Climate Vulnerability and Urban Resilience: A Data-Driven Analysis of Sea-Level Rise Impacts in South Asia

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Abstract

Coastal South Asia is on the frontlines of climate change. This study examines climate vulnerability and urban resilience in Bangladesh, the Maldives, and the Philippines through a data-driven lens, focusing on sea-level rise impacts. We integrate climate and socio-economic datasets (e.g. sea-level trends, flood frequencies, population and migration statistics) and apply time-series analysis (including lead-lag correlation) to uncover patterns and predictive insights. Our analysis finds that all three countries are experiencing accelerating sea-level rise – on the order of 3–4 mm per year – alongside increasing coastal flood incidents, with Bangladesh seeing especially sharp rises in flood days. Socio-economic stresses such as rapid urbanization, high population density, and poverty exacerbate these climate hazards, contributing to rural–urban migration and displacement. We observe that climatic stressors (like rising seas and flood shocks) are correlated with spikes in migration out of vulnerable areas in subsequent years, although complex socio-political factors mediate these outcomes. The paper discusses adaptation efforts – from Bangladesh's Delta Plan 2100[1] to the Maldives' new National Adaptation Plan[2] and the Philippines' disaster risk reduction investments – evaluating their potential to enhance urban resilience. We also address ethical considerations in forecasting climate migration, cautioning against deterministic misuse of data. These findings underscore the urgency for targeted climate resilience policies in South Asian coastal cities, and provide an evidence-based foundation for planners to develop adaptive, inclusive strategies. *Implications:* Proactive infrastructure investments, community relocation programs, and global emissions mitigation are critical to safeguard millions of people in Bangladesh, the Maldives, and the Philippines from escalating sea-level rise and climate extremes.

[1] Government of the People's Republic of Bangladesh. (2018). *Bangladesh Delta Plan 2100: A long term integrated and holistic plan for water and land management.*

[2] United Nations Environment Programme [UNEP]. (2024, February 15). *Maldives rests hope on new National Adaptation Plan to tackle climate change.*

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1. Introduction

In the Maldives, 80% of the land area lies less than 1 meter above sea level, prompting projections that up to 77% of its land could be underwater by 2100.[3] Across the Bay of Bengal, Bangladesh may lose 17% of its land by 2050 due to rising seas, potentially wiping out nearly one-third of its agricultural output.[4] Such stark figures illustrate the existential threat that sea-level rise poses to South Asian coasts. Coastal cities and communities in this region are already grappling with frequent flooding, erosion, and saltwater intrusion – challenges that climate change amplifies.

Indeed, Bangladesh and the Philippines consistently rank among the world's most climate-impacted countries:[5]

[3] Earth.org. (2022, September 26). *Sea level rise projection map – Maldives.*

[4] Veer A. *Climate change exposes Bangladesh to greater risk.* Johns Hopkins SAIS Bologna Institute for Policy Research (BIPR). (2023)

[5] Department of Environment [DOE], Government of Bangladesh. (2023). *National Adaptation Plan (2023–2050): Towards a Climate-Resilient Bangladesh.* Ministry of Environment, Forest and Climate Change.

The Global Climate Risk Index lists the Philippines and Bangladesh among the top ten countries affected by extreme weather in recent decades.[6] This convergence of high exposure and vulnerability makes South Asia's low-lying nations a ground zero for climate risk, underscoring the urgency of building urban resilience.

The relevance of this issue extends beyond humanitarian concern; it is also a question of sustainable development and regional stability. Coastal South Asia is home to tens of millions of people and several megacities (such as Manila and Dhaka) whose economic productivity and cultural heritage are invaluable.

However, these dense urban hubs face compound climate threats – rising sea levels aggravate storm surges and high tides, while warmer oceans fuel more intense cyclones and anomalous weather patterns. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) warns that with current warming trajectories, extreme coastal flood events that occurred once a century in the past could become annual occurrences by 2100 in many regions.[7] In 2019 alone, climate-related disasters (from cyclones to floods) displaced over 4 million people in each of Bangladesh and the Philippines[8] – a testament to how quickly climate extremes can translate into humanitarian crises. Against this backdrop, enhancing urban climate resilience – through data-driven planning and robust policy action – has become an urgent priority for South Asia.

[6] Climate Change Commission [CCC]. (2022, November 17). *PH ranks 1st in World Risk Index 2022; 5th most affected by climate change in past 2 decades.* Republic of the Philippines.
[7] Rahmstorf, S. (2021, August 13). *Sea level in the IPCC 6th Assessment Report (AR6).* RealClimate.
[8] Shaw, R., et al. *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press.

1.1 Contextual Background

Climate change operates through well-understood mechanisms that are already unfolding in the South Asian context. The greenhouse effect – excess emissions of carbon dioxide (CO_2) and other greenhouse gases – has trapped additional heat in the Earth's system, driving up global temperatures. As a result, the planet has warmed ~1.1°C above pre-industrial levels (as of the last decade) and is on a trajectory of further increase.[9]

This warming has myriad downstream effects. For one, higher temperatures are intensifying the hydrological cycle, leading to more erratic rainfall and more extreme weather volatility. Heavier downpours and more prolonged droughts are both observed in South Asia, contributing to extreme river floods and severe droughts in the region.[10] Warmer air and sea-surface temperatures also supercharge tropical cyclones – the North Indian Ocean and western Pacific have seen some of their strongest storms on record in recent years.

Crucially, global warming is causing sea levels to rise through thermal expansion of ocean water and the melting of land ice. Since 1900, global mean sea level has risen about 20 cm, an increase unprecedented in at least 3,000 years.[11] Moreover, the rate of sea-level rise is accelerating: from about 1.3 mm/year in the early 20th

[9] Rahmstorf, S. (2021)
[10] Shaw, R., et al. (2022)
[11] Rahmstorf, S. (2021)

century to 3.7 mm/year in recent decades,[12] and satellite data show the rate reached ~4.5 mm/year by 2023.[13] This means that coastal areas are not only gradually losing land to the sea, but also facing higher base water levels that make episodic flooding (from storms or tides) more destructive. Extreme ocean events that once occurred rarely – such as king tides or storm surges – now build on a higher sea-level baseline, reaching further inland.

Compounding this is ocean acidification: the ocean absorbs roughly a quarter of anthropogenic CO_2, which lowers pH and threatens marine ecosystems. Coral reefs, which protect many South Asian shorelines by buffering wave energy, are experiencing bleaching and erosion under the dual stresses of warming and acidification.[14] The loss of coral reefs would remove a critical natural barrier, further exposing coasts to wave action. In sum, rising temperatures, shifting precipitation extremes, climbing sea levels, and ocean chemistry changes form a multi-pronged threat to the coastal environments of South Asia.

1.2 Country-Specific Climate Vulnerability

Each of the three focus countries – Bangladesh, the Maldives, and the Philippines – faces unique geographic vulnerabilities and socio-economic challenges, even as they share the common peril of sea-level rise.

[12] Rahmstorf, S. (2021)
[13] Hamlington, B. D., Nerem, R. S., Kopp, R. E., & Thompson, P. R. (2024). *The rate of global sea level rise doubled during the past three decades. Communications Earth & Environment, 5, 601.*
[14] Intergovernmental Panel on Climate Change (IPCC). (2022b). *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of WG II – Chapter 15: Small Islands. Cambridge University Press.

1.2.1 Climate Vulnerability in Bangladesh

Bangladesh is often cited as ground zero for climate vulnerability. Situated on the world's largest river delta (the Ganges-Brahmaputra-Meghna delta), about 30% of Bangladesh's 170 million people live in coastal districts, and much of the country lies within only a few meters of sea level.

The IPCC notes that Bangladesh is *"one of the most vulnerable countries in the world to climate risks and natural hazards,"* facing severe floods, cyclones, storm surges, and droughts on a regular basis.[15] Low elevation and flat topography make storm surge from tropical cyclones (locally known as cyclones) especially devastating – for example, Cyclone Sidr (2007) and Cyclone Amphan (2020) both inundated vast areas. Riverine flooding is another perennial threat: Bangladesh's rivers swell with monsoon rains and glacial melt from the Himalayas, frequently overrunning embankments. Each year, on average, about one-fifth of Bangladesh's land is flooded during the monsoon, with extreme years seeing up to 2/3 of the country submerged.[16] These floods damage infrastructure and crops, and they are worsening as erratic heavy rainfall increases.

Bangladesh's socio-economic context amplifies these hazards – it is densely populated (over 1,300 people per sq. km) and still developing, which limits adaptive capacity. The poor often settle in the most flood-prone

[15] Intergovernmental Panel on Climate Change (IPCC). (2022b).
[16] Shaw, R., et al. (2022)

lands (such as char islands and low-lying slums), heightening their exposure.

Despite these challenges, Bangladesh has made strides in disaster preparedness (for instance, cyclone early warning systems and shelters), which dramatically reduced cyclone fatalities over the past decades.[17] Still, the country's Climate Risk Index ranking (7th) reflects a high toll from climate impacts,[18] and projections indicate 0.9–2.1 million Bangladeshis in the south may be displaced by sea-level rise by 2050 if adaptive measures are not scaled up.[19]

1.2.2 Climate Vulnerability in the Maldives

In the Maldives, vulnerability takes a different shape. This Indian Ocean nation is an archipelago of 26 atolls comprised of around 1,200 small coral islands. With an average ground elevation of only ~1 meter, the Maldives is the lowest-lying country on Earth.[20] Its very existence is under threat from sea-level rise. Already, some of its uninhabited islands have disappeared beneath the waves, and during storm surges or high tides, seawater can wash over large portions of land. Coastal erosion is eating away at beaches and undermining buildings. Saltwater intrusion is contaminating freshwater lenses, jeopardizing drinking water and agriculture on the islands. Critically, around 80% of the Maldives' land area is below 1 m elevation , meaning even a moderate rise in sea level (50 cm to 1 m, plausible by late century) would render most of the country uninhabitable or prone to chronic flooding.[21]

The entire population of ~540,000 is essentially coastal, and key infrastructure – airports, seaports, resorts (which drive the tourism-dependent economy) – hug the shorelines. For instance, the international airport in Malé, the capital, sits just meters above current sea level. The Maldives' vulnerability is somewhat unique in that it is *existential*: unlike larger nations, there is no hinterland to retreat to – the highest natural point in the country is only ~2.4 meters.

While extreme weather events (like Indian Ocean cyclones) are relatively rare compared to the Bay of Bengal or Pacific, the Maldives did suffer a devastating inundation from the 2004 Indian Ocean tsunami, and it experiences occasional flooding from distant cyclones and monsoonal swells. The country has limited resources and land for conventional adaptation (e.g. building seawalls for every island is impractical), though it has built a 3-m high seawall around Malé with international help. The Maldives has thus become a vocal climate canary, warning that failure to limit global warming could literally erase a nation.

In recent years, it has explored extraordinary adaptation measures – from creating artificial elevated islands (like Hulhumalé, built 2 m higher than normal islands) to proposing a floating city as a refuge that rises with the seas.[22] These efforts, along with a new National

[17]Eckstein, D., Künzel, V., & Schäfer, L. (2025). *Global Climate Risk Index 2025.* Germanwatch e.V.
[18] Department of Environment [DOE], Government of Bangladesh. (2023).
[19] Shaw, R., et al. Climate Change 2022: Impacts, Adaptation and Vulnerability. (2022).
[20] United Nations Environment Programme [UNEP]. (2024)

[21] Veer, A. (2023)
[22] World Economic Forum. (2021, May 17). *Threatened by rising sea levels, the Maldives is building a floating city.*

Adaptation Plan,[23] illustrate the Maldivian resolve, but the Maldives' Climate Risk Index (which doesn't fully capture slow-onset risks) is lower than Bangladesh's or the Philippines' simply because it has not historically suffered as many massive storms or deaths. Nevertheless, on a per-capita and long-term basis, the Maldives is arguably among the most climate-vulnerable countries in the world.

1.2.3 Climate Vulnerability in the Philippines

The Philippines faces yet another facet of climate vulnerability. An archipelago of over 7,600 islands with 36,000 km of coastline, the Philippines is highly exposed to tropical cyclones (typhoons) originating from the Pacific. On average, 20 typhoons enter Philippine waters each year, with around 8–9 making landfall, some of them extremely intense. This includes Super Typhoon Haiyan (Yolanda) in 2013, one of the strongest storm landfalls on record globally, which generated 5–6 meter storm surges and killed over 6,300 people.

