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EDITED BY
Matthew Collins,
University of Exeter, United Kingdom

REVIEWED BY
Goran Trbic,
University of Banjaluka,
Bosnia and Herzegovina

*CORRESPONDENCE
Aditi Modi
✉ aditi.modi@tropmet.res.in

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Bridging climate science, policy, and communities: collaborative pathways for climate resilience in the Indo-Pacific

Aditi Modi[1]*, Mathew Koll Roxy[1], Shipra Jain[2], Chi Huyen Truong[3], Quang-Van Doan[4], Christopher Jack[5], Svetlana Jevrejeva[6], Arvind Singh[7], Chirag Dhara[8] and Sahana Ghosh[9]

[1]Centre for Climate Change Research, Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune, India, [2]Department of Risk and Disaster Reduction, University College London, London, United Kingdom, [3]Himalayan University Consortium, ICIMOD, Kathmandu, Nepal, [4]Centre for Computational Sciences, University of Tsukuba, Tsukuba, Japan, [5]Climate System Analysis Group, University of Cape Town, Cape Town, South Africa, [6]National Oceanography Centre, Southampton, United Kingdom, [7]Physical Research Laboratory, Ahmedabad, India, [8]Krea University, Sri City, India, [9]Nature India, New Delhi, India

The Indo-Pacific region, a critical economic and geopolitical hub, faces intensifying climate risks, including accelerating sea-level rise, extreme weather events—particularly heatwaves amplified by rapid urbanization—and glacial retreat in the Hindu Kush Himalayas. While advancements in climate science have significantly improved future climate projections, gaps remain in translating this knowledge into actionable adaptation strategies. Barriers such as data inaccessibility, weak institutional and international coordination, and financial constraints hinder effective climate action. This study synthesizes existing climate knowledge for the Indo-Pacific region, emphasizing the need for localized, community-driven adaptation approaches. Key challenges include the vulnerability and exposure of coastal communities to sea-level rise, the limitations of current urban-scale climate modeling, and the underrepresentation of sociocultural factors in climate adaptation strategies. The integration of Artificial Intelligence (AI) and machine learning (ML) in climate models presents an opportunity to enhance urban climate resilience, while the incorporation of indigenous knowledge rooted in scientific principles offers a critical pathway to improving localized adaptation efforts. Additionally, science communication plays a pivotal role in ensuring that climate research reaches policymakers and communities in an accessible and actionable manner. We advocate for a paradigm shift from a linear value chain to a value cycle approach, where scientific insights inform policy and local contexts inform research priorities. By bridging climate science, policy, and communities through regional platforms such as the Indo-Pacific My Climate Risk Hub at the Indian Institute of Tropical Meteorology (IITM) Pune, India, this paper outlines pathways for collaborative climate action. This work proposes actionable strategies for regional resilience.

KEYWORDS

Indo-Pacific, climate change, urbanization, sea-level rise, Hindu Kush Himalayas, science communication, my climate risk

1 Introduction: understanding climate change in the Indo-Pacific

The Indo-Pacific region (Figure 1), with nearly two-thirds of the global population, serves as a major driver of the global economy. It is also one of the most culturally diverse regions on the planet. Spanning one-fifth of the Earth's ocean area, the Indo-Pacific supports a range of ocean-based economies that are expanding rapidly (Wenhai et al., 2019). Activities such as fisheries, aquaculture, and mangrove forestry are sustained by favorable climatic conditions (Anneboina and Kavi Kumar, 2017; Hagger et al., 2022). The region plays a critical role in global trade, hosting key maritime routes such as the Strait of Malacca and several of the world's busiest ports that facilitate commerce between Asia, Europe, and Africa. Over the past half-century, shifting economic and geopolitical landscapes have heightened the Indo-Pacific's prominence, with climate change now at the forefront of its growing challenges. Despite its economic significance, the region is highly vulnerable to challenges due to a warming climate. Globally, sea surface temperatures have been rising since the 1950s, with the tropical Indian Ocean and western Pacific warming at a rate exceeding the global average (Fox-Kemper et al., 2021). The Indo-Pacific warm pool, the largest region of permanently warm sea surface temperatures (SSTs >28°C), has been expanding in recent decades, altering global rainfall patterns (Koll et al., 2019). Changes in large-scale synoptic patterns over the tropical Indo-Pacific are leading to increased warm conditions and rainfall in Southeast Asia, while the equatorial Pacific experiences drier conditions (Dong et al., 2024). Coastal hazards, including flooding, erosion, and salinity intrusion, are intensifying due to rising sea levels, glacial melt, land subsidence, and increasing storm surges, posing significant threats to coastal communities.

Between 1901 and 2018, global mean sea level rose by 15–25 cm, with the rate of increase accelerating since the late 1960s (Fox-Kemper et al., 2021). The rise averaged 2.3 cm per decade from 1971 to 2018 but surged to 3.7 cm per decade between 2006 and 2018, with the western Pacific experiencing some of the most severe impacts (Fox-Kemper et al., 2021; IPCC, 2019). The western Pacific saw the fastest sea level changes from 1993 to 2018, primarily driven by wind stress anomalies associated with El Niño–Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (Han et al., 2017), in addition to global sea level rise due to anthropogenic greenhouse gas emissions (Slangen et al., 2016). Sea level rise over the western Pacific is largely driven by thermosteric changes, as rapid ocean warming causes the volume of ocean water to expand (Cheng et al., 2018). In the Indian Ocean, sea-level variations have been intensified by ENSO and Indian Ocean Dipole (IOD) modes (Han et al., 2017; Nidheesh et al., 2013). Rising sea levels pose increasing risks to coastal cities, where social and economic vulnerabilities further compound the threat. The impacts are particularly evident in parts of the Pacific, South Asia, and Africa, where climate-driven sea-level rise is contributing to inland migration (Connell, 2012; Gray and Wise, 2016; Szabo et al., 2016).

