

FLOOD-RESILIENT INFRASTRUCTURE AND COMMUNITY ADAPTATION: A COMPARATIVE STUDY OF BANGLADESH AND THE NETHERLANDS

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ABSTRACT

Achieving SDG 11 (Sustainable Cities and Communities) requires ensuring access for all to adequate, safe, and affordable housing and basic services (Target 11.1) and providing access to safe, affordable, accessible and sustainable transport systems for all (Target 11.2), with particular attention to the vulnerable. Target 11.5 significantly reduces the number of deaths and the number of people affected by disasters, including floods. Target 11.B increases the number of cities adopting integrated policies for climate change mitigation and adaptation.

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Floods are the most frequent and damaging natural disaster globally, affecting over 2 billion people between 1998 and 2017. Low-lying deltaic nations, including Bangladesh and the Netherlands, are among the most flood-vulnerable countries, yet they have developed contrasting models of flood-resilient infrastructure and community adaptation. This study conducts a comparative analysis of flood-resilient infrastructure and community adaptation in Bangladesh and the Netherlands, two countries with shared geography as low-lying deltas with major rivers and sea-level rise risk, but vastly different economic, technological, and institutional contexts.

The Netherlands has developed one of the world's most sophisticated flood defense systems, including the Delta Works with dikes, levees, dams, and storm surge barriers, the Room for the River programme which gives rivers more space to flood rather than only raising dikes, the Maeslantkering as the largest moving storm surge barrier in the world, the Oosterscheldekering as a 9-kilometer storm surge barrier, sand suppletion for beach nourishment, and high-resolution forecasting. The Dutch approach has shifted from fighting water through high dikes and engineering to living with water through spatial adaptation and multi-layered safety. Community adaptation in the Netherlands is advanced, with flood safety standards, early warning systems through mobile alerts, flood-risk awareness campaigns, and citizen science networks.

Bangladesh faces much higher flood risk, with 60 to 70 percent of land area flooded annually during monsoon floods, cyclones generating storm surges up to 10 meters, and projected sea-level rise. Bangladesh has developed low-cost, community-based flood adaptation, including the Cyclone Preparedness Programme with over 55,000 volunteers and more than 6,000 cyclone shelters, community-based early warning using indigenous forecasting, flood-resilient housing such as raised plinths and floating gardens, amphibious houses, flood shelters, and embankments. The Bangladesh Delta Plan 2100 provides a long-term adaptation roadmap. However, Bangladesh faces challenges including underfunding, embankment maintenance failures, cyclone shelter shortages, and climate migration.

Using a qualitative comparative case study methodology, the study analyzes secondary data from government reports, international databases, and peer-reviewed literature over the period 2000 to 2025. The study finds that both countries have reduced flood fatalities dramatically. The

Netherlands has recorded no storm surge deaths since 1953. Bangladesh has reduced cyclone deaths from 500,000 in 1970 to 35 in 2022, a 99.9 percent reduction.

The study concludes that flood-resilient infrastructure requires hybrid approaches combining hard infrastructure, nature-based solutions, and community-based adaptation. Recommendations for both countries and the international community are provided.

Keywords: Flood-resilient infrastructure; community adaptation; Bangladesh; Netherlands; SDG 11; delta management; early warning systems; climate adaptation

RÉSUMÉ

Atteindre l'ODD 11 (Villes et communautés durables) nécessite de réduire le nombre de personnes touchées par les catastrophes, y compris les inondations. Cette étude analyse les infrastructures résilientes aux inondations et l'adaptation communautaire au Bangladesh et aux Pays-Bas. Les Pays-Bas ont développé un système de défense contre les inondations sophistiqué : Delta Works (digues, barrières anti-tempête), Room for the River. L'approche néerlandaise est de haute technologie et coûteuse. Le Bangladesh a développé une adaptation à faible coût et communautaire : programme de préparation aux cyclones (plus de 55 000 bénévoles, plus de 6 000 abris), prévisions indigènes, maisons surélevées, jardins flottants. Les deux pays ont réduit les décès dus aux inondations de manière spectaculaire. Des recommandations sont fournies pour les deux pays et la communauté internationale.

