# Towards identifying barriers of floodwall infrastructure developments – a systematic review

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***Abstract***

*The growing impacts of climate change have brought into question the effectiveness of traditional floodwall designs, which were developed under assumptions of historical climate patterns. This study addresses the urgent need for climate-adaptive floodwall designs (CAFD) in response to the increasing challenges posed by climate change. The research problem focuses on identifying key barriers that hinder the design and implementation of both traditional and climate-adaptive floodwalls, with the goal of informing more resilient and adaptable infrastructure solutions. Through a literature review and thematic analysis, the research identifies and categorises key barriers in the design and implementation of floodwalls, focusing on historical projects prior to the widespread recognition of climate change. The analysis reveals that floodwall projects were historically hindered by environmental, economic, technological, and institutional challenges. While these barriers were sometimes mitigated through advancements in technology, resource management, and community involvement, they persist in more complex forms within the context of climate change. The study further explores emerging barriers specific to CAFD, such as uncertainties in climate projections, the need for adaptive technologies, and socio-political obstacles. These insights are then integrated into a comprehensive framework to guide future floodwall projects, ensuring they are resilient and adaptable to the impacts of climate change.*

***Keywords:*** Floodwall Infrastructure, Barriers, Critical Success Factors, Climate-Adaptive Floodwalls.

## 1. INTRODUCTION

There has been no lack of warnings about how climate change will cause alterations in flood hazard and an overall rise in flood risk worldwide (Wilby & Keenan, 2012). In particular, certain regions are believed to experience more substantial alterations in flooding patterns in the foreseeable future (Güneralp et al., 2015). The potential impacts of rising sea levels and alterations in storm patterns pose an increasingly significant threat to numerous coastal towns and cities (Klein et al., 2003). Additionally, the impact of increased storm precipitation and seasonal rainfall maxima will extend the floods along river basins, which is not only contained in those areas with heavy rainfall track records with some flood infrastructures (Few et al., 2004). With the above concerns, research studies in flood infrastructure have been growing (Jha et al., 2012; Jonkman & Dawson, 2012). In parallel, various flood mitigation measures have been proposed. For example, nature-based solutions combined with traditional grey infrastructure have been suggested to enhance flood protection (Singhvi et al., 2022); adaptive urban drainage systems and multi-path mapping have been implemented to address uncertainties in flood risk management (Ahmad et al., 2024); and advanced flood forecasting and early warning systems have been developed to improve preparedness and reduce flood impacts (Apel et al., 2009). However, barriers to effective implementation of these floodwalls, such as technical, socio-economic, and policy-related challenges, remain understudied. This means that despite advancements, there remain significant challenges that hinder effective floodwall deployment and adaptation. Therefore, this research focuses on identifying key barriers to floodwall infrastructure development, which is crucial for enhancing resilience against climate change-driven flood risks.
Structural flood-protection measures such as levees, floodwalls and dikes often act as the first line of

defence against the riverine flooding, storm surge, floods, and sea-level rise. These structures mitigate damage to other physical infrastructures and promote the sustainability of communities' economic and social activities by preventing water infiltration (Rickard, 2009). In particular, floodwalls have been popularly used and proven comparatively effective in flood control (Aerts, 2018). The construction of floodwalls has been the traditional means of protecting communities in the lower courses of large rivers against flooding (Rickard, 2009). Floodwalls are often constructed from concrete or concrete blocks, and often deployed in areas with too limited room to construct dikes or levees (Sherif, 2023). In this study, floodwall is defined as a flood retrofitting approach involving the implementation of barriers designed to prevent the ingress of floodwaters into the structure (FEMA, 2012).