Additionally, non-climatic factors such as population growth, urbanization, and anthropogenic subsidence interact with climatic drivers, exacerbating local sea-level changes. Coastal megacities like Bangkok, Ho Chi Minh City, Jakarta, and Manila face heightened risks due to subsidence from groundwater extraction, infrastructure development, and resource depletion (Nicholls, 2011; Oppenheimer et al., 2019). In Ho Chi Minh City, land subsidence has further

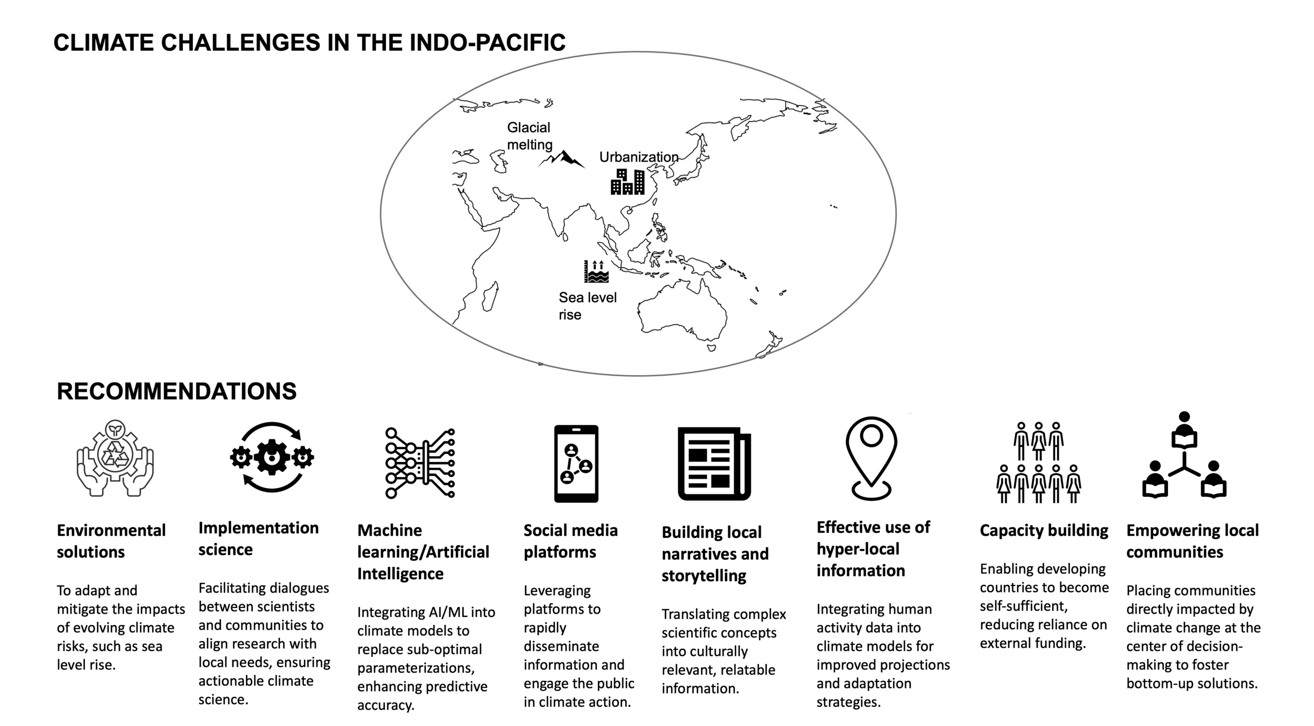

FIGURE 1
Schematic representing the climate challenges in the Indo-Pacific region, namely, the sea-level rise, urbanization and glacial melting in the Hindu-Kush Himalayas. Several recommendations are proposed for tackling these climate challenges (Icons courtesy: vecteezy.com and Becris-Flaticon).

intensified local sea-level rise and flood risks (Cheng et al., 2018; Nicholls, 2011; Vachaud et al., 2019; Yin et al., 2013). Similarly, the Ganges-Brahmaputra-Meghna Delta, including Kolkata and Dhaka, experiences land subsidence at rates of 6–9 cm per decade (Brown and Nicholls, 2015). Beyond urban areas, sea-level rise and climate-driven ocean changes threaten coastal and nearshore ecosystems such as mangroves, salt marshes, vegetated dunes, sandy beaches, coral reefs, and marine biodiversity, with severe implications for food security and livelihoods. The Indo-Pacific region currently holds over 70% of the global coastal population living below 10 meters of elevation (Glasser et al., 2022). In maritime Southeast Asia, especially Indonesia, sea levels are rising four times faster than the global average, endangering millions. Climate projections indicate that sea levels could rise by 0.5 to 1.1 meters by 2,100, depending on future emissions pathways, however, the possibility of a 2-m sea level rise, though unlikely, cannot be excluded due to large uncertainties in projections of ice mass loss from ice sheets (Fox-Kemper et al., 2021). By 2050, extreme sea level events that historically occurred once in 100 years may become annual occurrences, significantly reducing recovery time for coastal communities and increasing their vulnerability (Glasser et al., 2022; Vousdoukas et al., 2018). For tropical areas in Indian and Pacific regions these projected changes in the frequency of extreme sea levels are expected by 2030–2040 (Jevrejeva et al., 2023).

