broader context of planning "ambiguity," as identified by Silva (2018), where the uniform application of these limits across diverse zones may not adequately address varying local conditions and risks. This tension between standardization and local adaptation exemplifies the broader challenges facing the urban environmental policy in New Zealand. In addition, Duany and Talen (2002) outlined "a new approach to the implementation of New Urbanist and smart growth principles. The approach is termed transect planning and is based on the creation of a set of human habitats that vary by their level and intensity of urban character. In transect planning, this range of environments, from rural to urban, is the basis for organizing the components of the built world: building, lot, land use, street, and all of the other physical elements of the human habitat. The city's recent shift toward intensive housing development through upzoning (Greenaway-McGrevy and Phillips, 2023) highlights the complex relationship between development policies and environmental management. Although this approach offers potential benefits through density optimization, it also creates new challenges for flood resilience implementation. P-8's observations highlight the delicate balance between urban intensification goals and flood management requirements, particularly in the context of existing development patterns and private-land ownership constraints.

The effectiveness of these policies is significantly shaped by the multilevel governance structure in which they operate. P-1's emphasis on the need for national-level guidance on green infrastructure and nature-based solutions reflects a broader systemic challenge identified by Liu et al. (2022), who demonstrate how coordinated spatial planning across governance levels can enhance policy effectiveness. This finding is further reinforced by Salehi et al.'s (2022) research on multistage regulatory models, which reveals the critical importance of integrated governance approaches in achieving successful flood-management outcomes. P-1 described the regulatory challenges, *stating…. "There is a pressing need for national-level guidance on green infrastructure and nature-based solutions. We've identified a concerning misalignment between building and resource consent processes, while noting that Auckland's unitary plan has made progress through its implementation of impervious area limits." P-4 further elaborated on the cumulative impact problem, explaining….*

"There's a troubling disconnect between individual development approvals and their cumulative effects at the catchment level. The Auckland Unitary Plan sometimes permits development within floodplains, creating potential risks." This situation mirrors the broader criticism of New Zealand's environmental management framework as lacking a clear direction (Boyle 2000), suggesting a systemic issue in policy implementation.

International comparisons, particularly with the United States system, as analyzed by P-13, offer valuable insights into potential policy evolution pathways. The U.S. framework's greater flexibility in supporting private flood resilience projects through public-private funding arrangements contrasts sharply with New Zealand's more restricted approach. This difference becomes particularly significant when considering the challenges posed by existing use rights in New Zealand's regulatory context, suggesting opportunities for policy reforms that could enhance implementation effectiveness. The emergence of low-impact development (LID) as a key policy tool presents promising opportunities for improvement. Sohn et al.'s (2017) research demonstrates how optimal combinations of LID approaches can maximize the reduction of directly connected impervious areas, offering practical guidance for policy development. This aligns with P-18's advocacy for a comprehensive approach incorporating standardized service levels, robust technical solutions, and integrated strategies connecting individual property impacts to broader catchment effects. Community engagement has emerged as a crucial element in policy effectiveness. P-16's observations of increased public awareness and support following recent flood events facilitated through diverse engagement methods align with Dewa et al.'s (2022) findings on building public support for flood management policies. This growing public consciousness creates opportunities for more ambitious policy initiatives while highlighting the importance of maintaining strong community connections in policy implementation.

The evolution of Auckland's policy framework requires careful attention to several interconnected elements. The need for a clear central government direction regarding the development of flood-prone areas must be balanced against the importance of local implementation flexibility. Enhanced monitoring and enforcement capabilities need to be supported by improved professional development and training programs, whereas innovative funding models and stronger incentives for implementing flood resilience measures can help bridge the gap between policy goals and practical implementation. The path toward more effective impervious area reduction policies in Auckland ultimately requires recognizing the interconnected nature of urban development and environmental sustainability. Success depends on creating policy frameworks that can adapt to local conditions while maintaining consistent standards for flood resilience supported by robust implementation mechanisms and strong community engagement. This balanced approach, informed by both local experience and international best practices, offers the best opportunity to develop resilient urban environments capable of meeting both current needs and future challenges. The future effectiveness of these policies will depend on their ability to evolve with changing urban conditions, while maintaining a clear focus on environmental outcomes. Auckland can continue to develop more effective and responsive approaches to managing impervious surfaces and boosting urban flood resilience by learning from both new research and global experiences, as well as the successes and challenges of current implementation. Figure 4 depicts the comprehensive policy and regulatory framework regulating impervious surface reduction strategies in the residential areas of New Zealand.

Figure 4: *Policy and regulatory framework governing impervious area reduction strategies (Source: Authors' own work)*

4.4 Monitoring and compliance framework

Implementing, monitoring, and compliance to impervious area reduction strategies in Auckland is a challenging task as social dynamics, technology advancements, and resource constraints all interact to influence the results of urban environmental management. As cities grow under increasing pressure from climate change and urban densification, as highlighted by Rosenberger et al. (2021), the effectiveness of these strategies has become increasingly critical to urban resilience. The current landscape monitoring reveals significant structural challenges that undermine the effectiveness of impervious area reduction initiatives. Local councils face a stark imbalance between oversight requirements and available resources, with P-2 highlighting the daunting task of monitoring over 9,000 private discharge consent with limited staff. This resource constraint forced councils into a predominantly reactive stance toward compliance issues, as noted by P-3, rather than maintaining the proactive oversight necessary for effective environmental management. This resource limitation manifests itself in multiple ways throughout the implementation process. P-16's observation reveals the stark resource realities facing local authorities…. *"Budget constraints have forced our department to prioritise water quality monitoring over quantity assessments, while also limiting our capacity for comprehensive site inspections." This participant explained how these limitations create systematic gaps in oversight, noting that "we simply don't have the resources to monitor both water quality and quantity effectively, so we have to make difficult choices about where to focus our limited capacity."*

The situation becomes particularly acute in the compliance sphere, where P-15 described severe operational constraints…. *"We have a severely understaffed team of only two members managing the entire workload across the district. There's also a lack of specialised stormwater assessment expertise that impacts decision quality."* This participant further elaborated on the cascading effects of these limitations, explaining that "a disconnect between resource consent and building consent stages leads to missed checks and inconsistent enforcement. We're constantly trying to catch up rather than being proactive about compliance monitoring."

The social dimension adds another layer of complexity to implementation effectiveness. Drescher and Sinasac (2021) revealed that residents' decisions to adopt Green Stormwater Infrastructure (GSI) are primarily influenced by social norms and perceived control factors rather than a technical understanding of effectiveness. This insight suggests that successful implementation requires looking beyond purely technical solutions to address the social and behavioural factors that influence adoption rates, particularly in residential areas where lot-level installations on private properties may represent the primary opportunity for implementation. The equity implications of current implementation patterns further complicate the monitoring landscape. Colbert et al.'s (2024) analysis revealed disparities in urban greenspace accessibility in neighbourhoods with more public housing, highlighting that monitoring and compliance strategies must consider not only technical effectiveness but also social justice implications. This finding emphasizes the need for monitoring frameworks that can track and address emerging divisions in the distribution of environmental benefits across communities.

However, amid these challenges, innovative approaches that offer potential pathways are emerging. P-14's description of the Healthy Waters Department's use of aerial photo analysis for compliance tracking demonstrates how technological solutions can enhance monitoring capabilities, building on the sophisticated interventions explored by Prakash et al. (2023). Technological innovation, when properly integrated with human expertise, offers promising opportunities for more efficient and comprehensive oversight. The funding mechanism for monitoring and compliance activities is a critical leverage point for improvement. P-17's description of a structured compliance system funded through application fees, implementing sequential verification from pre-construction through final compliance, offers a model for sustainably monitoring funding. This approach aligns with P-5's advocacy for treating impervious area reduction solutions as formal assets, along with dedicated funding and depreciation schedules, ensuring proper ongoing maintenance and monitoring.

The path toward more effective implementation requires addressing multiple interconnected elements simultaneously. P-12's proposal offers a comprehensive approach to addressing funding challenges through market-based mechanisms. This participant explained…. *"We need to explore alternative funding mechanisms, such as adjusting property rates based on impervious areas, to incentivize the reduction of impervious surfaces and generate funds for compliance programs and green infrastructure maintenance." P-12 elaborated on the dual benefits of this approach, stating…. "This system would create financial incentives for property owners to reduce their impervious coverage while simultaneously generating dedicated revenue streams for monitoring and maintenance activities."* Meanwhile, P-7's identification of opportunities for enhanced public education and outreach programs aligns with research findings on the importance of social factors in GSI adoption, suggesting a need for integrated approaches that address both the technical and social dimensions of implementation. Moving forward, success in monitoring and compliance will require developing frameworks that can adapt to changing urban conditions while maintaining consistent effectiveness of oversight. This involves creating sustainable funding mechanisms that can support comprehensive monitoring programs, enhance technical capabilities through professional development and training, and ensure equitable implementation across communities. The approach must balance ambitious environmental goals with practical constraints, while leveraging emerging technologies and social insights to enhance the effectiveness of oversight.

The future of urban stormwater management in Auckland ultimately depends on developing integrated approaches that recognize the interconnected nature of technical, social, and financial factors in implementation success. By addressing these elements systematically while maintaining a focus on both immediate oversight needs and long-term sustainability goals, cities can work toward more effective and equitable environmental management strategies. The best opportunity to build resilient urban settings that can handle present demands as well as upcoming difficulties is provided by this well-rounded strategy, which is backed by strong monitoring frameworks and sustainable funding mechanisms. Figure 5 shows the monitoring and compliance framework for impervious surface reduction strategies.

***Figure 5:** Monitoring and compliance framework (Source: Authors' own work)*

4.5 Recommendations for improving impervious area reduction strategies

The 2016 upzoning project, which allowed for more intense construction on 75% of residential property, laid the groundwork for Auckland’s transition to better water management (Greenaway-McGrevy and Phillips, 2023). This policy shift represents more than a simple density adjustment; it offers the opportunity to fundamentally reimagine the relationship between urban development and environmental sustainability. P-2's vision of integrating flood resilience strategies with comprehensive urban planning builds on this foundation, suggesting that density optimization can work in harmony with environmental protection when properly conceived and executed. The effectiveness of this urban evolution critically depends on moving beyond traditional approaches to impervious surface management. P-4's emphasis on strategic disconnection of impervious areas, rather than simple reduction, points toward a more sophisticated understanding of urban water systems. This approach is supported by contemporary research on sustainable urban drainage systems (Ebrahimian et al., 2016), which demonstrates how integrated water management strategies can enhance both environmental performance and urban liveability.

