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From Glacial Melt to Groundwater Depletion: Climate-Induced Resource Stress in SAARC Nations

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Abstract

This paper investigates the interconnected climatic pressures facing the SAARC (South Asian Association for Regional Cooperation) nations, specifically focusing on the cascading effects of glacial melt and groundwater depletion. The study highlights how climate-induced changes in the cryosphere and hydrosphere are contributing to resource insecurity, affecting agriculture, drinking water availability, and socio-economic stability. Using interdisciplinary approaches combining remote sensing data, hydrogeological reports, and regional climate models, the research identifies key vulnerabilities and recommends coordinated policy responses across SAARC nations.

Keywords: SAARC, glacial melt, groundwater depletion, climate change, water stress, resource management, South Asia

1. Introduction

South Asia, comprising the eight member states of the South Asian Association for Regional Cooperation (SAARC)—Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka—is home to over 1.9 billion people, making it one of the most populous and environmentally diverse regions in the world. However, it is also one of the most vulnerable to climate change, particularly concerning water-related stressors such as glacial retreat and groundwater depletion [1]. The Himalayan mountain range, often called the "Third Pole," holds the largest reserves of fresh water outside the polar regions and serves as the source of major transboundary rivers such as the Indus, Ganges, and Brahmaputra. These rivers are the lifeblood of millions in downstream regions. However, accelerated glacial melting due to rising global temperatures is leading to drastic changes in hydrological cycles. Studies indicate that glaciers in the eastern Himalayas are retreating at an average rate of 0.3 to 1 meter per year, with some regions showing even faster declines [2]. This trend threatens the long-term sustainability of river systems, increasing the risk of both seasonal water scarcity and catastrophic floods triggered by glacial lake outburst floods (GLOFs) [3,4].

In parallel, groundwater resources across the Indo-Gangetic Basin, which spans multiple SAARC countries, are under increasing pressure. India, for instance, is the largest user of groundwater in the world, extracting more than 250 cubic kilometers annually, primarily for irrigation purposes [5]. The combination of unsustainable agricultural practices, population growth, and urban expansion has caused alarming drops in the water table, with aquifers in northwestern India and Pakistan reaching critical levels [6]. Research using satellite data (GRACE mission) has shown that groundwater levels are falling at a rate of over 4 cm per year in parts of the basin [7]. These dual crises—glacial melt and groundwater depletion—are symptomatic of a broader climate-induced resource stress that threatens regional stability. Water insecurity in South Asia has already begun to affect agricultural output, energy production (particularly hydropower), food security, and health outcomes [8,9]. Climate change acts as a "threat multiplier" in a region already grappling with poverty, inequality, and political tensions [10]. Moreover, the region's vulnerable socio-economic structure, with a heavy dependence on rain-fed agriculture and poor adaptive infrastructure, increases the susceptibility of communities to water stress. Women and marginalized groups, in particular, face disproportionate impacts in terms of workload, health issues, and displacement risks [11,12]. Migration, both seasonal and permanent, is emerging as a coping mechanism, further stressing urban infrastructure and social cohesion [13]. Despite the shared nature of these environmental challenges, regional cooperation among SAARC nations remains limited, often hindered by geopolitical tensions and lack of integrated resource management frameworks [14]. Institutions such as ICIMOD and SAARC Disaster Management Centre have attempted to facilitate knowledge-sharing and data cooperation, but policy implementation remains fragmented and under-resourced [15].

This paper examines how glacial retreat and groundwater depletion reflect deeper ecological and institutional vulnerabilities in the SAARC region. It highlights the need for a holistic, transboundary approach to water governance, integrating science, policy, and community participation. Without urgent, coordinated action, the region may face irreversible ecological damage, widespread displacement, and escalated geopolitical conflict in the near future [16,17].