At the same time, urbanization in the Indo-Pacific region is accelerating rapidly. Currently, Over half of the global population currently lives in urban areas, and this proportion is expected to grow to 68% by 2050 (Maharjan et al., 2018). The majority of future urban population growth will occur in developing and least-developed countries in Asia and Africa (Güneralp et al., 2020; Kuang, 2019; Shukla et al., 2019; United Nations Environment Programme, 2019). Within the Indo-Pacific, Eastern Asia, Southeast Asia, and the Pacific region have experienced the most extensive conversion of agricultural land to urban areas between 1970 and 2010 (Güneralp et al., 2020). Notably, India has seen an 85% increase in urban land conversion, despite a significant portion of its population still relying on agriculture (Wang et al., 2010). This urban growth brings complex challenges, including infrastructure gaps, energy demands, pollution, social inequality, and increased vulnerability to climate impacts. Indo-Pacific cities face increasing risks from climate change, such as more frequent heat waves, extreme weather events like typhoons and floods, and rising sea levels (Rosenzweig et al., 2018; United Nations Environment Programme, 2019). Additionally, extensive industrialization and urbanization pose climate risks related to the modification of local precipitation patterns (Doan et al., 2022; Doan Dipankar et al., 2021; Wang et al., 2021), urban thermal environment (Doan Kusaka and Nguyen, 2019; Georgescu et al., 2014; Xue et al., 2024), cloud and fog formation (Gu et al., 2019), and air pollution dispersion (Nguyen et al., 2022, 2023).

Urban areas generate over 70% of greenhouse gas emissions, making cities critical intervention points for achieving sustainable development goals and addressing climate change (UN.ESCAP, 2019). This is especially significant as the region now accounts for over half of global greenhouse gas emissions, which have doubled since 1990 due to urbanization, increasing demand for electricity, and growth in the manufacturing and transport sectors. During the past six decades, temperatures in the Indo-Pacific region increased faster than the global average, intensifying the urban heat island effect (Doan and Kusaka, 2016; Pierer and Creutzig, 2019) and drastically escalating the demand for cooling solutions (Khan et al., 2021; Shukla et al., 2019). While urban centers grapple with these escalating pressures, rural and remote regions of the Indo-Pacific face equally severe climate challenges. Cities are critically dependent on natural resources and ecosystems beyond their boundaries. Urban water supplies often rely on distant catchments, making them vulnerable to hydrological droughts. Additionally, cities are intricately tied to regional, national, and global food systems, exposing them to climate-driven food production shocks that impact food prices. Climate extremes such as tropical cyclones and heat waves further threaten food processing, transport, and safety (Lwasa et al., 2022). Especially in countries like India, inadequate and poorly targeted long-term heat action plans are likely to result in more frequent heat waves with higher mortality, as short-term emergency responses and community adaptive capacities are increasingly overwhelmed by rising temperatures (Pillai et al., 2025).

The Indo-Pacific region is intrinsically linked to the Hindu Kush Himalaya, often referred to as the "Water Tower of Asia." This vast mountainous region, spanning 4.2 million km^2, is warming at a rate faster than the global average, accelerating glacial decline (Krishnan et al., 2019). As a critical geo-ecological asset, it sustains 1.9 billion people who depend on its 10 major river systems for water, food, and energy (Bajracharya and Shrestha, 2011; Wester et al., 2019). The region's biodiversity, indigenous knowledge systems, and freshwater reserves not only shape local ecosystems but also influence broader climate and hydrological patterns across the Indo-Pacific (Singh et al., 2011). Elevation-dependent warming intensifies climate impacts, heightening risks to biodiversity, water security, and food production. Increasing rainfall variability is driving more frequent extreme weather events, including landslides and floods, with cascading consequences for ecosystems and livelihoods (ICIMOD, 2023). These changes reverberate throughout the Indo-Pacific, where many communities remain directly or indirectly dependent on the stability of Himalayan water sources.

At the same time, rapid urbanization in the Hindu Kush Himalaya is reshaping its landscape. Small towns, many with populations under 100,000, are expanding rapidly and are projected to evolve into major urban centers within a decade (ICIMOD, 2023). This transformation is driving significant land use changes, encroaching on groundwater recharge zones and threatening critical water sources, particularly springs (Shah and Badiger, 2018; Sharma, 2014; UNDESA, 2014). The Indo-Pacific's dependence on the Hindu Kush Himalaya is evident at multiple scales, from water availability and agricultural stability to broader ecological resilience. As climate change amplifies vulnerabilities across the region, disruptions in the Himalayas will have far-reaching consequences, shaping the future of both mountain and coastal communities (Bajracharya and Shrestha, 2011; Penjor et al., 2021; Wangchuk et al., 2021).

Scientific advancements over the past two to three decades have significantly improved our understanding of climate change in the Indo-Pacific. It is now well established that many of the observed changes in weather and climate are driven by observed shifts in land, ocean, and cryosphere dynamics in response to anthropogenic greenhouse gas emissions (IPCC et al., 2018; IPCC et al., 2023; IPCC, 2019; IPCC et al., 2007; IPCC et al., 2014). The Indian Ocean, in particular, has benefited from an expansion of observational networks (Beal et al., 2020), coupled with substantial efforts to model future climate scenarios, including projections for global temperature changes, extreme weather events, and changing sea levels. The Intergovernmental Panel on Climate Change (IPCC) states with "very high confidence" that the Indo-Pacific region will continue to face heightened climate risks with continued warming. Despite global and regional climate action plans aligned with UNFCCC Conference of the Parties (COP) commitments, current efforts remain inadequate, widening the gap between adaptation needs and accelerating climate risks (United Nations Environment Programme, 2023). Key barriers include informational gaps—such as low awareness, interpretable and accessible climate information, and inadequate monitoring and evaluation tools—alongside institutional challenges, including poor policy integration and weak coordination of adaptation priorities. Additionally, financial constraints, limited understanding of financing mechanisms, and insufficient public funds hinder effective climate action. Although climate change presents an immediate and escalating threat, the absence of robust adaptation and implementation strategies, particularly at local decision-making levels, exacerbates regional vulnerabilities (IPCC, 2022, Rodrigues and Shepherd, 2022).