The transformation of urban infrastructure is a crucial element in this evolution. P-10's vision of cities as potential hubs for biodiversity and hydrological neutrality challenges conventional urban development paradigms, suggesting that infrastructure renewal, particularly in brownfield areas, offers opportunities for ecological regeneration. This perspective gains depth through Rosenberger et al.'s

(2021) research on integrating ecological principles into urban infrastructure design, demonstrating how cities can evolve from passive landscapes into active ecological systems. The social dimension of urban water management has become an increasingly critical aspect of success. Colbert et al.'s (2024) analysis revealing disparities in urban green space accessibility highlights how environmental benefits often distribute unevenly across urban communities. This finding resonates with P-13's advocacy for enhanced community engagement strategies, supported by Tauhid and Zawani's (2018) research, demonstrating the transformative potential of community-driven resilience initiatives. Together, these insights suggest that effective environmental management must consider both technical and social equity. The technical evolution of water management solutions continues to expand the possibilities for urban adaptation. P-16's promotion of integrated approaches reflects a comprehensive strategy for addressing multiple urban constraints simultaneously. This participant detailed their vision.... *"We need to implement innovative solutions like integrated water reuse systems and rainwater harvesting that can address both water management and space efficiency challenges. Our approach combines mandatory LID requirements with precise district plan terminology to ensure clear implementation guidance." P-16 further emphasized the operational benefits, stating.... "We're focusing on improved funding mechanisms and streamlined stakeholder coordination to support these integrated systems at scale."*

P-17's focus on space-efficient solutions addresses the practical realities of urban development constraints. This participant explained.... *"We're developing space-efficient tank designs that address urban constraints while maintaining functionality. The key is strategic integration of planted swales that combine aesthetic appeal with functional efficiency through natural filtration systems." P-17 also highlighted the collaborative aspects… "Success depends on strengthening relationships between council authorities and community stakeholders, particularly improving dialogue with developers about sustainable solutions that work within their project parameters."* These approaches are particularly relevant when considered along with P-9's recommendations for Stockholm tree pits and green roof implementation, suggesting a comprehensive toolkit for urban water management.

The regulatory framework supporting these initiatives continues to evolve, with P-3's call for national policy on stormwater management complementing P-15's vision for a unified engineering code that maintains regional flexibility. This regulatory evolution must strike a balance between standardization and local adaptation, as demonstrated by Chang et al. (2021) in their analysis of comprehensive watershed management approaches. Financial innovation is crucial for supporting this transformation. P-6's advocacy for market-based solutions and rating systems, combined with P-12's exploration of alternative funding mechanisms and P-10's support for targeted financial incentives, suggest a comprehensive approach to economic sustainability. These financial tools can help bridge the gap between environmental imperatives and practical implementation, thus making sustainable practices more accessible and attractive to property owners and developers. The path forward requires weaving these elements into a cohesive urban fabric that supports both immediate needs and long-term sustainability goals. Success depends on recognizing the interconnected nature of urban systems, where changes in one area inevitably influence others. This understanding must inform approaches to density optimisation, the deployment of green infrastructure, and the equitable distribution of environmental benefits. In the future, Auckland's approach to impervious area reduction must remain adaptable while maintaining a clear focus on sustainability objectives. This requires balancing development pressures with environmental imperatives, supported by robust policy frameworks, and meaningful community engagement. Through this integrated approach, informed by both local experience and international best practices, cities can develop more effective and equitable strategies to manage urban water systems and enhance community resilience.

The evolution of urban water management ultimately reflects a broader transformation of our understanding of cities as living systems. Communities may establish urban landscapes that meet human needs and environmental imperatives while adopting this perspective and coming up with workable solutions for pressing issues. This will increase resilience for both present and future generations. Comprehensive suggestions for enhancing impervious surface reduction techniques are shown in Figure 6.

Figure 6: *Recommendations for improving impervious area reduction strategies (Source: Authors' own work)*

5. Conclusion

This study's examination of impervious area reduction strategies in New Zealand's residential areas reveals fundamental insights that extend beyond national borders, offering critical lessons for urban water management in developed nations worldwide. The scale-dependent effectiveness demonstrated here, where catchment-scale solutions significantly outperform site-specific interventions, challenges prevailing assumptions about distributed green infrastructure approaches that many cities have embraced. This finding suggests that urban planners globally may need to reconsider the allocation of resources between large-scale systematic interventions and numerous small-scale installations, particularly as climate change intensifies flood risks across developed nations facing similar urbanisation pressures. The implications resonate strongly with ongoing policy debates in cities like Copenhagen, Singapore, and Toronto, where substantial investments in distributed green infrastructure have yielded mixed results.

The regulatory fragmentation identified in this research mirrors governance challenges observed in federal systems like Australia, Canada, and Germany, where multiple jurisdictional levels create coordination difficulties. The misalignment between building consent and resource management processes documented here provides a cautionary tale for cities implementing green infrastructure policies without ensuring regulatory coherence. This research demonstrates that technical solutions, regardless of their engineering merit, remain ineffective without supportive institutional frameworks, a lesson particularly relevant for European cities implementing EU water directives or North American municipalities navigating complex federal-state-local regulatory environments. The findings suggest that successful policy integration requires not merely coordination mechanisms, but fundamental restructuring of how different governance levels interact, moving from hierarchical to collaborative models that can adapt to local contexts while maintaining strategic coherence.

The widespread property owner non-compliance and awareness gaps revealed through this qualitative analysis point to deeper social-behavioural dimensions of urban flood management that quantitative studies often overlook. These insights suggest that future quantitative research should incorporate behavioural economics frameworks to measure not just technical performance but also adoption rates, maintenance compliance, and long-term behavioural change. Specifically, quantitative studies could employ randomized controlled trials comparing different incentive structures, using the market-based mechanisms identified here such as impervious area-based property rates, as experimental variables. The qualitative themes emerging from this research provide essential foundations for developing validated survey instruments that could measure property owner attitudes, risk perceptions, and willingness-to-pay for flood resilience measures across larger populations. Advanced econometric approaches, including difference-in-differences analyses that compare properties before and after policy implementation, can quantify the behavioural impacts of different regulatory approaches while controlling for confounding variables.

The identification of critical implementation barriers, resource constraints, monitoring limitations, and stakeholder coordination failures suggests specific methodological approaches for measuring long-term effectiveness. Longitudinal studies employing mixed-methods designs could track both quantitative performance metrics (e.g., flood frequency, stormwater volumes, water quality parameters) and qualitative institutional changes over 10–to 15-year periods. Remote sensing technologies, combined with social network analysis, could quantify the relationship between catchment-scale implementation patterns and flood reduction outcomes. Meanwhile, ethnographic methods could document the evolution of institutional practices and professional coordination mechanisms. The finding that many councils lack resources for proper effectiveness assessment suggests that future research should prioritize developing cost-effective monitoring protocols using citizen science approaches and automated sensor networks. Machine learning algorithms could analyse historical weather data, implementation patterns, and flood outcomes to identify optimal intervention points and predict long-term performance trajectories across different urban contexts.

This research reveals that successful urban flood resilience requires transforming impervious area reduction from ad-hoc interventions into systematic asset management approaches, with implications extending to infrastructure financing models worldwide. The comparison with U.S. funding mechanisms highlights opportunities for developing innovative public-private partnerships that could be tested and adapted across different political-economic contexts. Future research should examine how different governance structures, from New Zealand's unitary councils to fragmented municipal systems, affect implementation success, providing comparative insights for institutional design in other developed nations. The integration of natural capital accounting frameworks could quantify the ecosystem service benefits of impervious area reduction, enabling more sophisticated cost-benefit analyses that capture both direct flood mitigation benefits and co-benefits such as urban heat reduction, biodiversity enhancement, and air quality improvement.

The broader implications for urban planning policy suggest a paradigm shift from technical optimization toward socio-technical systems thinking. This research demonstrates that effective flood resilience requires integrating behavioural insights, institutional design, and technical performance, a framework applicable to addressing climate adaptation challenges globally. Future quantitative studies should therefore employ systems dynamics modelling to capture feedback loops between policy implementation, property owner behaviour, and flood outcomes, while longitudinal case study research could document how different cities successfully navigate the institutional barriers identified here. Agent-based modelling approaches could simulate how different policy scenarios affect stakeholder behaviour and flood outcomes, while network analysis could identify key actors and institutions that facilitate or constrain implementation success across different urban contexts.

The methodological insights from this qualitative analysis provide a foundation for developing context-sensitive quantitative measures that could be applied across different urban environments. Future research should employ stratified sampling approaches that account for the scale-dependent effectiveness patterns identified here, while incorporating institutional variables that capture regulatory fragmentation and the quality of stakeholder coordination. Comparative studies examining similar challenges in cities like Melbourne, Vancouver, or Stockholm could test the transferability of these findings while developing generalizable frameworks for institutional analysis in urban water management. Advanced spatial analysis techniques, including geographically weighted regression and spatial autoregressive models, could quantify how local contextual factors influence implementation success and identify optimal intervention strategies for different urban morphologies.

The transformative potential of this research extends to fundamental questions about urban governance in the Anthropocene. The findings suggest that cities must evolve beyond traditional infrastructure paradigms toward adaptive management systems that can respond to uncertain climate futures. This requires developing new metrics that capture not just physical performance but institutional learning capacity, stakeholder engagement quality, and adaptive governance effectiveness. Future research should explore how different cities build these capacities, identifying the institutional innovations that enable sustained implementation of nature-based solutions despite changing political priorities and resource constraints. This research ultimately demonstrates that sustainable urban flood resilience requires not just technical innovation but fundamental transformation in how cities conceptualize, implement, and maintain nature-based solutions within complex socio-political environments. The implications extend beyond flood management to broader questions of urban sustainability, climate adaptation, and environmental governance in an era of rapid global change.

Funding Declaration: The research was funded by the Faculty of Design and Creative Technology Constable Research Fund, Auckland University of Technology (AUT), Auckland, New Zealand.

Acknowledgements: We confirm that no AI-based tools such as ChatGPT were used for drafting, summarising, or refining the manuscript. The manuscript, including the qualitative analysis and framework diagrams, was developed entirely by the authors. The only AI-based tool used was Grammarly, which was applied for basic grammar and spelling checks. AI generated no content, analysis, or interpretation.