Mots-clés : infrastructures résilientes aux inondations, adaptation communautaire, Bangladesh, Pays-Bas, ODD 11, gestion des deltas, systèmes d'alerte précoce, adaptation climatique

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1. INTRODUCTION

Achieving SDG 11 (Sustainable Cities and Communities) requires ensuring access for all to adequate, safe, and affordable housing and basic services (Target 11.1) and providing access to safe, affordable, accessible and sustainable transport systems for all (Target 11.2), with particular attention to the vulnerable. Target 11.5 significantly reduces the number of deaths and the number of people affected by disasters, including floods. Target 11.B increases the number of cities adopting integrated policies for climate change mitigation and adaptation.

Floods are the most frequent and damaging natural disaster globally, affecting over 2 billion people between 1998 and 2017 according to the United Nations Office for Disaster Risk Reduction. Low-lying deltaic nations are particularly vulnerable, with two of the most flood-exposed countries being Bangladesh and the Netherlands. Both countries are deltaic, with the Ganges-Brahmaputra-Meghna delta in Bangladesh and the Rhine-Meuse-Scheldt delta in the Netherlands. Both have large populations living below sea level. Both face sea-level rise from climate change. Both have developed world-renowned flood management systems. However, their approaches reflect vastly different economic realities and historical trajectories. This study compares flood-resilient infrastructure and community adaptation in Bangladesh and the Netherlands.

The Netherlands, a high-income country with a population of 17 million, has a long history of water management. After the catastrophic North Sea flood of 1953 which killed 1,836 people, the Netherlands launched the Delta Works, a massive engineering project consisting of dikes, dams, and storm surge barriers. A later paradigm shift occurred with the Room for the River programme from 2006 to 2018, which gave rivers more space to flood rather than only raising dikes. The current approach is multi-layered safety, combining prevention, spatial planning, and emergency management. Key infrastructure includes the Delta Works, the Maeslantkering (the largest moving structure in the world), the Oosterscheldekering (a 9-kilometer storm surge barrier), the Haringvlietdam, the Brouwersdam, and the Eastern Scheldt. The country has 22,500 kilometers of dikes, sand suppletion for beach nourishment, and high-resolution forecasting through KNMI weather models, the National Water Model, and the Coastal Foundation. Community adaptation includes flood safety standards, early warning through NL-Alert mobile alerts, citizen science through rainfall monitoring networks, and public education by water boards.

Bangladesh, a low-income country with a population of 170 million, faces extreme flood risk. Monsoon floods inundate 60 to 70 percent of land area annually. Cyclones in the Bay of Bengal generate storm surges up to 10 meters. Sea-level rise is projected to reach 0.5 to 1.0 meter by 2100, with 11 percent land loss from a 0.5 meter rise. Bangladesh has developed low-cost, community-based adaptation. The Cyclone Preparedness Programme, established in 1972, has over 55,000 volunteers and more than 6,000 cyclone shelters. Community-based early warning uses indigenous forecasting based on cloud patterns, wind shifts, animal behaviour, and sea recession. Flood-resilient housing includes raised plinths (homestead raising) and floating gardens (hydroponic agriculture on water hyacinth). Amphibious houses are being tested experimentally. The country has 139 polders with 6,000 kilometers of embankments, built in the 1960s to 1980s, now aging with poor maintenance. The Bangladesh Delta Plan 2100, adopted in 2018, provides a long-term adaptation roadmap with a 50-year plan.

Both countries have dramatically reduced flood fatalities. The Netherlands has recorded no storm surge deaths since 1953. Bangladesh has reduced cyclone deaths from 500,000 in the 1970 Bhola cyclone to 35 in Cyclone Sitrang in 2022, a 99.9 percent reduction. However, both face significant challenges. Bangladesh's adaptation costs are estimated at \$10 billion per year, but only 15 percent is funded. Embankment maintenance failures are common, and cyclone shelters are insufficient for a population of 170 million. Climate migration is increasing, with displaced populations moving to slums in Dhaka and Chittagong.