Addressing these challenges requires a robust bottom-up approach that empowers local communities to collaborate with scientists, policymakers, stakeholders, artists, and social media influencers to drive meaningful climate action (Coen, 2021). The World Climate Research Programme (WCRP) My Climate Risk initiative actively applies this approach, focusing on regional climate risk to help communities interpret and respond to their specific vulnerabilities (Montoya et al., 2024; Shepherd and Truong, 2023; Wells et al., 2023). Recognizing the Indo-Pacific as one of the most climate-vulnerable regions, WCRP My Climate Risk has established an Indo-Pacific Regional Hub, hosted at the Indian Institute of Tropical Meteorology, Pune, India. This hub serves as a platform to integrate climate science, policy, and community engagement, fostering collaborative pathways for climate resilience. While the IPCC provides broad assessments of climate challenges across Asia and the Pacific, literature specific to Indo-Pacific climate science and societal challenges remains fragmented. This article, developed under WCRP's My Climate Risk, aims to bridge this gap by synthesizing scientific knowledge on climate change in the Indo-Pacific, with a focus on accelerating sea-level rise, rapid urbanization, and glacial melting in the Hindu Kush Himalaya. It assesses current and projected climate changes, evaluates the challenges and opportunities for leveraging climate research and modeling for societal benefit, and highlights key uncertainties and research gaps. This article is intended to serve as a resource for researchers and stakeholders, providing a comprehensive overview of the challenges and opportunities in implementing climate science into actionable strategies across the Indo-Pacific. Our goal is to stimulate dialog within the scientific community, fostering discussions on key challenges and potential solutions for translating climate research and modeling into impactful climate action in the region (Figure 1).

Our analysis highlights significant gaps in localized climate projections, governance, and integration of indigenous knowledge rooted in scientific principles, which hinder effective adaptation. Addressing these requires a transdisciplinary, community-driven approach that bridges scientific advancements with real-world applications. Additionally, our findings underscore the need for improved representation of sub-grid scale urban processes in climate models, the incorporation of human-induced changes in risk assessments, and enhanced science communication strategies to reach diverse communities. Strengthening regional research networks, leveraging AI/ML for climate modeling, and fostering capacity-building efforts in developing nations are crucial steps toward meaningful climate adaptation. We advocate for a shift from a value chain to a value cycle approach (Göber et al., 2023) to enhance resilience in this dynamic region (Figure 2). This approach is already embraced by several communities, e.g., weather forecasting and disaster reduction, and is also strongly advocated by the United Nations' Office of Disaster Risk Reduction (UNDRR). The rest of the article is organized as follows: In Section 2, we frame a few key questions centered around our discussion with topic experts to identify and address critical knowledge gaps. Section 3 summarizes key points discussed in the article and outlines the way forward, while also highlighting certain limitations.

2 Key knowledge gaps in climate science and implementation in the Indo-Pacific region

2.1 Key challenges and potential solutions for safeguarding coastal communities from sea-level rise driven by climate change

Sea level rise exerts significant stress on highly populated coastal societies and low-lying island nations worldwide. Throughout the 20th century, coastal settlement patterns have shifted due to multiple factors, including population growth, urbanization, tourism development, and the displacement or (re)settlement of some indigenous communities (Bennett et al., 2016; Moser and Ekstrom, 2010; Serrao-Neumann et al., 2015). Approximately 57% of built infrastructure in Pacific Island nations is located in risk-prone coastal areas (Kumar and Taylor, 2015), making them highly vulnerable to sea level rise and associated hazards such as flooding, erosion, and saltwater intrusion. In addition to climate-driven sea level rise, non-climatic factors such as land subsidence, groundwater extraction, and infrastructure expansion exacerbate local sea-level changes, as discussed in detail in section 1. Beyond urban centers, coastal and nearshore ecosystems, including mangroves, salt marshes, vegetated dunes, sandy beaches, coral reefs, and seagrasses, are also under threat from rising sea levels and climate-induced ocean changes. These ecosystems provide critical ecosystem services, such as coastal protection, carbon sequestration, and habitat for marine biodiversity. Their degradation further exacerbates risks to food security and livelihoods, particularly for communities dependent on fisheries and coastal resources.

Existing approaches to increasing coastal resilience against flooding, erosion, and saltwater intrusion include hard engineering measures and ecosystem-based adaptation (also known as Nature-based Solutions). Hard engineering measures include dikes, breakwaters, seawalls, concrete barriers, and barrages (Giosan et al., 2014; Spencer et al., 2016). While effective in the short term, such measures are costly, require continuous maintenance, and may cause unintended environmental consequences (e.g., increased erosion in adjacent areas). Ecosystem-based adaptation include solutions such as mangrove restoration, coral and oyster reef conservation, and the preservation of beaches, dunes, and salt marshes are gaining

