Vivekananda
International
Foundation

A COMPENDIUM OF

CLIMATE CHANGE

ADAPTATION IN INDIA FROM THE PAST TO THE PRESENT

PK KHUP HANGZO | HEENA SAMANT

Published in 2023 by
Vivekananda International Foundation
3, San Martin Marg | Chanakyapuri | New Delhi - 110021
Tel: 011-24121764 | Fax: 011-66173415

E-mail: info@vifindia.org

Website: www.vifindia.org

Follow us on

Twitter | @vifindia
Facebook | /vifindia

ISBN: 978-93-91498-17-7

PK Khup Hangzo is an Associate Fellow at the Vivekananda International Foundation with a focus on internal security. Mr. Hangzo has a master's degree in Strategic Studies from the S. Rajaratnam School of International Studies (RSIS), Nanyang Technological University (NTU), Singapore. He acquired this degree in 2010 through the Research Analyst Study Award, a fully funded scholarship offered by NTU. Mr. Hangzo has also previous work experience as a Research Analyst and an Associate Research Fellow at the Centre for Non-Traditional Security (NTS) Studies at RSIS, NTU, Singapore from 2008-2014. His research interests includes transnational crime (human trafficking, drug trafficking, wildlife trafficking, and arms trafficking), ethnic conflicts and insurgencies, and the geopolitics of transboundary rivers.

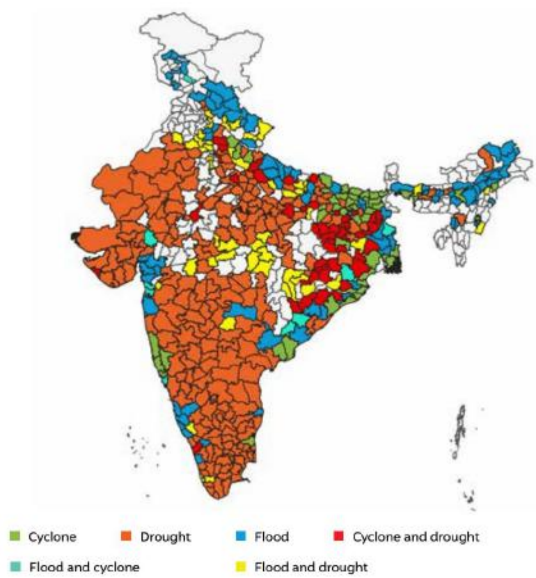
Heena Samant is a Research Associate at the Vivekananda International Foundation with a focus on internal security. Completed M.Phil in Southeast Asian and Southwest Pacific Studies from Centre for Indo-Pacific Studies, School of International Studies, Jawaharlal Nehru University. My M.Phil thesis titled "Lower Mekong River mainstream dams and its various implications 2000-2015" focussed on the dams being constructed on the Lower Mekong River and how that would impact the people inhabiting the region environmentally, economically, and socially. it also focussed on how the construction of these dams are a threat to the Lower Mekong Region's peace and security. Completed Masters in Politics with specialization in International Relations, School of International Studies, Jawaharlal Nehru University. Completed B.A. Hons in Philosophy from Gargi College University of Delhi.

Contents

Introduction

The impact of climate change have manifested in various ways including through extreme weather events. Extreme weather events are "weather phenomena that are at the extremes of the historical distribution and are rare for a particular place and/or time, especially severe or unseasonal weather. Such extremes include severe thunderstorms; severe snowstorms, ice storms, blizzards, flooding, hurricanes, and high winds, and heat waves." Extreme weather events are deemed to be the "showcase of climate variability" and "the day-to-day "face" of climate change." Scientists have argued that an increase in global average temperature beyond 1.5˚C will significantly worsen and "supercharge" extreme weather. Global average temperature has already reached 1.1˚C above the pre-industrial levels and was projected to reach 2.5˚C by the end of the century based on current pledges for action by 2030. And even if the long-term pledges by countries to hit net zero emissions by 2050 were delivered, global average temperature could still rise by 1.8˚C. That does not portent well for India.