2. Literature Review

Singh, P., & Jain, S. K. (2002) [18] conducted a seminal study on the impact of climate change on the hydrology of Himalayan basins, focusing on snow and glacier melt contributions to river flows in northern India. Using the degree-day method and hydrological modeling, they assessed glacier-fed basins such as Satluj and Beas. The authors concluded that glacier melt would initially increase river discharge but would decline significantly in the long term, leading to seasonal water scarcity. This study is grounded in systems theory, illustrating how environmental subsystems interact with broader climatic cycles to create cascading vulnerabilities [18]. Rodell, M., Velicogna, I., & Famiglietti, J. (2009) (with Indian collaborators in ISRO) [19] Using GRACE satellite data in collaboration with Indian scientists from ISRO, this study tracked groundwater depletion in the Indo-Gangetic Plain. The results revealed a steep annual decline in groundwater levels by more than 4 cm in parts of Punjab, Haryana, and Uttar Pradesh due to overextraction. The authors emphasized the absence of sustainable recharge mechanisms and poor policy regulation. Drawing on political ecology, the work highlighted how unequal power structures and irrigation subsidies encourage unsustainable practices [19].Aggarwal, R. & Singh, O. P. (2010) [20] explored agro-hydrological stress in the Ganges basin under climate change conditions. Their research used long-term rainfall, crop, and aquifer data across Uttar Pradesh and Bihar. They found that monsoonal unpredictability, compounded by excessive reliance on tubewells, was reducing agricultural resilience and increasing rural poverty. Their conclusion calls for integrated watershed development and agro-climatic zoning. The authors apply vulnerability theory, demonstrating how exposure, sensitivity, and adaptive capacity shape water insecurity in rural India [20]. Mall, R. K., Gupta, A., & Singh, R. (2006) [21] This study assessed climate variability's influence on water resources in the Indo-Gangetic plains, particularly Uttar Pradesh. The authors used climate simulation models and hydro-statistical techniques to analyze precipitation and evaporation trends. They concluded that rising temperatures, falling rainfall, and glacier retreat pose multidimensional threats to water security. They also called for immediate adaptation measures. Their findings are grounded in resilience theory, emphasizing the need for infrastructural and institutional flexibility in managing water systems under stress [21]. Sharma, A. K., & Tiwari, M. (2015) Focusing on the groundwater crisis in western Uttar Pradesh, Sharma and Tiwari carried out field-based surveys and water table mapping. They found that aggressive groundwater extraction for sugarcane cultivation, supported by free electricity and lax regulation, is leading to aquifer collapse. Their study is situated within institutional economics, arguing that faulty incentive structures and weak governance frameworks exacerbate water stress in agrarian regions [22]. Dash, S. K., & Hunt, J. C. R. (2007) [23] Dash, collaborating with Indian climatologists, examined long-term temperature trends in the Himalayan region. Their study noted a significant warming trend above 2000 meters, correlating with faster glacier melt. This phenomenon has direct implications for river regimes and water availability in northern India, Nepal, and Bhutan. The research uses climate determinism theory, linking topographic and meteorological shifts with socio-economic disruptions. Raina, V. K. (2009) [24] Commissioned by the Indian Ministry of Environment and Forests, Raina's study critically examined glacier retreat data across the Himalayas. Although controversial for questioning IPCC projections, Raina concluded that while some glaciers are retreating rapidly, others are relatively stable, suggesting spatial heterogeneity. His work uses a scientific positivist lens, calling for improved instrumentation and data verification instead of generalizing trends [24]. Gupta, A. & Deshpande, R. D. (2014) [25] studied isotopic tracing of groundwater sources in Maharashtra and Madhya Pradesh. They discovered that a large portion of water being pumped for irrigation comes from fossil aquifers, with minimal recharge. Their findings confirm that water use exceeds recharge by 150–200%, posing an intergenerational equity issue. The research applies ecological modernization theory, advocating for a shift to water-efficient technologies and sustainable practices. Jain, S. K., Kumar, V., & Saharia, M. (2012) [26] This team analyzed changing rainfall and temperature trends across northeastern India, including Meghalaya and Assam. Using IMD data, they reported declining monsoonal intensity but increasing frequency of extreme events, leading to erratic surface water flows and pressure on shallow groundwater systems. Their work emphasizes climate variability and hydrological extremes as key components of resource stress, applying hazards theory to explore risk and resilience. Bhadwal, S., & Sharma, R. (2011) [27] Affiliated with The Energy and Resources Institute (TERI), Bhadwal and Sharma assessed regional climate impacts on water governance in the Brahmaputra basin. They highlighted the fragmentation of water policy between Indian states and poor coordination with Bhutan and Bangladesh. Their research uses transboundary governance theory, arguing that climate-induced water stress cannot be mitigated without multi-level, cooperative institutional frameworks.