The contrast between Bangladesh and the Netherlands illuminates critical questions for flood-resilient infrastructure, community adaptation, and SDG 11, which this study addresses.

2. LITERATURE REVIEW

The literature on flood management is vast, spanning engineering, environmental science, disaster risk reduction, and climate adaptation.

2.1 Netherlands' Flood Defense System

The Netherlands' Delta Works and Room for the River programme are well documented. The Delta Programme publishes annual reports detailing progress on flood safety, freshwater supply, and

spatial adaptation. Kabat et al. (2005) analyzed climate proofing in the Netherlands, noting the need for adaptive strategies under sea-level rise. Van der Brugge and Rotmans (2007) examined transition management of European water resources, using the Netherlands as a case study. Rijkswaterstaat, the Dutch executive agency for infrastructure and water management, provides technical documentation on dike reinforcement, storm surge barriers, and sand suppletion. The KIWA (Knowledge for Climate) programme produced research on climate adaptation scenarios.

2.2 Bangladesh's Flood Adaptation

Bangladesh's flood adaptation is extensively documented. The Cyclone Preparedness Programme (CPP) has been evaluated by Haque (2009), who documented the programme's evolution from 1972 to 2009 and its impact on fatality reduction. Mallick et al. (2015) analyzed social vulnerability and cyclone preparedness in coastal Bangladesh, highlighting the role of community-based approaches. The Bangladesh Delta Plan 2100 (2018) provides the government's long-term strategy. The World Bank (2010, 2020) published assessments of cyclone preparedness and Delta Plan implementation.

2.3 Comparative Studies

Comparative studies of Bangladesh and the Netherlands are relatively rare. Some comparative analyses have been conducted by the World Bank, Deltares (a Dutch research institute for water and subsurface), and the Institute of Water Modelling (IWM) in Bangladesh. These studies typically focus on technical aspects of embankment design or polder management rather than community adaptation. This study contributes to filling the gap by providing a structured comparison of flood-resilient infrastructure and community adaptation in both countries.

3. RESEARCH QUESTIONS

This study addresses the following research questions:

1. What are the flood-resilient infrastructure systems in Bangladesh and the Netherlands, including dikes, barriers, shelters, embankments, and nature-based solutions?
2. What are the community adaptation mechanisms in each country, including early warning systems, indigenous forecasting, volunteer networks, raised housing, and floating gardens?

3. What can each country learn from the other about flood-resilient infrastructure and community adaptation?
4. How can hybrid approaches integrate hard engineering, nature-based solutions, and community-based adaptation?

4. METHODOLOGY

This study employs a qualitative comparative case study methodology to examine flood-resilient infrastructure and community adaptation in Bangladesh and the Netherlands. The comparative approach is appropriate for examining how different economic, technological, and institutional contexts shape flood management outcomes. Bangladesh and the Netherlands were selected as cases offering meaningful variation. Bangladesh is a low-income country with a population of 170 million, a reliance on community-based adaptation, and a dramatic reduction in flood fatalities. The Netherlands is a high-income country with a population of 17 million, a reliance on high-tech engineering, and a record of no storm surge deaths since 1953. Despite their differences, both countries have achieved remarkable fatality reduction, making them ideal for comparative analysis. The research design integrates secondary analysis of multiple data sources spanning the period 1953 to 2025, with a focus on the period 2000 to 2025. Government sources include, for Bangladesh, the Ministry of Disaster Management and Relief, the Cyclone Preparedness Programme (CPP), the Bangladesh Delta Plan 2100, and the Water Development Board; for the Netherlands, the Delta Programme, the Ministry of Infrastructure and Water Management, KNMI (Royal Netherlands Meteorological Institute), and Rijkswaterstaat. International databases include the United Nations Office for Disaster Risk Reduction (UNDRR), the World Bank, and the World Health Organization (WHO). Peer-reviewed literature from journals including Disaster Prevention and Management, Natural Hazards, and Water Resources Management was also analyzed. The analytical framework examines four dimensions: flood defense infrastructure (dikes, barriers, embankments, shelters); nature-based solutions (mangroves, sand suppletion, wetland restoration, floating gardens); early warning systems (scientific forecasting, indigenous forecasting, volunteer networks, mobile alerts); and community adaptation (raised housing, flood drills, emergency funds, evacuation protocols). The study has several limitations, including reliance on secondary data constrained by availability, quality, and comparability. Bangladeshi data on embankment condition and cyclone shelter capacity have gaps. The comparative case study design cannot

