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Drought, Flood, and Cyclone Trends in SAARC Countries (1970–2020): A Geo-climatic Retrospective

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Abstract

This study investigates the spatial and temporal trends of three major hydro-climatic hazards—droughts, floods, and tropical cyclones—across the SAARC region from 1970 to 2020. Utilizing satellite-derived indices, historical disaster databases, and regional climate models, the research identifies patterns, intensities, and frequencies of these events. The findings aim to inform disaster risk reduction strategies and climate adaptation policies within the SAARC nations.

Keywords: SAARC, Droughts, Floods, Tropical Cyclones, Risk Reduction

1. Introduction

1.1 Background: Climate Vulnerability of the SAARC Region

The SAARC region—comprising Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka—represents a diverse geo-climatic zone that is highly vulnerable to climate-induced hazards. This vulnerability is primarily driven by the region's dependence on the South Asian monsoon system, which governs over 70% of the annual precipitation and determines the hydrological stability, agricultural productivity, and socio-economic balance of the region [1]. The Himalayas in the north, the vast Indo-Gangetic plains, coastal deltas, and island nations such as the Maldives create a physiographic complexity that amplifies the effects of climatic anomalies like droughts, floods, and cyclones [2,3]. Over the past five decades, the frequency and intensity of extreme weather events have shown a marked increase across SAARC countries. This includes recurrent droughts in Afghanistan and central India, devastating floods in Bangladesh and Pakistan, and cyclonic storms affecting coastal zones of India, Sri Lanka, and the Maldives [4,5]. These phenomena are often linked to larger climatic oscillations such as the El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), which alter the spatiotemporal patterns of rainfall and temperature [6,7]. Additionally, anthropogenic factors such as rapid urbanization, deforestation, unplanned land use, and insufficient disaster-preparedness infrastructure have further exacerbated the region's fragility in the face of natural calamities [8]. Countries like Bangladesh, with its low-lying deltaic terrain, and the Maldives, with an average elevation of just 1.5 meters above sea level, are particularly vulnerable to sea-level rise and storm surges [9,10]. On the other hand, mountainous nations like Nepal and Bhutan face frequent landslides and glacial lake outburst floods (GLOFs), which are aggravated by rising global temperatures [11]. Given the transboundary nature of many of the region's rivers (e.g., the Indus, Ganges, and Brahmaputra systems), and the interconnected impacts of shared weather systems, a regional perspective on climate trends and disaster risks is essential. However, coordinated research and data-sharing across SAARC countries remain limited due to geopolitical tensions and policy fragmentation [12,13]. This study thus aims to provide a comprehensive retrospective of major climate-induced disasters in the region from 1970 to 2020—focusing on droughts, floods, and cyclones—to aid in more integrated risk reduction and adaptive strategies.

1.2 Objective

To analyze the historical trends of droughts, floods, and cyclones in SAARC countries over five decades, assessing their impacts and underlying climatic drivers.

