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Flood Risk reduction using protective and boulder walls: A review with special reference to Afghanistan

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Abstract

Afghanistan faces progressively regular and severe floods that cause substantial loss of life, destroy the infrastructure, and interrupt livings. Structural mitigation measures mainly protective walls built from locally available boulders offer practical, low-cost solutions in this resource-constrained context. This review synthesizes national and international literature on flood risk reduction using protective walls, with special importance on boulder walls in Afghanistan's flood-prone provinces. We assess design considerations, efficiency, environmental impacts, and implementation challenges. Key results show that while boulder walls provide cost-effective, community-driven flood mitigation, they require technical design support and integration with non-structural measures such as early warning systems and land-use planning to attain sustainable risk reduction. This review offers evidence-based guidance for practitioners, policymakers, and communities working to improve flood resilience across Afghanistan.

Keywords: Flood Risk Reduction; Protective Walls; Boulder Walls; Structural Mitigation; Afghanistan

1. Introduction

Flooding is one of the most significant natural hazards affecting Afghanistan, posing severe threats to human lives, property, and livelihoods [1]. The country's diverse topography, ranging from the high Hindu Kush mountains to extensive river valleys, combined with climate variability, contributes to frequent and unpredictable flood events [2]. Seasonal snowmelt, intense rainfall during the monsoon months, deforestation, and rapid unplanned urbanization exacerbate flood risks, particularly in mountainous and riverine regions [3]. According to national assessments, over 80 major flood events occurred between 2000 and 2024, resulting in thousands of casualties and millions of dollars in economic losses [4, 5].

The socio-economic impacts of floods are severe in Afghanistan, where a significant portion of the population depends on agriculture for subsistence [1]. Floods destroy croplands, livestock, irrigation systems, and transportation infrastructure, while also displacing communities [1, 2]. The economic burden is further compounded by limited government capacity, political instability, and inadequate disaster management systems [6]. Vulnerable provinces such as Nangarhar, Kunar, Badakhshan, Kabul, and Herat experience repeated flooding due to their proximity to major rivers and floodplains [7].

Structural mitigation measures are recognized as effective interventions to reduce flood damage and protect communities [8]. Among these measures, protective walls constructed using locally available materials, such as

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boulders, have been widely implemented in rural and semi-urban areas [9]. Boulder walls, also referred to as stone or rock walls, function as gravity-based barriers that resist hydraulic forces and prevent erosion along riverbanks [10, 11]. Their cost-effectiveness, reliance on local labor and materials, and ease of construction make them suitable for Afghanistan's resource-constrained environment [2].

Despite their widespread use, there is limited systematic documentation and critical review of the effectiveness, design principles, and sustainability of boulder walls in Afghanistan. Most existing studies focus on specific provinces or engineering aspects, lacking a broader synthesis that can inform national-level policy and planning [1-4]. A comprehensive review is particularly necessary to guide practitioners, policymakers, and communities in designing resilient, low-cost flood mitigation strategies [12]. This review aims to address this gap by systematically analyzing existing literature on flood risk reduction using protective walls, with a special focus on boulder walls in Afghanistan. The objectives are to: (a) summarize global and national research on structural flood mitigation, particularly boulder walls. (b) evaluate design considerations, performance, and sustainability of boulder walls in flood-prone regions. (c) identify gaps in knowledge and practice relevant to the Afghan context and (d) provide recommendations for effective implementation and policy interventions. By integrating scientific evidence, case studies, and practical experiences, this review provides a comprehensive resource for advancing flood resilience in Afghanistan while highlighting opportunities for further research and innovation.

2. Review Methodology

This review employs a systematic literature review approach, designed to identify, analyze, and synthesize relevant studies on flood risk reduction using protective walls, with an emphasis on boulder walls. A systematic approach ensures transparency, reproducibility, and comprehensiveness in identifying relevant literature.

2.1. Data Sources

Literature Relevant literature was collected from multiple electronic databases and institutional repositories to ensure comprehensive coverage of flood risk reduction and boulder wall applications (Figure 1). Peer-reviewed journal articles and conference proceedings were primarily obtained through Google Scholar and Scopus, which provided access to indexed research in engineering, environmental science, and disaster management. Additional preprints and open-access publications were retrieved from ResearchGate to include recent and region-specific studies.