establish causality as rigorously as experimental methods. No primary data collection, such as interviews with CPP volunteers or water board officials, was conducted. The study period (1953 to 2025) captures long-term trends but does not fully explore all historical flood events. Despite these limitations, the comparative analysis provides valuable insights for policy and future research.

5.

RESULTS

Table 1: Comparative Summary – Flood-Resilient Infrastructure and Community Adaptation

Dimension	Bangladesh	Netherlands
Population	170 million	17 million
GDP per capita (USD)	\$2,700 (low-income)	\$58,000 (high-income)
Land area below sea level	10% (coastal zone)	26%
Land area flood-prone	60-70% (annual monsoon floods)	50% (at risk)
Sea-level rise projection (2100)	0.5-1.0m (1.5m worst)	0.5-1.5m (2-3m worst)
Major flood/cyclone deaths (historic)	500,000 (1970 Bhola cyclone)	1,836 (1953 North Sea flood)
Recent flood/cyclone deaths	35 (Sitrang 2022), 200 (Amphan 2020)	0 (since 1953)
Flood defense infrastructure	Embankments (polders – 139, 6,000 km), cyclone shelters (6,000+), raised plinths	Dikes (22,500 km), storm surge barriers (Maeslantkering, Oosterscheldekering), sand suppletion (12 million m³/year)

Nature-based solutions	Mangroves (Sundarbans – 140,000 ha), floating gardens (hydroponic)	Sand suppletion (beach nourishment), salt marshes, Room for the River (floodplains)
Early warning system	CPP (55,000+ volunteers), indigenous forecasting (clouds, wind, animals), red flags, megaphones, door-to-door	KNMI weather models, National Water Model, Coastal Foundation, NL-Alert mobile alerts, sirens
Community adaptation	Raised plinths (homestead raising), floating gardens, flood shelters, community emergency funds, livestock relocation	Flood-risk awareness campaigns, citizen science (rainfall monitoring), public education by water boards, evacuation drills
Annual adaptation cost	\$10 billion (15% funded)	€1.5 billion (1.2% of GDP)
Source	CPP 2023; Delta Plan 2100; World Bank 2020	Delta Programme 2024; KNMI 2023; Rijkswaterstaat 2023

Table 2: Bangladesh – Community-Based Flood Adaptation

Element	Description
Cyclone Preparedness Programme (CPP)	Established 1972 after 1970 Bhola cyclone (500,000 deaths). Jointly run by Government (Ministry of Disaster Management) and Bangladesh Red Crescent Society. 55,000+ volunteers (33% women). 6,000+ cyclone shelters (schools, purpose-built raised platforms). Training: volunteers trained in indigenous forecasting, scientific warning interpretation, evacuation procedures, first aid, search & rescue.
Indigenous forecasting	Cloud indicators: dark black-brown cumulonimbus clouds from Bay of Bengal (“elephant cloud”). Wind indicators: sudden calm (lull) before cyclone, direction change (southeast to northwest). Animal behaviour: cattle restless, refuse to eat; birds flying low, seeking shelter; ants moving to higher ground; crabs moving inland from mangroves. Sea indicators: sea receding abnormally (storm surge warning). Celestial: moon halo indicates approaching cyclone. Integrated into CPP training.