The Philippines' high disaster frequency has placed it 4th on the Climate Risk Index in terms of impacts over 2000–2019.[24] Coastal cities like Manila, Cebu, and Tacloban are particularly at risk from storm surges and coastal flooding. Manila, the capital region, is a megacity of over 13 million (24 million in the greater urban area) sitting on a bay with low-lying sections; it regularly experiences flooding both from heavy rainfall (overwhelming drainage) and high tides.

[23] United Nations Environment Programme [UNEP]. (2024)
[24] Climate Change Commission [CCC]. (2022.

The Philippines also contends with slow-onset issues: rising sea levels have contributed to shoreline retreat and mangrove loss, and warming oceans plus ocean acidification threaten coral reefs that support fisheries and shield coasts. Approximately 60% of the Filipino population lives in coastal zones, often in dense settlements. Many poorer communities inhabit informal housing along flood-prone estuaries and coastlines (for example, parts of Metro Manila and Cebu City), making them highly vulnerable to any increase in flooding or storm intensity. Beyond geophysical exposure, the Philippines' socio-economic challenges – poverty (~18% of Filipinos), unequal development, and under-investment in infrastructure – exacerbate climate impacts. For instance, insufficient drainage and solid waste management in cities lead to flash floods with even moderate rains.

On the other hand, the Philippines has relatively stronger governance and response systems for disasters (e.g. the Nationwide Operational Assessment of Hazards, and a dedicated disaster risk reduction agency), having learned from frequent events. As a largely maritime nation, it is also acutely aware of sea-level rise: local sea levels in parts of the Philippines have been rising faster than the global average (due to regional variations), with rates over 5 mm/year observed.[25] This contributes to frequent "nuisance" tidal flooding in some communities. The combination of intense typhoons, heavier monsoon rains, and rising seas poses a complex threat matrix – e.g., a

[25] Intergovernmental Panel on Climate Change (IPCC). (2022a). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of WG II to the Sixth Assessment Report – Chapter 10: Asia. Cambridge University Press.*

typhoon hitting during a higher-than-usual high tide can produce unprecedented flood heights.

The Philippines' adaptive capacity is growing but uneven; Metro Manila might eventually afford Dutch-style storm surge barriers, but many provincial coastal towns must rely on restoring mangroves and improving evacuation systems. The country's experience underscores how island versus mainland geography affects risk: unlike Bangladesh's contiguous landmass (where inland retreat is possible) or the Maldives' tiny atolls, the Philippines has many islands – some mountainous (offering high ground) but others flat and exposed – requiring decentralized but coordinated adaptation strategies.

Having outlined the vulnerabilities, it is clear that while climate change is global, its impacts are intensely local. Bangladesh, the Maldives, and the Philippines each illustrate different dimensions of the coastal climate crisis – deltaic floods, existential island threats, and typhoon-driven disasters – making them critical case studies for understanding and enhancing urban resilience in the face of sea-level rise.

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2. Data and Methodology

This research adopts a data-driven approach, combining historical climate indicators with socio-economic metrics to analyze trends and interactions relevant to sea-level rise impacts.

We constructed a composite dataset from multiple sources: annual climate data (sea-level changes, flood occurrences) and socio-economic data (population, urbanization rate, GDP, migration) for Bangladesh, the Maldives, and the Philippines. Key indicators were drawn from reputable databases such as the World Bank (for population, urban population %, GDP) and climate agencies.

For sea-level data, we used satellite-derived records of relative sea level (RSL) change for each country's coastal region from 1993–2024 (1993 being the start of continuous satellite altimetry observations) – these records were derived from NASA's sea-level datasets and regional reconstruction data. Flood incidence was quantified using a record of high-tide flood days (sometimes called "nuisance" flooding) categorized by severity (minor, moderate, major) for 1979–2015, based on local tide gauge observations and meteorological reports.

Socio-economic variables (population, urban population %, net migration, GDP) were compiled for the period ~1975–2020 from World Bank and UN data, providing country-level annual values.[26] All these disparate data were merged by year and country to enable integrated analysis.

[26] United Nations Office for Disaster Risk Reduction (UNDRR). (2015). Global Assessment Report on Disaster Risk Reduction 2015. Geneva: UN.

2.1 Data Processing and Analysis

Using Python (Pandas for data wrangling), we performed time-series analyses to uncover trends and correlations.

We normalized some variables to enable comparison – for instance, sea-level data for each country were converted to anomalies relative to the 1993 baseline (so we could examine the change in sea level *relative* to 1993 for Bangladesh, Maldives, Philippines separately). We computed decadal averages and linear regressions to estimate rates of change (e.g. sea-level rise in mm/year for each country, trends in flood days per year).

To investigate the relationship between climatic stressors and human responses, we conducted a lead-lag correlation analysis: this involved correlating one time series (e.g. annual sea-level height) with another (e.g. net migration) at various time offsets. We calculated Pearson correlation coefficients at lags from -5 to +5 years, where a negative lag means the climate variable leads (comes before) the socio-economic variable. This helped identify potential predictive relationships (for example, whether rising sea levels in a given year are statistically associated with increased out-migration in subsequent years).

For mapping urban exposure, we utilized city-level data (latitude, longitude, city population) for major urban centers in the three countries, plotting these with D3.js to qualitatively assess how many large cities fall in low-elevation coastal zones. However, due to data limitations, our quantitative analysis is primarily at the national scale. It is important to acknowledge limitations of our data and methods:

(1) Constrained Temporal Coverage– precise sea-level data begin only in 1993, and the flood dataset ends in 2015, which may miss more recent developments.

(2) Coarse Spatial Resolution (national-level averages) and may mask local nuances (e.g. one part of a country might experience higher sea-level rise or flooding than another).

(3) Attribution Challenges – correlation does not equal causation. While we explore statistical relationships (like sea level vs migration), these are indicative and require deeper socio-economic research to confirm causality.

(4) Data Gaps — especially for the Maldives, consistent historical data on floods and migration were sparse (our flood days dataset had no entries for the Maldives),[27] which limits country-specific analysis. We mitigated this by supplementing with qualitative reports.

Despite these caveats, the data and methods are sufficient to draw broad insights into trends and to flag potential cause-effect linkages that merit further investigation.

2.2 Reproducibility

Our analytical workflow is reproducible: In our EDA sections, we used Jupyter/Python for scripting analysis steps, and Quarto to integrate text with data visualization. By leveraging these tools, we ensure

[27] Intergovernmental Panel on Climate Change (IPCC). (2022b)

transparency – the figures and statistics reported can be traced back to the underlying data transformations. Overall, our methodology blends descriptive trend analysis with simple predictive analytics (lead-lag correlations), all rooted in a synthesis of observational data.

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3. Visualizations and Insights

3.1 Sea-Level and Flooding Trends

The following section presents key findings supported by a series of targeted data visualizations, each aligned with a core thematic domain: sea-level and flooding dynamics, socio-economic vulnerability, climate-induced migration, and predictive linkages between environmental and human systems.

Observed Sea-Level Rise and Coastal Flooding

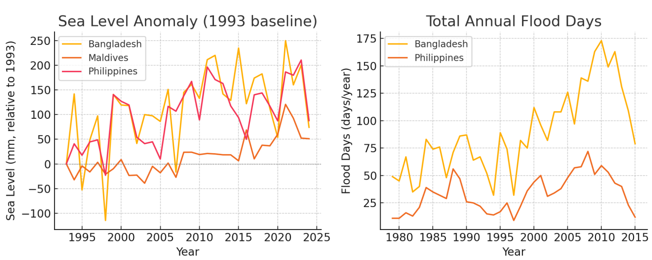

Figure 3.1: *Observed sea-level rise and coastal flooding trends in Bangladesh, the Maldives, and the Philippines. Left: Annual sea-level anomaly (mm) relative to 1993, based on satellite observations . Right: Total number of high-tide flood days per year for Bangladesh and the Philippines (1979–2015). Bangladesh shows a steep rise in flood days over time, while the Philippines' trend is relatively flat . (No flood day data was available for the Maldives, which nevertheless faces frequent tidal inundation.)*

3.1.1 Sea Level Analysis Results - Change Over Time

Figure 3.1 (left panel) illustrates the rise in sea levels over the past three decades. All three countries exhibit an upward trajectory in sea-level height.

Sea Level Change Over Time in Bangladesh

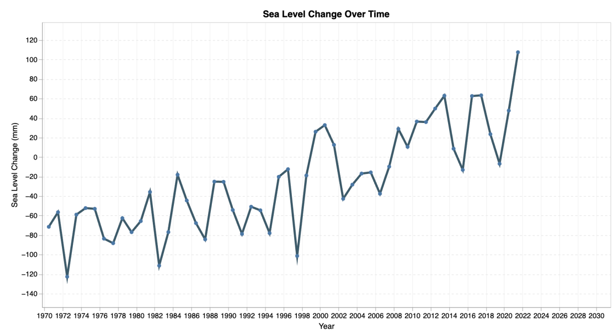

Figure 3.1.2: *Sea Level Change Over Time (Reconstruction)*

Bangladesh's coastal waters have risen by roughly + 75 mm from 1993 to 2024, which corresponds to an average rate of ~4. 6 mm/year (consistent with regional trends in the Bay of Bengal).

Sea Level Change Over Time in The Philippines

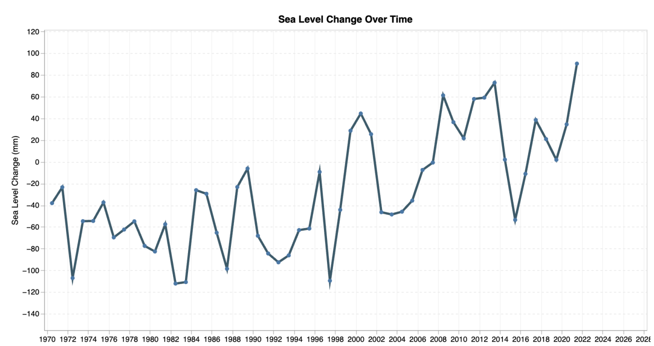

Figure 3.1.3: *Sea Level Change Over Time (Reconstruction)*

The Philippines shows a similar order of magnitude rise (~ 4. 1 mm/year), while the Maldives (Indian Ocean) experienced a slightly lower rate (~ 3.0 mm/year) over the period.

Sea Level Change Over Time in The Philippines

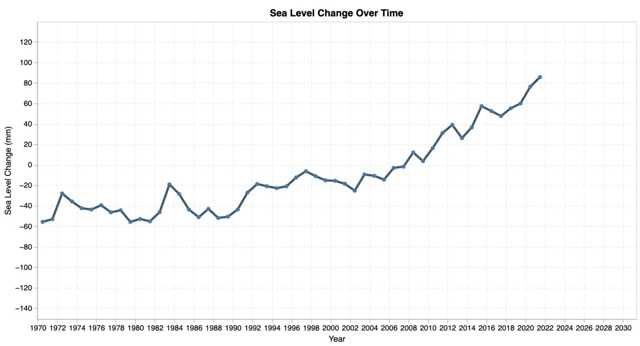

Figure 3.1.4 *Sea Level Change Over Time (Reconstruction)*

These rates align with global observations ($\approx 3–4.5$ mm/year) and confirm that sea-level rise is a present reality for South Asia's coasts, not just a future projection.

The year-to-year fluctuations (seen as wiggles in the lines) are influenced by climate variability (e.g. ENSO can cause regional sea levels to temporarily dip or rise), but the long-term trend is clearly upward. This rising baseline means that even ordinary high tides and monsoon surges are reaching higher inland than a few decades ago.