Furthermore, national and international institutional reports were reviewed to strengthen the evidence base and contextual relevance of the study. These sources included publications from the Afghanistan National Disaster Management Authority (ANDMA), United Nations Office for Disaster Risk Reduction (UNDRR), International Federation of Red Cross and Red Crescent Societies (IFRC), World Bank, and UNICEF. These institutional documents provided valuable information on flood impacts, risk management strategies, and community-based mitigation practices in Afghanistan and comparable regions.

2.2. Search Strategy

The search was conducted using combinations of the following keywords: "Flood mitigation" OR "Flood risk reduction" AND "protective wall" OR "boulder wall" OR "stone wall" AND "Afghanistan" OR "mountainous regions" OR "developing countries" The search included studies published between 2000 and 2025 to ensure relevance to current climatic, social, and infrastructural conditions (Figure 1).

2.3. Inclusion and Exclusion Criteria

Studies were selected for this review based on specific inclusion criteria to ensure relevance and quality. Included studies focused on structural flood mitigation, particularly walls, embankments, or boulder-based constructions. Only studies relevant to Afghanistan or comparable mountainous, developing-country settings were considered. Reports addressing design, construction, performance evaluation, environmental impacts, or socio-economic outcomes were included, and sources comprised peer-reviewed articles, government publications, and technical reports from NGOs. Exclusion criteria were applied to remove irrelevant or low-quality studies. Publications unrelated to flood risk reduction, opinion pieces, editorials, or studies lacking methodological rigor were excluded. Additionally, duplicate or inaccessible publications were omitted to maintain the integrity and reliability of the review.

2.4. Data Extraction and Analysis

Relevant information was extracted from each selected study to provide a comprehensive overview of flood mitigation using structural measures, particularly boulder walls. The data collected included the study location and context, types and characteristics of floods, the structural mitigation methods employed, design parameters of protective walls, observed performance and maintenance requirements, and the associated environmental and socio-economic impacts. The extracted information was then analyzed qualitatively to identify common trends, best practices, and research gaps. To facilitate comparison and visualization, key data were summarized using tables and figures, highlighting details such as flood events, wall design parameters, and cost-benefit assessments. This approach enabled a systematic evaluation of boulder walls and other structural interventions in Afghanistan and similar contexts, supporting evidence-based recommendations for flood risk reduction.