India is one of the most vulnerable countries in the world to the impact of climate change and was ranked as the seventh most affected country in the world by extreme weather events in 2019. In fact, India has consistently ranked as one of the most affected country by extreme weather events over several years. For example, it was the fifth most affected country in 2018, the 14th most affected country in 2017, the sixth most affected country in 2016, and the fourth most affected country in 2015 respectively. A 2021 report by the New Delhi-based Council on Energy, Environment and Water (CEEW) showed that 27 out of 35 Indian states and UTs, and 17 out of 20 people, are highly vulnerable to extreme "hydro-meteorological disasters" (cyclone, drought, and flood). The top ten most vulnerable states, according to CEEW, are Assam, Andhra Pradesh, Maharashtra, Karnataka, Bihar, Manipur, Rajasthan, Arunachal Pradesh, Sikkim, and Odisha. The report further observed that three out of four districts in India encompassing 75 per cent of the country's total land area where more than 80 per cent of its population resides are vulnerable to extreme hydro-meteorological disasters. CEEW also observed in an earlier report published in 2020 that India has experienced an "exponential increase" in extreme weather events during 1970–2019, with a marked acceleration in 2000–2019. And since 2005, at least 55 or more districts in India have witnessed extreme flood events annually, exposing 97.51 million people to it. The report also observed that 79 districts in India witnessed extreme drought events annually and that 140.06 million people are exposed to it. Additionally, 24 districts witnessed extreme cyclone events annually, exposing 42.50 million people to storm surges.



Extreme weather events hotspots in India

Purpose of this Compendium

It is imperative that India pay greater attention to adaptation as a matter of urgency. The longer adaptation efforts are put off, the more difficult and expensive responding to climate change will be. The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "reducing climate risks and vulnerability mostly via adjustment of existing systems". Adaptation is one of two main policy responses to climate change, the other being mitigation – reducing greenhouse gas emissions to address the root causes. Both approaches are necessary because even if emissions are dramatically decreased over the coming decade, further warming is now unavoidable and adaptation will be needed to deal with the climatic changes already set in motion.

This compendium focuses on India's adaptation measures. It observed that whereas India cannot completely avoid extreme weather, their impacts can be minimized by reducing the exposure of communities to them, increasing their capacities to withstand it, and/or by reducing their vulnerability. The compendium therefore focuses on three extreme weather events (heatwave, flood, and drought), and sea-level rise. A special section on adaptation in the agricultural sector is also included. The compendium classifies adaptation measures undertaken by India till date as Structural Measures (Traditional, Modern, and Nature-based Solutions) and Non-Structural Measures (Policies). Structural measures are any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems. Structural measures are further classified into traditional, modern, and nature-based solutions. Both traditional and modern structural measures often relied on hard, engineering structures or 'grey infrastructure' such as dams, embankments, sea walls, water treatment plants, etc. Nature-based solutions however relied on 'green infrastructure' such as forests, floodplains, wetlands, soils, etc. to reduce or avoid possible impacts of hazards. Non-structural measures on the other hand are measures that do not employ physical construction to reduce or avoid possible impacts of hazards. It includes policies and laws, public awareness raising, training and education, etc