Reference

Abi Aad, M. P., Suidan, M. T., and Shuster, W. D. (2010). Modeling Techniques of Best Management Practices: Rain Barrels and Rain Gardens Using EPA SWMM-5. *Journal of Hydrologic Engineering*, *15*(6), 434–443. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000136

Aernouts, Nele, Elena Maranghi, and Michael Ryckewaert. 2020. “The Regeneration of Large-Scale Social Housing Estates. Spatial, Territorial, Institutional and Planning Dimensions.” (access date: January 2025) https://hdl.handle.net/11311/1147130

Afifi, Z., Chu, H.-J., Kuo, Y.-L., Hsu, Y.-C., Wong, H.-K., and Zeeshan Ali, M. (2019). Residential Flood Loss Assessment and Risk Mapping from High-Resolution Simulation. *Water*, *11*(4), 751. https://doi.org/10.3390/w11040751

Al-Khuzaie, A. H., Alyaseri, I. J., and Nile, B. K. (2023). Flood reduction using green infrastructure in stormwater sewer systems: A case study in Al-Samawa city. *5TH INTERNATIONAL CONFERENCE ON ENGINEERING SCIENCES – ICES21*, 020015. https://doi.org/10.1063/5.0131325

Allen, N. (2015). Understanding the Importance of Urban Amenities: A Case Study from Auckland. *Buildings*, *5*(1), 85–99. https://doi.org/10.3390/buildings5010085

Asad, R., Ahmed, I., Vaughan, J., and von Meding, J. (2022). Traditional water knowledge: challenges and opportunities to build resilience to urban floods. *International Journal of Disaster Resilience in the Built Environment*, *13*(1), 1–13. https://doi.org/10.1108/IJDRBE-08-2020-0091

Auliagisni, W., Wilkinson, S., and Elkharboutly, M. (2022). Using community-based flood maps to explain flood hazards in Northland, New Zealand. *Progress in Disaster Science*, *14*, 100229. https://doi.org/10.1016/j.pdisas.2022.100229

Bera, D., Kumar, P., Siddiqui, A., and Majumdar, A. (2022). Assessing impact of urbanisation on surface runoff using vegetation-impervious surface-soil (V-I-S) fraction and NRCS curve number (CN) model. *Modeling Earth Systems and Environment*, *8*(1), 309–322. https://doi.org/10.1007/s40808-020-01079-z

Boamponsem, L. K., Hopke, P. K., and Davy, P. K. (2024). Long-term trends and source apportionment of fine particulate matter (PM2.5) and gaseous pollutants in Auckland, New Zealand. *Atmospheric Environment*, *322*, 120392. https://doi.org/10.1016/j.atmosenv.2024.120392

Boyle, C. A. (2000). Solid waste management in New Zealand. *Waste Management*, *20*(7), 517–526. https://doi.org/10.1016/S0956-053X(00)00023-4

Burinskienė, Marija, Vytautas Bielinskas, Askoldas Podviezko, Virginija Gurskienė, and Vida Maliene. 2017. "Evaluating the Significance of Criteria Contributing to Decision-Making on Brownfield Land Redevelopment Strategies in Urban Areas." *Sustainability* 9(5):759. https://doi.org/10.3390/su9050759

Chang, H.-S., Su, Q., and Katayama, T. (2021). Research on establishment of the region flood protection standard - a case of watershed of Dajiaxi, Taiwan. *Urban Water Journal*, *18*(3), 173–182. https://doi.org/10.1080/1573062X.2020.1864831

Colbert, J., Chuang, I.-T., and Sila-Nowicka, K. (2024). Measuring spatial inequality of urban park accessibility and utilisation: A case study of public housing developments in Auckland, New Zealand. *Landscape and Urban Planning*, *247*, 105070. https://doi.org/10.1016/j.landurbplan.2024.105070

Council, Auckland. 2013. *Auckland Unitary Plan Stormwater Management Provisions: Technical Basis of Contaminant and Volume Management Requirements*. Auckland Council technical report, TR2013/035. Prepared by Auckland Council. (access date: January 2025) https://knowledgeauckland.org.nz/media/1651/tr2013-035-auckland-unitary-plan-stormwater-management-provisions-no-appendices.pdf

Creswell, J. W. (2009). Mapping the field of mixed methods research. Journal of mixed methods research, 3(2), 95-108. https://doi.org/10.1177/1558689808330883

Dewa, O., Makoka, D., and Ayo-Yusuf, O. (2022). A Deliberative Rural Community Consultation to Assess Support for Flood Risk Management Policies to Strengthen Resilience in Malawi. *Water*, *14*(6), 874. https://doi.org/10.3390/w14060874

Dhakal, K. P., and Chevalier, L. R. (2016). Urban Stormwater Governance: The Need for a Paradigm Shift. *Environmental Management*, *57*(5), 1112–1124. https://doi.org/10.1007/s00267-016-0667-5

Dharmarathne, G., Waduge, A. O., Bogahawaththa, M., Rathnayake, U., and Meddage, D. P. P. (2024). Adapting cities to the surge: A comprehensive review of climate-induced urban flooding. *Results in Engineering*, *22*, 102123. https://doi.org/10.1016/j.rineng.2024.102123

Drescher, M., and Sinasac, S. (2021). Social-psychological Determinants of the Implementation of Green Infrastructure for Residential Stormwater Management. *Environmental Management*, *67*(2), 308–322. https://doi.org/10.1007/s00267-020-01393-3

Du, S., Shi, P., Van Rompaey, A., and Wen, J. (2015). Quantifying the impact of impervious surface location on flood peak discharge in urban areas. *Natural Hazards*, *76*(3), 1457–1471. https://doi.org/10.1007/s11069-014-1463-2

Ebrahimian, A., Wilson, B. N., and Gulliver, J. S. (2016). Improved methods to estimate the effective impervious area in urban catchments using rainfall-runoff data. *Journal of Hydrology*, *536*, 109–118. https://doi.org/10.1016/j.jhydrol.2016.02.023

Faruk, M. O., and Maharjan, K. L. (2022). Impact of Farmers' Participation in Community-Based Organizations on Adoption of Flood Adaptation Strategies: A Case Study in a Char-Land Area of Sirajganj District Bangladesh. *Sustainability*, *14*(14), 8959. https://doi.org/10.3390/su14148959

Fassman-Beck, E. A., Voyde, E. A., and Liao, M. (2013). *Defining Hydrologic Mitigation Targets for Stormwater Design in Auckland* (Auckland Council technical report 2013/024).

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., and Viklander, M. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, *12*(7), 525–542. https://doi.org/10.1080/1573062X.2014.916314

Fu, X., Bell, R., Reu Junqueira, J., White, I., and Serrao-Neumann, S. (2023). Managing rising residual flood risk: A national survey of Aotearoa-New Zealand. *Journal of Flood Risk Management*, *16*(4). https://doi.org/10.1111/jfr3.12944

Gao, B., Xu, Y., Sun, Y., Wang, Q., Wang, Y., and Li, Z. (2023). The impacts of impervious surface expansion and the operation of polders on flooding under rapid urbanization processes. *Theoretical and Applied Climatology*, *151*(3–4), 1215–1225. https://doi.org/10.1007/s00704-022-04318-8

García-Ayllón, S., and Franco, A. (2023). Spatial Correlation between Urban Planning Patterns and Vulnerability to Flooding Risk: A Case Study in Murcia (Spain). *Land*, *12*(3), 543. https://doi.org/10.3390/land12030543

Gnan, E., Friedland, C. J., Mostafiz, R. Bin, Rahim, M. A., Gentimis, T., Taghinezhad, A., and Rohli, R. V. (2022). Economically optimizing elevation of new, single-family residences for flood mitigation via life-cycle benefit-cost analysis. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.889239

Gnan, E., Friedland, C. J., Rahim, M. A., Mostafiz, R. Bin, Rohli, R. V., Orooji, F., Taghinezhad, A., and McElwee, J. (2022). Improved building-specific flood risk assessment and implications of depth-damage function selection. *Frontiers in Water*, *4*. https://doi.org/10.3389/frwa.2022.919726

Greenaway-McGrevy, R., and Phillips, P. C. B. (2023). The impact of upzoning on housing construction in Auckland. *Journal of Urban Economics*, *136*, 103555. https://doi.org/10.1016/j.jue.2023.103555

Guven, Huseyin, and Aysegul Tanik. 2020. "Water-Energy Nexus: Sustainable Water Management and Energy Recovery from Wastewater in Eco-Cities." *Smart and Sustainable Built Environment* 9(1):54–70. https://doi.org/10.1108/SASBE-07-2017-0030

Habib, Ahed, Abdulrahman Alnaemi, and Maan Habib. 2024. "Developing a Framework for Integrating Blockchain Technology into Earthquake Risk Mitigation and Disaster Management Strategies of Smart Cities." Smart and Sustainable Built Environment. https://doi.org/10.1108/SASBE-12-2023-0376.

Hameed, H. (2017). Estimating the Effect of Urban Growth on Annual Runoff Volume Using GIS in the Erbil Sub-Basin of the Kurdistan Region of Iraq. *Hydrology*, *4*(1), 12. https://doi.org/10.3390/hydrology4010012

Hammond, Ellis B., Frederic Coulon, Stephen H. Hallett, Russell Thomas, Drew Hardy, Andrew Kingdon, and Darren J. Beriro. 2021. "A Critical Review of Decision Support Systems for Brownfield

Redevelopment." *Science of the Total Environment* 785:147132. https://doi.org/10.1016/j.scitotenv.2021.147132

Harrington, L. J., Dean, S. M., Awatere, S., Rosier, S., Queen, L., Gibson, P. B., Barnes, C., Zachariah, M., Philip, S., Kew, S., Koren, G., Pinto, I., Grieco, M., Vahlberg, M., Snigh, R., Heinrich, D., Thalheimer, L., Li, S., Stone, D., … Otto, F. E. L. (2023). The role of climate change in extreme rainfall associated with Cyclone Gabrielle over Aotearoa New Zealand's East Coast. *Research Commons*. https://researchcommons.waikato.ac.nz/entities/publication/972141df-3269-4f8f-b9c6-3f4f01288892

Hermans, O. F. (2017). *Flood Management in New Zealand: Exploring Management and Practice in Otago and the Manawatu* [Masters degree]. University of Otago. (access date: February 2025) https://hdl.handle.net/10523/8172

Hou, Deyi, Abir Al-Tabbaa, David O'Connor, Qing Hu, Yong-Guan Zhu, Liuwei Wang, Niall Kirkwood, Yong Sik Ok, Daniel C. W. Tsang, and Nanthi S. Bolan. 2023. "Sustainable Remediation and Redevelopment of Brownfield Sites." *Nature Reviews Earth & Environment* 4(4):271–86. https://www.nature.com/articles/s43017-023-00404-1

Jayawardena, Iresh. 2024. "And Opportunities in Auckland's Urban Development." *Rethinking Stormwater Management Through Sustainable Urban Design* 153. https://link.springer.com/chapter/10.1007/978-981-97-4924-9_8

Jin, Y., Zhang, J., Liu, N., Li, C., and Wang, G. (2022). Geomatic-Based Flood Loss Assessment and Its Application in an Eastern City of China. *Water*, *14*(1), 126. https://doi.org/10.3390/w14010126