2. Glacial Melt and the Cryospheric Crisis

The Himalayas, spanning across Afghanistan, Pakistan, India, Nepal, Bhutan, and extending influence over Bangladesh and China, are often called the "Third Pole" due to their immense glaciated terrain—containing the largest reserve of freshwater outside the Arctic and Antarctic regions [28]. These glaciers are the primary source of major South Asian rivers, including the Ganga, Brahmaputra, and Indus, which together support the livelihoods of more than 700 million people. However, mounting scientific evidence shows that glaciers in the Himalayas are melting at an accelerating pace, largely due to anthropogenic climate change. Recent studies using satellite remote sensing data from NASA (Landsat) and ISRO's Cartosat and RISAT missions confirm that since the 1980s, Himalayan glaciers have lost more than 25% of their ice mass, with glacial retreat rates doubling since the early 2000s [29]. The short-term impact of this rapid melting is a surge in river runoff, leading to frequent and intensified flash floods. However, in the long term, it presents a severe threat of water scarcity, particularly during the dry seasons when glacial meltwater traditionally sustains river flow [30].

Case Study: Nepal and Bhutan – The Rising Threat of GLOFs

In the high-altitude Himalayan regions of Nepal and Bhutan, the accelerated pace of glacial melt due to climate change has led to the proliferation of glacial lakes, many of which are inherently unstable. These lakes often form behind moraines—unconsolidated ridges of rock and debris left behind by retreating glaciers—which are geologically weak and prone to collapse. As a result, these lakes are vulnerable to Glacial Lake Outburst Floods (GLOFs), sudden breaches that release massive volumes of water and debris downstream, with catastrophic effects. According to long-term monitoring by the International Centre for Integrated Mountain Development (ICIMOD), the frequency and intensity of GLOFs in Nepal and Bhutan have significantly increased over the past three decades [31]. Rising temperatures, along with more frequent extreme weather events, are contributing to the expansion and destabilization of glacial lakes, making these disasters more likely and more damaging. A prominent example is Imja Tsho, a glacial lake located at an altitude of 5,010 meters in the Khumbu region of eastern Nepal, near Mount Everest. Formed in the 1960s, the lake has expanded rapidly, increasing by more than 70% in surface area since its formation. It now holds over 17 million cubic meters of water, and is considered one of the most dangerous glacial lakes in Nepal. A breach in Imja Tsho's moraine could cause a GLOF that threatens lives, villages, trekking infrastructure, and the fragile ecology of the Sagarmatha National Park, a UNESCO World Heritage Site [32]. Several mitigation measures, including controlled drainage through an engineered outlet and installation of early warning systems, have been initiated, but the risk remains high, particularly in the face of unpredictable seismic or climatic triggers. In Bhutan, the situation is equally alarming. The government has conducted national glacial lake inventories that have identified Thorthormi and Lugge Tsho as two of the most potentially hazardous lakes. Lugge Tsho was responsible for a destructive GLOF in 1994, which killed 21 people and damaged critical infrastructure in the Punakha Valley. Today, Thorthormi Lake is growing rapidly and lies dangerously close to other unstable lakes, with risk of coalescence and compounded flooding. Bhutan has since implemented GLOF risk-reduction projects in collaboration with international agencies such as the UNDP, JICA, and ICIMOD, including lowering lake levels manually and training local communities for emergency response [33]. The human and ecological costs of these floods are severe. Downstream communities face displacement, loss of agricultural land, damage to roads and bridges, disruption to hydropower plants, and destruction of sacred cultural sites. Furthermore, these impacts often fall hardest on remote and economically marginalized populations, compounding their existing vulnerabilities. The biodiversity of these alpine ecosystems, already under stress from warming, faces further threat from sudden landscape transformations caused by floods and debris flow. From a theoretical perspective, this case aligns with the climate risk framework and environmental justice theory. It reveals how climate change disproportionately affects those with the least capacity to adapt, and underscores the need for equitable adaptation financing and regional cooperation. Furthermore, the transboundary nature of glacial lakes and rivers underscores the urgency of a regional, cooperative approach to glacier monitoring, early warning systems, and disaster preparedness—something that remains limited due to political and logistical barriers.