Climate Adaptation Measures in India

	Heatwave	**Flood**	**Drought/Water scarcity**	Sea **level rise**
Structural Measures: Traditional	Kheri ghar, Ikra house, Tong ghar, Chala, Bungalow, Bhunga, Wada, Pol, Koti banal, Rammed earth home, Guthu mane, Nalukettu, Chutillu.	Chang ghar, Kaso pithiya, Check dam.	Ahar pyne, Dobha, Pukhri, Bamboo drip irrigation, Dong, Zabo, Beri, Taanka, Johad, Baoli, Virda, Zing, Kuhl, Baudi, Naula, Panam keni, Suranga, Eri, Ooranga.	
Structural Measures: Modern	Coated cool roof (Slaked lime or choona, White cement paint, Elastomeric paint), Membrane cool roof, Earthen pot ventilation system.	Dams, Barrage, River channelization, Embankment, Drainage improvement.	Bore well, Tube well, Water recycling, Seawater desalination, Cloud seeding.	Seawalls, Groynes, Geotextile tube.
Structural Measures: Nature-based Solutions	Green roofs, planting trees, vertical gardens, parks, Conservation of forests, Restoring wetlands in and around cities, Afforestation.	Planting trees, Hydroseeding, Planting vetiver grass, Floodplain widening, Restoring wetlands, Afforestation.	Wetland restoration, Afforestation.	Mangrove plantation, Sea grass preservation.
Non-structural Measures: Policies	Heat Action Plan (HAP), Indian Cooling Action Plan (ICAP), Mahatma Gandhi National Employment Guarantee Act (MNREGA), National Action Plan on Climate Change (NAPCC), State Action Plan for Climate Change (SAPCC), National Adaptation Fund for Climate Change (NAFCC), Nagar Van Yojana, Amrit Dharohar.	Nagar Vana Udyan Yojana (NVUY), National Water Policy, Flood Management and Border Areas Programme (FMBAP), Flood Plain Zoning, National Plan for Conservation of Aquatic Eco-systems (NPCA).	National Water Policy (NWP), Jal Shakti Abhiyan (JSA), Jal Jeevan Mission (JJM), Atal Mission for Rejuvenation & Urban Transformation 2.0 (AMRUT 2.0), Atal Bhujal Yojana (ABY), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), National River Conservation Plan (NRCP), Namami Gange, National Plan for Conservation of Aquatic Eco-systems (NPCA), Amrit Dharohar.	Coastal Regulation Zones (CRZ), Mangrove Initiative for Shoreline Habitats and Tangible Incomes (MISHTI).

Heatwave Conditions

Heatwave is a condition of air temperature which becomes fatal to human body when exposed. Heatwave is considered in India when the maximum temperature reached at least 30°C in the hills, 40°C in the plains, and crosses 37°C in the coastal areas. It occurs mainly during March to June and sometimes even in July. The number of heatwave days in India has increased from 413 in 1981-1990 to 575 in 2001-2010 and 600 in 2010-2020. A 2017 study by experts at the Massachusetts Institute of Technology (MIT) observed that even if the world succeeded in limiting the predicted rise in average global temperatures, parts of India will become so hot they will test the limits of human survivability. The authors of the study further noted that after the Persian Gulf, northern India could become "the region of the worst heatwaves on the planet." A 2022 report by the World Bank also echoed this sentiment. It argued that India could soon become "one of the first places in the world to experience heatwaves that break the human survivability limit." The World Bank further observed that up to 75 per cent of India's workforce, or 380 million people, depend on heat-exposed labour. With heat-exposed work contributing to nearly half of the country's GDP, India is extremely vulnerable to job losses. And by 2030, the country may account for 34 million of the projected 80 million global job losses from heat stress associated productivity decline. Cities are uniquely vulnerable to heatwave. Urban canyons formed between tall buildings, trapping heat at the street level. That has contributed towards a phenomenon called the "urban heat island" effect, which resulted in cities being up to 10-15°C hotter than the surrounding countryside.

Adaptation Measures	
Structural Measures: Traditional	Kheri ghar, Ikra house, Tong ghar, Chala, Bungalows, Bhunga, Wada, Pol, Koti banal, Rammed earth home, Guthu mane, Nalukettu, Chutillu.
Structural Measures: Modern	Coated cool roof (Slaked lime or choona, White cement paint, Elastomeric paint), Membrane cool roof, Earthen pot ventilation system.
Non-structural Measures: Nature-based Solutions	Green roofs, planting trees, vertical gardens, parks, Conservation of forests, Restoring wetlands in and around cities, Afforestation.
Non-structural Measures: Policies	Heat Action Plan (HAP), Indian Cooling Action Plan (ICAP), Mahatma Gandhi National Employment Guarantee Act (MNREGA), National Action Plan on Climate Change (NAPCC), State Action Plan for Climate Change (SAPCC), National Adaptation Fund for Climate Change (NAFCC), Nagar Van Yojana, Amrit Dharohar.