Joshi, P., Leitão, J. P., Maurer, M., and Bach, P. M. (2021). Not all SuDS are created equal: Impact of different approaches on combined sewer overflows. *Water Research*, *191*, 116780. https://doi.org/10.1016/j.watres.2020.116780

Li, Y., and Babcock, R. W. (2014). Green roof hydrologic performance and modeling: a review. *Water Science and Technology*, *69*(4), 727–738. https://doi.org/10.2166/wst.2013.770

Lin, Hongli, Yuming Zhu, Naveed Ahmad, and Qingye Han. 2019. "A Scientometric Analysis and Visualization of Global Research on Brownfields." *Environmental Science and Pollution Research* 26:17666–84. https://link.springer.com/article/10.1007/s11356-019-05149-3

Liu, W., Chen, W., and Peng, C. (2015). Influences of setting sizes and combination of green infrastructures on community's stormwater runoff reduction. *Ecological Modelling*, *318*, 236–244. https://doi.org/10.1016/j.ecolmodel.2014.11.007

Manchikatla, S. K., and Umamahesh, N. V. (2022). Simulation of flood hazard, prioritization of critical sub-catchments, and resilience study in an urban setting using PCSWMM: a case study. *Water Policy*, *24*(8), 1247–1268. https://doi.org/10.2166/wp.2022.291

Miller, J. D., and Hutchins, M. (2017). The impacts of urbanisation and climate change on urban flooding and urban water quality: A review of the evidence concerning the United Kingdom. *Journal of Hydrology: Regional Studies*, *12*, 345–362. https://doi.org/10.1016/j.ejrh.2017.06.006

Murphy, L. (2008). Third-wave Gentrification in New Zealand: The Case of Auckland. *Urban Studies*, *45*(12), 2521–2540. https://doi.org/10.1177/0042098008097106

Murphy, L. (2016). The politics of land supply and affordable housing: Auckland's Housing Accord and Special Housing Areas. *Urban Studies*, *53*(12), 2530–2547. https://doi.org/10.1177/0042098015594574

NZ CarbonNews. 2024. "New Record for NZ's Costliest Weather Events". (access date: January 2025) https://aon.co.nz/AonNZ/media/Docs/NZ_PressRelease_Climate-and-Catastrophe-report.pdf

Oertli, B., and Parris, K. M. (2019). Review: Toward management of urban ponds for freshwater biodiversity. *Ecosphere*, *10*(7). https://doi.org/10.1002/ecs2.2810

Omurakunova, G., Bao, A., Xu, W., Duulatov, E., Jiang, L., Cai, P., Abdullaev, F., Nzabarinda, V., Durdiev, K., and Baiseitova, M. (2020). Expansion of Impervious Surfaces and Their Driving Forces in Highly Urbanized Cities in Kyrgyzstan. *International Journal of Environmental Research and Public Health*, *17*(1), 362. https://doi.org/10.3390/ijerph17010362

Palermo, S. A., Talarico, V. C., and Turco, M. (2020). On the LID systems effectiveness for urban stormwater management: case study in Southern Italy. *IOP Conference Series: Earth and Environmental Science*, *410*(1), 012012. https://doi.org/10.1088/1755-1315/410/1/012012

Phillips, C., Marden, M., and Basher, L. R. (2018). Geomorphology and forest management in New Zealand's erodible steeplands: An overview. *Geomorphology*, *307*, 107–121. https://doi.org/10.1016/j.geomorph.2017.07.031

Prakash, C., Barthwal, A., and Acharya, D. (2023). FLOODWALL: A Real-Time Flash Flood Monitoring and Forecasting System Using IoT. *IEEE Sensors Journal*, *23*(1), 787–799. https://doi.org/10.1109/JSEN.2022.3223671

Przestrzelska, K., Wartalska, K., Rosińska, W., Jurasz, J., and Kaźmierczak, B. (2024). Climate Resilient Cities: A Review of Blue-Green Solutions Worldwide. *Water Resources Management*, *38*(15), 5885–5910. https://doi.org/10.1007/s11269-024-03950-5

Puttinaovarat, S., and Horkaew, P. (2020). Flood Forecasting System Based on Integrated Big and Crowdsource Data by Using Machine Learning Techniques. *IEEE Access*, *8*, 5885–5905. https://doi.org/10.1109/ACCESS.2019.2963819

Qian, Y., and Wu, Z. (2019). Study on Urban Expansion Using the Spatial and Temporal Dynamic Changes in the Impervious Surface in Nanjing. *Sustainability*, *11*(3), 933. https://doi.org/10.3390/su11030933

Qin, Y. (2020). Urban Flooding Mitigation Techniques: A Systematic Review and Future Studies. *Water*, *12*(12), 3579. https://doi.org/10.3390/w12123579

Rosenberger, L., Leandro, J., Pauleit, S., and Erlwein, S. (2021). Sustainable stormwater management under the impact of climate change and urban densification. *Journal of Hydrology*, *596*, 126137. https://doi.org/10.1016/j.jhydrol.2021.126137

Salehi, F., Najarchi, M., Najafizadeh, M. M., and Hezaveh, M. M. (2022). Multistage Models for Flood Control by Gated Spillway: Application to Karkheh Dam. *Water*, *14*(5), 709. https://doi.org/10.3390/w14050709

Sarigul, Fatma Handan, and Husnu Murat Gunaydin. 2025. "Integrated BIM, GIS and Interoperable Digital Technologies in Lifecycle Management of Building Construction Projects: Systematic Literature Review." Smart and Sustainable Built Environment. https://doi.org/10.1108/SASBE-08-2024-0312.

Scawthorn, C., Flores, P., Blais, N., Seligson, H., Tate, E., Chang, S., Mifflin, E., Thomas, W., Murphy, J., Jones, C., and Lawrence, M. (2006). HAZUS-MH Flood Loss Estimation Methodology. II. Damage and Loss Assessment. *Natural Hazards Review*, *7*(2), 72–81. https://doi.org/10.1061/(ASCE)1527-6988(2006)7:2(72)

Shao, Z., Cheng, T., Fu, H., Li, D., and Huang, X. (2023). Emerging Issues in Mapping Urban Impervious Surfaces Using High-Resolution Remote Sensing Images. *Remote Sensing*, *15*(10), 2562. https://doi.org/10.3390/rs15102562

Silva, C. (2018). Auckland's Urban Sprawl, Policy Ambiguities and the Peri-Urbanisation to Pukekohe. *Urban Science*, *3*(1), 1. https://doi.org/10.3390/urbansci3010001

Sohn, W., Kim, J.-H., and Li, M.-H. (2017). Low-impact development for impervious surface connectivity mitigation: assessment of directly connected impervious areas (DCIAs). *Journal of Environmental Planning and Management*, *60*(10), 1871–1889. https://doi.org/10.1080/09640568.2016.1264929

Sperotto, A., Torresan, S., Gallina, V., Coppola, E., Critto, A., and Marcomini, A. (2016). A multi-disciplinary approach to evaluate pluvial floods risk under changing climate: The case study of the municipality of Venice (Italy). *Science of The Total Environment*, *562*, 1031–1043. https://doi.org/10.1016/j.scitotenv.2016.03.150

Stillwell, C. C., Hunt, W. F., Page, J. L., Baird, J. B., and Kennedy, S. G. (2018). Stormwater management in nutrient-sensitive watersheds: a case study investigating impervious cover limits and pollutant-load regulations. *Water Science and Technology*, *78*(3), 664–675. https://doi.org/10.2166/wst.2018.338

Taghinezhad, A., Friedland, C. J., Rohli, R. V., and Marx, B. D. (2020). An Imputation of First-Floor Elevation Data for the Avoided Loss Analysis of Flood-Mitigated Single-Family Homes in Louisiana, United States. *Frontiers in Built Environment*, *6*. https://doi.org/10.3389/fbuil.2020.00138

Tang, S., Luo, W., Jia, Z., Liu, W., Li, S., and Wu, Y. (2016). Evaluating Retention Capacity of Infiltration Rain Gardens and Their Potential Effect on Urban Stormwater Management in the Sub-Humid Loess Region of China. *Water Resources Management*, *30*(3), 983–1000. https://doi.org/10.1007/s11269-015-1206-5

Twohig, C., Casali, Y., and Aydin, N. Y. (2022). Can green roofs help with stormwater floods? A geospatial planning approach. *Urban Forestry and Urban Greening*, *76*, 127724. https://doi.org/10.1016/j.ufug.2022.127724

Veról, A. P., Bigate Lourenço, I., Fraga, J. P. R., Battemarco, B. P., Linares Merlo, M., Canedo de Magalhães, P., and Miguez, M. G. (2020). River Restoration Integrated with Sustainable Urban Water Management for Resilient Cities. *Sustainability*, *12*(11), 4677. https://doi.org/10.3390/su12114677

Wang, J., Zhang, S., and Guo, Y. (2019). Analyzing the Impact of Impervious Area Disconnection on Urban Runoff Control Using an Analytical Probabilistic Model. *Water Resources Management*, *33*(5), 1753–1768. https://doi.org/10.1007/s11269-019-02211-0

Wang, R.-Q. (2021). Artificial Intelligence for Flood Observation. In *Earth Observation for Flood Applications* (pp. 295–304). Elsevier. https://doi.org/10.1016/B978-0-12-819412-6.00013-4

Wu, W., Jamali, B., Zhang, K., Marshall, L., and Deletic, A. (2023). Water Sensitive Urban Design (WSUD) Spatial Prioritisation through Global Sensitivity Analysis for Effective Urban Pluvial Flood Mitigation. *Water Research*, *235*, 119888. https://doi.org/10.1016/j.watres.2023.119888

Zapata-Diomedi, Belén, Claire Boulangé, Billie Giles-Corti, Kath Phelan, Simon Washington, J. Lennert Veerman, and Lucy Dubrelle Gunn. 2019. "Physical Activity-Related Health and Economic Benefits of Building Walkable Neighbourhoods: A Modelled Comparison between Brownfield and Greenfield Developments." *International Journal of Behavioral Nutrition and Physical Activity* 16:1–12. https://link.springer.com/article/10.1186/s12966-019-0775-8

Zhang, H., Cheng, J., Wu, Z., Li, C., Qin, J., and Liu, T. (2018). Effects of Impervious Surface on the Spatial Distribution of Urban Waterlogging Risk Spots at Multiple Scales in Guangzhou, South China. *Sustainability*, *10*(5), 1589. https://doi.org/10.3390/su10051589

Zhou, S., Zhang, D., Wang, M., Liu, Z., Gan, W., Zhao, Z., Xue, S., Müller, B., Zhou, M., Ni, X., and Wu, Z. (2024). Risk-driven composition decoupling analysis for urban flooding prediction in high-density urban areas using Bayesian-Optimized LightGBM. *Journal of Cleaner Production*, *457*, 142286. https://doi.org/10.1016/j.jclepro.2024.142286