2. Literature Review

Ramaswamy (1987) [14] conducted a seminal study on climatic hazards across South Asia, emphasizing the agricultural impact of monsoon failure. His work identified the years 1972, 1979, and 1987 as critical drought periods that significantly disrupted agricultural output, particularly in India and Pakistan. Using historical rainfall data, he established an early link between deficient monsoons and widespread food insecurity. Ramaswamy's analysis aligns with the Climate Variability and Vulnerability Theory, which underscores how regional economies highly dependent on rainfall are disproportionately affected by droughts. His conclusions served as a foundation for drought prediction models in India and were among the first to relate climatic data to socio-economic outcomes in the region [14]. Gadgil and Kumar (1999) [15] expanded the understanding of South Asian droughts by conducting a century-long rainfall analysis across SAARC nations. Their research confirmed a strong correlation between El Niño events and weakening monsoons, which often led to agricultural droughts in India, Sri Lanka, and Nepal. The study utilized the Systems Theory to demonstrate how global ocean-atmosphere interactions (such as ENSO) influence regional hydrological cycles. Gadgil and Kumar concluded that improved oceanic monitoring and climate modeling could serve as early indicators for drought preparedness. This work influenced several national policies on monsoon forecasting and agro-climatic zoning in India [15]. Mohapatra (2006) [16], in a comprehensive analysis published by the India Meteorological Department, tracked cyclonic disturbances in the North Indian Ocean between 1970 and 2005. His findings revealed that while the total frequency of cyclones had declined, the proportion of extremely severe cyclonic storms (ESCS) had increased significantly—posing intensified threats to the eastern coastal states of India such as Odisha and Andhra Pradesh. The study applied the Disaster Risk Reduction (DRR) Framework, focusing on the relationship between hazard intensity and vulnerability. Mohapatra emphasized the urgency for cyclone-resilient infrastructure and institutional preparedness. His work directly influenced revisions in India's coastal disaster preparedness protocols. Sharma and Thakur (2010)[17] approached hydro-meteorological disasters from a geospatial perspective, using GIS and remote sensing tools to map drought- and flood-prone regions across India, Nepal, and Bangladesh. Their study revealed a shifting geography of extreme weather—highlighting that areas previously unaffected, such as parts of Assam and Jharkhand, were becoming increasingly flood-prone. Meanwhile, prolonged dry spells were being recorded in traditionally semi-arid zones like Gujarat and Rajasthan. Through the lens of Political Ecology, they argued that socio-political neglect, deforestation, and poor land-use planning contributed as much to vulnerability as climatic changes. They advocated for participatory GIS and decentralized disaster planning. Singh and Swain (2014) [18] presented a case study on Cyclone Phailin (2013) in Odisha, examining its socio-economic impacts and the success of India's evacuation and early warning systems. Despite Phailin's magnitude, casualties were minimal—demonstrating the effectiveness of pre-disaster planning and inter-agency coordination. Their study, based on Resilience Theory, emphasized that robust institutional systems can buffer communities against climatic extremes. Singh and Swain recommended that India's cyclone mitigation model be adapted by other SAARC countries such as Bangladesh and Sri Lanka, where similar climatic threats exist but preparedness levels vary significantly [18]. Das and Bhatia (2015) [19] analyzed four decades of flood data in Eastern India, with a focus on flood-prone districts of Bihar and West Bengal. Their study found a significant rise in flash floods and short-duration high-intensity events, which severely affected rice and jute agriculture. Using the theoretical lens of Environmental Determinism, they argued that geography—specifically low-lying floodplains and unregulated river systems—predetermined agricultural vulnerability. The authors emphasized the need for river interlinking, canal modernization, and wetland conservation to create a buffer against future flood events, particularly under unpredictable monsoon conditions [19]. Kumar and Rani (2017)[20] examined long-term drought trends using the Standardized Precipitation Index (SPI) in Central Indian states like Madhya Pradesh and Chhattisgarh. Their results showed a significant increase in both frequency and severity of droughts post-1980, with 2002 and 2015 being especially dry. They framed their findings within Anthropocene Theory, arguing that human-induced factors—such as land degradation, groundwater exploitation, and deforestation—exacerbated natural climatic variability. The authors recommended integrated watershed management, drought-resistant crops, and

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participatory irrigation planning to build resilience in vulnerable agrarian districts. Joshi and Pillai (2020) [21] conducted modeling simulations to assess coastal vulnerability to tropical cyclones under various Representative Concentration Pathways (RCPs). Focusing on Tamil Nadu and Andhra Pradesh, they predicted a doubling in cyclone intensity by 2050 under RCP 8.5, with urban centers like Chennai facing severe storm surge risks. Their work applied the Climate Justice framework, emphasizing that marginalized fishing and slum communities bear disproportionate risks without adequate policy protection. They called for inclusive climate-resilient urban planning, early warning system access for vulnerable groups, and regional cooperation on coastal zone management across SAARC countries .

3. Methodology

Data Sources:

- Drought data from the Standardized Precipitation Evapotranspiration Index (SPEI) and the Drought Severity Index (DSI).Nature+1esgdata.worldbank.org+1
- Flood records from EM-DAT and regional hydrological studies.ResearchGate
- Cyclone data from the India Meteorological Department (IMD) and the Regional Specialized Meteorological Centre (RSMC).

Analytical Tools:

- Time-series analysis to identify trends.
- Geospatial mapping using GIS for spatial distribution.
- Statistical correlation to assess relationships between events and climatic indices like ENSO.