Impact on Downstream Nations – India and Bangladesh

The cryospheric crisis in the Himalayas has cascading consequences for downstream nations, particularly India and Bangladesh, where the livelihoods of millions are intricately tied to the stability of glacier-fed river systems. The Ganga, Brahmaputra, and Indus rivers—originating from rapidly melting glaciers—sustain agriculture, energy production, and drinking water supplies for vast stretches of South Asia. However, climate-induced glacial retreat and associated hydrological instability are disrupting these critical lifelines, exposing both countries to heightened ecological, economic, and geopolitical vulnerability.

In India, the northern state of Uttarakhand has become emblematic of the increased frequency of glacier-induced disasters. The Chamoli tragedy of February 2021, triggered by a glacier fragment collapse or rock-ice avalanche in the Ronti valley, released massive volumes of debris and water into the Rishiganga and Dhauliganga rivers. This resulted in flash floods that destroyed infrastructure, killed over 200 people, and severely damaged the Tapovan Vishnugad hydropower project [34]. Such events, which were once rare, are becoming more common due to a combination of rapid ice melting, formation of glacial lakes, and loosening of permafrost. The increasing reliance on hydropower in glacial regions adds further risk, as energy infrastructure lies directly in the path of such natural hazards. Simultaneously, Bangladesh, a densely populated deltaic nation downstream of the Ganga-Brahmaputra-Meghna basin, is experiencing the dual burden of seasonal excess and scarcity. During the monsoon months, accelerated glacier melt combines with heavy rainfall to increase the volume and velocity of river inflows, resulting in frequent and prolonged flooding. In 2020, more than 25% of Bangladesh was submerged, affecting over 5 million people, partly due to unusually high river discharges linked to Himalayan runoff [35]. Conversely, in the dry season, the reduction in glacial meltwater and upstream water diversions result in low river flows, exacerbating water scarcity for irrigation, fisheries, and domestic use, particularly in regions like Rajshahi, Khulna, and Barisal.

3. Groundwater Depletion: A Hidden Crisis

Groundwater is the lifeblood of agriculture and rural livelihoods in the SAARC region, serving as the primary source of irrigation, drinking water, and industrial use. Across South

Asia, more than 60% of irrigation demands are met through groundwater abstraction, making it a critical but increasingly threatened resource [37]. The region's heavy reliance on this hidden resource is driven by the monsoonal variability, unreliable surface water supply, and the need for year-round water availability in high-yield cropping systems.

According to the World Bank, India extracts more groundwater annually than China and the United States combined, making it the world's largest groundwater user [38]. This phenomenon, termed the "groundwater revolution", once helped India achieve food security during the Green Revolution, but has since devolved into a resource crisis. The rapid expansion of tube wells, lack of regulation, free electricity in agriculture, and water-intensive crops such as sugarcane, paddy, and wheat have led to widespread overextraction, particularly in the Indo-Gangetic plains and semi-arid zones of western India, Pakistan, and Afghanistan [39]. Compounding the issue is poor natural recharge, exacerbated by urbanization, deforestation, and soil sealing. Climate variability, including erratic monsoons and increasing temperatures, further hampers aquifer replenishment. Studies using satellite data from NASA's GRACE mission have detected severe declines in groundwater storage across northern India and eastern Pakistan, with an estimated loss of 109 cubic kilometers of groundwater between 2002 and 2016 [40].