I. Structural Measures: Traditional

Modern houses are built using heat-absorbing concrete materials and they have worsened the impact of heatwave especially in cities. As heatwaves become increasingly common and long-lasting, there is an urgent need to look back to India's past and rediscover its rich vernacular traditions that had been developed over thousands of years to cope with the weather extremes of various parts of the country. Vernacular architecture is an architectural style that is designed based on local needs and availability of construction materials. Such architectural style reflected the environmental, cultural, technological, economic, and historical context in which it existed and, at least originally, they did not use formally schooled architects, but relied on the design skills and tradition of local builders. As such, Indian vernacular houses are typically built using locally available construction materials such as mud/clay, cow dung, husk, wood, lime, bamboo, hay, straw, sungrass, palm leaves, timber, stone, laterite, basalt, graphite, etc. Climate is one of the most critical considerations in vernacular architecture. It influences the orientation, form, organization, pattern of built forms, and use of materials. Houses built with vernacular architectural styles using locally available materials therefore have the ability to mitigate high temperatures, channel breezes, and adjust the degree of humidity.

Eastern India

Kheri Ghar. Thatch roofing is a traditional roofing method that involve the use of dry vegetation such as straw, water reed, palm leaves, grass and so on to create a roof covering. In Assam, a local variety of long perennial grass known as *kher* is often employed to build roof coverings. Also known as cogon grass or blady grass, *kher* grows abundantly in the Brahmaputra valley. Ripe green *kher* was cut and dried under the sun until they turn brown. They are then used for roof coverings. Thatch roofs provide excellent insulation since the bulk of the *kher* grass stays dry and is densely packed thereby trapping air. The mud walls and floor further allowed *kheri ghar* to maintain comfortable temperature. Mud have high thermal mass. It absorbs heat slowly during the day and releases it slowly at night. That prevented *kheri ghar* from becoming too hot.

Kheri ghar in Assam

Another example of kheri ghar

Ikra House: *Ikra* House, commonly referred to as "Assam-type house," is typically found in Assam and Meghalaya. The plinth of the house is raised to avoid marshy ground, water run-off during rains, and also stray animals. The vertical posts, roof trusses, and elevated floor are made of wood. A weed, called *ikra*, which grows abundantly in river plains and adjoining lakes across Assam, is used extensively in the walls and roof of the house. The wall panels are made of bamboo frames infilled with the shoots of the *ikra* reed oriented in the vertical direction. The *ikra* reed shoots are then plastered from either side with mud-dung mixture. The covering on the roof truss is a thick stack of *ikra* reed. Metal sheets are also used extensively instead of *ikra* reed for the roof. The design of the house with its high ceilings and choice of construction materials keeps *ikra* houses cool. It also protects them from earthquakes.

An Assam-type House in Shillong, Meghalaya

Tong Ghar. *Tong Ghar* is found primarily in Tripura. It is a hut with thatched, sungrass roofing and walls made from split bamboo. The hut rest upon a raised platform made from wood and bamboo. Being a poor conductor of heat, bamboo keeps the interior of *tong ghar* cool and the permeable floors keep its room adequately ventilated. Also, the walls of the hut helped maintain low moisture content inside the hut.

Tong Ghar in Tripura

Chala. *Chala* is a traditional, curved roofing style that originated from Bengal. The roof is made of local materials like straw or reed. The interior curvature of the roof is supported by bamboo or wooden posts. The hot and humid climate of the region necessitated the deployment of curved roofs. Later, the roof materials were replaced with more durable options like bricks and terracotta. Temples in Bengal have also adopted this form of roofing style. These temples often have one, two, four or eight layers of curved roofs. Hence they are referred to as *do-chala*, *char-chala* or *at-chala* temples.

A hut with a chala roof in West Bengal

Another example of thatched chala roof hut in West Bengal

Bungalows. Bungalow is a one-storey, spacious building, internally divided, having a symmetrical layout with a veranda all around. The bungalow-style architecture originated in Bengal. Original bungalows were developed to try and alleviate problems associated with heat, humidity, and flooding.

Its general design - with wide hallways, high ceilings, large windows, and shade-giving verandas – helped distribute air throughout the building and is therefore well-suited for hot and humid tropical climate. Also, the house was raised above the ground and that protected it from flooding. This basic model was adopted with modifications almost everywhere British imperial rule existed at that time.