***Table 1**: Demography of Participants (Source: Authors' own work)*

Participant	Organisation Type	Position	Experience (years)
P1	Government	Policy Advisor	25 years
P2	Government	Planner	13 years
P3	Consultant	Civil Engineer	17 years
P4	Consultant	Flood Modeller / Civil Engineer	12 years
P5	Consultant	Climate Change Specialist	11 years
P6	Developer	Technical Director	24 years
P7	Developer	Supervisor	4 years
P8	Consultant	Planner	28 years
P9	Government	Civil Engineer	40 years
P10	Government	Physical Geographer	41 years
P11	Consultant	Director -Environmental Engineer	20 years
P12	Consultant	Director – Engineer and Environmental Planner	20 years
P13	Government	Chief Advisor, Stormwater and Climate Resilience	18 years
P14	Government	Senior Policy Planner	5 years
P15	Government	Land Development Engineer	7 years
P16	Government	Senior Land Development Engineer	8 years
P17	Consultant	Civil Engineer	10 years
P18	Government	Policy and Strategy Advisor	15 years

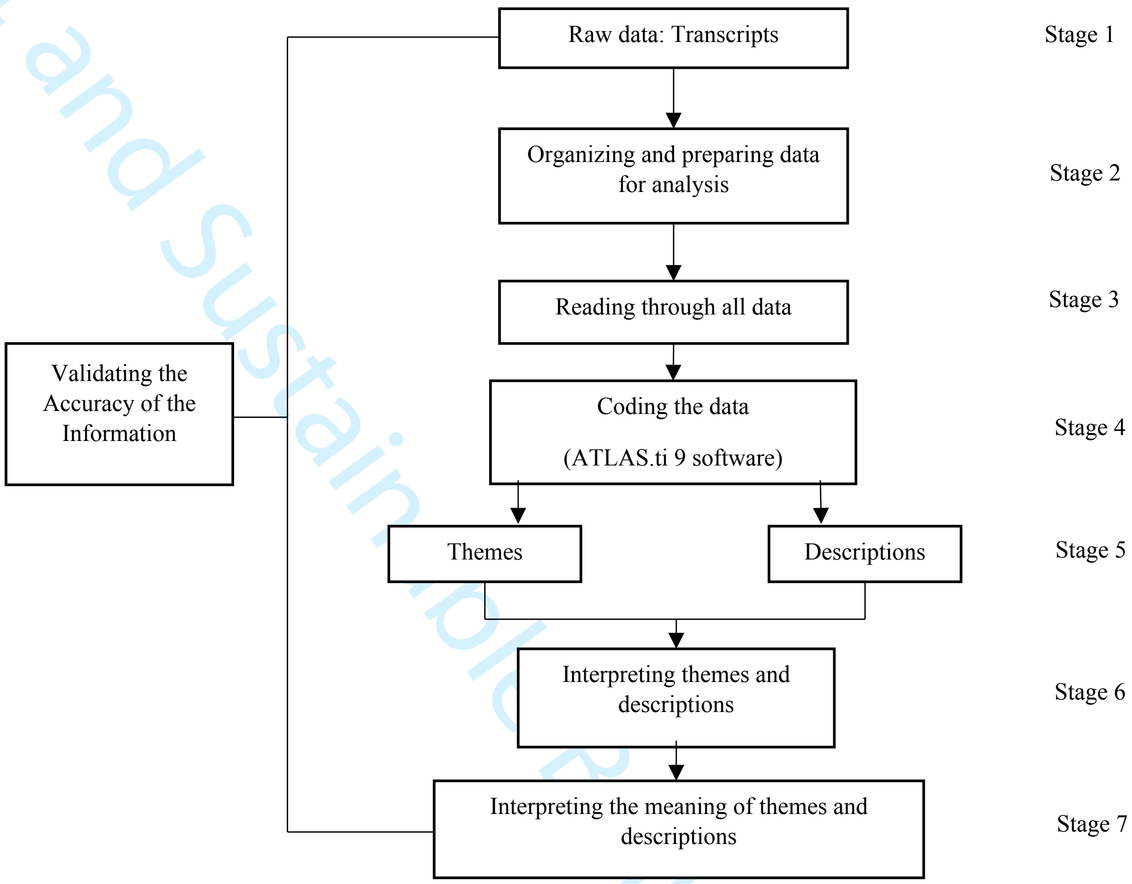


Fig. 1. Qualitative Analysis Framework and Procedures *(Source: Authors' own work)*

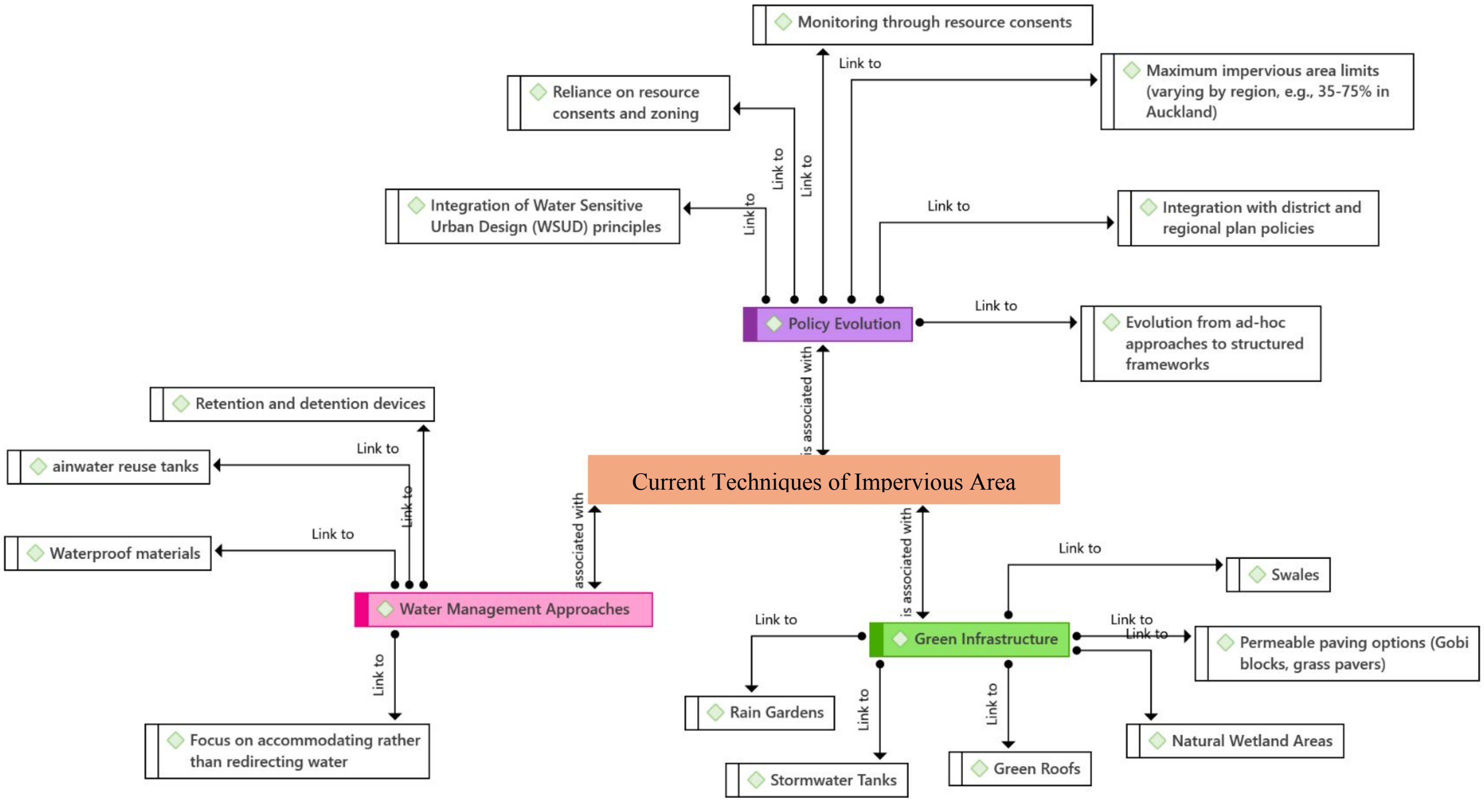
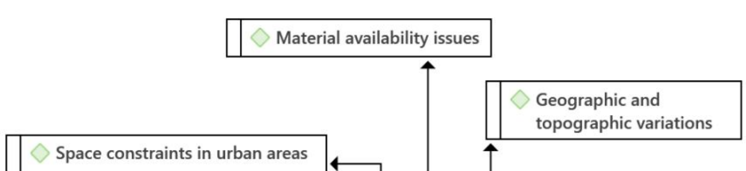


Figure 2: Current techniques identified for reducing impervious areas (Source: Authors' own work)