Case Study: North India and Punjab – Alarming Declines in Water Table

The crisis is most visible in the northwestern states of India such as Punjab, Haryana, and western Uttar Pradesh, where the water table has fallen by more than 10 meters in just two decades [41]. Punjab, once hailed as the "granary of India," now faces an unsustainable aquifer crisis. High-yielding paddy cultivation during the Kharif season consumes 2,000 to 5,000 liters of water per kilogram of rice, heavily reliant on tube wells. With over 1.2 million tube wells in operation and nearly free electricity subsidies, groundwater is being pumped faster than it can be replenished [42]. This unchecked extraction is creating long-term risks including land subsidence, drying up of shallow wells, and increased inter-state water disputes. Furthermore, the burden of water access increasingly falls on small and marginal farmers, many of whom lack deep-bore well access, driving social and economic inequalities. This scenario also exemplifies tragedy of the commons theory, where individual overuse depletes shared resources, ultimately undermining collective welfare [43].

Case Study: Bangladesh and Arsenic Contamination – A Dual Crisis

In Bangladesh, the groundwater crisis is complicated by the presence of naturally occurring arsenic, a carcinogenic element found in sediment layers of the Ganga-Brahmaputra delta. The large-scale installation of hand-pumped tube wells since the 1980s for drinking water—meant to reduce waterborne diseases from surface water—unintentionally exposed millions to arsenic poisoning [44]. The over-extraction of groundwater has worsened the situation by altering hydrochemical balances, causing arsenic to mobilize more readily into water columns. As per national health surveys, more than 20 million people are still exposed to arsenic levels above WHO safety standards, resulting in chronic health effects including skin lesions, cancer, cardiovascular disease, and developmental issues in children [45]. This crisis reflects a failure of integrated groundwater management and a disconnect between public health policy and hydrogeology.

The critical theory lens reveals how vulnerable populations, often from poor, rural, and marginalized communities, disproportionately bear the health and economic burdens of groundwater degradation. Despite international funding and pilot projects for arsenic filters and safe water access, inequities persist, worsened by lack of public awareness, weak governance, and low institutional accountability.

Toward a Sustainable Groundwater Future

To address this hidden crisis, regional experts call for a multi-level governance framework involving:

- Water accounting and monitoring using satellite and local data
- Crop diversification and promotion of less water-intensive alternatives

- Price reform and regulation of agricultural power subsidies
- Community-based groundwater recharge projects (e.g., check dams, recharge wells, percolation tanks)

Additionally, trans boundary cooperation is essential, particularly in aquifer systems shared across India, Pakistan, Bangladesh, and Nepal, where upstream pumping may affect downstream recharge. Yet, groundwater remains invisible in most water treaties, requiring a shift toward hydro-diplomacy that includes subterranean flows.

4. Climate Change as a Multiplier of Water Stress

Climate change is not merely an environmental issue—it is a force multiplier that intensifies existing water-related vulnerabilities across the SAARC region. As confirmed by the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), South Asia is experiencing increasing hydroclimatic volatility due to anthropogenic warming. Rising temperatures are shifting the timing, intensity, and reliability of water availability, thereby affecting glacial melt, monsoon patterns, groundwater recharge, and surface flows [46].

One of the key mechanisms of this stress amplification is the increased frequency and intensity of hydrological extremes—namely floods, droughts, and heatwaves. As temperatures rise, snow accumulation in the Himalayas decreases, reducing seasonal buffering for river systems that rely on slow-melting snowpacks. Instead, glaciers melt rapidly, creating sudden surges in river flow followed by longer periods of reduced discharge. Simultaneously, evapotranspiration increases in lowland regions, reducing soil moisture, affecting crop yields, and amplifying water demand in agriculture [47]. The Southwest monsoon, which contributes 70–80% of the region's annual rainfall, is becoming erratic and spatially uneven. Some regions experience intense downpours and flash flooding, while others suffer prolonged dry spells—a phenomenon linked to jet stream weakening, El Niño events, and land-sea thermal contrasts. This unpredictability poses major challenges to rain-fed farming, reservoir management, and aquifer recharge, which rely on stable seasonal rainfall [48].