4. Drought Trends (1970–2020)

Frequency and Severity: Between 1970 and 2020, the SAARC region experienced several significant drought events, notably in the years 2000, 2001, 2004, 2010, 2012, and 2016. These droughts had widespread impacts across South Asian countries, affecting agriculture, water resources, and livelihoods. For instance, the 2002 drought was particularly severe, with more than 60% of the region experiencing extreme drought conditions. ResearchGate

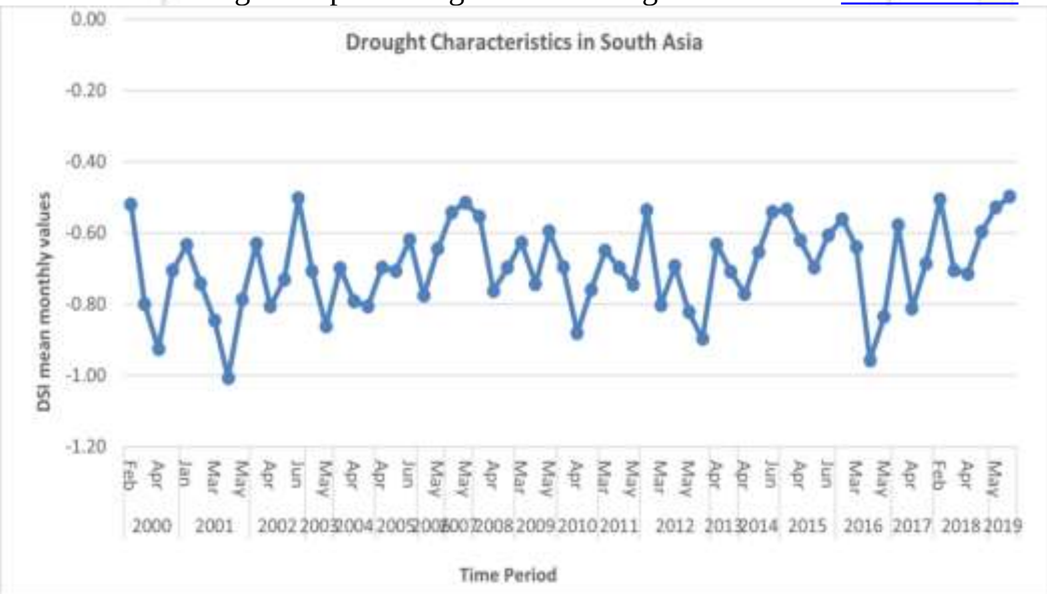

Figure 1: Drought Characteristics in South Asia

Spatial Distribution: Droughts in South Asia exhibit distinct spatial patterns. India, Pakistan, and Afghanistan have experienced recurrent droughts, with certain regions being more vulnerable. In India, the northwest, central, and southern regions are frequently affected. Pakistan's central-eastern, southwestern, southern, and some scattered south coastal regions are most vulnerable to severe droughts, mainly during winter and dry–wet periods. Afghanistan's northwestern and southeastern zones have also faced significant drought periods. Conversely, Bhutan and the Maldives lack comprehensive drought studies, indicating a gap in regional drought assessments.

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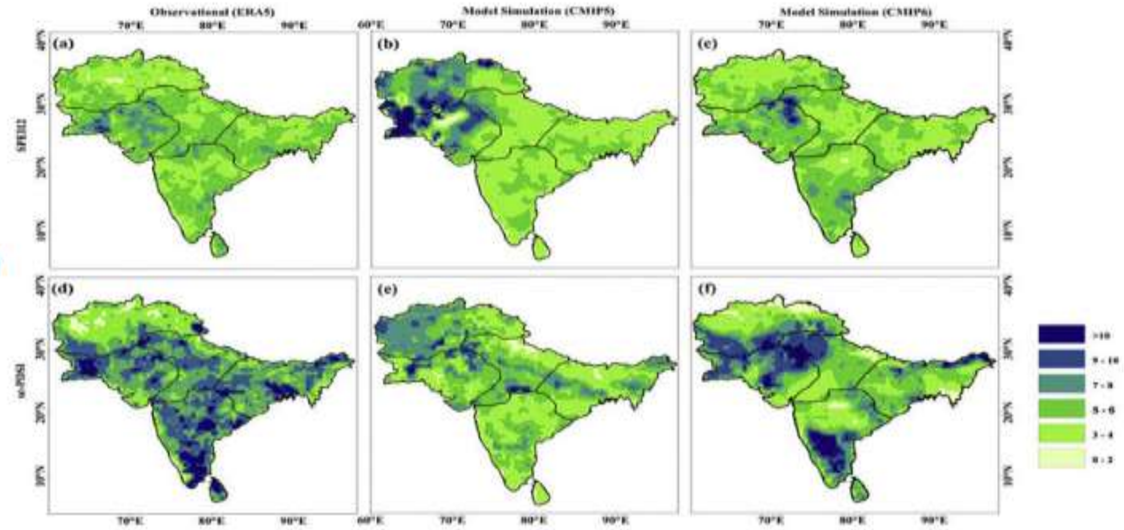