Given the increasing severity of climate change impacts, including rising sea levels and more frequent extreme weather events, floodwall infrastructure faces critical challenges in maintaining its effectiveness (Demirbilek et al., 2008; Melby et al., 2005). These infrastructures, developed under assumptions of historical climate patterns, may no longer be sufficient to protect the community. For example, as early as 2001 in Grafton, New South Wales, floodwalls were unable to cope with the increased capacity during significant flood events, highlighting early concerns about their adequacy (Pfister, 2002). More recently, during the 2022 flood event at Flemington Racecourse in Victoria, the floodwalls were similarly overwhelmed, leading to significant inundation despite the existing defences (Parliament of Victoria, 2024). Studies have identified several common failures of floodwall infrastructure, including overtopping, structural failure, rotation, sliding, seepage, and piping (Adhikari et al., 2014; Rickard, 2009), all of which highlight the need for a revised approach to floodwall infrastructure. The problem is further exacerbated by climate variability, which impacts the soil foundations of flood defence infrastructures in general and floodwalls in particular. Global warming results in elevated temperatures, leading to increased evaporation and soil fissuring. Additionally, the non-stationary distribution of rainfall causes moisture imbalance, leading to the instability of embankments (Illés & Nagy, 2022). Therefore, conducting a comparative analysis to pinpoint the main obstacles in the design of traditional floodwalls versus Climate-Adaptive Floodwall Design (CAFD) is essential, and this is the objective of this paper.

## 2. RESEARCH OBJECTIVES

This study aims to identify the barriers to developing floodwall infrastructures, with a particular emphasis on the transition from conventional designs to climate-adaptive floodwall designs (CAFD) in the context of climate change. The scope of this work includes both a review of historical floodwall designs to understand past barriers and a focus on recent developments in CAFD to address the current gaps in flood infrastructure resilience against climate changes. The research contributes to the field by bridging the gap between traditional floodwall designs and the need for innovative, climate-adaptive solutions, ultimately aiming to enhance the effectiveness and sustainability of floodwall infrastructures in protecting communities from the growing threat of flooding.

## 3. RESEARCH METHOD

This study adopts a systematic literature review with thematic analysis to identify and analyse the barriers associated with the development of floodwall infrastructures, with a particular focus on climate-adaptive floodwall designs (CAFD). This study did not merely review literature in recent years, but publications focused on the design and implementation of floodwall infrastructures before 2000, a point before climate change was widely recognised as a significant factor in engineering, as highlighted by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2001). Barriers identified from these publications are considered the barriers to the Traditional Floodwall Design (TFD). The year 2000 was chosen as the dividing point because it corresponds to the release of the IPCC's Third Assessment Report, which highlighted the critical influence of climate change on infrastructure development and planning. Identifying barriers of TFD provides a historical baseline for future research on climate-adaptive floodwall designs (CAFD).

A Systematic Literature Review (SLR) was employed to search, assess, and synthesise relevant

scholarly articles (Ferlito et al., 2022). This approach ensures a comprehensive analysis of the technological, financial, regulatory, and socio-political challenges of historical floodwall designs (Kelly et al., 2014). The review process was conducted in two phases: a pre-climate change phase for TFD (before 2000) and a post-climate change phase for CAFD (after 2000). This two-phase approach enables a comparative analysis of barriers over time.
The development of the query string is an iterative process, typically starting with a pilot study to refine the search terms and ensure the retrieval of relevant studies (Sánchez-Garrido et al., 2023). Initially, the search string was constructed using Boolean operators such as AND, OR, and NOT, and piloted across Web of Science, Emerald Insight, and ScienceDirect databases. This pilot phase allowed for adjustments to ensure that the string could effectively capture pertinent literature on floodwall infrastructures. The final search structure was then designed using the query string: ("floodwall" OR "flood wall" OR "levee" OR "dike" OR "embankment" OR "dam") AND ("design" OR "construction" OR "engineering") AND ("barriers" OR "challenges" OR "obstacles" OR "critical success factors" OR "CSFs" OR "limitations"). This query string was chosen to provide a comprehensive search of literature related to the barriers and critical success factors in floodwall design and implementation, ensuring that the study captures a broad spectrum of relevant research on both traditional floodwalls and related flood defence structures.
The inclusion and exclusion criteria were carefully defined to ensure the relevance and quality of the studies included in the SLR. The inclusion criteria focused on selecting peer-reviewed publications related to floodwall design, construction, barriers and within the fields of Civil Engineering, Environmental Science, and Construction Management. The pre-climate change phase included studies before 2000, while the post-climate change phase focused on those conducted after 2000. Exclusion criteria were applied to filter out irrelevant studies, non-peer-reviewed sources, and publications outside the specified year range or subject areas. The initial pre-climate change search yielded 956 articles, which were screened down to 27 for in-depth analysis. The post-climate change search yielded 1,080 articles, of which 35 were selected for thematic analysis. This rigorous process ensures a high-quality data set, enabling a comprehensive analysis of how barriers and CSFs in floodwall development have evolved over time.