Sea-Level Rise in Maldives and Sri Lanka – Coastal Aquifer Salinization In island nations like the Maldives and coastal zones of Sri Lanka, rising sea levels caused by global warming are leading to saltwater intrusion into freshwater aquifers—a critical but often overlooked dimension of climate-induced water stress. The Maldives, with an average elevation of only 1.5 meters above sea level, is extremely vulnerable. Its freshwater lens aquifers, which float on seawater in porous coral islands, are now being compromised by saline water intrusion, rendering wells undrinkable and farmland infertile [49]. In Sri Lanka, low-lying areas in Jaffna, Batticaloa, and Puttalam are facing similar threats. Studies show that salinity levels in groundwater have increased, particularly after the 2004 Indian Ocean tsunami and recent climate-related storm surges. The saline encroachment has degraded paddy fields, reduced crop productivity, and increased dependency on bottled or piped water in poor rural communities. These challenges align with vulnerability theory, which emphasizes how environmental stress disproportionately affects those with low coping capacity and poor adaptive infrastructure [50].

Interconnected Systems – Cascading Effects on Surface Flow, Agriculture, and Ecosystems

Climate change has interconnected impacts on the entire hydrological cycle. As glaciers retreat, snowfall declines, and groundwater is over-extracted, the overall availability of surface water diminishes, especially in dry seasons. This results in lower river base flows, drying wetlands, and reduced recharge of natural springs. These effects are further intensified by higher evapotranspiration, where increased atmospheric heat leads to more rapid loss of water from soil and vegetation. Moreover, climate change is shifting agroecological zones. For instance, warming trends in northern India and Nepal are prompting vertical shifts in cropping patterns, where traditional crops like wheat or rice are becoming less viable due to reduced soil moisture and increased temperature stress. In response, farmers are either shifting to more climate-resilient crops (millets, pulses) or abandoning agriculture altogether—leading to agrarian distress, food insecurity, and rural-to-urban migration [51]. In southern Pakistan and Afghanistan, drought-prone regions are witnessing the collapse of traditional irrigation systems like karez and canal-fed agriculture, causing desertification and livelihood loss. These phenomena illustrate the "syndrome of coupled water stress," where multiple sources of water—glacial, rainfall, surface, and groundwater—are simultaneously degraded, leaving no fallback option. This cascading crisis illustrates the theory of planetary boundaries and complex adaptive systems, where climate shocks push interconnected systems—hydrological, agricultural, ecological—towards tipping points, beyond which non-linear, irreversible damage can occur. In the SAARC region, the overlapping of glacial retreat, groundwater depletion, sea-level rise, and erratic rainfall represents a multi-scalar threat that demands integrated climate adaptation.

5. Socio-Economic and Political Implications

Water insecurity in the SAARC region is no longer a distant ecological threat—it is an unfolding socio-economic and political crisis. Climate-induced resource stress, manifesting in the form of glacial melt, groundwater depletion, irregular monsoons, and salinization, has far-reaching implications for livelihoods, public health, food production, interstate cooperation, and regional stability. As water availability declines and its distribution becomes increasingly erratic, the region is witnessing a surge in agrarian distress, forced migration, trans boundary conflict, and political unrest.

Food and Livelihood Security – The Collapse of Agrarian Stability Agriculture in South Asia remains overwhelmingly dependent on natural water sources, with over 70% of employment in some SAARC nations linked directly or indirectly to farming. Climate variability and water scarcity are now disrupting cropping patterns, reducing yields, and increasing the risk of crop failure, especially for rice, wheat, and sugarcane—the dominant staples [52]. In India, groundwater-dependent states such as Punjab, Haryana, and Uttar Pradesh are facing the twin crisis of water table collapse and stagnant productivity, forcing small and marginal farmers into debt cycles and despair [53]. This pressure has contributed to mass mobilizations such as the 2020–21 Indian farmers' protests, in which millions of farmers protested against agricultural reforms, demanding legal safeguards for minimum support prices (MSP) and access to affordable water and electricity. While the protests were framed around market deregulation, they were also implicitly driven by declining environmental viability of farming, where water insecurity undermines traditional livelihoods [54]. In Bangladesh, erratic monsoons and groundwater salinity are pushing communities to abandon traditional paddy cultivation. Migration from drought-prone zones like Khulna, Satkhira, and Rajshahi to urban slums in Dhaka is rising, contributing to unregulated urbanization, poverty, and socio-environmental conflict. These developments confirm the predictions of the Environmental Scarcity and Conflict Theory, which links resource degradation to displacement and instability, particularly where adaptive capacity is weak.