Figure 2: Spatial pattern of Drought Frequency per decade (number of drought events per decade) with SPEI-12 and sc-PDSI calculated from the observation (ERA5), and simulations (CMIP5 and CMIP6) for the baseline period (1986-2005).

Source: **https://www.researchgate.net/figure/Spatial-pattern-of-Drought-Frequency-per-decade-number-of-drought-events-per-decade_fig8_342484835**

Climatic Drivers: Climatic phenomena, particularly the El Niño-Southern Oscillation (ENSO), have been closely linked to drought occurrences in South Asia. El Niño events in 2002, 2004, 2006, 2010, and 2016 have correlated with severe drought conditions across the region. These events disrupt normal monsoon patterns, leading to reduced rainfall and prolonged dry spells. However, recent studies suggest that while ENSO plays a role, other factors such as land-use changes, deforestation, and regional climate variability also significantly influence drought patterns. MDPI

Visualization: Drought severity maps provide a visual representation of the spatial and temporal distribution of droughts across South Asia. The Asia-Pacific Network for Global Change Research (APN) has developed drought severity maps using the Drought Severity Index (DSI) for the period 2000–2020. These maps highlight areas experiencing moderate to severe drought conditions, particularly during the pre-monsoon months. APN Global Change Research+2APN Global Change Research+2Academia+2 . MDPI

Figure 3: Drought severity across South Asia (2000–2020) based on DSI

.Academia+2APN Global Change Research+2APN Global Change Research+2

4. Flood Trends (1970–2020)

Incidence and Impact

- **Global Share**: Between 1976 and 2005, Asia accounted for 41% of global flood disasters, with South Asia contributing 33% of Asia's floods.
- **Human Toll**: During the same period, South Asia was responsible for 50% of flood-related deaths in Asia and 38% of those affected globally.

Temporal Patterns

- **Increasing Frequency**: The frequency of extreme floods has been on the rise in Bangladesh, India, and Pakistan. ResearchGate

Contributing Factors

- **Climate Change**: Warming temperatures have intensified monsoon patterns, leading to more erratic and extreme rainfall events.
- **Urbanization and Deforestation**: Rapid urban growth and deforestation have reduced natural water absorption, increasing runoff and flood risks.
- **Inadequate Infrastructure**: Many regions lack sufficient flood defenses and early warning systems, exacerbating the impact of floods.

Visualizations

1. Annual Flood Events in Asia (1970–2020)

Between 1970 and 2020, Asia has witnessed a marked increase in the frequency, intensity, and geographical spread of flood events, with South Asia emerging as one of the most affected subregions. Countries like India, Bangladesh, Pakistan, and Nepal experienced recurrent annual floods, largely due to monsoon overflow, glacial melt, and poor drainage infrastructure. According to EM-DAT and World Bank data, over 1,600 flood events were recorded in Asia during this 50-year period, with South Asia alone accounting for nearly 33% of these occurrences. The annual average of flood events rose significantly—from approximately 10 per year in the 1970s to over 40 per year by the 2010s. Notable high-impact floods occurred in 1988 (Bangladesh), 1998 (China), 2005 (India and Pakistan), and 2010 (Pakistan), each affecting millions. Rapid urbanization, encroachment on floodplains, and deforestation further worsened flood vulnerability across river basins such as the Ganga, Brahmaputra, and Indus. Additionally, the combination of climate change and irregular monsoon patterns contributed to shorter, more intense rainfall episodes, increasing flash floods and urban flooding. This trend not only caused devastating economic losses but also highlighted the urgent need for regional flood governance and climate-resilient infrastructure planning.