Flood-resilient housing	Raised plinths (homestead raising): house built on earth mound 2-4m above flood level. Used in floodplains, coastal areas (Chittagong, Barisal, Khulna, Satkhira, Bhola). Materials: earth, brick, concrete, bamboo. Cost: \$500-2,000 per house. Floating gardens (hydroponic agriculture on water hyacinth – used in low-lying areas (Gopalganj, Pirojpur, Jhalokathi) during monsoon; vegetables grown on floating beds (cucumber, bitter melon, spinach, okra, pumpkin). Amphibious houses (experimental, pilot in Satkhira, Khulna – house floats on buoyant foundation during flood, rests on ground during dry season).
Cyclone shelters	Multipurpose buildings (schools, community centers, mosques) on raised platforms (15-20 feet above flood level). Capacity 500-1,000 people per shelter. Amenities: water tanks, toilets (gender-segregated), livestock shelter (adjacent), storage for food, medicine, relief materials. Red flag (danger) signals evacuation. Shelters constructed by government, NGOs (BRAC, Red Crescent), World Bank funded.
Embankments (polders)	139 polders (coastal embankment system, built 1960s-1980s with Dutch assistance). 6,000 km of embankments. Protect agriculture, settlements from tidal flooding, salinity intrusion. Managed by Bangladesh Water Development Board (BWDB). Challenges: poor maintenance (embankment breaches – e.g., 2009 Aila cyclone breached 30 polders, 500,000 people affected), salinity intrusion (polders cut off sediment replenishment, land subsidence), aging infrastructure (50+ years).
Nature-based solutions	Mangroves: Sundarbans (largest mangrove forest in the world, 140,000 ha, UNESCO World Heritage). Reduce cyclone wave energy (mangroves can reduce wave height by 50-90%). Mangrove plantation (coastal afforestation programme – 100,000+ ha planted since 1960s). Wetland restoration (Haor basins – freshwater wetlands).
Community emergency funds	“Mutuelles” (community savings, rotating funds). Used for post-flood recovery (food, medicine, housing repair).
Challenges	Shelter shortage: 6,000 shelters for 170 million population (1 shelter per 28,000 people). Many cannot reach shelter in time (distance, transport, warning time). Shelters lack gender-segregated facilities (women risk sexual violence). Embankment maintenance failures (BWDB underfunded). Underfunding: Delta Plan 2100 requires

	\$10 billion/year, only 15% funded (donor-dependent). Climate migration: displaced populations moving to Dhaka slums (400,000+ climate migrants annually).
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Table 3: Netherlands – High-Tech Flood Defense

Element	Description
Delta Works	Maeslantkering (Rotterdam, 1997): largest moving structure in the world (2x210 meter steel arms). Closes during storm surge (3.0 meter above NAP). Oosterscheldekering (1986): 9 km storm surge barrier, gates lowered during surges. Haringvlietdam, Brouwersdam, Eastern Scheldt, Volkerakdam, etc.
Dikes	22,500 km of primary and secondary dikes. Safety standards: coastal 1/10,000-year (0.01% annual exceedance probability), river 1/1,250-year (0.08% AEP), upgraded after 1995 near-flood. Dike reinforcement (strengthening, heightening).
Room for the River (2006-2018)	Paradigm shift: instead of only raising dikes, give rivers more space to flood safely. 30+ projects: floodplains (bypass channels, dike relocation, flood storage areas, lowering groynes, removal of obstacles). Integrated local knowledge (historical flood patterns, farmer interviews). Cost €2.3 billion.
Sand suppletion (beach nourishment)	12 million m ³ /year of sand added to beaches and dunes to compensate for erosion, sea-level rise. Nourishment extends seaward, wave energy dissipates before reaching dunes.
Forecasting	KNMI (Royal Netherlands Meteorological Institute): global model (ECMWF), high-resolution regional model (HARMONIE-AROME, 2.5 km), 10-day probabilistic forecasts. National Water Model (hydrological forecasting for Rhine, Meuse, Scheldt). Coastal Foundation (storm surge predictions).
Early warning	NL-Alert: mobile alerts (cell broadcast) for emergencies (flood, fire, disaster). Sirens (monthly testing). Water boards notify residents of flood risk. Evacuation plans (regional).
Multi-layered safety	Layer 1: prevention (dikes, barriers). Layer 2: spatial planning (land-use zoning, avoiding high-risk areas). Layer 3: emergency management (early warning, evacuation, crisis management).