Health and Sanitation – The Hidden Public Health Emergency Water stress also has a profound impact on public health and sanitation infrastructure. Inadequate or polluted water supply leads to outbreaks of waterborne diseases, especially diarrhea, cholera, dysentery, and skin infections, which disproportionately affect children and elderly populations in rural and peri-urban areas. According to UNICEF, more than 40 million people in India rely on contaminated groundwater, often with elevated levels of arsenic or fluoride [55]. In Pakistan, prolonged droughts in Balochistan, Sindh, and southern Punjab have led to widespread water shortages, causing residents to rely on unsafe water sources, often shared with livestock. Reports from Tharparkar district show that infant mortality due to diarrheal diseases has increased during dry spells due to lack of access to safe drinking water and adequate sanitation [56]. Moreover, as temperatures rise, the burden of vector-borne diseases such as malaria and dengue is also shifting geographically, expanding into new ecological zones where water stagnation from floods or unplanned irrigation creates breeding grounds for mosquitoes. These complex outcomes underscore the synergistic interaction between water stress and health crises, requiring integrated climate-health policy frameworks.

Geopolitical Tensions – Rivers as Flashpoints At the political level, transboundary water tensions are rising. The Indus Waters Treaty (IWT) between India and Pakistan, brokered by the World Bank in 1960, has long been regarded as a successful example of river-sharing. However, increased glacier melt and shifting hydrology have intensified competition over control, timing, and volume of water flows. Indian hydropower projects on the Chenab and Jhelum rivers, such as the Baglihar and Kishanganga dams, have triggered diplomatic protests from Pakistan, which views them as violations of treaty provisions [57]. Similarly, between India and Bangladesh, the Teesta River remains a contentious issue, particularly as dry-season flows decline due to upstream diversion and lower glacial contribution. Bangladesh has repeatedly demanded equitable sharing, but domestic political dynamics in India—especially state-level opposition from West Bengal—have stalled negotiations, highlighting the complexity of internal-external policy alignments [58]. These disputes are worsened by a lack of trust, transparency, and institutionalized data-sharing mechanisms. Climate change has made historical flow patterns unreliable, yet water-sharing agreements remain rigid, failing to incorporate flexible, adaptive clauses that reflect current realities. The emerging risk is that rivers may become tools of political leverage, threatening regional peace.

6. Regional Policy and Adaptation Strategies

While the SAARC region faces a shared threat in the form of climate-induced water stress, the response has been largely fragmented and inconsistent, hampered by geopolitical tensions, institutional inertia, and a lack of long-term strategic planning. The SAARC Environment Action Plan (1997) and the SAARC Framework on Climate Change (2008) were early regional attempts to build a coordinated climate response, but these initiatives have suffered from limited political will, resource constraints, and bilateral mistrust, particularly between India and Pakistan. Despite these shortcomings, regional resilience is still achievable through targeted, cooperative adaptation strategies that recognize the transboundary nature of water systems, the shared vulnerability of member states, and the urgency for climate action. Below are key recommendations:

1. Joint Hydro-Meteorological Monitoring Networks

One of the most significant gaps in regional adaptation is the absence of a harmonized water data system. Accurate and real-time data on glacier melt, river flow, precipitation, groundwater levels, and evapotranspiration is critical for climate modelling, early warning, and water allocation decisions. Currently, much of this data remains nationally siloed, or treated as a strategic asset, particularly in sensitive border regions. Establishing a SAARC-wide hydro-meteorological monitoring network, under the leadership of institutions like ICIMOD, can foster collaborative science diplomacy. This system should include:

- Shared satellite imagery, hydrological stations, and radar networks
- Joint training programs for climate scientists and disaster response teams
- A centralized, open-access data portal for regional hydrology

Such infrastructure will enhance trust-building and enable predictive modelling for droughts, floods, and GLOFs—saving lives and strengthening regional cohesion.