## 4. RESULTS AND FINDINGS

### 4.1. Identification of Barriers

The systematic literature review identified 6 key barriers to the design and implementation of floodwalls before the widespread recognition of climate change (Table 1).

**Table 1. Barriers in Traditional Floodwall Design and Climate-Adaptive Floodwall Design**

| Barrier Type | Traditional Floodwall Design (TFD) | Climate-Adaptive Floodwall Design (CAFD) |
|---|---|---|
| Environmental and Ecological Challenges | ▪ Habitat loss, pollution, ecosystem degradation (Williams, 1999).<br>▪ Insufficient emphasis on sustainability (Thompson, 1999) | ▪ Climate uncertainties affect design (Hale 2024).<br>▪ Difficulty in balancing ecological preservation with flood barriers (Scheres & Schüttrumpf, 2019). |
| Economic and Resource Constraints | ▪ High construction and maintenance costs (Cuny, 1991).<br>▪ Projects unfeasible in low-income regions (Wakeling, 1984). | ▪ Resilient floodwall designs entail high upfront costs (Nakazawa et al., 2021).<br>▪ Funding complexities for balancing floodwalls and nature-based solutions (Albert et al., 2019). |

| | | |
|---|---|---|
| Technological and Design Limitations | ▪ Outdated materials and techniques (Thompson, 1999).<br>▪ Difficulty predicting reinforcement stresses (Hoeg et al., 1993). | ▪ Need for advanced modelling and data (Al-Ghosoun et al., 2021).<br>▪ Geotechnical challenges and data quality issues (Wang et al. 2021). |
| Institutional and Policy Barriers | ▪ Regulatory inefficiencies and delays (Mattingly et al., 1993).<br>▪ Shift from structural to non-structural priorities (Arnell, 1984). | ▪ Outdated policies and fragmented governance (Shi, 2019).<br>▪ Poor coordination among agencies and investment towards climate-adaptive solutions (Hale, 2024). |
| Social and Cultural Factors | ▪ Opposition to structural flood mitigation measures (Shrubsole & Scherer, 1996).<br>▪ Impact of floodplain laws on land values (Cuny, 1991). | ▪ Public resistance to climate-adaptive solutions due to poor awareness of climate risks (Pidot, 2015).<br>▪ Social norms and insufficient community engagement (Halbe et al. 2013). |
| Construction and Material Challenges | ▪ Poor material quality and foundation failure (Wang & Solymár, 1997).<br>▪ Recurrent structural weaknesses (Visser, 1998). | *No equivalent in CAFD* |
| Interdisciplinary and Stakeholder Collaboration | *No equivalent in TFD* | ▪ Lack of interdisciplinary coordination (Venkataramanan et al., 2019)<br>▪ Limited stakeholder involvement and top-down decision-making (Halbe et al., 2015). |

Environmental and ecological challenges were significant, as habitat loss, pollution, and the degradation of ecosystems hindered the effectiveness of flood defence projects (Williams, 1999). Economic and resource constraints also posed major obstacles, with the high costs of construction and maintenance often making large-scale floodwall projects economically unfeasible, particularly in low-income regions (Cuny, 1991). Technological and design limitations further compounded these issues, with outdated materials and construction techniques, along with difficulties in predicting reinforcement stresses, leading to suboptimal floodwall performance (Thompson, 1999). Institutional and policy barriers, such as regulatory inefficiencies and delays in project approvals, significantly impeded the progress of floodwall projects (Thompson, 1999). Social and cultural factors, including resistance to structural flood mitigation measures and the impact of floodplain regulations on land values, also presented considerable challenges, complicating the design and implementation of floodwalls (Cuny, 1991). Finally, construction and material challenges, such as poor-quality materials, foundation issues, and structural vulnerabilities, frequently led to failures in floodwall projects, highlighting the need for improved construction practices and material selection (Wang & Solymár, 1997).