Minor High Tide Flood Days – Bangladesh

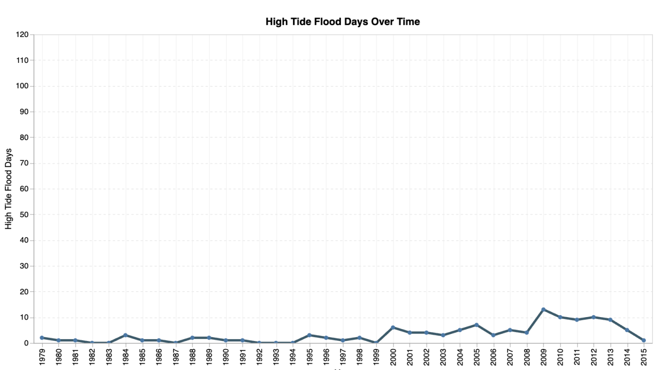

Figure 3.1.5: *Minor High Tide Flood Days – Bangladesh*

The right panel of **Figure 3.1** reveals a stark difference in chronic flooding trends between Bangladesh and the Philippines, we look closer at these charts in **Figure 3.1.6** and **Figure 3.1.7**.

Major High Tide Flood Days – Philippines

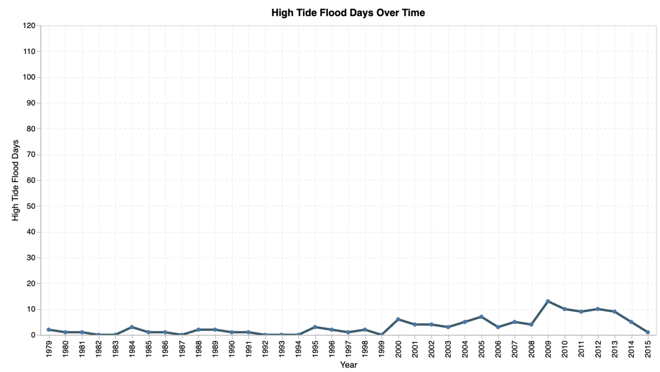

Figure 3.1.6: *Major High Tide Flood Days – Philippines*

In Bangladesh, the number of coastal flood days per year has more than doubled from the early 1980s to the 2010s. In the late 1970s and early 1980s, Bangladesh saw on the order of 40–50 high-tide flood days per year (mostly minor floods). By the 2000s and 2010s, this total frequently exceeded 100 days/year, peaking at over 170 flood days in 2014 (nearly every other day on average) in our record. There is an evident rising trend ($\sim +2.7$ flood days per year per annum on average), indicating that tidal flooding has become progressively more frequent.

Minor floods (nuisance flooding that causes local puddles and minor disruptions) are primarily responsible for this increase – Bangladesh's minor flood days rose significantly, which is *consistent with rising sea levels and increased urban vulnerability*.[28]

[28] World Bank. (2021). Climate Change Knowledge Portal: Bangladesh and Philippines flood day indicators (1979–2015).

Minor High Tide Flood Days – Bangladesh

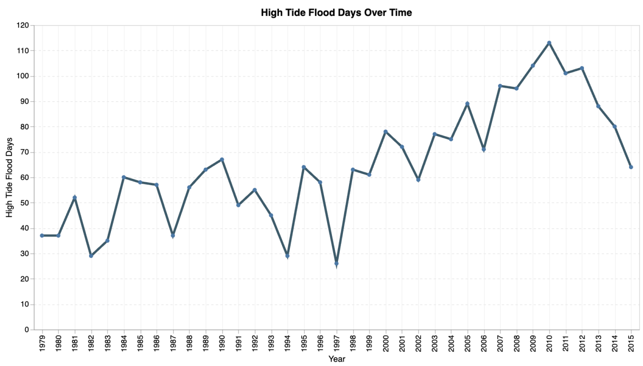

Figure 3.1.7: *Minor High Tide Flood Days – Bangladesh*

Major floods (significant inundation events) in Bangladesh also show incidents in the data (e.g. around 13 days of major coastal flooding in 2009, which stands out as an exceptional year).[29] In contrast, the Philippines' flood day trend is relatively stable.[30]

Moderate High Tide Flood Days – Bangladesh

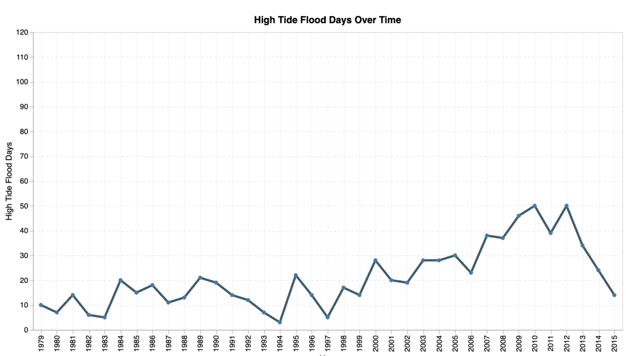

Figure 3.1.8: *Moderate High Tide Flood Days – Bangladesh*

Total flood days per year in the Philippines hovered in the range of ~10–60 and do not exhibit a clear upward trend over 1979–2015. Notably, the Philippines had far fewer *major* high-tide flood days – the worst year (2008) saw 2 major flood days, versus Bangladesh's 13 in 2009.

This difference can be attributed to geography and perhaps adaptive measures: much of the Philippine coastline is steep or ocean-facing without large tidal plains, and major cities like Manila, while low-lying, have invested in some flood defenses.

Minor High Tide Flood Days – Philippines

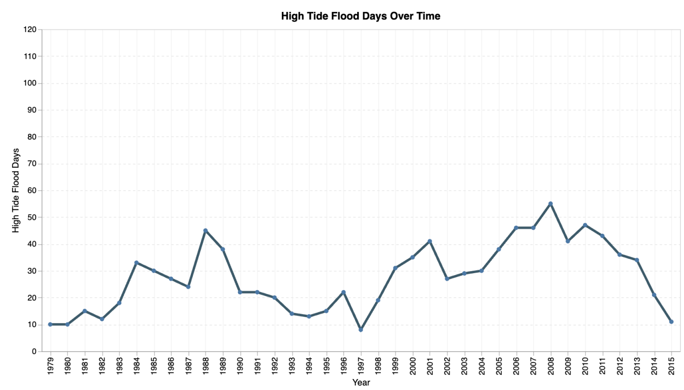

Figure 3.1.9: *Minor High Tide Flood Days – Philippines*

Moreover, many Philippine flood events are tied to typhoons (acute events) rather than just incremental sea-level rise, so they manifest as disaster spikes (which our data on high-tide flooding may not fully capture, since it focuses on tidal flooding).[31]

[29] World Bank. (2021).
[30] *Ibid.*

[31] Intergovernmental Panel on Climate Change (IPCC). (2022a).

Moderate High Tide Flood Days – Philippines

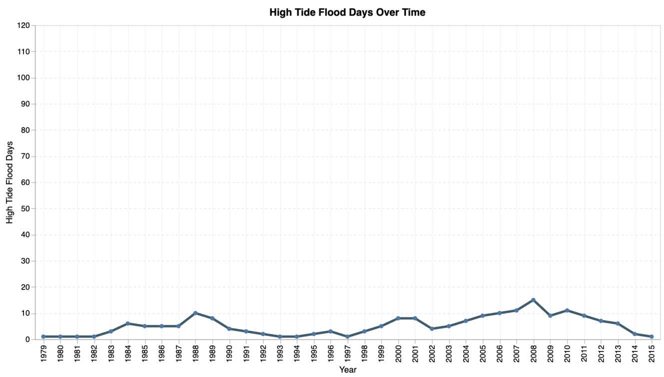

Figure 3.1.10: *Moderate High Tide Flood Days – Philippines*

In the Philippines, the relatively stable trend we see for moderate high tide flood days **(Figure 3.1.10)** could imply that *relative* sea-level rise has been partly offset by improvements in urban flood management or simply that many Philippine cities have slightly higher elevation buffers.

However, one must be cautious: the Philippines still experiences devastating flooding from storm surges (e.g. Tacloban during Typhoon Haiyan) – those just occur episodically rather than as recurrent nuisance floods. Indeed, if we consider extreme flood events, the Philippines has been hit repeatedly; its Climate Risk Index rank of 4th is largely due to those catastrophic floods and storms,[32] even if daily tidal flooding is less of an issue than in Bangladesh.

3.1.2 Examining The Maldives Data Gap

Malé in the Maldives has reported being inundated by distant storm surges and high tides multiple times in recent decades, but systematic data were unavailable. The absence of Maldives in the flood-day dataset is a finding in itself: it highlights a data gap that needs addressing given Maldives' vulnerability.

These trends support the narrative that sea-level rise is already translating into more frequent "everyday" flooding in highly exposed areas. Bangladesh's rise in minor flood days hints that what used to be occasional high tide events are now far more common, likely overwhelming drainage infrastructure and affecting agriculture (through saltwater intrusion in coastal fields).

A crucial insight is that Bangladesh shows a "living with water" pattern, where vast areas face inundation for large parts of the year. In response, Bangladesh's adaptation strategy has often been described as "living with floods" – reflected in traditional homes on stilts, floating agriculture (e.g. hydroponic raft gardens), and community-based warning systems.

On the other hand, the Philippines invests heavily in flood control infrastructure and disaster risk reduction. For example, in 2024 the Philippines launched a USD $144 million urban flood management project focused on improving Manila's drainage, building flood barriers, and enhancing early warning systems.[33] Such investments might be why chronic tidal flood days haven't exploded in Philippine cities despite rising seas. Still, given enough sea-level rise in coming decades, even these defenses will be tested. For the Maldives, every millimeter of sea-level rise directly eats into the nation's habitable land; anecdotal reports of more

[32] Climate Change Commission [CCC]. (2022)

[33] World Bank. (2022). *Philippines Metro Manila Flood Management Project – Implementation Status Report.*

frequent seawater overtopping in island communities align with the rising trend seen in **Figure 3.1 (left)**.

In summary, sea-level rise is not just a future threat – it has already increased the baseline of coastal hazards. Bangladesh is experiencing this through frequent tidal floods and drainage challenges, the Maldives through existential land loss concerns, and the Philippines through heightened risks when storms strike. The data underscores the importance of aggressive adaptation measures (e.g., improved seawalls, surge barriers, restored mangroves) to protect these coasts as the sea continues to rise.

3.2 Socio-Economic Stress and Exposure

Climate impacts do not occur in a vacuum – socio-economic conditions determine how severe a given physical hazard becomes for a country. Here we examine key indicators like population growth, urbanization, and economic capacity in Bangladesh, the Maldives, and the Philippines, to understand their stress levels and preparedness.

One striking commonality is rapid population growth and urbanization in all three countries, albeit at different scales. Bangladesh's population has roughly doubled from about 78 million in 1975 to about 166 million by 2020.

Total Population Growth Rate – Bangladesh

Figure 3.2.1: *Total Population Growth Rate – Bangladesh*

While Bangladesh's population growth rate has slowed in recent years, it remains one of the most densely populated countries globally. Importantly, the share of people living in cities has ballooned – Bangladesh was ~10% urban in the 1970s; today about 38% of the population is urban.

Total Urban Population Growth Rate – Bangladesh

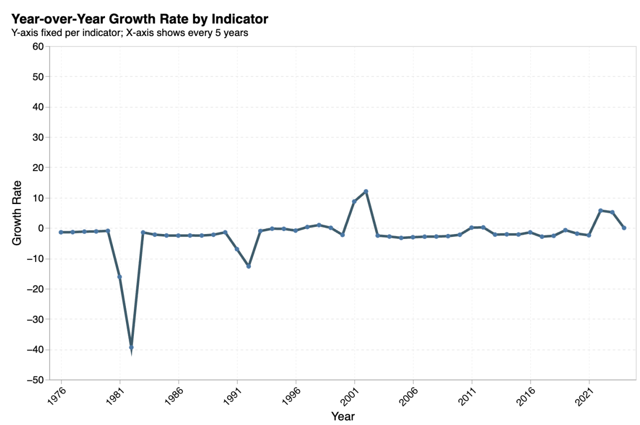

Figure 3.2.2: *Urban Pop Growth – Bangladesh*

This represents tens of millions of new urban dwellers, many of whom reside in megacities like Dhaka (over 20 million in the metro area) or burgeoning coastal cities like Chittagong (5+ million).

The World Bank reports that *"four major cities – Dhaka, Chittagong, Khulna, and Rajshahi – have absorbed 90% of the country's migrant population"* in recent decades,[34] reflecting a massive rural-to-urban exodus often driven partly by environmental push factors.