Citizen science	Rainfall monitoring networks (citizens report rainfall via mobile app). Biodiversity observation apps (Waarneeming.nl). Water level monitoring (some citizen gauges).
Challenges	Sea-level rise acceleration: worst-case 2-3 meters by 2100 exceeds Delta Works design basis (Maeslantkering designed for 0.5-1.0m). Costs: €1.5 billion/year projected to double by 2050. Flood memory loss: citizens unaware of flood risk (1953 was 70+ years ago; younger generation not prepared). Freshwater scarcity: summer droughts (Rhine discharge reduced). Soil subsidence: peat oxidation, polders sinking 0.5-1.0 cm/year.

Table 4: Comparative Flood Fatalities Reduction

Event (Bangladesh)	Deaths	Event (Netherlands)	Deaths
1970 Bhola cyclone	500,000	1953 North Sea flood	1,836
1991 cyclone	138,000	1916 flood	~500
1997 cyclone	100	1995 near-flood (evacuated)	0 (evacuated 250,000)
2007 Sidr	10,000	2021 (no major flood)	0
2009 Aila	190	2023 (no major flood)	0
2020 Amphan	200	2024 (no major flood)	0
2022 Sitrang	35	2025 (forecast)	N/A
Reduction (1970-2022)	99.93%	Reduction (1953-2025)	100%

6. DISCUSSION OF RESULTS

6.1. Explaining the Netherlands' High-Tech, High-Cost Model

The Netherlands' success in flood management is built on several factors. Massive investment in engineering created the Delta Works, dikes, and barriers. Post-1953 political commitment established a national resolve of "never again." Strong institutions with a 1,000-year history of water boards, as well as Rijkswaterstaat and the Delta Commissioner, provide governance

continuity. Integrated planning through the Delta Programme and Room for the River coordinates water management across sectors. As a high-income economy, the Netherlands can afford to spend 1.2 percent of GDP on water management. High-quality forecasting through KNMI and the National Water Model provides accurate warnings. However, the model is expensive at €1.5 billion per year and may not be affordable or replicable for low-income countries.

6.2. Explaining Bangladesh's Low-Cost, Community-Based Model

Bangladesh's success in reducing cyclone deaths by 99.9 percent is built on low-cost interventions. The Cyclone Preparedness Programme uses volunteers, cyclone shelters, red flags, megaphones, and indigenous forecasting. Community participation is strong, with over 55,000 volunteers, indigenous knowledge, and mutual aid. International support from the World Bank, Red Cross, and UNDP has been crucial. Incremental learning has occurred over decades: after 1970 there was no CPP, after 1991 shelters were built, and after 2007 warning systems and night evacuation were improved. Bangladesh demonstrates that low-income countries can dramatically reduce flood fatalities without high-tech infrastructure.

6.3. Hybrid Approaches: Hard Infrastructure, Nature-Based Solutions, and Community-Based Adaptation

Both countries benefit from hybrid approaches. Bangladesh uses embankments as hard infrastructure, mangroves as nature-based solutions, CPP volunteers as community-based adaptation, and raised plinths for resilient housing. The Netherlands uses dikes as hard infrastructure, sand suppletion as a nature-based solution, NL-Alert as a technological early warning system, and citizen science as community-based adaptation. The optimal mix depends on context. High-income countries can afford high-tech solutions. Low-income countries should prioritize low-cost community-based adaptation.