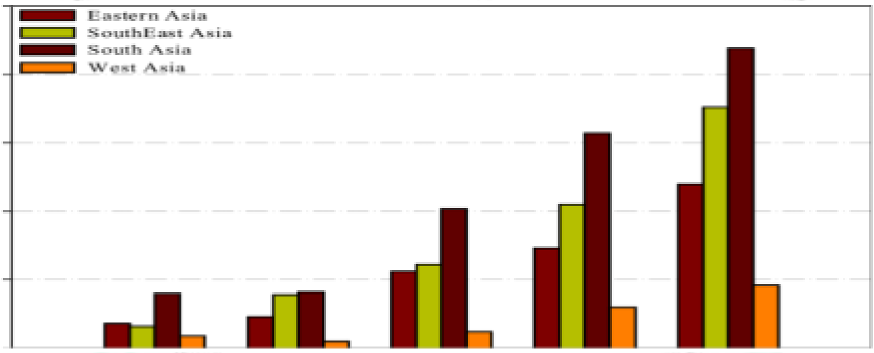

Figure 4: Flood disaster trend in Asia in the last 48 years

ResearchGate+2ResearchGate+2ResearchGate+2

Source: ResearchGate

2. Annual Damage from Floods in South Asia (1970–2016)

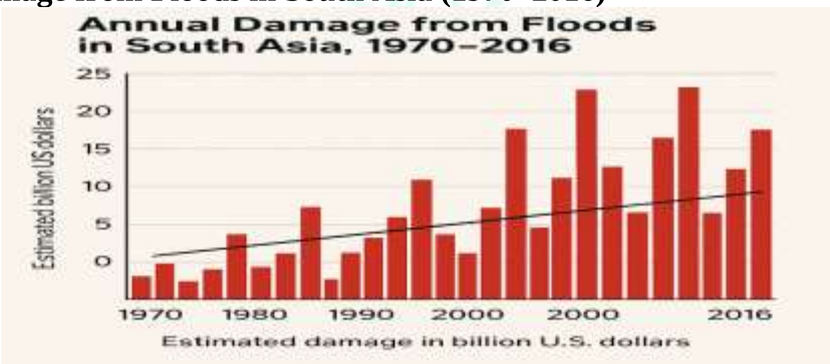

Figure 5: Annual Damage from floods in South Asia (1970-2016)

https://sdgasiapacific.net/advocacy-resources/0000027?
Source: Asia-Pacific SDG Partnership

3. South Asia Floods Factbox Infographic

Source: Graphic News

5. Cyclone Trends (1970–2020)

Historical Events

- **1970 Bhola Cyclone**: On November 12, 1970, the Bhola cyclone struck East Pakistan (now Bangladesh), resulting in an estimated 300,000 to 500,000 fatalities. This event remains the deadliest tropical cyclone on record, primarily due to a massive storm surge that inundated low-lying areas of the Ganges Delta. Wikipedia+2Wikipedia+2World Meteorological Organization+2

1970 Bhola Cyclone

The ITOS 1 weather satellite image of the cyclone making landfall in East Pakistan on 12 November

1970 Bhola Cyclone: Meteorological Summary and Impact

Parameter	Details
Formation Date	8 November 1970
Dissipation Date	13 November 1970
IMD Wind Speed (3-min)	185 km/h (115 mph)
JTWC Wind Speed (1-min)	240 km/h (150 mph)
Minimum Pressure	960 hPa (28.35 inHg)
Fatalities	300,000–500,000 (Deadliest tropical cyclone)
Estimated Damage (1970 USD)	$86.4 million
Affected Areas	East Pakistan (now Bangladesh), India

Trend Analysis

Increasing Frequency of Severe Cyclones: Studies have identified a rise in the frequency of extremely severe
cyclonic storms (ESCS) in the North Indian Ocean, particularly during May. This trend is attributed to factors such as accelerated warming of the ocean surface and weakening of the summer monsoon circulation. ResearchGate+1OUCI+1