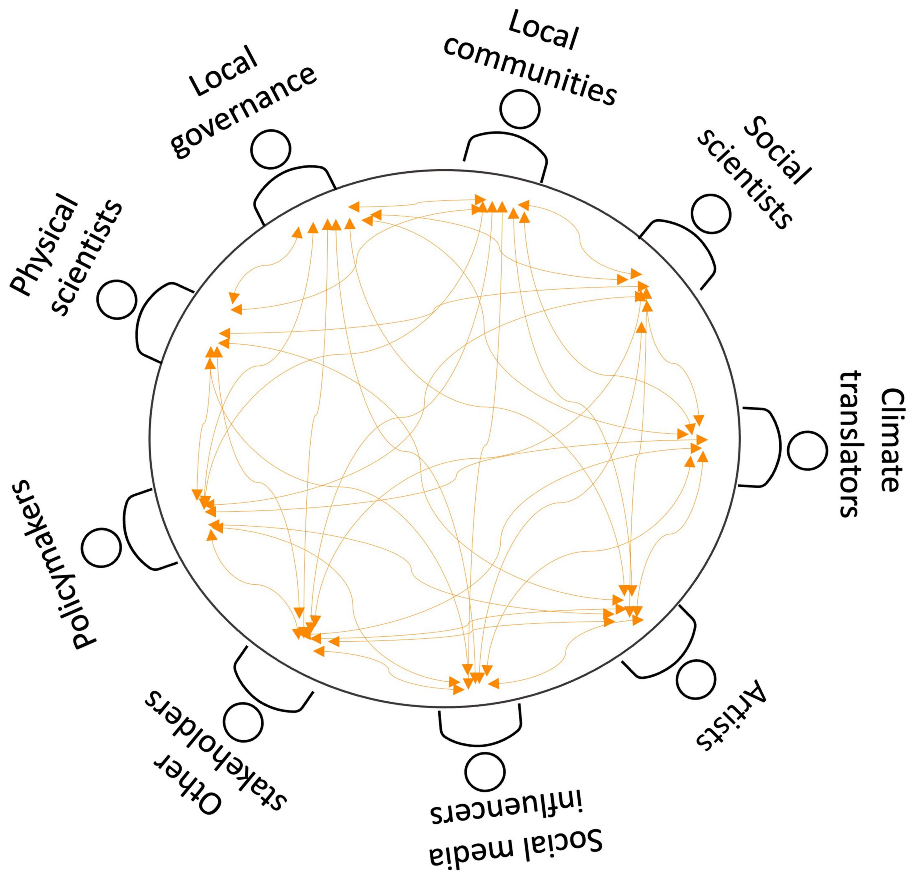

FIGURE 2
Schematic illustrating discussions among physical and social scientists, policymakers and other stakeholders, local communities, and communicators to develop localized, actionable solutions for climate change. Orange arrows indicate possible discussion pathways.

traction due to their multiple co-benefits (Krauss and Rippy, 2022; Rupprecht et al., 2021; Verburg et al., 2006). These approaches enhance biodiversity, provide natural storm barriers, and support local fisheries. However, uncertainties remain regarding their cost-effectiveness and long-term adaptability across different regions. Further observations and modeling experiments are required to assess the feasibility of large-scale implementation of these nature-based solutions.

The long planning and implementation timescales (e.g., decades) for these adaptation strategies pose a significant challenge. Decision-makers must constantly adjust strategies to align with new climate projections from IPCC assessments and emerging research. A key issue is determining critical infrastructure parameters, such as the required height of seawalls, in response to evolving sea-level estimates. Additionally, the increasing frequency of extreme sea level events—which are projected to become annual occurrences by 2050 in many coastal areas—reduces the recovery time for affected communities, further intensifying vulnerability (Glasser et al., 2022; Vousdoukas et al., 2018). For low-lying nations like Tuvalu, Kiribati, the Maldives, and Indonesia, these changes pose a severe and escalating threat (Glasser et al., 2022). Thus, safeguarding coastal communities will require a multi-pronged approach, integrating engineering solutions, ecosystem-based strategies, improved land-use planning, and governance mechanisms to address both climatic and non-climatic drivers of risk. These strategies and their broader implications have been extensively discussed in IPCC reports (Oppenheimer et al., 2019).

2.2 Current approaches and persistent challenges in urban-scale climate modeling, and the evolving role of artificial intelligence and machine learning (AI/ML)

It is only recently since early 2000s, that the global climate modeling groups are implementing urban parameterization within the land surface scheme into the global circulations models (Best et al., 2006; McCarthy et al., 2010). These parameterization schemes account for energy and water exchanges between urban surfaces and the atmosphere, improving the representation of urban-atmosphere interactions (Grimmond et al., 2011; Hamdi et al., 2020; Kusaka et al., 2001). The increasing availability of open data systems, big data, and high-performance computing presents new opportunities for analyzing urban systems (Frantzeskaki et al., 2019). There is a growing effort to integrate AI/ML into physical models to replace suboptimal parameterizations, particularly for improving the representation of sub-grid-scale processes such as urban effects, which are often neglected in current global models. Land-use and land-cover modeling offers an alternative for predicting future urban trends and expansion (Gaur and Singh, 2023; Verburg et al., 2006). While remote sensing has proven valuable for large-scale land-cover monitoring, rapid land-cover changes remain difficult to quantify due to significant uncertainties (Lepers et al., 2005).

As modeling scales shift from regional (100–200 km) to city (10–20 km) and eventually to street level (<100 m), the demand for high-performance computing increases, making city-scale climate modeling impractical for large nations like India. In contrast, smaller countries like Singapore are experimenting with meter-scale urban weather models, though challenges in representing sub-grid urban processes persist (Lim et al., 2017). In the meantime, approaches such as land-surface-physics-based downscaling offer a computationally feasible alternative (Xue et al., 2024). Additionally, urban informatics and AI/ML offer promising avenues for refining urban representations in climate models, addressing persistent challenges in sub-grid-scale processes.

2.3 Challenges and opportunities in integrating climate science with diverse sociocultural contexts in the Hindu-Kush region for effective climate adaptation

The Hindu Kush mountain ranges lie at the crossroads of South Asia, East Asia, and Central Asia, leading to the emergence of distinct cultural and politico-economic groups (Wester et al., 2019). Climate change in the region not only disrupts the environment but also amplifies existing social and economic challenges. Vulnerable Indigenous communities face a range of challenges, including political and economic exclusion, displacement from their land and resources, human rights violations, discrimination, and high unemployment rates (Chavez-Rodriguez, 2014). There is growing recognition that mountain regions require tailored policies due to their unique characteristics (Singh et al., 2011). The diverse topography of the region leads to microclimatic conditions over short distances, demanding high-resolution hydrometeorological data to address the challenges faced by regional climate models. The absence of observational monitoring stations and sufficient long-term historical data, caused by the region's extreme weather conditions and complex terrain, makes it difficult to validate climate models or predict future climatic trends. Moreover, global and regional climate models remain predominantly grounded in physical sciences, often overlooking sociocultural dimensions that contribute to system resilience and vulnerability—such as local knowledge of mangrove species in coastal zones or native tree varieties in the Hindu Kush—thereby compounding uncertainties in climate projections.