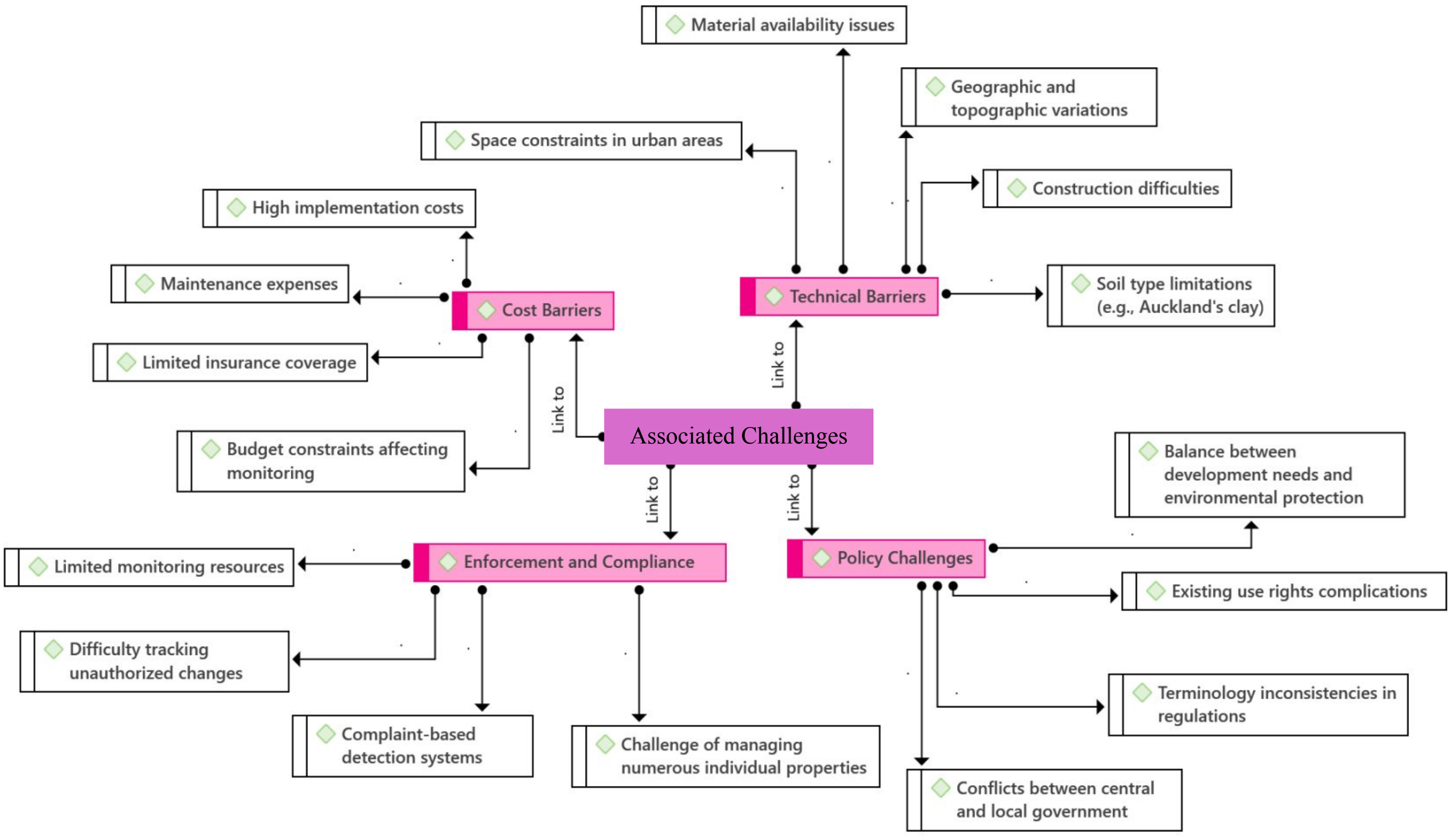


Figure 3: *Associated challenges to impervious area reduction techniques (Source: Authors' own work)*

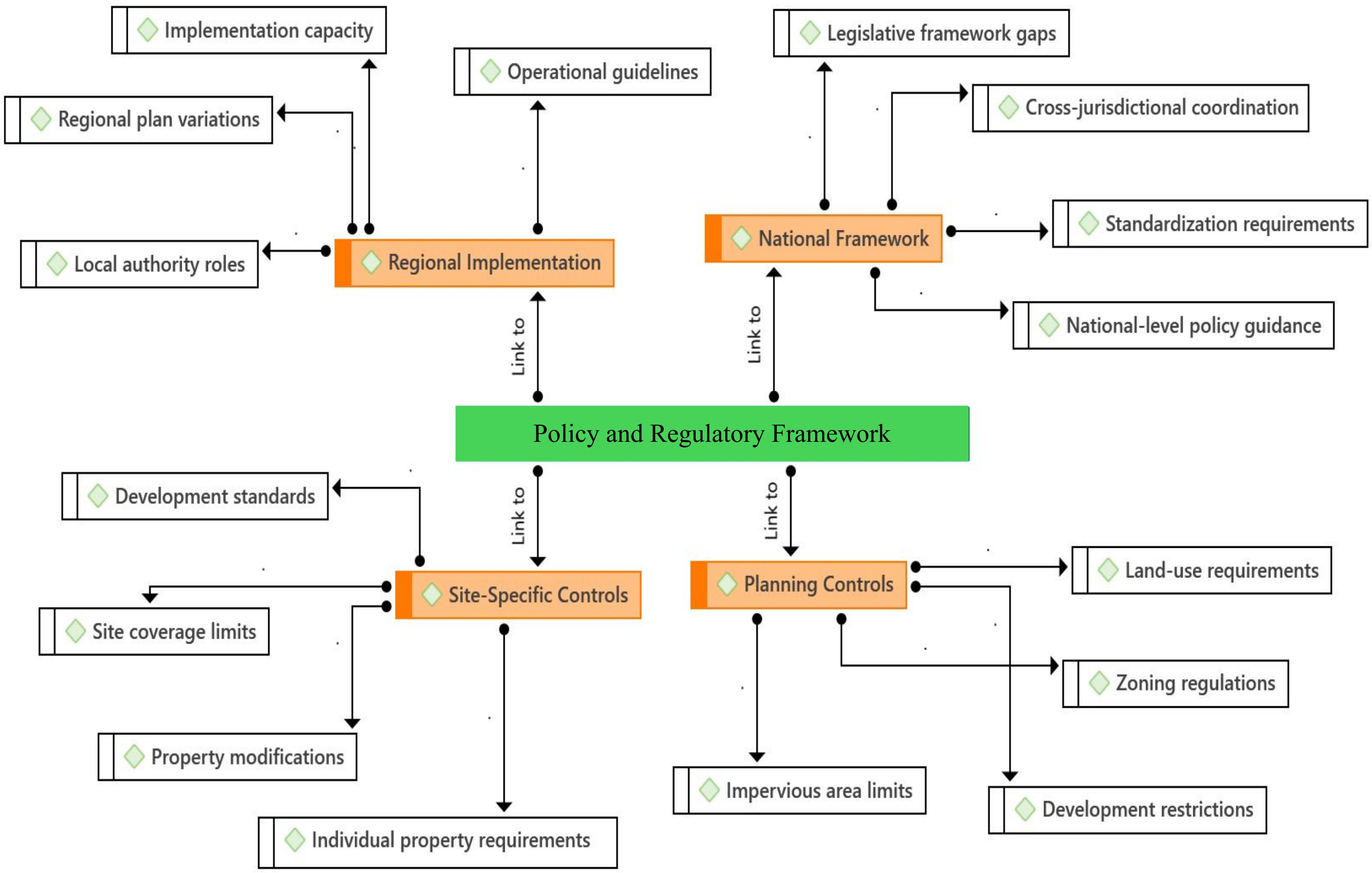


Figure 4: *Policy and regulatory framework governing impervious area reduction strategies (Source: Authors' own work)*