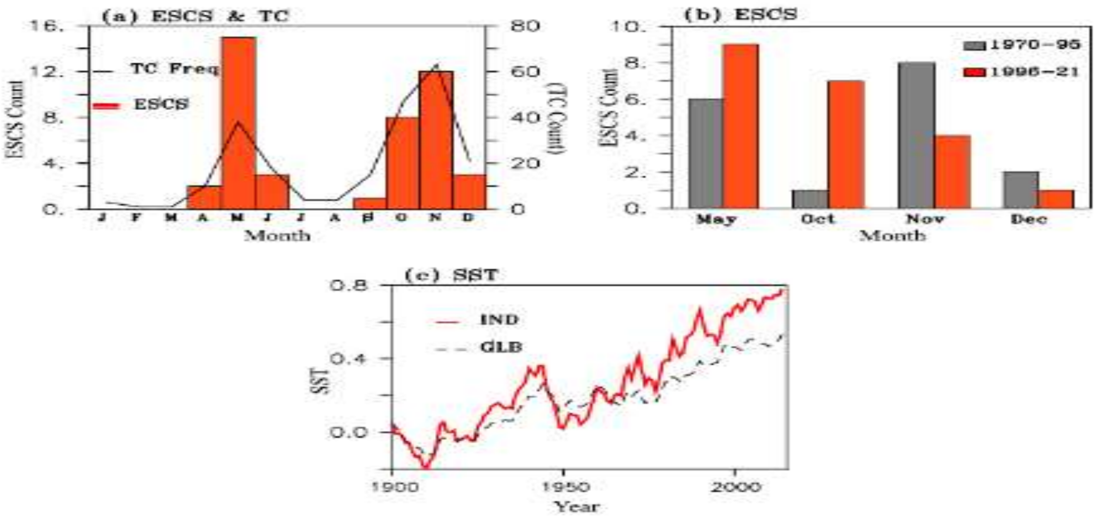

Figure 1. (a). Monthly count of Extremely Severe Cyclonic Storms (ESCS, red bars) and Tropical Cyclones (black curve) in

North Indian Ocean (NIO) since 1970 and (b) Monthly count in ESCS for 1970–1995 (gray bar) and 1996–2021 (red bar) for
May, October, November, and December in NIO. (c) Time-series of sea surface temperature (SST) anomalies (°C) for global
(black) and for NIO (50°–100°E, 0°–20°N; red) from Hadley Centre SST data. The SST anomalies are shown as difference
relative to preindustrial period (1870–1900)

Figure 6: (a). Monthly count of Extremely Severe Cyclonic Storms (ESCS, red bars) and Tropical Cyclones (black curve) in North Indian Ocean (NIO) since 1970 and (b) Monthly count in ESCS for 1970–1995 (gray bar) and 1996–2021 (red bar) for May, October, November, and December in NIO. (c) Time-series of sea surface temperature (SST) anomalies (°C) for global (black) and for NIO (50°–100°E, 0°–20°N; red) from Hadley Centre SST data. The SST anomalies are shown as difference relative to preindustrial period (1870–1900)

Rapid Intensification: The North Indian Ocean has experienced an increase in the rapid intensification of cyclones, where storms escalate to severe categories within a short time frame. This phenomenon poses significant challenges for forecasting and preparedness.

Regional Vulnerability

- **Bangladesh and Eastern India**: The coastal regions of Bangladesh and eastern India, including states like Odisha and West Bengal, are particularly susceptible to cyclones due to their geographical positioning along the Bay of Bengal. The low-lying topography and high population density exacerbate the impact of storm surges and flooding.
- **Arabian Sea Coastline**: While historically less active, the Arabian Sea has witnessed an uptick in severe cyclonic activity in recent decades, affecting western coastal areas of India such as Gujarat and Maharashtra. The Guardian

Figure 7: A petrol station flattened by Cyclone Tauktae in India's western state of Gujarat. Photograph: Amit Dave/Reuters

https://www.theguardian.com/environment/2021/may/27/rapid-heating-of-indian-ocean-worsening-cyclones-say-scientists?