Dhaka's population density now exceeds 20,000 persons per sq.km ,[35] and nationwide over 4.4 million people live in urban slums.[36] This urban crowding means that any climate hazard impacting a city (e.g. an urban flood) can affect enormous numbers of people and can strain infrastructure that is already over capacity. Bangladesh's urban infrastructure has not kept pace with this growth – basic services like drainage, sewage, and housing lag behind. As one analysis noted, *"rapid and forced urbanization [in Bangladesh] is outpacing the necessary infrastructure development, exacerbating daily challenges"*.[37]

This gap leaves cities extremely vulnerable to flooding, as observed in the correlation below **(Figure 3.2.3)**: for instance, heavy rains regularly inundate Dhaka because drainage canals are clogged and insufficient for the urban extent.

[34] Veer A.(2023)
[35] *Ibid.*
[36] *Ibid.*
[37] *Ibid.*

Flood Days and Urban Population Growth

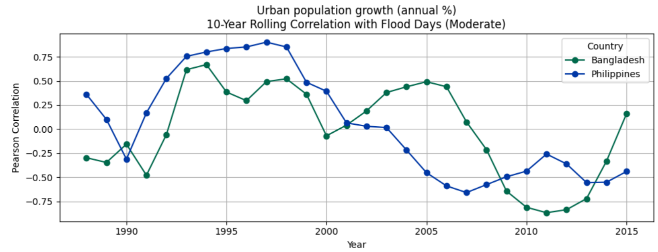

Figure 3.2.3: *Flood Days and Urban Population Growth in the Philippines and Bangladesh*

Thus, the socio-economic stress of high population density and inadequate infrastructure amplifies flood impacts (turning what might have been minor water logging into a major crisis for public health and mobility).

Total Population Growth Rate – Philippines

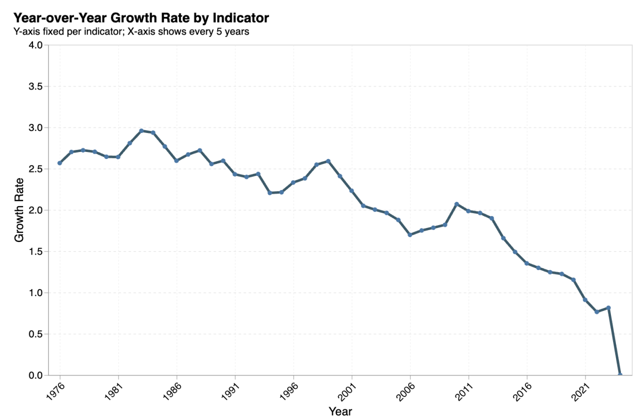

Figure 3.2.4: *Total Population Growth Rate from 1975 to 2022– Philippines*

The Philippines has also seen steady population increase – from ~45 million in 1975 to about 112 million by 2021. Its urbanization rate also reached 47% by 2020, meaning nearly half of Filipinos live in urban area **(Figure 3.2.5)** The Metro Manila conurbation is the primary hub (over 13 million city proper, ~24 million including surrounding suburbs), dwarfing other cities; this primacy implies that a large share of economic activity (and people) are concentrated in one coastal metropolis.

Urban Pop Growth – Philippines

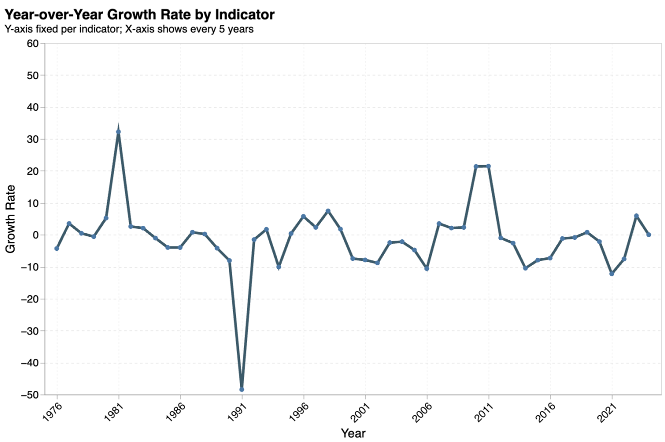

Figure 3.2.5: *Urban Pop Growth – Philippines*

Indeed, Metro Manila is *overwhelmingly* the dominant urban hub – its population far exceeds any other Philippine city. Other significant cities like Cebu, Davao, or Zamboanga (each 1–3 million) are much smaller. This centralization of population and economy means any climate shock to Manila (be it a direct typhoon hit, or chronic land subsidence and flooding) has outsized national consequences. The Philippines has invested in urban infrastructure more robustly than Bangladesh (higher GDP per capita allows somewhat better utilities in big cities), but many challenges remain. For example, informal settlements along riverbanks in Manila often flood badly during monsoons.

The country's economic geography (many distributed islands) also means that while Manila gets much attention, smaller coastal municipalities might lack resources – e.g., a mid-size city like Tacloban was devastated by Typhoon Haiyan's storm surge in 2013 due in part to inadequate coastal defenses and planning.[38]

GDP Over Time — Philippines

Figure 3.2.6: *GDP Over Time — Philippines*

The Philippines' economy is classified as lower-middle income,[39] with a GDP per capita around $3,200 (current US$ in 2020) **(Figure 3.2.6)**.

While its economy is more diversified and larger in absolute terms (about $362 billion GDP in 2020) than that of Maldives or even Bangladesh (see **Figure 3.2.7**), poverty and inequality persist. Regions like Eastern Visayas or Mindanao have high poverty rates and thus lower capacity to recover from climate shocks.

[38] International Federation of Red Cross and Red Crescent Societies (IFRC). (2020). World Disasters Report 2020: Come Heat or High Water
[39] World Bank. (2023). *World Development Indicators – GDP per capita (Philippines)*

GDP Over Time — Bangladesh

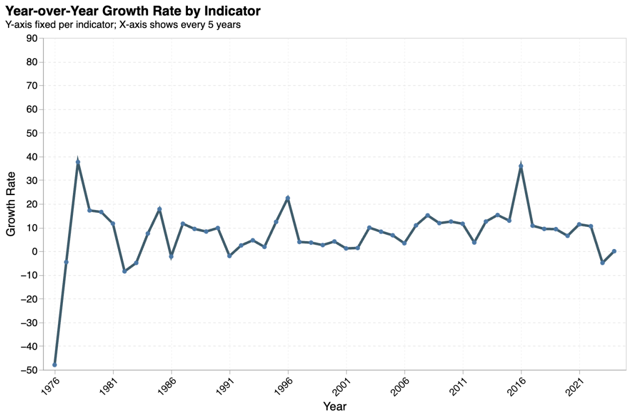

Figure 3.2.8: *GDP Over Time — Bangladesh*

In those places, people may live in makeshift housing that stands little chance against floods or wind. Additionally, the Philippines relies heavily on agriculture and fisheries in rural areas – sectors highly sensitive to climate variability (droughts, changing rainfall, coral reef loss).

Total Population – Maldives

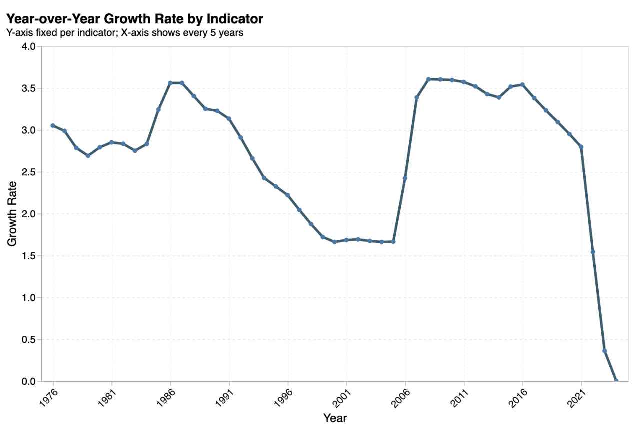

Figure 3.2.9: *Total Population – Maldives*

Maldives has the smallest population by far – about 0.5 million people – but it has urbanized quickly as well. Around 40% of Maldivians live in urban centers (notably the capital Malé), up from perhaps 10–15% urban in the 1970s.

Urban Pop Growth – Maldives

Figure 3.2.10: *Urban Pop Growth – Maldives*

In fact, Malé Island itself houses over 200,000 people on an area of only 9 km², making it one of the most densely populated islands in the world. This boom in population hyper-concentration is partly due to deliberate policy: to improve services, the government has encouraged migration from outer atolls to the capital.

However, it creates a scenario where one city holds a large fraction of the nation's population and infrastructure – a single point of failure risk for climate impacts. If Malé were to be extensively flooded (as nearly happened in 1987 when storm-driven waves inundated it, prior to the sea wall construction), the disruption would affect a huge portion of the Maldivian populace and governance.

GDP Over Time — Maldives

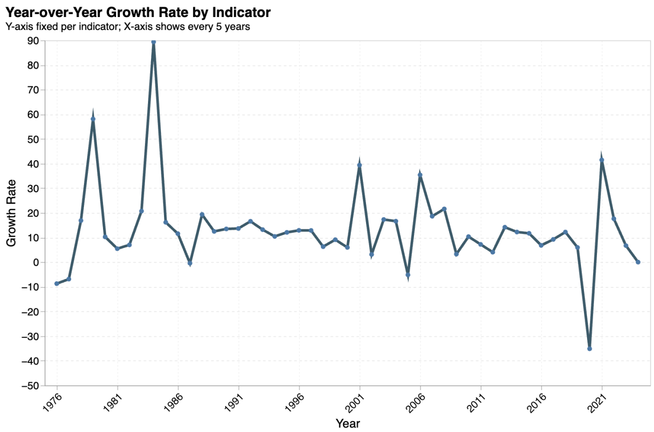

Figure 3.2.11: *GDP Over Time — Maldives*

On the economic front, Maldives is relatively wealthier (upper-middle income); its **GDP per capita ($7,400 in 2020) is much higher than Bangladesh's ($2,200) or the Philippines', thanks largely to high-end tourism and fisheries. This wealth provides some buffer and funding for adaptation (the Maldives spends a significant chunk of its budget on climate adaptation). Yet, the **absolute size of the economy ($3.7 billion GDP) is tiny, limiting what can be built. For instance, relocating or elevating infrastructure across all inhabited islands would cost orders of magnitude more than the country's GDP.[40]

Moreover, the tourism sector itself is vulnerable – many resorts are on low sandy islands; beach erosion and coral bleaching directly hurt the Maldives' economic lifeline. Socio-economically, Maldives has near-universal literacy and good health indicators, which aid in resilience, but it is completely dependent on imports for staple foods and fuel. Thus any climate disruption to port operations (e.g. harbor damage from storms) or freshwater supply can quickly escalate into a crisis.

Another socio-economic factor is agricultural reliance and livelihood sensitivity. In Bangladesh, about 85% of rural households depend on agriculture for their livelihood.[41] Climate change is already affecting this sector through erratic rain and flooding. Loss of crops or salinization of soil (from creeping sea water) can push more farmers to abandon their land and move to cities. Similarly, many Filipinos rely on subsistence fishing; when typhoons destroy coral reefs or mangroves, fish catches drop, affecting food security and income, possibly driving migration. These economic stresses can compound: for example, after a major flood, food prices spike, which disproportionately affects the poor and can contribute to social unrest or further migration.

In terms of preparedness, socio-economic conditions influence how well each country can implement adaptation.

(1) **Bangladesh,** despite low per capita income, has been quite proactive with community-based adaptation and securing international climate funds (for building cyclone shelters, embankments, etc.).

(2) **The Philippines,** with a larger economy, finances many of its own disaster responses but still requires significant support for large-scale protective infrastructure.

[40] World Bank. (2023). *World Development Indicators – GDP per capita (Maldives)*

[41] Veer A. (2023).

(3) **The Maldives** leverages its higher GDP per capita and international spotlight to advocate for aid and innovative solutions (like seeking loans for green infrastructure, exploring insurance schemes for climate risks, etc.).