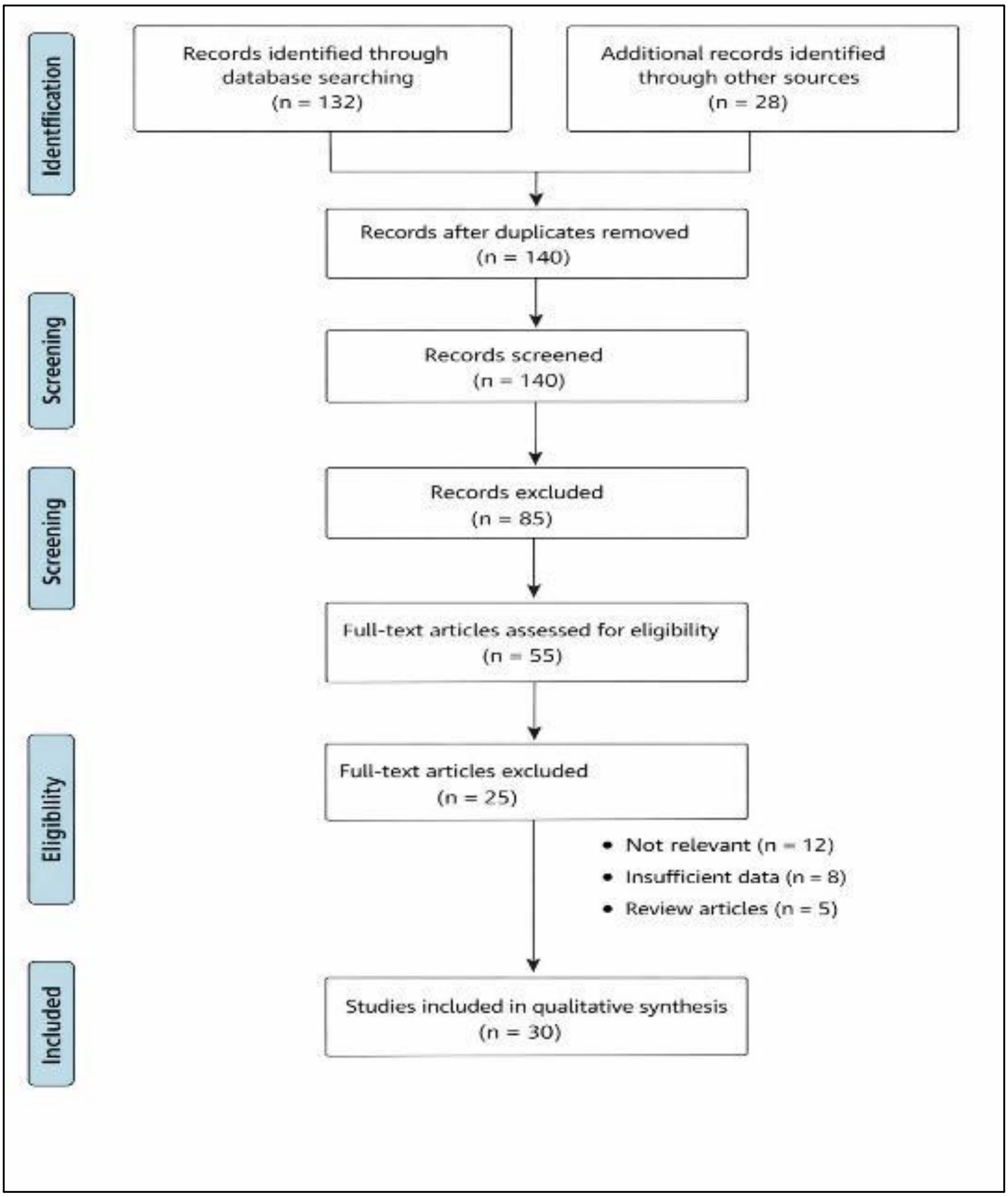

Figure 1 PRISMA-style flowchart illustrating the systematic review process, including identification, screening, eligibility assessment, and inclusion of studies for analyzing flood mitigation using boulder walls in Afghanistan

3. Flood Risk in Afghanistan

Afghanistan is highly vulnerable to floods due to its complex topography, extreme seasonal weather, and socio-economic conditions [13]. Floods in the country occur mainly as flash floods in mountainous areas and riverine floods along major rivers [2]. The combination of steep slopes, rapidly melting snow, and high-intensity rainfall events can result in sudden, devastating floods, particularly in narrow valleys where communities are concentrated. According to national reports, over 80 significant flood events occurred between 2000 and 2024, leading to thousands of fatalities, the displacement of tens of thousands of people, and extensive damage to infrastructure, agriculture, and livelihoods [4, 5].

3.1. Geographic and Climatic Factors

Afghanistan's northern and northeastern regions, including Badakhshan, Takhar, and Nangarhar provinces, are particularly susceptible to flash floods due to steep mountain slopes and narrow river valleys [1]. Conversely, provinces along the Kabul, Helmand, and Amu Darya rivers are prone to riverine flooding during snowmelt or heavy rainfall periods [14]. The Hindu Kush mountains contribute significantly to snowmelt-driven floods during spring, while seasonal rainfall during July–September can trigger additional flood events, especially when intense storms coincide with saturated soils [15]. Climate change is expected to exacerbate flood risks in Afghanistan [2, 4]. Rising temperatures increase snowmelt rates, while altered rainfall patterns result in more intense and erratic precipitation events [16]. As a result, flood frequency and intensity are projected to rise in the coming decades, posing greater challenges to disaster risk management [6].

3.2. Socio-Economic Vulnerability

Afghanistan's socio-economic context magnifies flood risk [2]. Most rural communities rely on subsistence agriculture, with homes and fields often located near rivers and streams [1]. Infrastructure is frequently underdeveloped, and early warning systems are limited, reducing the capacity for timely evacuation. Socio-economic vulnerability also stems from decades of conflict, which has disrupted governance and the development of resilient infrastructure [7]. Consequently, even moderate floods can result in disproportionate damage, particularly in rural and peri-urban areas [1].

3.3. Historical Flood Events

Several major flood events in Afghanistan illustrate the scale and impact of flood hazards. Table 1 summarizes significant floods from 2000–2024, highlighting their location, type, economic damage, and the presence or absence of structural mitigation measures.