A Bungalow at the Kumlai Tea Estate in West Bengal

Western India

Bhunga. *Bhungas* are round mud houses with thatched roofs. They are typically found in the Kutch district of Gujarat. The circular design of *Bhunga* houses provide insulation against the external environment by resisting high-velocity desert winds and reducing exposure to heat. It also resists lateral forces of earthquake. Their thick mud walls keep the interior of the house cool during summer and warm during winter. They can also withstand desert storms and earthquakes. Also, *Bhunga* houses are intricately decorated with *lippan kaam* or mud-mirror art work. Though the art work is limited mainly to the interior walls, it can also be found on the outer walls as well. These scintillating art works or murals bring life, gaiety, and beauty to the generally harsh life of people of Kutch. *Bhunga* houses require periodic maintenance with regular application of lime plastering to the walls and floor as well as replacement of dried grasses on the roof.

Bhunga in Kutch, Gujarat

Wada. *Wada* or 'large mansion' is a type of courtyard house that is found in Maharashtra. It dates back to the time of the Marathas. *Wada* consisted of two or more storey with rooms arranged around an open courtyard. The courtyard opens to the sky and that ensures light and ventilation. There are two types of *Wada*. The first type has many families living in it like in an apartment building. The second type has only one family living in it. Meanwhile, the thick walls with few and small openings on the outside provide security against intruders. *Wada* houses are built using basalt, granite, limestone, bricks, timber, etc. and they are considered cultural and architectural heritage of Maharashtra.

Vishrambaug Wada in Pune was built by Peshwa Bajirao in 1807 It is now home to various government offices

Pol. *Pols* are gated housing clusters. It is typically found in Ahmedabad, Gujarat. They are built using composite construction techniques with timber and brick-lime and they contain courtyards, water storage systems, and richly embellished facades with intricate decorations, including carvings of religious symbolism. The design elements of *Pol* houses allow less radiation of heat. Moreover, the open courtyard conserve the cool breeze and the water tank below it keep the surface cooler. The clay roof tiles also kept the rooms cooler, creating a bearable microclimate within *pol* houses. *Pols* houses of Ahmadabad that was founded by Sultan Ahmad Shah in 1411 AD was declared a UNESCO World Heritage Site in 2017.

Pol houses in Ahmedabad, Gujarat

Northern India

Koti Banal. *Koti Banal*, found in Uttarakhand, is a multi-story house that rest upon a raised platform made from dry masonry over the foundation. The walls are made of timber reinforced stone masonry with the paste of pulse as mortar. Natural stone is piled up without cement, alternated with wooden beams made from the deodar conifer. The house has minimum openings so that heat can be trapped inside. The upper two floors have balconies running around the whole building cantilevered with the support of wooden logs of the flooring system with a wooden railing. The roof consists of a wooden frame and is cladded with slate tiles.

Koti banal in Uttarakhand

Rammed Earth Homes. Rammed earth homes are typically found in the Spiti Valley of Himachal Pradesh as well as Ladakh. Rammed earth is a natural construction technique that involves compacting a damp mixture of soil with correct proportions of clay, sand, gravel, and occasionally a stabilizing material such as cement. This soil mixture is placed in formwork or temporary frame and compacted. The temporary formworks are removed after the soil mixture has dried and hardened. Rammed earth provides excellent thermal mass. Thermal mass absorbs or slows down the passage of heat through a material and then releases that heat when the surrounding ambient temperature goes down.

Rammed earth houses in Spiti, Himachal Pradesh

Southern India

Guthu Mane. In Karnataka, *Guthu Mane* is built to fit the requirements of matrilineal joint families. As such, they are large, square in shape, and have ample space for storage. All *Guthu* houses had a veranda that acted as a sit-out. The houses usually emphasised a lot of woodwork. The doors were made from intricately carved teakwood or rosewood. Ornate and exquisitely sculpted wooden pillars decorated the interiors of the inner courtyard. These pillars supported a decorated wooden ceiling, which usually had designs of mango and floral motifs, foliage, and coin patterns. Solid wooden beams held this grand ceiling.

Guthu mane in Karnataka

Nalukettu. *Nalukettu* is a traditional architectural style of Kerala. It is a rectangular house that consisted of four blocks joined together with a central courtyard that opens to sky. *Nalukettu* houses were typically made of teak wood or the wood from wild jackfruit trees. Most of the materials used in the construction - wood, red bricks, mud - were sourced locally. *Nalukettu* had excellent ventilation and lighting which kept the house well aerated and lit up at almost all times. Extended versions of *Nalukettu* is called *Ettukettu* (eight blocks with two courtyards) or *Padhinarukettu* (16 blocks with four courtyards).