All three countries face a significant adaptation gap. Meeting the infrastructure demands—such as seawalls, drainage, and climate-resilient housing—will require massive investment. For developing nations, adaptation costs may exceed tens of billions annually by 2030, and for Bangladesh and the Philippines, could surpass 1% of GDP by mid-century. These fiscal challenges are compounded by high-risk populations, limited adaptive capacity, and under-resourced infrastructure systems.

3.2.1 Key Takeaways

(a) *High Exposure:* Coastal cities concentrate large, at-risk populations and assets.

(b) *Infrastructure Gaps:* Rapid urbanization has outpaced drainage, housing, and services, increasing flood vulnerability.

(c) *Economic Constraints:* Limited budgets and poverty hinder adaptive capacity and slow resilience efforts.

(d) *Uneven Capacity:* The Maldives is wealthier but small; Bangladesh is populous with limited per capita resources; the Philippines falls in between. Without major adaptation, even moderate hazards could have disproportionate impacts.

Structural and socio-economic stresses not only heighten exposure to climate hazards but also influence how communities respond. When adaptive capacity is limited or uneven, migration often emerges as a coping strategy. The next section examines how these vulnerabilities are reflected in population movements—both from sudden disasters and long-term environmental change.

3.2.2 Composite Vulnerability Index Trends

To further contextualize these trends, we visualized a Composite Vulnerability Index (1993–2014) that combines climate exposure, social sensitivity, and adaptive capacity. As shown in **Figure 3.2.2a,** vulnerability rose across all three countries, with the Philippines peaking after 2009 due to repeated typhoons and coastal stress.

Composite Vulnerability Index Heatmap

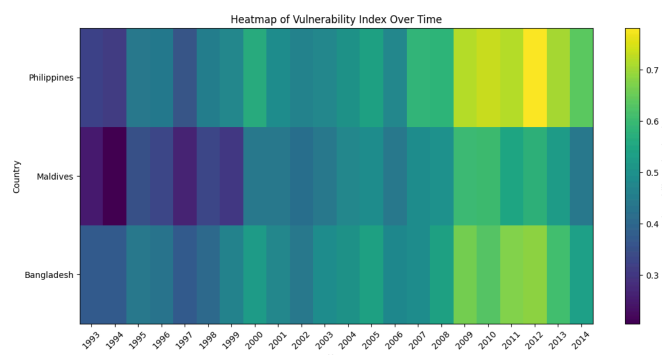

Figure 3.2.2a: *Heatmap of Composite Vulnerability Index (0–1) for Bangladesh, Maldives, and the Philippines, 1993–2014.*

Bangladesh shows a steady rise in vulnerability, while the Maldives, despite starting lower, remains elevated due to its acute exposure and lack of retreat options. The stacked area chart **(Figure 3.2.2b)** highlights a regional peak around 2010, with the Philippines contributing the largest share, followed by Bangladesh—underscoring the compounding risks of coastal urbanization and population growth.

Stacked Area Composite Vulnerability Chart

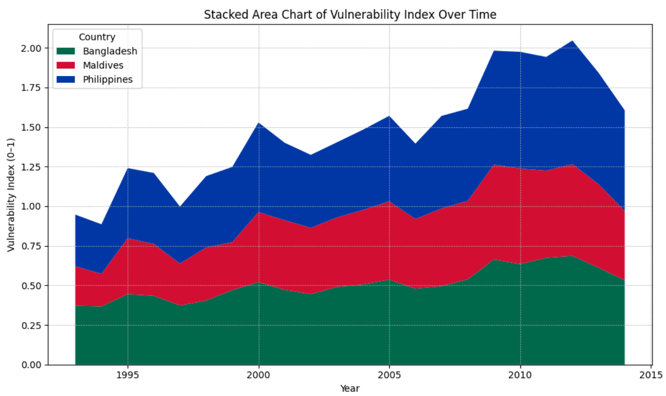

Figure 3.2.2c: *Stacked Area Chart of Composite Vulnerability Index by Country, 1993–2014.*

To complement these aggregate views, **Figure 3.2.2d** provides a time-series line chart of the vulnerability index by country. This figure emphasizes year-to-year divergence in country trajectories.

Composite Vulnerability Index (1993–2014)

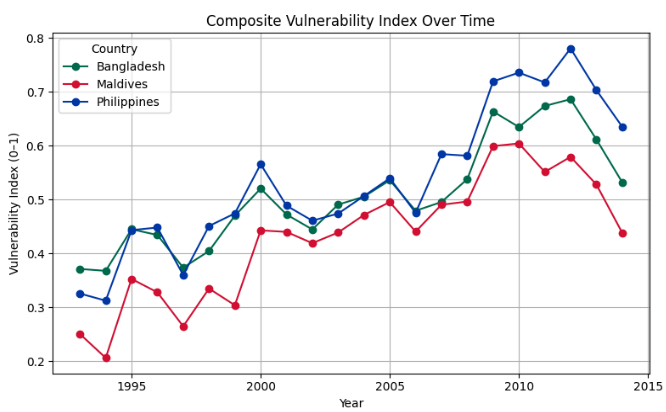

Figure 3.2.2d: *Line Chart of Composite Vulnerability Index by Country, 1993–2014.*

Notably, the Philippines' index climbs rapidly between 2007 and 2012, surpassing both peers. Bangladesh rises steadily, while the Maldives maintains a slower but consistent upward trajectory. These distinctions reveal not only absolute vulnerability but the pace of escalation, which is critical for prioritizing policy responses.

Together, these three visualizations offer a triangulated view of climate vulnerability. The index serves as a synthetic measure of both hazard and preparedness, reinforcing the broader narrative that national vulnerability is shaped not only by environmental risks, but also by disparities in protection, capacity, and investment.

3.3 Migration Patterns and Climate Shocks

Human migration is one of the key outcomes (and indicators) of climate stress in vulnerable regions. In South Asia's low-lying areas, communities are increasingly faced with a wrenching choice: to stay and endure worsening floods and erosion, or to relocate to safer ground. We examine migration data and reports to discern patterns in Bangladesh, the Maldives, and the Philippines, and how climate shocks are influencing these movements.

3.3.1 Net Migration Trends

Both Bangladesh and the Philippines have historically experienced net out-migration (more people leaving than entering each year), for a mix of economic and environmental reasons.

Yearly Net Migration – Bangladesh

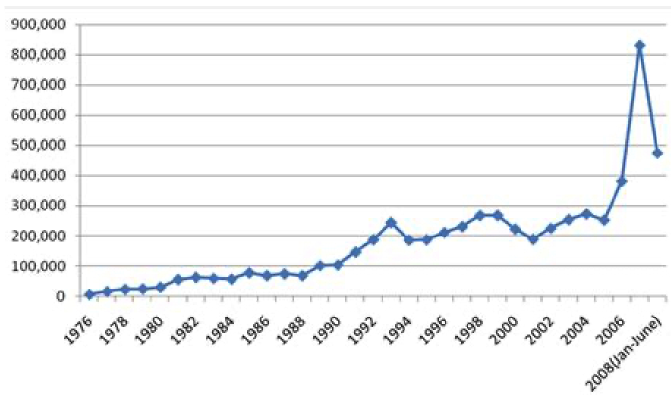

Figure 3.3a: Yearly *net migration in Bangladesh, with recent annual figures ranging from approximately -300,000 to -550,000. For instance, in 2023, the net migration was -549,918, and in 2024, it was -473,362.*

World Bank data show that Bangladesh's net migration has remained negative for decades, with recent annual figures ranging from approximately $-300,000$ to $-500,000$, indicating that significantly more people emigrate than immigrate each year **(Figure 3.3a).**

Net Migration Growth Rate – Bangladesh

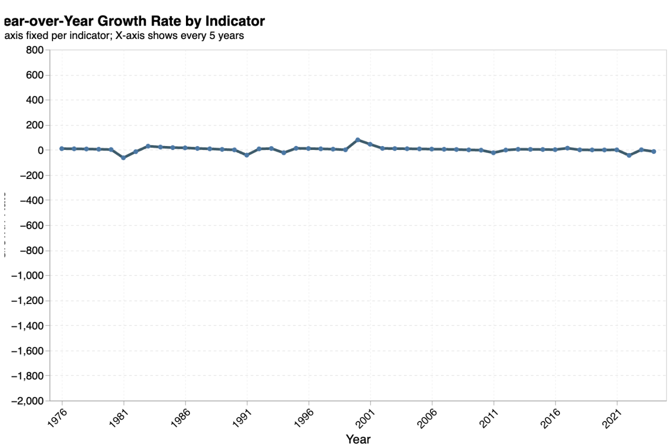

Figure 3.3.1: *Net Migration – Bangladesh*

As shown in **Figure 3.3.1,** the growth rate of net migration has remained relatively stable over time, suggesting that the scale of out-migration has not experienced a marked upward or downward trend during the observed period.

Many of these migrants are workers going abroad, but a portion are also displaced internally and eventually seek better livelihoods elsewhere.

Net Migration Growth Rate – Philippines

Figure 3.3.2: *Net Migration – Philippines*

The Philippines **(Figure 3.3.2)** similarly has substantial emigration (Filipino workers overseas), with net migration around $-100,000$ to $-160,000$ per year in the 2010s.

Net Migration Growth Rate – Maldives

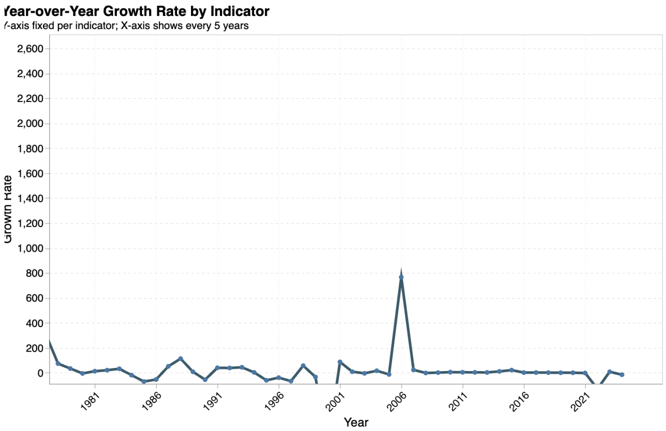

Figure 3.3.3: *Net Migration – Maldives*

In the Maldives **(Figure 3.3.3)**, migration is smaller in absolute numbers; interestingly Maldives saw net *inflows* in some recent years (e.g. labor migrants coming for construction and tourism jobs), but that turned to net outflow of a few thousand annually around 2022 – possibly due to economic slowdowns or climate anxieties.[42] Internal migration is more pertinent for Bangladesh and the Philippines: rural families moving to cities like Dhaka or Manila form a major migratory stream.

3.3.2 Climate-Related Displacement and Internal Migration

Sudden-onset disasters are a major driver of displacement in all three countries. In 2019 alone, Bangladesh and the Philippines each recorded over 4 million disaster displacements.[43][44] In Bangladesh, river floods and cyclones frequently force mass evacuations—Cyclone Amphan (2020) displaced 2.4 million people. While many return, some are unable to rebuild due to salinized land or destroyed homes. The Philippines shows similar dynamics: Typhoon Haiyan (2013) displaced over 4 million people, some permanently.[45] These are "pulse" events—sharp, high-volume migrations triggered by catastrophic events.

In contrast, "press" migration unfolds more gradually. In southern Bangladesh, repeated flooding and erosion have led to preemptive relocation, especially in Khulna and Barisal districts. Rising sea levels could displace up to 2.1 million people by 2050.[46] A Reuters modeling study projects at least 1.3 million climate-displaced Bangladeshis by mid-century, triggering migration waves that initially head toward Dhaka and eventually ripple outward due to overcrowding.[47] Such cascading movement reshapes settlement patterns and urban pressure.[48]

The Philippines reflects similar migration trends. People from provinces like Samar and Leyte relocate to cities like Manila or Cebu following storms. Although some eventually return, many remain in informal urban settlements. After Typhoon Ketsana (2009) flooded large parts of Metro Manila, some middle-class families permanently relocated or emigrated. While rebuilding is common, climate impacts increasingly push rural-to-urban migration.[49]

[42] World Bank. (2023).
[43] IPCC. (2022)
[44] Internal Displacement Monitoring Centre [IDMC]. (2023). Global Report on Internal Displacement 2023 (GRID 2023). Geneva: Norwegian Refugee Council.