Table 1 Major Flood Events in Afghanistan (2000–2024)

Year	Province	Flood Type	Casualties	Damage (USD)	Protective Measures
2002	Kabul	Flash Flood	30	1.2M	None
2005	Nangarhar	Riverine	45	2.8M	Temporary boulder walls
2010	Badakhshan	Flash Flood	70	3.5M	None
2014	Herat	Riverine	25	1.5M	Embankments
2018	Kunar	Flash Flood	60	4.2M	Boulder walls installed
2020	Kabul	Flash Flood	15	2.1M	Partial boulder walls
2023	Helmand	Riverine	40	3.8M	None
2024	Nangarhar	Flash Flood	50	4.5M	Community-built boulder walls

Note: Data compiled from reference [1, 2, 3, 4, 7].

3.4. Flood-Prone Regions

Figure 2 illustrates the flood-prone provinces of Afghanistan. Provinces in the northeast (Badakhshan, Takhar, and Nuristan), central highlands (Bamyan, Kapisa), and river valleys (Kabul, Helmand, Nangarhar) experience the most frequent and destructive flood events. These areas combine high rainfall or snowmelt runoff with dense settlement in vulnerable zones, emphasizing the need for targeted mitigation measures.

Figure 2 Provinces at risk of flash floods (orange, mountainous areas) and riverine floods (blue, along rivers) are highlighted, including Nangarhar, Kunar, Badakhshan, Kabul, Helmand, and Herat.

3.5. Implications for Flood Mitigation

Understanding the spatial distribution of flood risk in Afghanistan is critical for prioritizing mitigation strategies [4]. Structural interventions, such as protective and boulder walls, must be targeted to high-risk provinces while incorporating local knowledge, topography, and hydrological characteristics. Moreover, the integration of structural measures with non-structural approaches, such as early warning systems, land use planning, and community awareness programs, is essential for sustainable flood risk reduction [17].

4. Structural Mitigation Measures

Flood mitigation strategies can be broadly classified into structural and non-structural measures [16]. Structural measures involve the construction of physical infrastructure to prevent, divert, or contain floodwaters [18]. In Afghanistan, structural measures are particularly important in high-risk provinces, where floods frequently threaten lives, agriculture, and infrastructure [4]. Common structural interventions include levees, embankments, floodwalls, check dams, and boulder walls, each with unique advantages, limitations, and suitability based on local conditions.

4.1. Levees and Embankments

Levees and embankments are raised earth or concrete barriers designed to prevent river water from overflowing into populated or agricultural areas [19]. They are widely used along major rivers, such as the Kabul, Helmand, and Amu Darya, to protect urban and rural communities [20]. The effectiveness of levees depends on their design height, slope stability, soil compaction, and maintenance. Failures are often linked to overtopping during extreme floods, poor construction quality, or erosion at the base [2].

4.2. Floodwalls

Floodwalls are vertical barriers, typically made of reinforced concrete or masonry, that provide higher resistance to flooding compared to earthen levees [3]. They are often used in urban areas where space constraints limit the construction of wide embankments [1]. Floodwalls require detailed engineering design, including foundations capable of withstanding hydraulic pressures and lateral soil forces. Although effective, their construction and maintenance costs are relatively high, limiting widespread implementation in Afghanistan's resource-constrained provinces [4].

4.3. Check Dams and Retention Structures

Check dams and small retention structures are designed to reduce runoff velocity, capture sediment, and store floodwaters temporarily [21]. In mountainous provinces like Badakhshan and Kunar, these measures help mitigate flash floods and reduce downstream sediment deposition. Check dams can be constructed using local materials, such as stone or concrete, and are often combined with vegetation to enhance slope stabilization [21].

4.4. Boulder Walls

Boulder walls, also referred to as gravity or stone walls, are low-cost, community-based solutions widely used in rural Afghanistan [22]. Constructed from locally sourced rocks, boulder walls rely on their weight to resist hydraulic forces [22]. They are particularly effective for protecting riverbanks, small settlements, and agricultural fields from flash floods [1]. Their advantages include low material costs, simple construction techniques, and the potential for community involvement in building and maintenance [5]. However, their effectiveness is limited during extreme floods, and they require periodic inspection and repair to maintain structural integrity [22].

4.5. Comparison of Structural Measures

Structural measures vary in terms of cost, technical complexity, durability, and effectiveness. Table 2 summarizes a comparison of commonly used flood mitigation structures in Afghanistan, highlighting their suitability for different provinces and flood types.