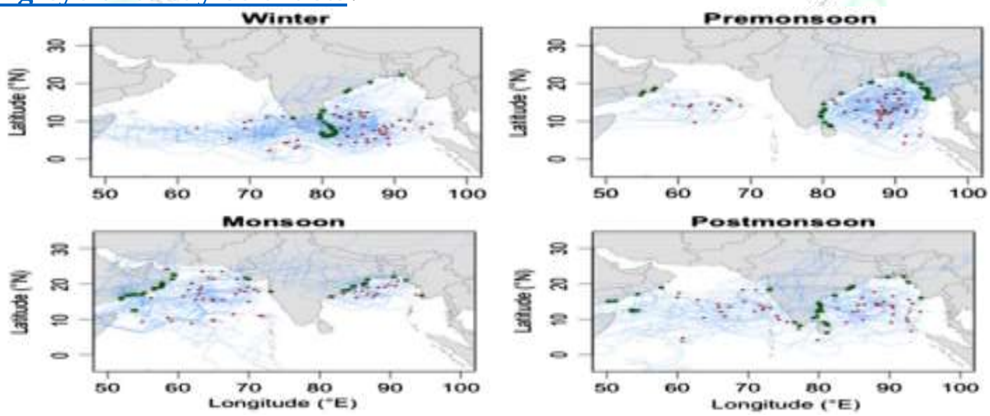

Figure 8: Simulation of tropical cyclones across the North Indian Ocean region as a function of season. A total of 50 tropical cyclone genesis points were randomly selected from the modelled kernel density and the tropical cyclone tracks were simulated using the fitted generalised additive model combined with the random innovations. Red dots show the TC genesis points, blue lines indicate the tropical cyclone tracks, and green dots indicate landfall locations

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Source: https://www.researchgate.net/figure/Simulation-of-tropical-cyclones-across-the-North-Indian-Ocean-region-as-a-function-of_fig8_311448382

Visualization

- **Cyclone Tracks and Landfall Points**: The following maps illustrate the tracks and landfall points of tropical cyclones over the North Indian Ocean:ResearchGate
  - **Cyclone Tracks (1961–2020)**: This map showcases the paths of cyclones over the North Indian Ocean during the specified period.

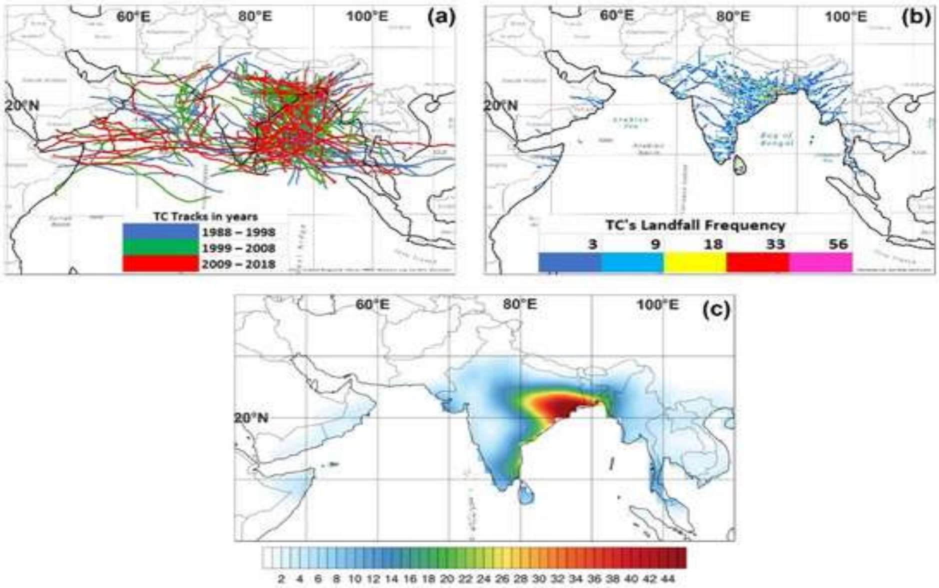

Figure 9: North Indian Ocean tropical cyclones that made landfall during 1989–2018: (a) full tracks; (b) frequency map of landfall locations with inland tracks (grid 25 × 25 km^2 resolution); and (c) track density (0.1° latitude resolution).

https://www.mdpi.com/2073-4433/13/9/1421?

  - **Landfall Frequency Map (1989–2018)**: This visualization indicates the frequency of cyclone landfalls across different coastal regions.MDPI
  - **Seasonal Cyclone Simulation**: This figure presents simulated cyclone tracks across the North Indian Ocean, highlighting seasonal variations.