[45] Shaw et al. (2022)
[46] IPCC. (2022)
[47] Karim N., Migration to flee rising seas could affect 1.3 million Bangladeshis by 2050. Reuters. (2021)
[48] World Bank. (2023)
[49] Shaw et al. (2022)

The Maldives faces a distinct challenge: while large-scale climate migration hasn't occurred yet, existential risk looms. Former President Mohamed Nasheed proposed buying land abroad to relocate Maldivians if sea-level rise makes the islands uninhabitable.[50] So far, climate-driven relocations have been internal, primarily from low-lying outer islands to Hulhumalé, an elevated artificial island designed to accommodate future population movements.[51] These moves remain voluntary and incentivized, but underscore the nation's limited retreat options. International displacement has been minimal to date, though this could change under more extreme scenarios.

3.3.3 Migration Factors: Beyond Climate Risks

It is important to recognize that climate is rarely the sole driver of migration; it interacts with factors such as economic opportunity, governance, and social networks.[52] However, in Bangladesh, the Philippines, and the Maldives, climate stress increasingly acts as a tipping point. Even without advanced modeling, the empirical evidence points to clear links between environmental pressures and population movement.[53]

The World Bank's Groundswell report (2018) projects that South Asia could see over 40 million internal climate migrants by 2050, with Bangladesh comprising a substantial share. More recent estimates suggest that figure could rise to 143 million globally, although such projections carry significant uncertainty.[54]

Many displaced individuals resettle in informal urban settlements, where they face new risks—a phenomenon termed the "double insecurity" of climate migrants.[55] For example, families displaced by coastal erosion in Bangladesh may relocate to flood-prone slums in Dhaka; similar patterns have been observed in Manila following typhoons and storm surges.[56] These patterns underscore the need for inclusive adaptation strategies that address not only physical relocation, but also housing, livelihoods, and service provision in destination areas.

Conversely, the most vulnerable—those unable to migrate—remain trapped in high-risk zones. Migration data therefore reflect both mobility and immobility under climate stress. With adequate planning, migration can function as an adaptive strategy. Anticipatory infrastructure development and targeted support in receiving areas will be essential to minimize cascading risks and ensure protection for displaced populations.

[50] Goldberg, S. (2008). Maldives president seeks land for nation faced with 'climate Armageddon'. The Guardian.
[51] Mozaharul, A. (2024, February 15). Maldives rests hope on new National Adaptation Plan to tackle climate change
[52] Shaw et al. (2022)
[53] IDMC (2023)

[54] World Bank. (2018). Groundswell: Preparing for Internal Climate Migration. Washington, DC: International Bank for Reconstruction and Development
[55] Lustgarten, A. (2020, July 23). The great climate migration has begun. The New York Times Magazine.
[56] Veer A. (2023).

3.4 Evolving Climate–Society Relationships: Rolling Correlation Analysis

To understand how climate-society relationships evolve over time, we applied a 10-year rolling Pearson correlation between key climate indicators—specifically sea-level rise, precipitation, and flood-day frequency—and socio-economic variables such as GDP, net migration, total population, and urban population growth. This approach captures time-varying patterns in the strength and direction of associations, offering insight into when and where environmental stressors begin to exert greater influence on societal outcomes.

Rolling Correlation between Sea-Level Rise and GDP (2000–2022)

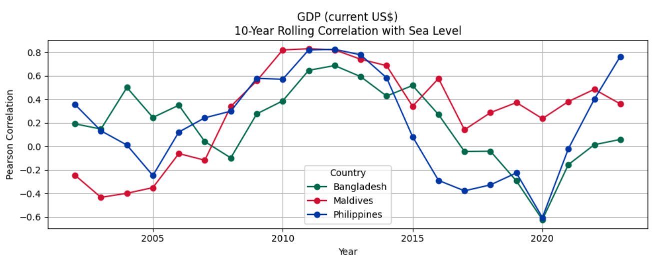

Figure 3.4.1: *10-Year Rolling Pearson Correlation between Sea Level and GDP (Bangladesh, Maldives, Philippines), 2000–2022.*

The analysis reveals significant variation across countries and indicators. For sea-level correlations, **Figure 3.4.1** shows that GDP was strongly positively correlated with sea-level rise in the Maldives and the Philippines from 2008 to 2015 ($r > 0.8$), a period marked by robust coastal development and tourism investment. Bangladesh also showed positive correlations, though they weakened after 2015—possibly reflecting rising exposure costs or infrastructure strain.

Rolling Correlation between Sea-Level Rise and Net Migration (2000–2024)

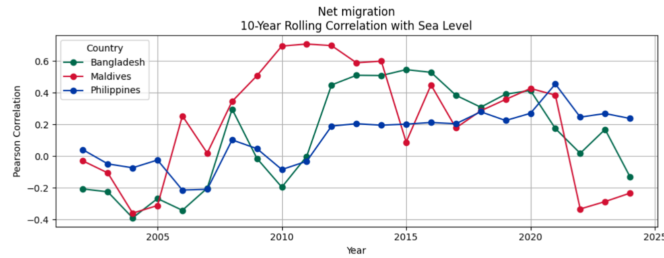

Figure 3.4.2: *10-Year Rolling Pearson Correlation between Sea Level and Net Migration, 2000–2024.*

Net migration correlations with sea-level rise **(Figure 3.4.2)** diverged significantly by country. In the Maldives, the 2010–2015 period exhibited strong positive correlations ($r > 0.6$), aligning with growth-driven in-migration. In contrast, Bangladesh's correlation weakened and turned negative after 2020, suggesting a possible link between rising sea levels and out-migration. The Philippines displayed generally mild or stable correlations, likely reflecting a broader mix of migration drivers.

Rolling Correlation between Sea-Level Rise and Total Population (2000–2022)

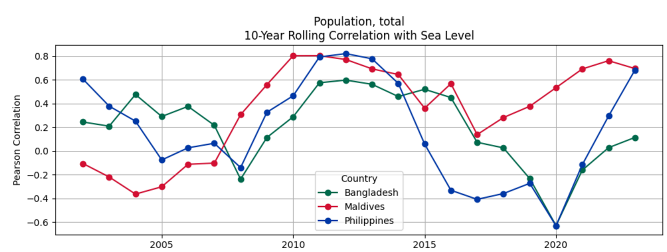

Figure 3.4.3: *10-Year Rolling Pearson Correlation between Sea Level and Total Population, 2000–2022.*

Population metrics responded to sea-level trends in more varied ways. As shown in **Figure 3.4.3,** total population remained positively correlated with sea level in the Maldives, while Bangladesh and the Philippines exhibited more variability.

Rolling Correlation between Sea-Level Rise and Urban Population Growth (2000–2022)

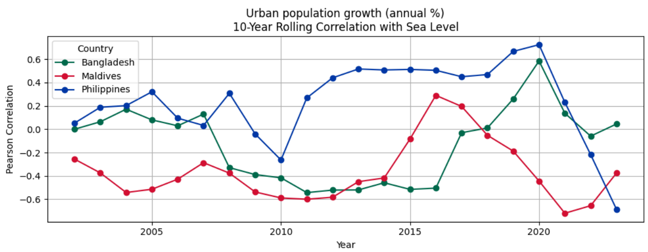

Figure 3.4.4: *10-Year Rolling Pearson Correlation between Sea Level and Urban Population Growth, 2000–2022.*

Urban population growth **(Figure 3.4.4)** showed a strong positive correlation in the Philippines throughout the 2010s, consistent with continued coastal urbanization. By contrast, the Maldives exhibited a persistently negative correlation, potentially due to geographic constraints or strategic planning aimed at de-risking vulnerable coastal zones. Bangladesh showed a declining urban correlation after 2010, possibly indicating saturation or increased vulnerability in urban coastal centers.

Rolling Correlation between Precipitation and GDP (1980–2015)

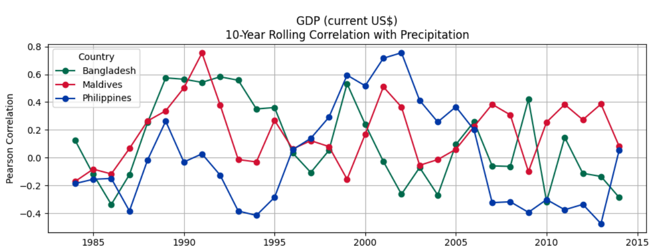

Figure 3.4.5: *10-Year Rolling Pearson Correlation between Precipitation and GDP, 1980–2015.*

Figure 3.4.5 reveals that GDP correlations with precipitation were moderate and positive in Bangladesh from the early 1990s through the mid-1990s, peaking near $r = 0.6$. The Maldives also exhibited strong positive correlations around 1990. The Philippines, in contrast, displayed largely weak or negative correlations during this period, with only a brief positive uptick around 2000. These patterns suggest that precipitation-sensitive sectors like agriculture may have contributed to economic fluctuations in Bangladesh and the Maldives during wetter years, while the Philippines' economy was likely less dependent on hydrological variability during the same timeframe.

Rolling Correlation between Precipitation and Net Migration (1980–2015)

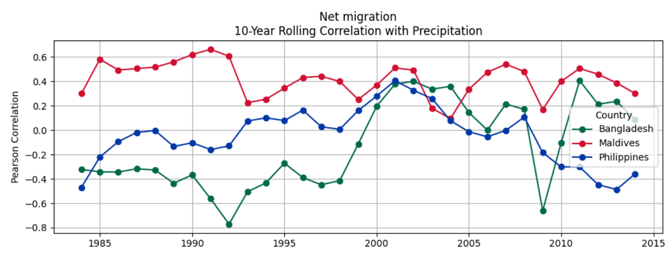

Figure 3.4.6: *10-Year Rolling Pearson Correlation between Precipitation and Net Migration, 1980–2015.*

Migration trends also reflect rainfall sensitivity. In **Figure 3.4.6,** Bangladesh shows a strong negative correlation with precipitation in the early 1990s ($r < -0.8$), coinciding with major flood years. The Maldives exhibited generally positive correlations through the early 2000s, consistent with migration linked to favorable economic and climate conditions.

Rolling Correlation between Precipitation and Total Population (1980–2015)

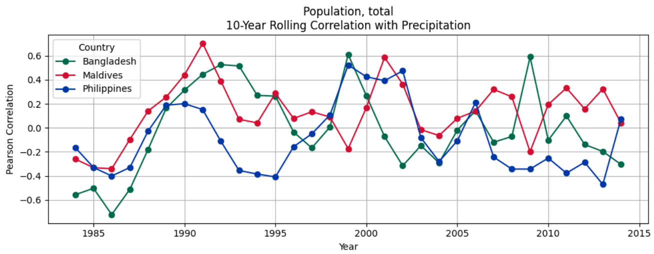

Figure 3.4.7: *10-Year Rolling Pearson Correlation between Precipitation and Total Population, 1980–2015.*

Population metrics correlated variably with precipitation. **Figure 3.4.7** shows that total population correlations shifted over time and between countries, while **Figure 3.4.8** reveals similar instability in urban population growth correlations.

Rolling Correlation between Precipitation and Urban Population Growth (1980–2015)

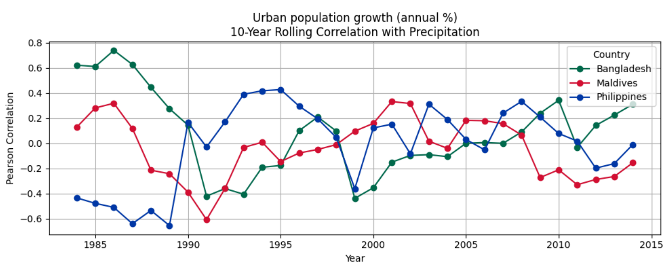

Figure 3.4.8: *10-Year Rolling Pearson Correlation between Precipitation and Urban Population Growth, 1980–2015.*

These fluctuations suggest that hydrological variability can influence population dynamics in nonlinear and regionally specific ways.