Table 2 Comparison of Structural Flood Mitigation Measures

Structural Measure	Description	Typical Application	Advantages	Limitations
Levees / Embankments	Raised earth or concrete barriers along rivers	Riverine floodplains (Kabul, Helmand)	Cost-effective, large protection area	Requires maintenance; risk of overtopping
Floodwalls	Vertical concrete or masonry walls	Urban areas with space constraints	High flood resistance, durable	Expensive; complex engineering
Check Dams	Small barriers in rivers/streams	Mountainous flash flood areas (Badakhshan, Kunar)	Reduce runoff velocity; sediment control	Limited flood volume capacity
Boulder Walls	Gravity walls made from local stones	Rural settlements, small rivers	Low cost; community-built; simple construction	Limited protection for extreme floods; maintenance required
Retention Ponds	Temporary water storage	Upstream flood control	Reduce downstream flood peaks	Requires land; seasonal storage only

4.6. Key Considerations for Structural Measures

- Site-Specific Design: Structural measures must be tailored to local topography, hydrology, and flood characteristics. A boulder wall suitable for a small river in Nangarhar may be inadequate for a larger river in Kabul province.
- Community Participation: Engaging local communities in the construction and maintenance of structures, particularly boulder walls, enhances sustainability and reduces long-term costs.
- Integration with Non-Structural Measures: Combining structural interventions with flood forecasting, early warning systems, and land-use planning ensures comprehensive flood risk reduction.
- Maintenance and Monitoring: Regular inspection and repair are essential to prevent failure of levees, walls, and check dams, especially after flood events.

4.7. Relevance to Afghanistan

In Afghanistan, where resources are limited and flood-prone communities often lack access to professional engineering services, boulder walls and small-scale levees provide practical solutions [4]. They can be implemented rapidly after a flood event, involve local labor, and leverage readily available materials. These measures complement government-led projects, such as larger embankments and concrete floodwalls in urban areas, creating a multi-tiered flood protection system that addresses both rural and urban vulnerabilities [4].

5. Boulder Walls

Boulder walls, also known as gravity or stone walls, are low-cost, community-based structural flood mitigation measures widely used in rural and semi-urban areas of Afghanistan [2, 22]. They are constructed from locally sourced rocks or stones and rely primarily on gravity and mass to resist the force of flowing water. Boulder walls are particularly effective along small rivers, streams, and agricultural fields, providing a practical solution in resource-constrained regions [22].

5.1. Design Principles

The main geometric and structural parameters summarized in Table 3 are visually illustrated in Figure 3.

- Wall Height and Width: The height is determined based on expected flood depth, typically ranging from 0.2 to 2 meters for small streams and up to 3 meters in high-risk areas. The width at the base is generally 1.2–2 times the wall height to ensure stability [5].
- Stone Selection: Stones should be angular, durable, and resistant to erosion. Large stones are placed at the base, with smaller stones on the top layers to provide structural integrity and reduce seepage.
- Slope and Batter: A slight backward slope (batter) of 5–10° toward the river reduces the risk of toppling during high-velocity floods.
- Foundation: Foundations are dug to a depth of 0.3–0.5 meters and compacted to prevent undermining by floodwater.
- Drainage and Interlocking: Gaps between stones are filled with gravel or smaller rocks to allow water drainage and increase friction between layers. Proper interlocking prevents displacement under hydraulic pressure.
- Maintenance: Regular inspections, particularly after flood events, are essential to identify displacement, scouring, or erosion. Repairs should be made immediately to maintain protection.

Table 3 Boulder Wall Design Parameters in Afghanistan

Parameter	**Recommended Range**	**Notes**
Height	0.5–3.0 m	Based on flood depth
Base Width	1.2–2 × wall height	Ensures stability
Slope/Batter	5–10° backward	Reduces risk of toppling
Foundation Depth	0.3–0.5 m	Compacted soil to prevent undermining
Stone Size	0.2–0.8 m diameter	Larger stones at base
Drainage	Gravel infill	Prevents seepage
Maintenance Frequency	After every flood season	Inspect and repair cracks