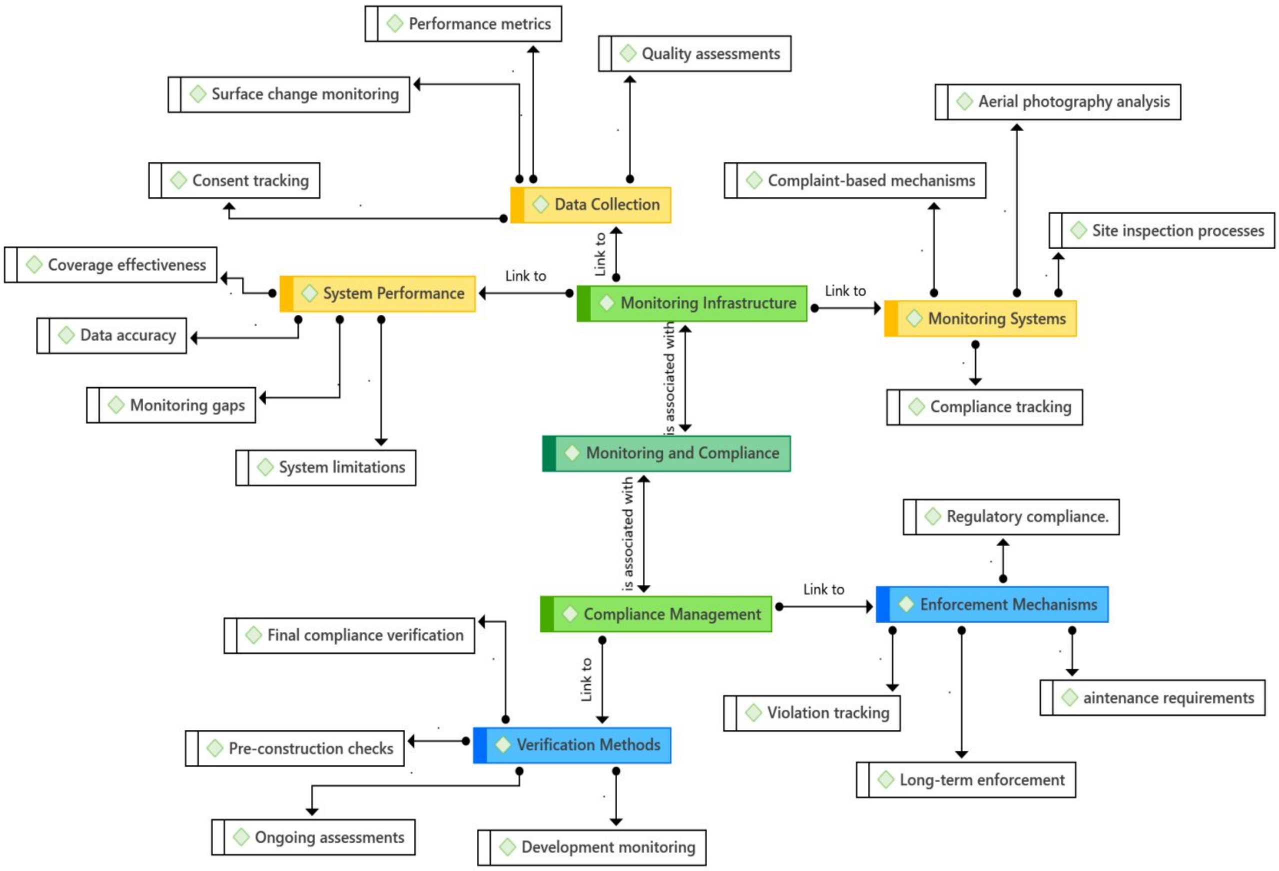


Figure 5: *Monitoring and compliance framework (Source: Authors' own work)*

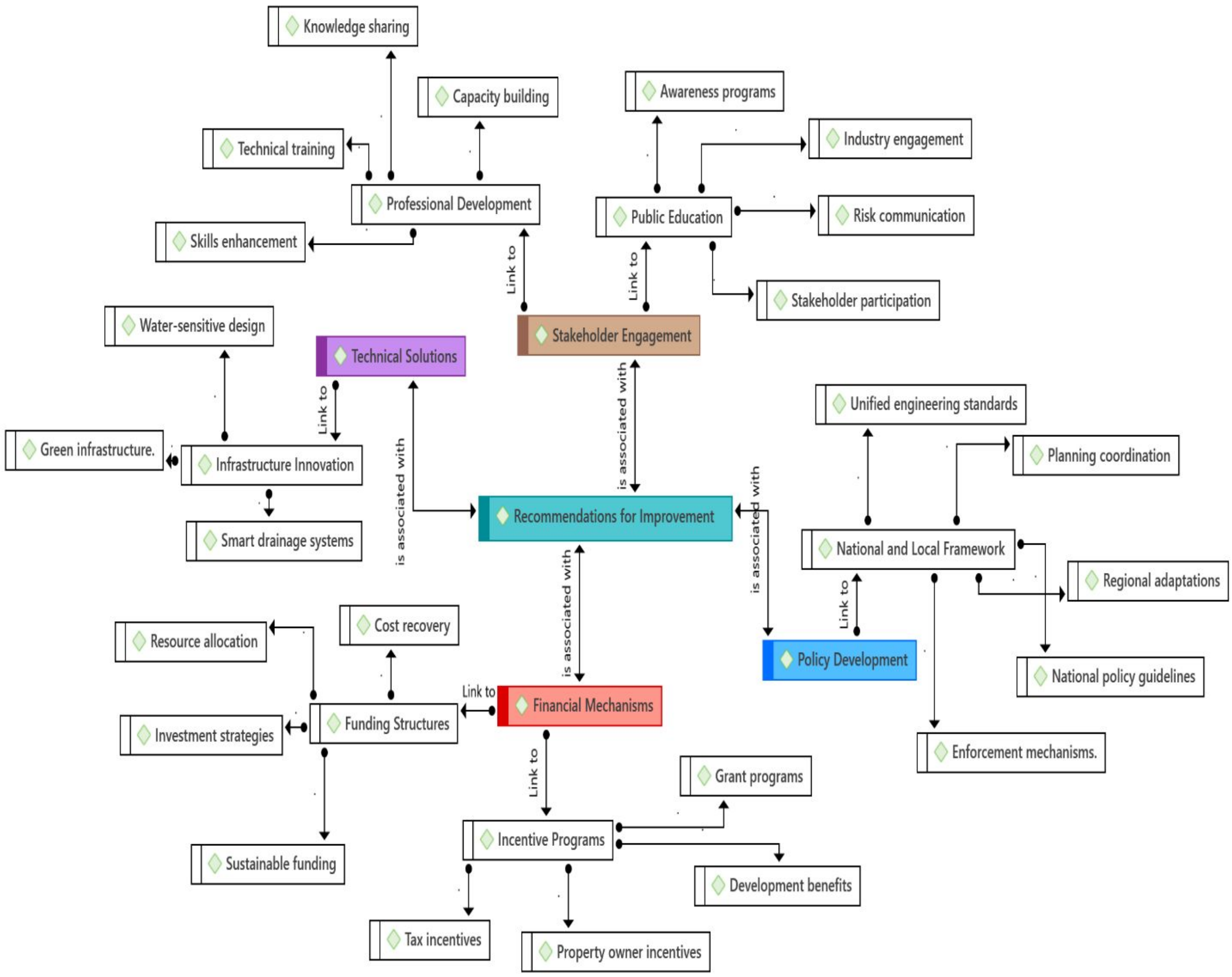


__Figure 6__: Recommendations for improving impervious area reduction strategies (Source: Authors' own work)

Smart and Sustainable Built Environment

Author(s') Response to Reviewers

Manuscript Title: Navigating Urban Hydrology: A Comprehensive Exploration of Impervious Area Reduction Techniques in New Zealand's Residential Landscapes

Manuscript ID: SASBE-07-2025-0430

Editor Comment's			
Comment	**Response**	**Section No**	**Page No.**
1. Please note that it is now mandatory for all authors to clarify the ethical approval process for studies involving human participants or animals. Your study involved semi-structured interviews with 18 experts, which constitutes human participant research. You mention approval by the AUT Ethics Committee (reference 24/70), but you must provide more comprehensive details about the ethical approval process, including the full name of the ethics committee and any specific conditions of approval. If necessary, you may anonymise details, such as replacing the university name with "XXX." Without full compliance with this requirement, your paper cannot be accepted for publication.	Thank you for the opportunity to submit a revised version of our manuscript. We have addressed all the concerns raised by the editor and the reviewers to enhance the quality of our work. Our study, which involved semi-structured interviews with 18 experts, received approval from the XXX University of Technology Ethics Committee (AUTEC) under reference number 24/70. The approval covered the recruitment process, participant information and consent procedures, data collection through interviews, and data management protocols. There were no specific conditions attached beyond compliance with AUTEC's standard requirements for confidentiality, voluntary participation, and secure data storage. We have now revised the manuscript to include these details in the methodology section. In accordance with your guidance, we have anonymised the committee's name (e.g., replace with "XXX University Ethics Committee") as required by the journal's policy.	**Methodology**	**Page 9**
2. Ensure quality, consistency, and readability of the figures and associated captions. Your paper	Thank you for your comments. The explanation for Figure 1 has been revised.	**Figure 1 Qualitative Analysis**	**Page 7 to 8**

contains six complex figures (Figures 1-6) that require significant improvement. Figure 1 (Analysis of Qualitative Study) needs clearer labelling of the seven stages. Figures 2-6 are overly complex flowcharts that are difficult to read and interpret - these need simplification, better colour contrast, and more descriptive captions that clearly explain what each diagram represents and how it relates to your findings.	In response to the reviewer's comment, Figures 2-6 were generated using ATLAS.ti 9 software, where colour-coded symbols systematically distinguished between themes and networks identified from the qualitative data analysis. The figures represent thematic relationships derived from key words, phrases, sentences, and paragraphs that were systematically identified and categorised during the coding process. Each figure has been enhanced with detailed captions that clearly describe what the diagram represents (see Figure 2-6), how the visual elements relate to the research findings, and the methodological process used to develop these thematic networks.	**Framework and Procedures**	
3. Ensure you provide structured abstract as the universal requirement of all Emerald journals. Your abstract lacks the proper structured format with clear headings (Purpose, Design/methodology/approach, Findings, Research limitations/implications, Practical implications, Social implications, Originality/value). Please restructure your abstract according to the journal's requirements with these specific headings.	In response to the reviewer's comment, the abstract has been comprehensively modified and restructured to address the identified concerns and improve clarity.	**Abstract**	**Page 1**
4. Consider referring to and citing where relevant articles published recently in SASBE so that the journal maintains continuity in the discourse it generates. Your literature review could benefit from incorporating recent SASBE publications on urban water	Based on the reviewer's recommendation, additional SASBE references relevant to our study have been incorporated into the manuscript and highlighted throughout the text. Guven, Huseyin, and Aysegul Tanik. 2020. "Water-Energy Nexus: Sustainable Water Management and Energy Recovery from Wastewater in Eco-Cities." *Smart and Sustainable Built*	**SASBE References**	**Page 3 and 4**

management, flood resilience, sustainable drainage systems, and green infrastructure in urban residential areas.	*Environment* 9(1):54–70. https://doi.org/10.1108/SASBE-07-2017-0030 Habib, Ahed, Abdulrahman Alnaemi, and Maan Habib. 2024. "Developing a Framework for Integrating Blockchain Technology into Earthquake Risk Mitigation and Disaster Management Strategies of Smart Cities." Smart and Sustainable Built Environment. https://doi.org/10.1108/SASBE-12-2023-0376. Sarigul, Fatma Handan, and Husnu Murat Gunaydin. 2025. "Integrated BIM, GIS and Interoperable Digital Technologies in Lifecycle Management of Building Construction Projects: Systematic Literature Review." Smart and Sustainable Built Environment. https://doi.org/10.1108/SASBE-08-2024-0312		
5. The references are incorrectly formatted, and all references need to follow the journal requirements with no exception. Follow the author guidelines for further details. Most importantly, all references should have at least one of the followings: doi, ISBN (books only), URL (even for journal articles, where there is no doi). When you are referring to URL, you must indicate the last access date. Several references lack proper doi information, including Hermans (2017), Murphy (2008, 2016), Silva (2018), and the NZ CarbonNews (2024) reference. The NZ CarbonNews reference particularly needs a proper last access date. ALL	Thank you for your observation. The reference list has been comprehensively updated to include DOI numbers for all applicable references, ensuring enhanced accessibility and compliance with current academic standards.	**References**	**Page 20 to 24**

references must be sorted in alphabetical order.			
6. The whole paper needs some thorough proofreading before final submission. There are instances of inconsistent terminology, formatting issues in the participant table, and some grammatical errors throughout the manuscript that require attention.	Thank you. We have now carried out a thorough proofreading of the entire manuscript to address the issues you identified. Specifically, we have ensured consistent use of terminology throughout the paper, corrected grammatical errors, and revised the formatting of the participant table to align with the journal's requirements.	**All**	**All**
7. The Conclusions section of the paper lacks thought-provoking observations, elaboration on the directions for further research and future applications of the presented results. While you mention future research directions, you should expand on the broader implications of your findings for urban planning policy in other developed nations, discuss how your qualitative insights could inform quantitative studies, and suggest specific research methodologies for measuring the long-term effectiveness of the impervious area reduction techniques you identified.	In response to the reviewer's comment, we have carefully revised the Conclusions section to address your concerns and strengthen the impact of the paper. In the revised version, we have expanded the discussion to include more insightful reflections on the implications of our findings. Specifically, we now elaborate on how the impervious area reduction strategies identified in this study could inform urban planning policy in other developed nations, particularly in contexts where stormwater management and resilience planning are pressing concerns. We also highlight how our qualitative insights can serve as a foundation for future quantitative studies, offering concrete examples of measurable indicators (such as reductions in stormwater runoff volume or improvements in infiltration rates) that can be tested in longitudinal research. Additionally, we propose specific research methodologies to evaluate the long-term effectiveness and scalability of the techniques identified by participants.	**Conclusions**	**Page 22 to 24**
8. When you upload your revisions, please make sure that you submit a clean version (without track-changes), a track-changes version, and a table clearly indicating all changes	Thank you.		