We also examined correlations with moderate flood-day frequency to evaluate the role of more localized, chronic hazards. As shown in **Figure 3.4.9**, GDP in both Bangladesh and the Philippines was positively correlated with flood days in the 2005–2012 period ($r > 0.8$), implying either resilience or flood-linked recovery spending. However, correlations turned sharply negative after 2013 in both countries, possibly due to increased economic strain or exposure costs. Flood-day correlation analysis was limited to Bangladesh and the Philippines due to the absence of historical flood-day records for the Maldives. This omission reflects broader regional data availability issues and underscores the importance of investment in long-term, high-resolution environmental monitoring in small island states.

Rolling Correlation between Moderate Flood Days and GDP (1985–2015)

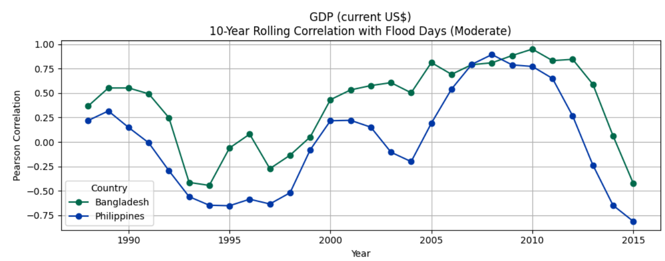

Figure 3.4.9: *10-Year Rolling Pearson Correlation between Moderate Flood Days and GDP, Bangladesh and Philippines, 1985–2015.*

Rolling Correlation between Moderate Flood Days and Net Migration (1985–2015)

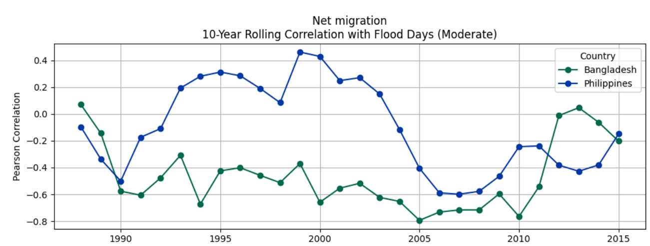

Figure 3.4.10: *10-Year Rolling Pearson Correlation between Moderate Flood Days and Net Migration, Bangladesh and Philippines, 1985–2015.*

Migration correlations with moderate flood days **(Figure 3.4.10)** were notably negative in Bangladesh from 1990 to 2010 ($r \approx -0.6$), consistent with displacement dynamics. The Philippines showed mild positive correlations in the late 1990s, perhaps reflecting internal migration to better-adapted areas.

Rolling Correlation between Moderate Flood Days and Total Population (1985–2015)

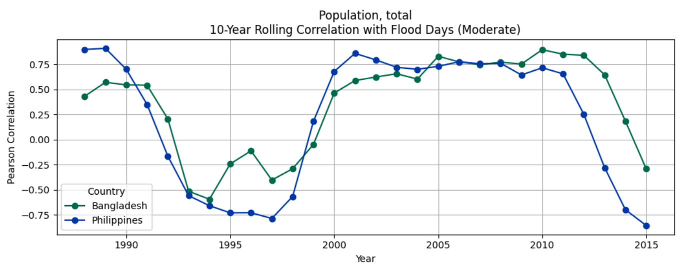

Figure 3.4.11: *10-Year Rolling Pearson Correlation between Moderate Flood Days and Total Population, Bangladesh and Philippines, 1985–2015.*

Population variables again show strong climate sensitivity. **Figure 3.4.11** illustrates that total population was positively correlated with flood-day frequency during the 2000s, particularly in Bangladesh.

However, **Figure 3.4.12** reveals a negative shift in urban population growth correlations during 2010–2015, especially in Bangladesh, where r dropped below -0.6 —suggesting that worsening flood conditions may be suppressing urban expansion in highly exposed zones.

Rolling Correlation between Moderate Flood Days and Urban Population Growth (1985–2015)

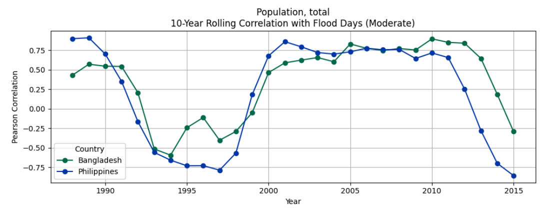

Figure 3.4.12: *10-Year Rolling Pearson Correlation between Moderate Flood Days and Urban Population Growth, Bangladesh and Philippines, 1985–2015.*

Overall, these findings underscore the importance of dynamic, context-specific analyses in understanding climate-society interactions. Correlations between environmental and demographic-economic indicators are not static but evolve in response to shifting exposure, adaptation, and socio-economic development. Policymakers should interpret these trends not as deterministic outcomes, but as signals of when and where intervention may be most needed to mitigate cascading risks.

3.5 Predictive Insights from Lead-Lag Correlations

To further probe the connection between climate change and socio-economic responses, we analyzed lead-lag correlations between selected indicators. In particular, we examined whether changes in climate stressors (like sea-level rise or rapid urbanization) tend to precede changes in outcomes (like migration, population growth, or GDP growth) in our dataset. While such statistical correlations cannot prove causation, they can highlight temporal patterns suggestive of cause and effect or common driving factors.

3.5.1 Sea Level Rise and Net Migration

A notable finding is the delayed relationship between sea-level rise and net migration. In Bangladesh, elevated sea levels were followed 4–5 years later by increased out-migration, with a correlation of approximately -0.56. This suggests that coastal stressors—flooding, erosion, or salinization—may take time to erode livelihoods before prompting relocation.

A similar, though weaker, lagged correlation was observed in the Philippines, likely due to more diverse migration drivers and spatial variability in exposure.

Lead-Lag Correlation Grid – Philippines

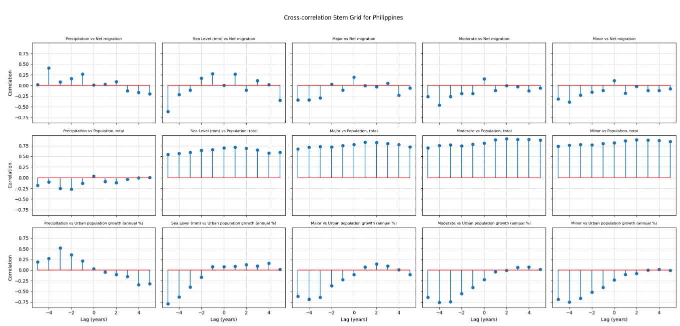

Figure 3.5.1: *Lead-Lag Correlation Grid – Philippines*

While sea-level rise is not a direct cause of migration, it serves as a proxy for worsening conditions that interact with other factors like poverty or employment. The data **(Figure 3.5.1)** supports the view that climate acts as a gradual "push" toward migration, often manifesting only after adaptive capacity is exceeded.

3.5.2 Urbanization Rates and Demographic Changes

We also examined urbanization and demographic dynamics. In Bangladesh, spikes in urban population growth were followed by declines in total population growth roughly five years later (correlation ≈ -0.81), consistent with demographic transition patterns—urban migration is often linked to reduced fertility due to improved access to education and health services.

Lead-Lag Correlation Grid – Bangladesh

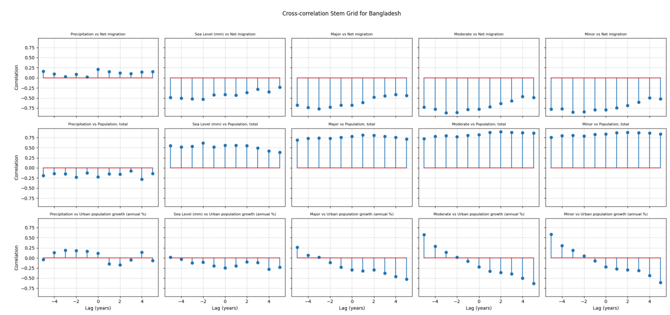

Figure 3.5.2: *Lead-Lag Correlation Grid – Bangladesh*

Additionally in **Figure 3.5.2,** rapid urban influx showed a mild negative correlation with GDP growth, possibly reflecting short-term economic strain from infrastructure and service pressure. While notable, these socio-economic patterns fall outside the central scope of this analysis.

3.5.3 Sea Level and Economic Growth

We observed a positive correlation between sea-level rise and Bangladesh's GDP at a 5-year lead ($r \approx +0.59$), likely reflecting a spurious relationship driven by coinciding upward trends rather than causality. Both GDP and sea level have increased since the 1990s, illustrating the importance of controlling for confounding factors when interpreting climate-socio economic linkages.

In the Lead-Lag Correlation for the Maldives **(Figure 3.5.3),** sea-level rise also showed a positive correlation with net migration ($r \approx +0.81$), suggesting that rising economic activity—particularly in tourism—coincided with increased labor in-migration.

Lead-Lag Correlation Grid – Maldives

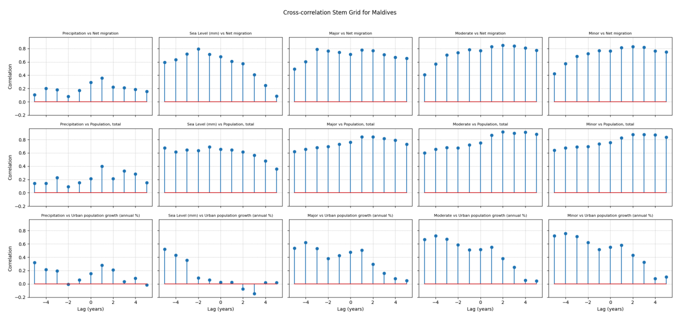

Figure 3.5.3: *Lead-Lag Correlation Grid – Maldives*

Figure 3.5.3 highlights that short-term migration patterns may reflect economic conditions rather than climate stress. However, if sea-level rise continues to intensify, we expect this relationship could reverse as climate risks become dominant drivers.

3.5.4 Predictive Data Limitations

These findings suggest that environmental indicators—such as sea-level anomalies and flood frequency —may serve as early warning signals for emerging socio-economic stress, including climate-induced migration. Anticipating these trends could enable targeted interventions, such as bolstering inland livelihoods or investing in local adaptation to reduce displacement pressures.

However, predictive models must be interpreted cautiously. A 2021 Nature study found that climate variables like drought and temperature anomalies were poor predictors of asylum migration compared to conflict and governance factors.[57] Similarly, our results show that migration is shaped by a complex interplay of climate, economic opportunity, and institutional capacity. Economic growth can delay or deter migration even in high-risk areas, while economic decline may accelerate it regardless of climate conditions.

While climate signals are increasingly influencing population dynamics, they are one part of a broader socio-political system. Without robust adaptation or emissions reductions, climate-driven displacement is likely to intensify. The next section examines how infrastructure and urban planning can help mitigate this risk and support resilience.

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4. Urbanization and Infrastructure Risk

Urban resilience in the face of rising seas and climate change hinges on how cities and governments adapt their infrastructure and land-use planning. In Bangladesh, the Maldives, and the Philippines, a number of adaptation strategies and infrastructure initiatives are being deployed – but each faces challenges of scale and financing. This section discusses the measures in place or proposed, and assesses infrastructure vulnerabilities that remain.

[57] Schutte, S., et al. (2021)

4.1 Engineered Solutions in Bangladesh

Bangladesh has historically adapted to seasonal flooding through practices like stilted housing, boat-based transport, and flood-resilient agriculture. However, escalating climate risks have driven the adoption of large-scale engineered solutions, most notably the Bangladesh Delta Plan 2100 (BDP2100). Adopted in 2018 and modeled after Dutch delta management, BDP2100 provides a long-term, integrated strategy encompassing over 80 initiatives in water, land, and disaster risk governance.

Key projects include upgrading 5,700 km of coastal embankments, constructing climate-resilient polders, restoring wetlands, enhancing drainage, and expanding cyclone early warning systems and shelters. These measures have reduced disaster mortality but face implementation barriers, including inter-agency coordination and financing demands projected in the tens of billions by 2030.

Complementary efforts under the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) promote resilient infrastructure and housing. Yet major vulnerabilities persist: many embankments remain breach-prone, informal urban expansion has overtaken floodplains, and sediment mismanagement worsens flood risk. For example, 2022 floods in Sylhet damaged a key power substation, underscoring infrastructure fragility.

Bangladesh's strategy represents a hybrid approach—combining community-based adaptation with infrastructural investment—but sustained, coordinated implementation will be essential to meet the escalating scale of climate impacts.