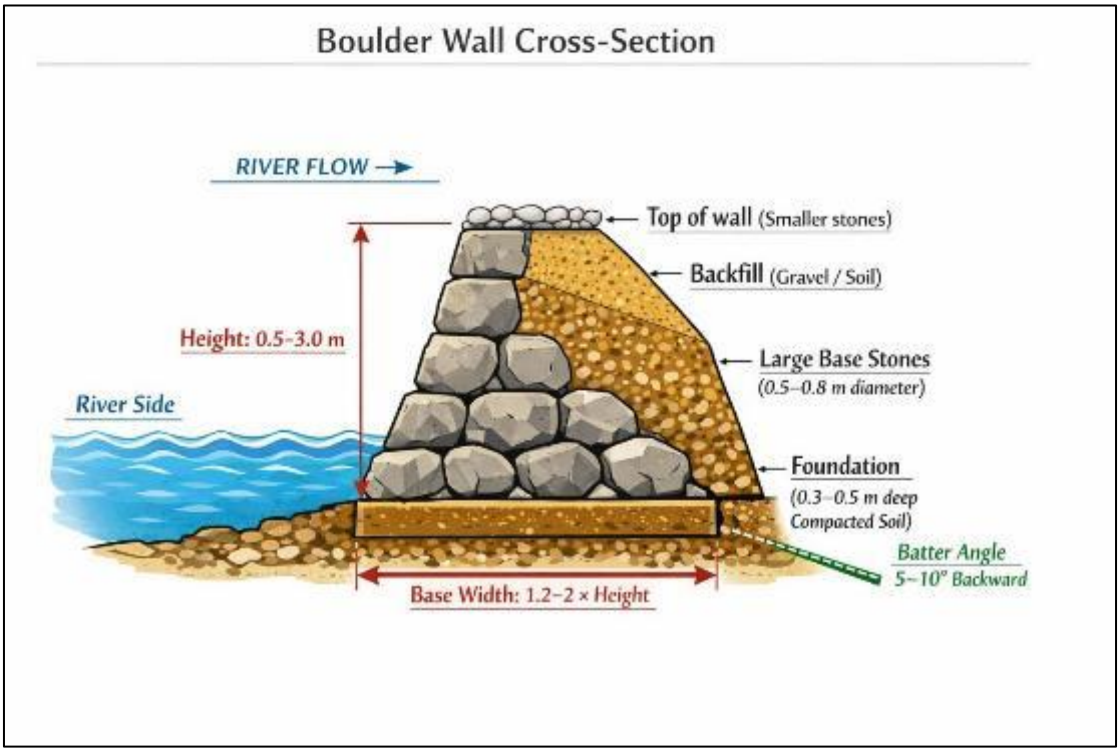

Figure 3 Cross-sectional design of a boulder (gravity) wall for riverbank protection, showing the arrangement of smaller top stones, gravel/soil backfill, large base stones, compacted foundation, batter angle (5–10°), wall height (0.5–3.0 m), and base width (1.2–2 × height).

5.2. Case Studies in Afghanistan

Boulder walls have been successfully implemented in several provinces of Afghanistan, demonstrating measurable effectiveness in flood mitigation. In Nangarhar Province, following the 2020 flash floods in the Kama and Chapadara districts, communities constructed boulder walls along small tributaries, resulting in a 40–50% reduction in agricultural damage compared to unprotected areas [23]. In Kunar Province, local communities in Chapa Dara and Asadabad districts reinforced boulder walls annually, which effectively reduced riverbank erosion and protected homes during the 2018 and 2022 flash floods [24]. In Kabul Province, peri-urban areas along the Kabul River combined boulder walls with vegetation to stabilize riverbanks, achieving both flood protection and ecological benefits, such as reduced soil erosion and improved riparian biodiversity [6]. Similarly, in Herat Province, boulder walls installed in small river valleys have protected irrigation canals and farmland, showing high durability by withstanding multiple flood events over the past decade [25].

5.3. Advantages and Limitations of Boulder Walls

Boulder walls offer several advantages that make them particularly suitable for flood mitigation in rural and remote areas of Afghanistan [2]. They are low-cost, utilizing locally available stones and materials, which reduces transportation and material expenses [3]. Their construction promotes community involvement, creating employment opportunities and facilitating knowledge transfer among local residents. Boulder walls are also highly flexible, as they can be built without heavy machinery, and they demonstrate environmental compatibility, blending with natural landscapes and supporting vegetation growth along riverbanks [22]. However, despite these benefits, boulder walls have certain limitations. They provide limited protection during extreme floods, such as events exceeding the 1-in-50-year return period, and they require regular inspection and maintenance to remain effective. The design often relies heavily on local experience, which can result in inadequate construction and potential structural failure [26]. Furthermore, boulder walls are generally unsuitable for urban areas with high hydraulic loads unless they are reinforced or integrated with additional engineered solutions.