The integration of cultural aspects into climate policy and planning is increasingly acknowledged as vital for developing resilient and sustainable cities, as emphasized in international agreements such as the SDGs (Naheed and Shooshtarian, 2022; United Nations, 2023). Local communities hold invaluable knowledge, accumulated through generations of observing and interacting with their environment. This knowledge enables them to identify local climate impacts and adaptive strategies, serving as a critical, documented baseline for understanding climate variability and informing the scientific community (Chaudhary and Bawa, 2011; Deshar et al., 2021). Interviews with farmers from mountain communities highlight their observations of local weather changes and adaptive approaches to water-related stressors. As such, there is an increasing need for innovative strategies to build capacity within these communities, preserving traditional knowledge while integrating modern mitigation and adaptation techniques. This approach, which blends local innovations with scientific advances, offers a holistic framework for addressing the challenges posed by climate change in the Hindu Kush region.

However, the key challenge lies in aligning research design with local community needs to ensure climate science is actionable. This is also known as implementation science one size fits all solutions do not work in the complex context featured by intricate interdependence. Not until local knowledge is integrated into the scientific understanding and local practice is incorporated into solutions, success in mitigation and adaptation remain slim. Initiatives like "Cryosphere and Society" Thematic Working Group and High Mountain of Asia Cross Cutting Workgroup (HiRISK, n.d.) led by the Himalayan University Consortium, aim to flip this narrative by fostering regular dialogs between scientists, policymakers and communities, thus offering a promising way forward, and demonstrating how science can be made more relevant and impactful (ICIMOD, n.d.).

2.4 Potential and limitations of social media for scientific communication in the Indo-Pacific, and strategies to navigate cultural and linguistic diversity

Social media platforms provide significant advantages for scientific communication, allowing researchers to reach wider audiences, disseminate findings in real time, collaborate, advocate for science, and engage in direct discussions beyond the scope of scientific journals (Lynn and Peeva, 2021; Van Eperen and Marincola, 2011). These platforms facilitate the rapid dissemination of information and promote public involvement. Recognizing this, the scientific community is increasingly prioritizing effective science communication (Harold et al., 2016, 2019). The Intergovernmental Panel on Climate Change (IPCC), widely regarded as the "gold standard of climate science," has long worked to improve its outreach to policymakers, stakeholders, and the general public, ensuring accurate and reliable climate information (Corner et al., 2018; Gomis and Pidcock, 2018; Lynn, 2018; Lynn and Peeva, 2021). However, the process of simplifying complex scientific information for these platforms can obscure uncertainties and assumptions inherent in the research, especially when targeting a non-specialist audience. Therefore, it is crucial for the public to approach science-related news and media headlines with a critical mindset, recognizing that simplified portrayals may not fully capture the complexities of the scientific findings. In response, efforts to strengthen public education on misinformation and miscommunication can enhance the quality of climate science communication. Moreover, scientific content must be tailored for diverse audiences, including scientists, policymakers, stakeholders, and the general public.

A robust institutional communication strategy extends beyond merely disseminating information—it requires understanding audience dynamics across different platforms, using visuals effectively (especially to present numerical data), and fostering interactive, two-way engagement rather than one-way messaging (Peters et al., 2024). A broad analysis of activity on *X* shows that many Indian institutions engaged in climate research primarily share event updates, awards, and recent publications. However, effective science communication should go beyond merely presenting facts; it should aim to build long-term trust in science and scientists as a public good. This shift necessitates two-way communication. Dedicated communication teams with expertise in public engagement are essential for transforming social media into interactive spaces for climate discussions. These teams play a crucial role during disasters, where an overflow of information—or lack thereof—can fuel misinformation. Active dialog can also help counter climate anxiety and feelings of helplessness that might delay climate action. Scientists and institutions, in collaboration with science communicators and journalists, must develop strategies to communicate the scientific consensus on climate change effectively. This is especially critical in combating climate denialism. Additionally, further research is needed to assess whether science agencies should actively engage in public debates on contentious science issues, define the legal and ethical boundaries of such participation, and evaluate the risks of remaining silent.

Cultural differences significantly influence how people engage with scientific information. Epistemological orientations—how individuals perceive and interact with nature—vary across societies (Dehghani et al., 2013; Medin and Bang, 2014; Medin and Bang, 2013). Consequently, the effectiveness of science communication is highly dependent on recipient characteristics and cultural contexts (Nisbet and Scheufele, 2009). In the Indo-Pacific, where linguistic and cultural diversity is vast, science communication must be adapted to local contexts (Hall et al., 2022). When scientific messages align with lay epistemologies, public engagement with climate issues increases (Medin and Bang, 2014). Recognizing translation as a crucial element of climate communication allows scientists to refine their messaging and explore innovative ways to convey scientific discoveries (Pi and Zhong, 2025). Bridging communication gaps across diverse cultures requires multi-tiered engagement. With at least three-quarters of the global population not speaking English—the primary language of climate science dissemination—multilingual communication is essential (Crystal, 2000). Initiatives like Climate Cardinals have addressed this challenge by translating climate information into multiple languages (Climate Cardinals, n.d.). The HUC-supported HiRISK initiative coordinates between scientists and the local community to produce rapid risk assessment reports in local languages such as Urdu and Pashto and thus make scientific data and information readily available for policymakers and communities for knowledge-based decisions and action.