4.2 Relocation or Defense in the Maldives

The Maldives faces an existential threat from sea-level rise, with most of its territory lying below one meter in elevation. A one-meter rise could render large portions of the nation uninhabitable. In response, the country has pursued both physical defenses and strategic relocation.[58]

A 3-meter seawall constructed around Malé in the 1990s has proven effective against storm surges, but extending similar protections to all 187 inhabited islands is economically unfeasible. Instead, the government has invested in climate-resilient urban expansion—most notably Hulhumalé, a 2-meter elevated artificial island designed to house over 100,000 people. In 2022, it also launched a pilot Floating City project: a modular, lagoon-based community designed to rise with the sea.

Adaptation efforts also include voluntary relocation from highly exposed islands to more defensible locations, supported by the National Adaptation Programme, and upgrades to water, sanitation, and transportation infrastructure. Desalination systems powered by solar energy and elevation of critical assets, including the national airport, are key components of this strategy.

The Maldives is also leveraging blue economy tools, including coral reef restoration—which can dissipate up to 97% of wave energy—and financing mechanisms

[58] Mozaharul, A. (2024, February 15). Maldives rests hope on new National Adaptation Plan to tackle climate change

such as climate insurance and blue bonds. Its 2024 National Adaptation Plan outlines a multi-pronged strategy of fortification, elevation, and managed retreat.[59]

Despite these efforts, long-term habitability remains uncertain. The Maldives continues to advocate for ambitious global mitigation, serving as a frontline example of the stakes facing low-lying coastal nations.

4.3 Philippines' Disaster Reduction and Prevention Through Infrastructure

The Philippines, highly exposed to typhoons and coastal flooding, has developed a comprehensive Disaster Risk Reduction and Management (DRRM) system. This includes early warning systems, mandatory evacuation protocols, and coordinated emergency response—credited with saving lives during events like Typhoon Haiyan (2013), when over 750,000 people were evacuated. Despite this, Haiyan's extreme storm surge still caused significant casualties, highlighting infrastructure gaps.

Post-Haiyan, the government strengthened building codes in coastal zones and began evaluating large-scale protective infrastructure, such as a proposed storm surge barrier at the mouth of Manila Bay. While this remains in the planning stage due to cost and feasibility concerns, smaller seawalls have been constructed in vulnerable coastal barangays. In Tacloban, a 27-kilometer flood wall now buffers the coastline.

[59] Department of Environment [DOE], Government of Bangladesh. (2023).

The Philippines is also pursuing nature-based solutions, including mangrove reforestation in areas like Eastern Visayas. While effective at attenuating wave energy and trapping sediment, mangrove conservation faces competing land-use pressures from aquaculture and tourism. "No-build zones" have been designated along high-risk coastlines, though enforcement is inconsistent.

Urban flooding remains a persistent issue, especially in Metro Manila, where outdated drainage systems, informal settlements, and dense development converge. The World Bank–supported Metro Manila Flood Management Project addresses these challenges by upgrading pumps and waterways and relocating at-risk informal settlers. Efforts also include improved flood forecasting and coordinated dam management to prevent flash flooding.

Cities like Cebu and Davao have begun integrating climate projections into urban planning, but implementation capacity varies across local government units. As a middle-income country, the Philippines funds some projects domestically but continues to rely on international support, especially post-disaster. Instruments such as the Southeast Asia Disaster Risk Insurance Facility and "Build Back Better" initiatives contribute to recovery and resilience.

While progress has been made, infrastructure systems in the Philippines remain under pressure from escalating climate risks. Urban centers like Manila continue to face recurrent flooding, and key defenses—such as the Roxas Boulevard seawall—are increasingly overwhelmed by high tides and storm surges. Addressing these vulnerabilities will require not only continued investment, but also stronger local implementation, long-term planning, and coordination across national and subnational levels.

4.4 Shared Challenges and Adaptation Pathways

Despite ambitious national plans, infrastructure upgrades in Bangladesh, the Maldives, and the Philippines continue to lag behind the escalating pace of climate threats. For instance, Manila's seawall is now frequently overtopped by storm surges, underscoring the limitations of existing defenses and the urgency of further investment in resilience.

Still, several success stories demonstrate what is possible. In Bangladesh, the Coastal Embankment Improvement Project upgraded dikes in 17 coastal polders, substantially reducing flood impacts during Cyclone Amphan (2020). In the Maldives, the elevated island of Hulhumalé withstood the 2004 tsunami with minimal damage, validating the strategy of engineered high-ground retreat. In the Philippines, the Marikina River Rehabilitation Project transformed vulnerable informal settlements into floodways and parkland, significantly lowering flood risk for residents relocated to safer housing.

Yet critical vulnerabilities persist. Bangladesh's coastal roads, often serving double duty as embankments, remain only 1–2 meters above sea level. Salinity intrusion is degrading water supply infrastructure. In the Maldives, harbor facilities on outer atolls are increasingly damaged by wave action. And in the Philippines, recurring typhoon damage in regions like Bicol highlights the fragility of key transport networks.

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Across all three nations, governments are now embracing forward-looking design codes and planning tools. The Philippines' updated building code accounts for typhoon wind loads in a warming climate. Bangladesh is piloting floating agriculture and amphibious housing, blending traditional resilience strategies with innovation. Efforts to prevent development in high-risk zones—such as hazard mapping and zoning in the Philippines, or no-inhabitation zone proposals in Bangladesh—are in progress but face enforcement challenges, especially where land scarcity or informal settlements limit flexibility.

Ultimately, the three countries are deploying a mix of structural and non-structural interventions: seawalls, raised islands, upgraded drainage systems, managed relocation, land-use regulations, and ecosystem restoration. However, the scale of projected risk demands far more ambitious and coordinated action.

Plans such as Bangladesh's Delta Plan 2100, the Maldives' National Adaptation Plan, and the Philippines' disaster risk frameworks provide a roadmap, but their success will depend on sustained implementation, funding, and governance. The viability of coastal cities like Dhaka, Malé, and Manila will hinge on whether these adaptation strategies can keep pace with rising seas and compounding socio-environmental pressures.[60]

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5. Ethical Considerations

As climate data and predictive modeling increasingly inform adaptation policy, ethical concerns around interpretation, implementation, and equity become paramount. This section highlights key considerations around predictive uncertainty, data governance, distributive justice, and narrative framing.

5.1 Predictive Limitations

Migration models are often presented with unwarranted certainty. Headlines projecting "200 million climate refugees by 2050" obscure the complex, multi-causal nature of migration. While climate change is a growing pressure, it is rarely the sole driver. A 2021 Nature Communications study found climate variables to be weaker predictors of asylum migration than conflict and economic instability.[61] Over-reliance on such projections risks misallocating resources, stigmatizing communities, or justifying neglect of adaptation investments. Ethical modeling requires transparent communication of uncertainty, contextual interpretation, and avoidance of deterministic framing.

5.2 Data Use and Community Rights

The increasing granularity of climate risk data raises questions of consent and representation. For example, designating a coastal village as unsustainable based on predictive data may lead to involuntary relocation, particularly in contexts with limited participatory governance. Ethical adaptation planning must center community agency—ensuring affected populations are consulted, informed, and empowered in decisions that affect their futures. Programs like the Maldives' National Adaptation Plan must balance national survival with the rights and preferences of local residents.

5.3 Equity and Distributional Justice

Adaptation strategies can unintentionally reinforce existing inequalities. In Manila, for example, flood defenses built for wealthier districts may divert water into informal settlements. International finance may prioritize high-visibility urban projects over marginalized rural communities. Ethical adaptation requires that the most vulnerable—those least responsible for emissions and least able to recover—receive priority support. Failure to do so can produce "double vulnerability," where climate-displaced persons are relocated to equally precarious conditions.

[60] Government of the People's Republic of Bangladesh. (2018)
[61] Schutte et al. (2021)

5.4 Misuse of Data and Modeling

Climate models are valuable but must be interpreted as tools—not truths. If projections are misused to justify rigid responses (e.g., preemptively building infrastructure for a predicted number of migrants), resources may be misdirected, while urgent present-day needs go unmet. Ethical modeling emphasizes probabilistic reasoning, contextual relevance, and continuous revision based on new data.

5.5 Narrative Framing and Dignity

The language of climate discourse influences both policy and public perception. Terms like "climate refugees" lack legal definition and can diminish the agency of displaced individuals. Similarly, fatalistic claims—such as "the Maldives will disappear"—may foster inaction, while excessive optimism can lead to complacency. Ethical communication should convey urgency without undermining dignity or agency.

Emerging tools like mobile and satellite data raise concerns around privacy and consent. Although not used in this study, future research must ensure anonymization and community-informed data practices.

Finally, decisions about aid allocation often reflect economic logic rather than vulnerability. Ethical frameworks should prioritize justice—supporting at-risk communities even when they offer limited economic return. This principle underlies calls for international loss and damage mechanisms to address disproportionate climate impacts.

Ethical climate adaptation requires more than technical expertise—it calls for moral clarity. As data increasingly guide policy, their use must be transparent, inclusive, and rooted in justice. Climate strategies should be not only effective but also equitable, designed to protect the most vulnerable, uphold dignity, and ensure that adaptation efforts are co-developed with the communities they aim to support.

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6. Conclusion

This study has analyzed the climate vulnerabilities and adaptive responses of Bangladesh, the Maldives, and the Philippines, three South and Southeast Asian nations on the frontlines of sea-level rise. Drawing on integrated climate and socio-economic data, our analysis reveals converging patterns of hazard exposure, socio-demographic stress, and evolving human responses, particularly in urban coastal regions.

Sea-level rise, occurring at 3–5 mm per year across the region, is already manifesting in recurrent flooding, coastal erosion, and land loss. In Bangladesh, flood days have more than doubled since the 1980s, while the Maldives faces existential threats from land submergence, and the Philippines continues to endure storm-driven coastal disasters. These environmental risks intersect with rapid urbanization, infrastructure deficits, and constrained adaptive capacity, particularly in low-income and densely populated communities.

Migration has emerged as a salient socio-demographic response. Our correlation and lead-lag analyses suggest that climatic stressors, particularly sea-level anomalies and chronic flood frequency, are linked to out-migration with lagged effects of 4–5 years. This points to migration as a delayed but increasingly visible adaptation strategy in contexts where in situ resilience is insufficient. However, as our ethical analysis underscores, migration alone is not a solution—it must be accompanied by anticipatory support, safe resettlement planning, and attention to the immobile poor.

In response, each country has articulated ambitious national adaptation frameworks—Bangladesh's Delta Plan 2100, the Maldives' National Adaptation Plan, and the Philippines' DRRM strategies. While promising, these plans face shared implementation barriers: financial constraints, enforcement gaps, and uneven governance capacity. Notable innovations such as: Bangladesh's cyclone shelter network, the Maldives' elevated artificial islands, and the Philippines' hybrid infrastructure-nature-based approaches, demonstrate what is possible, but scaling them remains a challenge.

Several policy imperatives emerge from our findings:

(1) Accelerate infrastructure investment in flood defenses, drainage, and climate-resilient housing, particularly in secondary cities and informal urban areas.

(2) Integrate climate-migration dynamics into national planning, with proactive support for vulnerable populations—both those who move and those who stay.

(3) Embrace long-term adaptation horizons: planning beyond 2050 is essential to address the multi-century trajectory of sea-level rise.

(4) Strengthen international climate finance to support adaptation in lower-income countries, and operationalize loss and damage frameworks to address unavoidable impacts.

(5) Center equity and community agency in adaptation, ensuring that data-driven decisions uphold justice, participation, and local knowledge.

Above all, mitigation remains indispensable. Without a sharp global reduction in greenhouse gas emissions, the pace and scale of sea-level rise may outstrip even the most robust adaptation efforts. As former Maldivian President Nasheed cautioned: "We do not want to leave the Maldives. But we also do not want to be climate refugees living in tents for decades." His words remind us that what is at stake is not only land, but sovereignty, dignity, and the right to remain.

The path forward lies in coordinated, evidence-based, and ethically grounded action. If adequately supported, the adaptation models emerging in South Asia's coastal nations can serve as blueprints for resilience—offering critical lessons for the rest of the world as it confronts a rising tide.

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