5.4. Implications for Flood Risk Reduction

Boulder walls provide a practical, scalable, and low-cost solution to reduce flood impacts in Afghanistan's rural and peri-urban regions. While they cannot replace large-scale engineered floodwalls in urban centers, their effectiveness in community-based applications makes them critical for protecting vulnerable populations, farmlands, and infrastructure. Integrating boulder walls with early warning systems, vegetation, and other low-cost mitigation measures can further enhance resilience to flash floods and riverine flooding.

6. Environmental and Socio-Economic Impacts of Boulder Walls

Boulder walls are widely recognized not only for their flood mitigation capabilities but also for their environmental and socio-economic benefits. Understanding these impacts is crucial for sustainable implementation, especially in resource-constrained and vulnerable areas of Afghanistan [27-29].

6.1. Environmental Impacts

6.1.1. Riverbank Stabilization and Soil Erosion Control

Boulder walls act as barriers that stabilize riverbanks, preventing erosion caused by strong flood currents. In provinces like Nangarhar and Kunar, communities reported that boulder walls helped maintain the shape of river channels, reducing sediment deposition downstream [2].

6.1.2. Integration with Vegetation

When constructed with gaps for soil and small plants, boulder walls can support vegetation growth. This vegetative layer enhances slope stability, reduces erosion, and improves the ecological integrity of riparian zones. For instance, in peri-urban Kabul, vegetation along boulder walls has increased local biodiversity and provided natural filtration for floodwater [30].

6.1.3. Minimal Environmental Disruption

Compared to large concrete floodwalls or levees, boulder walls require minimal alteration of the natural landscape. This is particularly important in Afghanistan, where fragile mountain ecosystems are sensitive to construction activities.

6.1.4. Sediment and Water Flow Management

By slowing water velocity and trapping sediments, boulder walls help maintain the fertility of downstream agricultural lands. This reduces the loss of topsoil, which is critical for sustaining local farming communities.

6.2. Socio-Economic Impacts

6.2.1. Protection of Agricultural Land and Livelihoods

Agriculture is the main source of income for rural communities in Afghanistan. Boulder walls protect croplands from floodwaters, reducing crop loss and preserving livelihoods. Post-flood assessments in Nangarhar Province after the 2020 floods reported 40–50% lower crop damage in fields protected by boulder walls [6].

6.2.2. Community Engagement and Employment

Construction and maintenance of boulder walls involve local labor, creating temporary employment opportunities and fostering community ownership of flood protection measures. This approach strengthens social cohesion and ensures long-term maintenance.

6.2.3. Cost-Effectiveness

Boulder walls rely on locally available stones, reducing transportation and material costs. Compared to engineered floodwalls, they provide a high benefit-to-cost ratio, making them ideal for developing regions with limited resources.

6.2.4. Safety and Displacement Reduction

Boulder walls reduce the likelihood of homes and settlements being inundated. This lowers displacement risks and associated humanitarian costs, such as emergency shelters and relief supplies.

6.3. Cost-Benefit Considerations

A comparative assessment of boulder walls versus alternative measures shows that they are affordable and locally sustainable, especially in rural settings. The following Table 4 summarizes key socio-economic and environmental factors associated with different structural measures.

Table 4 Cost-Benefit Comparison of Structural Flood Mitigation Measures in Afghanistan

Structural Measure	Construction Cost	Maintenance Cost	Environmental Impact	Community Involvement	Socio-Economic Benefit
Levees/Embankments	High	Moderate	Moderate disruption	Low	Protects large areas; urban-focused
Floodwalls	Very High	High	High disruption	Low	High urban protection; costly
Check Dams	Moderate	Low	Positive (sediment control)	Moderate	Protects upstream communities; small-scale
Boulder Walls	Low	Low	Positive (stabilization & vegetation)	High	Protects farmland, homes; community-driven

6.4. Implications

The environmental and socio-economic benefits of boulder walls make them a practical and sustainable choice for rural and semi-urban communities in Afghanistan. Their integration into broader flood risk management strategies, along with complementary measures such as vegetation planting and community awareness programs, enhances resilience and reduces long-term economic losses.

7. Challenges and Research Gaps

Boulder walls in Afghanistan face several challenges that limit their effectiveness and broader adoption [3, 5]. Technically, many walls are built based on local experience rather than formal engineering standards, which can lead to failures during extreme floods. Limited stone quality, poor compaction, and inadequate maintenance further reduce durability. Institutionally, weak government support, lack of national guidelines, and poor coordination among communities and NGOs hinder consistent implementation. Environmental factors such as increasing flood intensity due to climate change and the degradation of natural buffers further compromise wall performance. Socio-economic constraints, including limited funding, labor, and uneven community participation, also affect construction and long-term upkeep [31].