Beyond translation, integrating storytelling into science communication—particularly through local narratives—can make complex scientific concepts more accessible and culturally relevant. While labor-intensive, this approach holds great promise. Co-creating future-oriented narratives within local contexts can significantly enhance public understanding of scientific reasoning. Achieving this requires climate translators—individuals who operate at the intersection of science and society. Establishing and incentivizing the role of "climate translators" could accelerate climate resilience efforts at the local level. Robust and tested strategies exist to create translators. The use of cultural perspectives in children's books, leverages the reciprocal relationship between worldviews and cultural artifacts to encourage engagement with scientific ideas (Jr et al., 2012; Kozma et al., 2000). Dedicated summer and winter schools, as well as residencies hosted by science agencies, institutes (government and private), and philanthropies, can convene educators, artists, musicians, scientists, social scientists, and journalists to foster regional collaborations. These initiatives can co-create bilingual or multilingual science content, integrating indigenous wisdom rooted in scientific principles alongside modern scientific insights (Systems Transformation Hub, 2024; Whittaker et al., 2024). Such spaces can also drive the development of interactive communication apps and AI tools with multilingual capabilities. Regional, cross-border examples include bootcamps centered on the Himalayas[1] and the Bay of Bengal,[2] which could be expanded. Scientists can also establish dedicated spaces within scientific conferences—such as *Town Halls*—to engage journalists, educators, and other key actors in deliberating pressing issues. Within the collaborative learning of Understanding Risk Climate Field Lab 2024, visual artists, game designers, and climate data scientists collaborated to co-generate innovative data visualization, serious board games, and other communication media (UR Field Lab, 2024). However, strategic communication demands intent and sustained funding. Without consistent support, these efforts risk stagnation, limiting their potential impact.

2.5 Persistent barriers to effective local-scale implementation of climate science in developing nations, despite significant advancements in climate modeling and policy frameworks

Local governance remains a major barrier to effective climate adaptation in developing countries. Despite their crucial role as actor in responding to climate change impacts, local governments are often disconnected from policy implementation, limiting their impact (Boydell, 2010; Measham et al., 2011). Climate-affected communities must be central to decision-making, enabling a bottom-up approach where scientific inquiries align with local risk perceptions and indigenous adaptation strategies. Recognizing and integrating indigenous and local wisdom grounded in scientific principles is essential for participatory adaptation efforts (Deshar et al., 2021; Hurlbert et al., 2019). However, power imbalances between knowledge holders must be addressed. Effective adaptation requires including indigenous and local communities in environmental conservation, formal education, land management planning, and tenure rights security (Cools et al., 2016). Formal education enhances the adaptive capacity of these knowledge systems, particularly as environmental change accelerates and intergenerational knowledge transfer declines (Ifejika Speranza et al., 2010).

A major challenge in adaptation efforts is the need for highly localized climate models to assess risks and guide decision-making (French, 2015). Strengthening communication between weather forecasters, stakeholders, and end users ensures hyper-local climate information is effectively utilized (Cools et al., 2016). Additionally, climate models alone cannot capture all climate impacts—human

1 https://himalayanbootcamp.com/

2 https://www.prameyafoundation.org/baybridges

activities like reservoir construction and groundwater extraction exacerbate climate-driven effects such as land subsidence and sea level rise (Oppenheimer et al., 2019). Therefore, accounting for these factors in regional climate projections and adaptation measures is essential for providing holistic solutions that incorporate climate, human society, and the economy. This also opens a need for climate experts who are not only trained in interpreting scientific results from models but also aware of local and regional challenges and processes that are not included in the models and can provide insights when designing local and regional adaptation efforts. A further challenge is the timeframe of climate projections. While IPCC assessments focus on 50–100-year horizons, stakeholders often require seasonal to decadal-scale projections suitable for impact assessment and decision-making in coastal areas—an area needing greater scientific focus (Jevrejeva et al., 2024).

In some regions, migration serves as a climate adaptation strategy. In Pacific small island developing states, communities have relocated to customary areas, as seen in Vunidogoloa, Fiji (Charan et al., 2017; Mcmichael and Powell, 2021). In the Carteret Islands of Papua New Guinea, migration is used for livelihood diversification (Connell, 2012). Meanwhile, Kiribati has adopted a “migration with dignity” approach, leveraging voluntary migration to enhance education and international networks (Heslin et al., 2019; Voigt-Graf and Kagan, 2017). Competing demands for resources, finances, and infrastructure highlight the need for cross-boundary collaboration and capacity-building support from developed nations. However, international cooperation must be strategic, focusing on strengthening local research institutions to promote self-reliance. Establishing strong networks for early-career researchers and fostering academia-industry partnerships are essential for advancing long-term climate adaptation efforts.

3 Summary and way forward

The Indo-Pacific region faces escalating climate risks, including sea-level rise, extreme weather, glacial retreat, and rapid urbanization. While advancements in climate science have improved understanding of these challenges, significant barriers persist in translating knowledge into effective policies and adaptation strategies. Institutional constraints, financial limitations, and interpretable and accessible climate information issues hinder climate solutions, necessitating a more integrated and interdisciplinary approach. The Indo-Pacific My Climate Risk Hub at IITM serves as a critical platform to bridge these divides, promoting collaborative efforts to enhance climate resilience across urban and coastal regions, as well as the Hindu Kush Himalaya.

One of the most urgent concerns is the impact of sea-level rise on coastal communities, particularly in low-lying island nations. Rising sea levels exacerbate coastal hazards, threatening infrastructure, livelihoods, and ecosystems. Adaptation efforts must balance engineered solutions such as seawalls and breakwaters with nature-based approaches like mangrove restoration and coral reef conservation. While hard infrastructure provides immediate protection, it is costly and can disrupt natural coastal dynamics and, in worst case scenarios, result in maladaptation (Magnan et al., 2016). Ecosystem-based solutions offer long-term resilience and ecological benefits but require further validation regarding their effectiveness at scale. Ensuring these strategies remain responsive to evolving climate projections is crucial, particularly as extreme sea-level events become more frequent (Krishnan et al., 2025; Sreeraj et al., 2022; Unnikrishnan and Antony, 2022). Governance mechanisms, improved land-use planning, and dynamic risk assessments will play a central role in shaping successful adaptation frameworks. Moreover, human-induced changes need to be integrated in the climate risks assessment models. Urban-scale climate modeling has advanced significantly, yet numerous challenges remain in capturing fine-scale processes necessary for precise climate projections. High-resolution urban modeling faces substantial computational, data, and methodological constraints, particularly for the inherent complexity of urban environments, characterized by heterogeneous land cover, diverse building geometries, anthropogenic heat emissions, and intricate interactions between the built environment and atmospheric dynamics (Emanuel, 2020; Hamdi et al., 2020; Langendijk et al., 2024). While countries like Singapore have pioneered meter-scale urban modelling (Doan Dipankar et al., 2021), uncertainties in representing very high-resolution urban morphology and energy consumption patterns persist. Also, running physics-based models at meter-scale resolution requires vast computing power and storage, making it infeasible for regions with limited computational resources. Additionally, the scarcity of high-quality observational data for model validation further complicates efforts to improve accuracy. The integration of AI and machine learning (Rampal et al., 2024) has emerged as a potential solution to refine urban climate projections, yet this approach comes with its own challenges. AI models require large datasets for training, which are not always available at the necessary spatial and temporal resolutions. Moreover, AI-driven methods often function as “black boxes,” making it difficult to interpret physical processes and ensure model transparency. Recent development of hybrid modeling approaches that combine physical process-based models with AI-driven insights presents a potential pathway to bridge existing gaps and improve urban climate predictions.