6.4. Indigenous Forecasting: Bangladesh's Asset

Bangladesh's indigenous forecasting based on clouds, wind, animals, sea conditions, and celestial signs is accurate, trusted, and accessible, requiring no technology. It fills critical gaps when scientific warnings fail due to power outages or communication breakdowns. The CPP trains

volunteers in indigenous indicators. The Netherlands has limited indigenous forecasting due to landscape transformation, urbanization, and a technocratic culture. The Netherlands could learn from Bangladesh by documenting local knowledge such as farmers' observations of soil saturation and river level changes, and integrating this knowledge into forecasting systems.

6.5. Cyclone Shelters versus Dikes

Bangladesh's cyclone shelters, numbering over 6,000, save lives but are insufficient, with a target of 10,000 needed. The Netherlands' dikes, totaling 22,500 kilometers, prevent flooding, but if a dike breaches, catastrophic flooding can occur as happened in 1953. Shelters provide last-resort protection, while dikes provide prevention. Both are necessary.

6.6. Sea-Level Rise: Future Challenges

Both countries face accelerating sea-level rise. The Netherlands' worst-case scenario of 2 to 3 meters by 2100 challenges the Delta Works, which were designed for 0.5 to 1.0 meter. The Netherlands must raise dikes higher, expand sand suppletion to 20 million cubic meters per year, invest in innovative barriers, and consider managed retreat by relocating vulnerable populations. Bangladesh faces a similar challenge with 1 to 2 meters of sea-level rise by 2100 and needs higher embankments, mangrove restoration, raised plinths, floating agriculture, and climate migration planning.

6.7. Transferability: What Bangladesh Can Learn from the Netherlands and What the Netherlands Can Learn from Bangladesh

Bangladesh can learn from the Netherlands in several areas. Sand suppletion for beach nourishment could address coastal erosion. Room for the River approaches such as floodplain restoration and bypass channels could be adapted. High-resolution forecasting using KNMI models could be adopted through investment in weather radar and ensemble forecasting.

The Netherlands can learn from Bangladesh in several areas. Indigenous forecasting should be documented and integrated into NL-Alert. Cyclone shelters provide a model for community shelters, which the Netherlands currently lacks. The CPP volunteer model offers a blueprint for a

volunteer early warning network, which the Netherlands does not have. Floating gardens could be adapted as hydroponic agriculture for flood-prone areas in the Netherlands.

6.8. Implications for SDG 11

Flood-resilient infrastructure and community adaptation are central to SDG Target 11.5, which aims to reduce disaster deaths and the number of people affected. Bangladesh and the Netherlands demonstrate that different economic contexts require different adaptation pathways, but both can achieve dramatic fatality reduction. The international community, including the Green Climate Fund, the World Bank, and the United Nations Office for Disaster Risk Reduction, should fund community-based adaptation programmes including the CPP, shelters, and indigenous forecasting. They should support nature-based solutions such as mangroves, wetlands, and sand suppletion. They should promote hybrid approaches combining hard infrastructure and soft measures. They should facilitate South-South and North-South exchange among Bangladesh, the Netherlands, Vietnam, Mozambique, and Kiribati.

7. CONCLUSION

This comparative analysis reveals that flood-resilient infrastructure and community adaptation in Bangladesh and the Netherlands have achieved remarkable fatality reduction through different pathways.

The Netherlands, as a high-income country with a high-tech approach, uses the Delta Works including dikes, storm surge barriers, the Maeslantkering, and the Oosterscheldekering; the Room for the River programme; sand suppletion of 12 million cubic meters per year; and high-resolution forecasting through KNMI and the National Water Model. The country has recorded no storm surge deaths since 1953.

Bangladesh, as a low-income country with a community-based approach, uses the Cyclone Preparedness Programme with over 55,000 volunteers and more than 6,000 cyclone shelters; indigenous forecasting based on clouds, wind, animals, and sea conditions; raised plinths for homestead raising; floating gardens; embankments (polders); and mangroves. Cyclone deaths have been reduced from 500,000 in 1970 to 35 in 2022, a 99.9 percent reduction.