6. Comparative Analysis

Aspect	Drought	Flood	Cyclone
Frequency (1970–2020)	Recurrent, especially during El Niño years (e.g., 2002, 2009, 2015)	Increasing, especially post-2000; intensified in monsoon seasons	Increasing frequency of Extremely Severe Cyclonic Storms (ESCS), particularly post-1990
Most Affected Countries	India, Pakistan, Afghanistan	India, Bangladesh, Pakistan	Bangladesh, India (Odisha, Andhra Pradesh, West Bengal), Maldives (occasionally)
Climatic Drivers	ENSO (El Niño), Monsoon failure	Monsoonal intensity, ENSO (La Niña), glacial melt	Sea surface temperature rise, Indian Ocean Dipole (IOD), ENSO
Major Historical Events	India (2002, 2015), Pakistan (2000, 2018), Afghanistan (1999–2002)	Bangladesh (1988, 2004, 2007), India (2008, 2013, 2018, 2020 Bihar & Kerala floods)	Bhola Cyclone (1970), Cyclone Sidr (2007), Fani (2019), Amphan (2020)
Geographical Hotspots	Central & Western India, Balochistan, Southern Afghanistan	Indo-Gangetic Plains, Brahmaputra Basin, Southern Sri Lanka	Bay of Bengal coastlines (East India, Bangladesh); some recent activity in the Arabian Sea

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Socioeconomic Impact	Crop failure, food insecurity, migration, rural distress	Displacement, infrastructure loss, disease outbreaks, GDP loss	Large-scale mortality, coastal infrastructure damage, saltwater intrusion, long-term rehabilitation
Ecological Impact	Land degradation, groundwater depletion	Riverbank erosion, wetland loss, ecosystem disruption	Mangrove loss, biodiversity depletion, coral reef damage
Policy & Response Challenges	Poor water management, delayed drought declaration, lack of crop insurance	Inadequate flood forecasting, poor drainage planning, urban encroachment	Lack of early warning systems (earlier), low cyclone-resilient infrastructure in rural areas
Mitigation Strategies	Rainwater harvesting, micro-irrigation, drought-resilient crops	River basin management, flood zoning, improved embankments	Cyclone shelters, evacuation planning, satellite-based early warning systems
Regional Cooperation Needed	Shared drought monitoring, climate-resilient agriculture planning	Joint river basin flood governance (e.g., Ganges, Brahmaputra, Indus)	SAARC-level cyclone alert systems, data sharing across meteorological departments

7. Policy Implications and Recommendations

Early Warning Systems: Enhance regional collaboration to develop and implement effective early warning mechanisms.

Infrastructure Development: Invest in resilient infrastructure to mitigate the impacts of floods and cyclones.

Research and Data Collection: Conduct comprehensive studies in under-researched areas like Bhutan and the Maldives to fill data gaps.

Community Engagement: Promote community-based disaster risk reduction strategies and awareness programs.

8. Conclusion

The escalating vulnerability of the SAARC region to hydro-climatic disasters—such as floods, droughts, cyclones, and glacial lake outburst floods—over the past five decades is a stark indicator of the compounded effects of climatic variability and human-induced environmental degradation. This vulnerability is not uniform but varies across geographies, socio-economic groups, and governance capacities within the region. Countries like Bangladesh, India, Nepal, and Pakistan face heightened risks due to their geographic exposure, dense populations, weak infrastructure, and inadequate disaster preparedness systems. A deep-rooted and systemic approach is now essential to break the cycle of repeated disaster impacts. Data-driven policies—informed by high-resolution climate models, GIS-based risk mapping, and historical disaster databases—must form the backbone of national and regional disaster response frameworks. This requires upgrading hydrological and meteorological monitoring systems, establishing early warning protocols, and mainstreaming disaster risk reduction (DRR) into national development plans. Equally critical is regional The transboundary nature of river basins (such as the Ganges, Brahmaputra, and Indus) and shared climatic threats (such as monsoon variability and glacial melt) demand coordinated action through institutions like SAARC Disaster Management Centre (SDMC) and collaborative frameworks like the SAARC Environment Action Plan. Regional knowledge exchange, harmonized data sharing, and joint emergency response mechanisms are key to confronting challenges that do not recognize political boundaries. Furthermore, community engagement must be prioritized, especially among the most vulnerable—women, rural populations, urban slum dwellers, and indigenous communities. Community-based adaptation strategies, decentralized planning, and investment in resilient infrastructure (e.g., flood-resistant housing, rainwater harvesting, cyclone shelters) can significantly enhance local coping capacities. In essence, the path forward for the SAARC nations must be rooted in climate justice, inclusive governance, and sustainability. Only by integrating scientific knowledge with policy reform and grassroots participation can the region hope to mitigate future hydro-climatic shocks and build a resilient, adaptive, and equitable future.

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