Climate adaptation in the Hindu Kush Himalaya is particularly complex due to deeply interconnected environmental and social vulnerabilities. The region’s diverse cultural and economic landscape influences how communities perceive and respond to climate risks. While hydrometeorological models have improved understanding of climate impacts, they often fail to incorporate indigenous knowledge systems, leading to gaps in actionable solutions. Integrating traditional knowledge with scientific advancements is crucial for addressing climate challenges effectively. However, aligning research priorities with local community needs remains a challenge. Initiatives such as “Cryosphere and Society,” HiRISK and UR Climate Field Lab collaborative learning highlight the importance of fostering two-way communication between scientists and local stakeholders to enhance adaptation strategies (ICIMOD, 2025). Science communication also plays a critical role in climate adaptation. Social media has emerged as a powerful tool for disseminating climate science, yet its effectiveness varies across different linguistic and cultural contexts. While it facilitates rapid public engagement, the oversimplification of complex climate information can lead to misinterpretation and misinformation. A more effective approach involves multi-tiered communication strategies tailored to specific audiences, utilizing visual storytelling and fostering interactive discussions rather than one-way messaging. Strengthening science communication through digital platforms, localized knowledge dissemination, and professional climate translators such as the *Climate Cardinals* will be essential in making climate science more accessible and actionable. Greater capacity-building support from developed nations can help developing countries become more self-sufficient and less dependent on external funding. The concepts of interconnectedness, mutual dependence, and shared responsibility for the planet should be embedded in school and university curriculums (Bogert et al., 2022).

Local governance remains a key bottleneck in translating climate science into policy, particularly in South Asian and African developing nations. A bottom-up approach that integrates indigenous wisdom rooted in scientific principles with scientific insights is essential for community-driven adaptation. However, power dynamics and resource disparities often hinder inclusive decision-making. While climate models provide long-term projections, policymakers require near-term predictions for planning. Strengthening local research networks, fostering international collaboration, and prioritizing hyper-localized climate assessments can enhance adaptation efforts. Ultimately, climate action must be a collective, iterative process involving scientists, policymakers, stakeholders, local communities, and science communicators (Figure 1). Moving from a linear value chain to a cyclical model—where science informs action and action refines science—can accelerate meaningful adaptation. Adopting a value cycle process will help scientists and the communities to better understand the needs and challenges of each other (Figure 2). And since we know that the timeframes to solve the climate challenges is critical, this process will help us construct the right questions and design research projects based on these challenges. As climate risks intensify, encouraging localized expertise and empowering regional actors will be critical in bridging the gap between knowledge and policy implementation.

Furthermore, while some climate risks, such as sea-level rise and extreme weather events, have received significant attention, others—such as ocean acidification and deoxygenation—remain underexplored despite their far-reaching consequences (Roxy et al., 2024). Ocean acidification and deoxygenation are two critical consequences of climate change that are disrupting marine life and the services they provide. One main challenge is the complexity of accurately predicting the effects of acidification and deoxygenation on marine biodiversity, as their impacts vary across different regions, ecosystems, and species. While laboratory studies and short-term field observations offer valuable insights, they often fail to capture the long-term dynamics or the combined effects of multiple stressors (such as warming, pollution, and habitat loss). Furthermore, much of the research is geographically uneven, with certain regions, particularly in the tropics, underrepresented in the scientific literature. The spatiotemporal variability of ocean conditions makes it difficult to draw generalized conclusions that can be applied globally, further complicating the formulation of effective policies.

From a policy and community perspective, these limitations make it all the more urgent to conduct more in-depth and widespread research on ocean acidification and deoxygenation. Policy frameworks often struggle to keep pace with the rapidly evolving scientific understanding of oceanic changes, leading to gaps in regulation and preparedness. Without a clearer grasp of the ecological, economic, and social impacts of these processes, decision-makers are left with limited tools to mitigate potential risks or adapt to emerging challenges. Communities that depend on marine resources are particularly vulnerable to changes in ocean chemistry. Collective efforts must be directed toward these overlooked issues to ensure comprehensive climate resilience strategies (IPCC, 2019; IUCN, 2019; Turley et al., 2014).

As these discussions evolve, there are glimmers of hope. Strengthening local expertise, capacity-building, and implementing actionable solutions tailored to regional contexts—while keeping in mind the broader global picture—can drive meaningful climate action.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary material.

Author contributions

AM: Conceptualization, Visualization, Writing – original draft. MR: Conceptualization, Writing – review & editing. ShJ: Resources, Writing – review & editing. CT: Resources, Writing – review & editing. Q-VD: Resources, Writing – review & editing. CJ: Resources, Writing – review & editing. SvJ: Resources, Writing – review & editing. AS: Resources, Writing – review & editing. CD: Resources, Writing – review & editing. SG: Resources, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2025.1538123/full#supplementary-material

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