Both countries face future challenges, including accelerating sea-level rise, underfunding with Bangladesh needing \$10 billion per year but only 15 percent funded and the Netherlands facing projected cost doubling from €1.5 billion to €3 billion per year, and climate migration.

Several cross-cutting insights emerge from this comparison:

1. Low-cost community-based adaptation involving volunteers, shelters, and indigenous forecasting is highly effective in low-income contexts.
2. High-tech engineering involving dikes and barriers is effective but expensive.
3. Hybrid approaches that combine hard infrastructure, nature-based solutions, and community-based adaptation are optimal.
4. Indigenous forecasting complements scientific forecasting, especially where infrastructure is weak.
5. Cyclone shelters and flood-resilient housing save lives.

For Bangladesh, priorities include scaling up cyclone shelters to a target of 10,000 by 2030; strengthening embankment maintenance through polder rehabilitation and increasing the BWDB budget; integrating indigenous forecasting into the national early warning system through formal standard operating procedures; expanding mangrove restoration in the Sundarbans and through coastal afforestation; scaling up floating gardens and raised plinths; and developing a climate migration policy for urban planning in Dhaka.

For the Netherlands, priorities include accelerating sea-level rise adaptation through Delta Programme 2100 scenarios, innovative barriers, and expanding sand suppletion to 20 million cubic meters per year; investing in nature-based solutions such as mangroves where climate allows, salt marshes, and wetland restoration; sharing forecasting technology with Bangladesh through technical cooperation, satellite data, and model transfer; learning from Bangladesh's CPP volunteer model by piloting a community early warning network in Zeeland; and addressing flood memory loss through public education campaigns, school curriculum, and flood evacuation drills.

For the international community, the lessons are clear. Flood-resilient infrastructure saves lives, but one size does not fit all. Low-income countries can achieve dramatic results with community-

based adaptation. High-income countries can afford high-tech engineering. Hybrid approaches that combine hard infrastructure and soft measures are best.

The ultimate measure of success for flood management policy is not dike height or shelter count, but whether a family in coastal Bangladesh and a family in Rotterdam can survive a 1-in-100-year flood without loss of life.

8. LIMITS OF THE STUDY

This study has several limitations. First, reliance on secondary data from government reports, UNDRR, the World Bank, and peer-reviewed literature means the analysis is constrained by data availability, quality, and comparability. Bangladeshi data on embankment condition and cyclone shelter capacity have gaps. Second, the comparative case study design cannot establish causality as rigorously as experimental or quasi-experimental methods. Third, the study does not include primary data collection, such as interviews with CPP volunteers or water board officials, which would provide richer insights. Fourth, the study period (1953 to 2025) captures long-term trends but does not fully explore all historical flood events. Fifth, the focus on national-level systems obscures subnational variation within Bangladesh, including coastal versus riverine regions, and within the Netherlands, including different provinces. Sixth, the study does not quantify the cost-effectiveness of different flood management interventions. Despite these limitations, the comparative analysis provides valuable insights for policy and future research.

9. ACKNOWLEDGMENTS

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10. AUTHOR CONTRIBUTIONS

ZERBO HAMIDOU conceived the study, designed the methodology, conducted the literature review and document analysis, synthesized findings, and drafted the complete manuscript.

11. COMPETING INTERESTS

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential competing interest.

12. FUNDING INFORMATION

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

13. DATA AVAILABILITY

All sources are publicly available documents cited in the bibliography and accessible through the referenced publications and organizations, including the Cyclone Preparedness Programme, the Bangladesh Delta Plan 2100, the Delta Programme, KNMI, Rijkswaterstaat, UNDRR, and the World Bank.

14. DISCLAIMER

The views expressed in this article are solely those of the author and do not necessarily reflect the views of any institution or organization with which the author may be affiliated. The analysis is provided for scholarly purposes and should not be construed as policy guidance or programmatic advice.

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