Several research gaps remain that need to be addressed to improve flood risk management. There is a lack of systematic monitoring of wall performance, quantitative evaluations of failure rates, and formal cost-benefit analyses comparing boulder walls to other mitigation measures. Research on adapting walls to future flood scenarios and integrating them with ecosystem-based approaches is minimal. Additionally, nationally recognized design and maintenance standards tailored to local flood conditions are absent. Addressing these gaps requires technical research, policy development, capacity building, and integrated planning to ensure sustainable and effective flood risk reduction across Afghanistan.

8. Policy Implications

Effective flood risk reduction in Afghanistan requires combining structural measures, such as boulder walls, with supportive policies, institutional frameworks, and community-based management. Based on this review, several key policy actions are recommended. First, national standards for boulder wall design, construction, and maintenance should be established. These standards should define recommended wall heights, base widths, slope angles, foundation depth, material quality, drainage specifications, and maintenance schedules. Standardization will ensure consistent quality, improve effectiveness, and give communities and local authorities confidence in implementation.

Second, community participation should be formally integrated into policy frameworks. Policies should encourage local labor involvement, provide technical training, and include communities in decision-making for site selection, wall design, and maintenance. This strengthens social ownership, sustainability, and proactive flood protection. Third, funding and resource allocation must be prioritized. High-risk provinces should receive targeted financial support, including micro-financing programs, grants, and public-private partnerships, to enable construction and maintenance of boulder walls. Reliable funding ensures long-term effectiveness and reduces flood-related losses.

Fourth, structural measures should be integrated with non-structural interventions. Policies should promote early warning systems, floodplain zoning, watershed management, reforestation, and community awareness programs. Combined approaches improve flood resilience while protecting ecological systems. Fifth, climate change adaptation should be incorporated. Policies should support adaptive wall designs, research on reinforced materials, and long-term monitoring to ensure structural measures remain effective under future flood conditions.

Finally, institutional coordination and capacity strengthening are essential. The Afghanistan National Disaster Management Authority (ANDMA) and provincial units should be empowered, with centralized data-sharing platforms to consolidate flood information, best practices, and guidance. Coordinated efforts between NGOs, communities, and government agencies will standardize interventions and maximize resource use. In summary, by developing national standards, promoting community-led approaches, securing funding, integrating structural and non-structural measures, implementing climate-resilient designs, and strengthening institutions, Afghanistan can optimize the benefits of boulder walls and other structural interventions while building sustainable, community-focused flood resilience.

9. Conclusion

Floods are a persistent threat in Afghanistan, particularly in provinces such as Nangarhar, Kunar, Badakhshan, Kabul, Helmand, and Herat. Factors such as seasonal rainfall, snowmelt, deforestation, and unplanned settlements increase flood risk, affecting livelihoods, agriculture, infrastructure, and human safety. Structural measures, particularly boulder walls, offer a practical, low-cost, and community-driven solution, especially in rural and semi-urban areas.

Boulder walls stabilize riverbanks, reduce erosion, protect croplands, and safeguard homes. Their use of local materials, affordability, and potential for community engagement make them well-suited to Afghanistan's resource-constrained context. Case studies from Nangarhar, Kunar, Kabul, and Herat show measurable reductions in flood damage and enhanced community ownership. Challenges remain, including inconsistent design, material limitations, maintenance deficiencies, and increasing flood intensity due to climate change. Institutional constraints, lack of national standards, and limited coordination also impede wider adoption. Addressing these issues requires national standards, community training, sustainable funding, integration with non-structural measures, climate-resilient designs, and stronger institutional coordination. When combined with supportive policies and community engagement, boulder walls provide a scalable and sustainable approach to flood risk reduction in Afghanistan, contributing to resilient communities, reduced socio-economic losses, and long-term disaster risk management.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflicts of interest.

Author Contributions

S.U. and M.A.S.; Methodology: S.U. and M.A.S.; Data collection and literature review: S.U. and M.A.S.; Formal analysis: S.U.; Visualization and figures: S.U.; Writing—original draft preparation: S.U.; Writing—review and editing: S.U. and M.A.S.; Supervision: S.U.; Project administration: S.U. Both authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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