Emerging barriers in climate-adaptive floodwall designs (CAFD) are also presented in Table 1, These barriers build on the challenges identified in traditional projects, now complicated by climate change. Uncertainty in climate projections makes it difficult to design floodwalls that can withstand a wide range of future scenarios, exacerbating existing environmental and ecological challenges (Hale, 2024; Scheres & Schüttrumpf, 2019). The integration of adaptive technologies introduces further complexities, requiring advanced materials and ongoing maintenance, which are not always cost-effective or readily available, especially in resource-limited regions (Shibuo & Furumai, 2021). Socio-political and regulatory challenges also intensify, as existing frameworks often fail to address the complexities of CAFD, necessitating updated policies and greater community involvement (Huang & Wang, 2024). Additionally, the demand for resilient and sustainable materials heightens logistical and financial pressures, complicating construction efforts (Pariartha et al., 2023). These challenges, combined with increased economic pressures due to the advanced requirements of CAFD, reflect and extend the barriers faced in traditional floodwall projects, now intensified by the need to adapt to an uncertain future (Albert et al., 2019). Ultimately, other emerging barriers in CAFD involve interdisciplinary collaboration and stakeholder involvement. Unlike traditional designs, the resilient one requires a broad input base from the engineering, urban planning, and environmental science disciplines and active community involvement. This is further exacerbated by fragmented governance and inadequate coordination among these stakeholders (Adeyeye & Emmitt, 2017; Halbe et al., 2015).

### 4.2. Implications of findings & Next Steps

Recognising such barriers in both Traditional Floodwall Design (TFD) and Climate-Adaptive Floodwall Design (CAFD) highlights the need for a more adaptive and resilient approach to floodwall infrastructure. Chronic issues such as environmental degradation, economic constraints, outdated technologies, and regulatory inefficiencies are some critical impediments to the effective design of floodwalls historically. These are now further compounded by the uncertainties of climate change, making the situation increasingly difficult. Such challenges will need to be addressed through the integration of various factors, including advanced technologies, adaptive design approaches, and enhanced stakeholder involvement. In that way, future floodwalls will be better prepared to respond to evolving climate risks.

The study should be followed by the identification of such critical success factors (CSFs) which would help in overcoming these barriers. These CSFs would thus form the basis of a detailed framework that could guide future floodwall designs with the foresight of flexibility and stakeholder involvement. The framework should integrate structural and non-structural measures, enabling floodwalls to remain effective in changing environmental and socio-political contexts. Given the traditional and emerging climate-related issues being addressed, the study can help further the course of CAFD.

## 5. CONCLUDING REMARKS

The research framework presented in this paper offers an opportunity to address the complex barriers for the implementation of climate-adaptive floodwall designs (CAFD).

It emphasises the importance of incorporating advanced technologies, adaptive management practices, and stakeholder engagement to ensure that floodwalls are resilient to current climate conditions and adaptable to future uncertainties.

As climate change introduces new challenges, these lessons must be adapted to meet contemporary needs. The identification of barriers highlights the necessity of flexibility in design, ongoing technological advancement, and proactive stakeholder engagement to ensure the success of future CAFD projects.

Moving forward, the development of a framework, incorporating advanced technologies, stakeholder engagement, and adaptive design principles will be essential in safeguarding communities against the increasing risks associated with climate-induced flooding. Future research should continue to refine this framework, exploring new technologies and strategies that enhance the adaptability and sustainability of floodwall infrastructures in a changing climate.

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