2. Sustainable Groundwater Management Policies

Groundwater depletion, particularly in India, Pakistan, Bangladesh, and Afghanistan, requires urgent and coordinated management. A regional groundwater framework under SAARC could promote:

- Aquifer mapping and recharge zone protection
- Water-use efficiency through incentives and cropping pattern reforms
- Cross-border regulation of shared aquifers
- Community-based water stewardship models

Policy frameworks must shift from supply augmentation to demand-side management, integrating behavioral change, local water budgeting, and digital water accounting tools. India's Atal Bhujal Yojana and Pakistan's Punjab Irrigated Agriculture Productivity Improvement Project (PIPIP) can serve as replicable models within a SAARC-wide policy context.

3. Climate-Resilient Agricultural Practices

Agriculture, being both water-intensive and climate-sensitive, is central to regional adaptation. Transitioning to climate-resilient agriculture can reduce water dependency and enhance food security. Key strategies include:

- Promoting drought-resistant crops (e.g., millets, legumes)
- Scaling micro-irrigation (drip, sprinkler) and laser land-leveling
- Providing weather-indexed crop insurance
- Integrating agroforestry and soil moisture conservation techniques

These interventions require knowledge exchange platforms, regional seed-sharing agreements, and SAARC-led innovation hubs for agro-climate technologies.

4. Conflict Resolution Frameworks for Transboundary Water Governance

The lack of institutionalized dispute resolution mechanisms within SAARC leaves water-sharing agreements vulnerable to political disruption. Existing treaties like the Indus Waters Treaty and the Ganges Water Sharing Treaty are bilateral and rigid, with little room for adaptation to changing hydrology due to climate change [62].

SAARC needs to develop a regional water diplomacy framework with:

- Flexible allocation clauses that account for climate variability
- Mediation and arbitration mechanisms to resolve disputes
- Multi-stakeholder dialogues involving civil society, farmers, and experts
- Periodic treaty reviews based on scientific input

Such an approach would build on the Integrated Water Resources Management (IWRM) paradigm, promoting equity, efficiency, and ecological sustainability across borders.

7. Conclusion

Climate-induced water stress is reshaping the hydro-geography of South Asia, stretching from the Himalayan glaciers to the coastal aquifers of the Maldives and Sri Lanka. The combined threats of glacial retreat, groundwater depletion, erratic monsoons, rising sea levels, and increased evapotranspiration are creating a systemic and multi-dimensional water crisis across the SAARC region. This crisis deeply affects agriculture, public health, migration, regional cooperation, and national security, underscoring the intricate interdependence between climate systems and human societies. Evidence such as the increasing frequency of Glacial Lake Outburst Floods (GLOFs) in Nepal and Bhutan, groundwater depletion in India's Punjab region, arsenic contamination in Bangladesh, and saline intrusion in the Maldives highlights how climate change is acting as a threat multiplier, exacerbating vulnerabilities and exposing governance gaps. The transboundary nature of rivers and aquifers further complicates unilateral solutions, making coordinated regional action essential. Although SAARC has introduced frameworks like the Environment Action Plan and Climate Change Framework, their effectiveness is limited by political tensions and fragmented implementation. To avert a deeper crisis, SAARC must adopt Integrated Water Resource Management (IWRM) strategies that are climate-adaptive, inclusive, and ecologically sustainable. These must prioritize shared hydrological data systems, sustainable groundwater use, resilient agriculture, and mechanisms to resolve transboundary water disputes. Without such reforms, the region faces a future of ecological instability and social unrest; yet, this crisis also offers an opportunity to transform water from a point of contention into a catalyst for regional cooperation and peace.

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