been made. Without this, I will need to return your revisions back to you.			
9. In the acknowledgements, please confirm whether AI-based tools (e.g., ChatGPT, Grammarly) were used for drafting, summarising, or refining this manuscript. If AI assistance was used, specify which sections were AI-generated or AI-edited. This is particularly important given the comprehensive nature of your qualitative analysis and the complexity of your framework diagrams.	Thank you for your comment. We confirm that no AI-based tools such as ChatGPT were used for drafting, summarising, or refining the manuscript. The manuscript, including the qualitative analysis and framework diagrams, was developed entirely by the authors. The only AI-based tool used was Grammarly, which was applied for basic grammar and spelling checks. No content, analysis, or interpretation was generated by AI. We have added this clarification in the Acknowledgements section of the manuscript, as requested	**Grammarly software**	**All**
Reviewer 1			
Comment	**Response**	**Section No**	**Page No.**
Comments: The following two issues need to be addressed in the context of Auckland: 1. The paper discusses the relationship between intensification and impervious areas. However, intensification in Auckland is taking place through two mechanisms, i.e., brownfield (where old houses are being demolished and new intensified housing constructed in their place); and, greenfield, i.e. original development. The context of impervious areas of both would be substantially different. This aspect,	Thank you for your feedback. Section 2.6 has been added to address the critical distinction between brownfield and greenfield development contexts and their differential impacts on impervious area management within Auckland's intensification framework.	**Section 2.6**	**Page 6 to 7**

therefore, needs to be discussed in detail before the qualitative analysis			
2. In the context of the linear Auckland sprawl, Silva (2018) has been cited at a few places in the paper. This study is quite relevant and significant, especially in the context of establishment of a Rural Urban Boundary (RUB), and the expansion of urban areas into farmland. This raises the issue of the nature of soils/ground as urbanisation moves from the city centre to the RUB. A discussion on the nature of soils vis-a-vis the concept of transects discussed in the work of Duany and Talen (2002) would be very relevant in the context of Auckland's linear urban sprawl.	Following the reviewer's suggestion, Duany and Talen (2002) has been incorporated into the literature review. These authors introduced "a new approach to the implementation of New Urbanist and smart growth principles" known as transect planning. This approach categorizes human habitats along a continuum based on their level and intensity of urban character. In transect planning, the spectrum of environments ranging from rural to urban serves as an organizing framework for all components of the built environment, including buildings, lots, land uses, streets, and other physical elements of human habitats.	**4.3 Policy and Regulatory Framework**	**Page 13**
Additional Questions: 1. Originality: Does the paper contain new and significant information adequate to justify publication?: Yes, the information contained in the paper is relevant and current.	Thank you.	**Originality**	**All**
2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: No significant work seems to be ignored. However, the following two issues need to be addressed:	In response to the reviewer's comment, both issues raised have been comprehensively addressed: the critical distinction between brownfield and greenfield development contexts has been incorporated through the addition of Section 2.5, and the Duany and Talen (2002) transect planning reference has been integrated to provide a theoretical framework for understanding how soil characteristics and urban intensity should inform context-specific impervious area management strategies.	**Section 2.6 and 4.3**	**Page 7 to 13**

1. The paper discusses the relationship between intensification and impervious areas. However, intensification in Auckland is taking place through two mechanisms, i.e., brownfield (where old houses are being demolished and new intensified housing constructed in their place); and, greenfield, i.e. original development. The context of impervious areas of both would be substantially different. This aspect, therefore, needs to be discussed in detail before the qualitative analysis.	In response to the reviewer's comment, Section 2.5 has been added to address the critical distinction between brownfield and greenfield development contexts and their differential impacts on impervious area management within Auckland's intensification framework.	**Section 2.6**	**Page 6 to 7**
2. In the context of the linear Auckland sprawl, Silva (2018) has been cited at a few places in the paper. This study is quite relevant and significant, especially in the context of establishment of a Rural Urban Boundary (RUB), and the expansion of urban areas into farmland. This raises the issue of the nature of soils/ground as urbanisation moves from the city centre to the RUB. A discussion on the nature of soils vis-a-vis the concept of transects discussed in the work of Duany and Talen (2002) would be very relevant in the context of Auckland's linear urban sprawl.	Following the reviewer's suggestion, Duany and Talen (2002) has been incorporated into the literature review. These authors introduced "a new approach to the implementation of New Urbanist and smart growth principles" known as transect planning. This approach categorizes human habitats along a continuum based on their level and intensity of urban character. In transect planning, the spectrum of environments ranging from rural to urban serves as an organizing framework for all components of the built environment, including buildings, lots, land uses, streets, and other physical elements of human habitats.	**4.3 Policy and Regulatory Framework**	**Page 13**
3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas?	Thank you.	**Methodology**	**All**

Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: Yes			
4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: Yes	Thank you.	**Results**	**All**
5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: The paper bridges the gap between research and practice by bringing out the means to achieve a shift towards reduced impervious areas in the context of Auckland, a contemporary challenge in urban development.	Thank you.	**Implications for research, practice and/or society**	**All**
6. Quality of Communication: Does the paper clearly express its case,	Thank you.	**Quality of Communication**	**All**

measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Yes			
Reviewer 2			
Comment	**Response**	**Section No**	**Page No.**
Recommendation: Major Revision Comments: Hi author(s), While a significnt revision is expected, I wish you all the best with the next revision. Thanks Additional Questions: 1. Originality: Does the paper contain new and significant information adequate to justify publication?: Not in the current form. While the significance of the study is clearly articulated, the rationale would be stronger with a more explicit discussion of the existing knowledge gap. Highlighting what is currently missing in the literature will better justify the need for this research.	In response to the reviewer's comments, we have revised the introduction and literature review sections to clearly identify the current gaps in the literature. The revised manuscript now explicitly highlights critical knowledge gaps that justify this research. These knowledge gaps collectively justify the need for qualitative research that examines not only what strategies exist but also how they perform in New Zealand's specific institutional and environmental context, and why implementation challenges persist despite apparent policy support. The revised manuscript now explicitly connects these gaps to the research objectives and methodology, demonstrating how the qualitative approach addresses limitations in existing quantitative and technical studies.	**Originality**	**Page 2 to 3**

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: Introduction Consider adding a brief paragraph at the end of this section to outline the structure and content of the remainder of the paper. This will help guide the reader and improve the overall flow.	Thank you for your suggestion. We have now added a brief paragraph at the end of the Introduction (Section 2) that outlines the structure and content of the remainder of the paper. This addition provides readers with a roadmap of the paper and improves the flow between sections.	**Structure and content of the remainder of the paper**	**Page 3**
Literature review, Section 2.2 does not add substantial value in its current form. The limitations of traditional drainage-centric approaches are well-established. Consider summarizing this section into a few concise sentences and integrating it into Section 2.3. The literature review currently reads like a textbook summary. To strengthen it, revisit your research objectives throughout the section and explicitly connect the reviewed content to your study's aims. This will help highlight the knowledge gap and your contribution to addressing it. A structured table summarizing key literature could enhance clarity and	In response to the reviewer's comment, both the introduction and literature review sections have been substantially revised to articulate the existing knowledge gaps more explicitly and strengthen the research rationale. Additionally, sections 2.2 and 2.3 have been merged to improve the overall structure and coherence of the paper.	**Section 2.2**	**Page 4 to 5**

provide a more analytical overview of the existing research landscape.			
3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: The choice of research method should be more clearly aligned with the research questions. A brief justification of how the selected approach effectively addresses the study's aims would strengthen the methodological rigor. The number of participants appears sufficient to achieve theoretical saturation, and their industry experience adds credibility to the findings. Figure 1 is currently labeled as a "validation framework," but it functions more as an analysis or evaluation framework. Consider revising the label and description to better reflect its actual role in the study. A key limitation is the absence of a validation phase. Given the subjective nature of qualitative research, this is a significant gap. Incorporating a validation step - such as a focused group interview - would enhance the	Following the reviewer's feedback, the methodology section has been comprehensively restructured to establish a clear constructivist epistemological foundation, better justify the semi-structured interview approach, and explicitly connect the philosophical framework to the research objectives and data collection methods. In addition, the label for Figure 1 has now been revised and it reads "*Qualitative Analysis Framework and Procedures*". Also a comprehensive step-by-step explanations that clearly illustrate each phase of the qualitative analysis methodology, from initial data organization through final theme development and interpretation has been added. We agree that validation is a key consideration in qualitative research. As you noted, we have explicitly acknowledged the limitation of the research method.	**Methodology**	**Page 9** **Page 10** **Page 23 to 24**

trustworthiness of the findings. If this has not yet been conducted, it's important to clarify that the results are preliminary and situated between inductive and abductive reasoning.			
4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: The results section would benefit from stronger contextual grounding. Participant insights should be supported with clearer premises to help the reader understand the "how" and "why" behind the findings - core to qualitative research. Consider incorporating direct quotes from participants to reinforce your interpretations and add authenticity to the narrative. While there is an attempt to integrate literature with findings, the current structure blurs the line between results and discussion. To improve clarity and impact, clearly separate what was found (results) from how those findings relate to existing theories (synthesis). This will help your fieldwork stand out as a meaningful contribution. Figures 2–6: If these are outputs from your fieldwork, please clarify how they were derived. Without this	Thank you. We have revised the results section to incorporate direct quotes, enhancing it with substantial participant quotations across all thematic areas. These authentic voices support our analytical interpretations and strengthen the credibility of findings. All figure captions (Figures 2-6) have been improved to include more descriptive titles, clearer explanations of what each diagram represents, and better integration with the research findings.	**Results**	**Page 11 to 22**

context, it's difficult for readers to critically assess their validity. Figure 4 appears to have missing conceptual links. For example: National frameworks may influence regional implementation. Regional implementation may shape planning controls. Planning controls may inform site-specific controls. If these relationships were not explicitly mentioned by participants but are logically inferred, consider representing them with dashed arrows and briefly explaining them in the text. This will demonstrate the depth of your synthesis and critical thinking.			
5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: Can be significnt upon	We appreciate your thorough and constructive feedback. The entire manuscript has been comprehensively revised, with substantial improvements made to address each specific concern raised, including enhanced theoretical outlines, expanded literature review sections, improved figure captions, strengthened methodology descriptions, and extensive integration of direct participant quotations throughout the results section.	**Implications for research, practice and/or society**	**All**

significnt revisions to address the comments.			
6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: There are several random grammatical errors throughout the manuscript. A careful proofreading or language editing pass is recommended to enhance clarity and professionalism. Some factual statements could be more specific to improve credibility. For example, the claim that “urbanization runoff was 85% higher in 2014 than in 1984” should clarify whether this is a global trend or specific to a region or country. Argument structure requires improvements to demonstrate critical thinking and analysis.	Thank you. We have now carried out a thorough proofreading of the entire manuscript to address the issues you identified. Specifically, we have ensured consistent use of terminology throughout the paper, corrected grammatical errors, and revised the formatting of the participant table to align with the journal’s requirements. In response to the reviewer's comment, section 2.2 has been revised to clarify the geographic scope of the 85% runoff increase claim. Urban hydrology theory provides the foundational understanding of how impervious surfaces fundamentally alter natural water cycles through disrupted infiltration, increased surface runoff, and modified evapotranspiration processes (Hameed, 2017). Empirical evidence demonstrates the magnitude of these changes, with urbanization increasing runoff volumes by up to 85% over three decades due to expanded impervious coverage (Hameed, 2017; Miller and Hutchins, 2017). This dramatic alteration of hydrological processes creates cascading effects throughout urban watersheds, affecting flood frequency, stream morphology, and ecosystem health.	**Quality of Communication** **Section 2.2**	**All** **Page 5**