Nalukettu in Kerala

Chutillu. *Chuttillu* is a circular house and they are typically found along the coastal areas of Andhra Pradesh. The house is constructed using wood, clay, cow dung mixed with margossa leaf paste and turmeric, sand, straw, and water. The room provided ample ventilation as they were circular and, more importantly, they were cool during hot summer months.

Chutillu in Andhra Pradesh

II. Structural Measures: Modern

More modern techniques are being increasingly employed to make contemporary houses cooler. Such technique aim to reduce the Solar Reflectance Index (SRI) of roofs and walls. SRI is an indicator of the ability of a roof surface to return solar energy to the atmosphere. Roofing material surfaces with high SRI are often cooler than surfaces with low SRI under the same solar energy exposure, especially on a sunny day. High thermal emittance is another property that keeps roofs cool. Thermal emittance is the efficiency with which a surface cools itself by emitting thermal infrared radiation.

Cool Roofs. Cool Roofs are roofs that minimizes solar absorption and maximising thermal emittance. They are viewed as a solution to increase temperature especially in urban areas. Study have found that urban areas are between 10-15°C hotter than neighbouring rural areas. A primary reason for this is that buildings and roads in urban areas are constructed using hard, dark, dense materials like concrete, brick, tarmac and asphalt, which absorb the sun's heat during the day, and re-radiate it at night. Collectively, many hot surfaces together can result in increased temperatures across an entire urban area, adding to the heat island effect in cities. Not surprisingly, Indian cities such as Ahmedabad and Hyderabad have already launched cool roofs programmes aimed at providing access to affordable cooling for those who are more vulnerable to the health effects of extreme heat such as slum residents and urban poor.

Coated Cool Roof. This involves the coating of a material or paint on top of an existing roof material. For example, white or light reflective paint is a cost-effective cool roof coating. A white roof reflects around 85 per cent of the sunlight that hits it – at least when it is clean – and heats to just a few degrees warmer than the outside air temperature. A black roof, by contrast, can heat to more than 80°C. Depending on the setting, cool roofs can help keep indoor temperatures lower by 2°C to 5°C as compared to traditional roofs.

- **Slaked Lime or *Chuna***. Calcium hydroxide (also called slaked lime) is a colourless crystal or white powder and is produced when quicklime is mixed with water.

This is one of the most common techniques and also the most affordable option. They are typically mixed with adhesive (usually Fevicol) and are applied on roofs as well as walls.

- **White Cement Paint**. White cement has essentially the same properties as grey cement, except for colour and fineness. The colour of white cement is determined by its raw materials and the manufacturing process. Metal oxides, primarily iron and manganese, influence the whiteness and undertone of the material. White cement paint lasts longer than slaked lime and is affordable as well.
- **Elastomeric Paint.** Elastomeric paint is a coating specifically made to protect masonry surfaces. Like other paints, it is applied in liquid form, which then hardens into a flexible, watertight covering. Dr. Fixit Newcoat, Asian Paints Damp Proof, Xcel Coatings Roof Paint, Berger Roof Paint, etc. are some examples of elastomeric paint that are available in India.

A low income house painted with white colour in Madhya Pradesh

Buildings in Jodhpur, Rajasthan are painted with bright colours

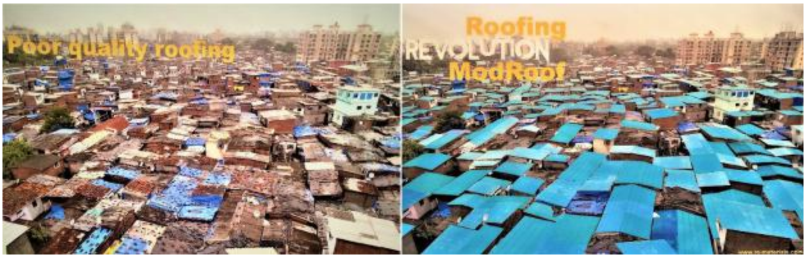
Membrane Cool Roof. Membrane cool roof involve the application of a pre-fabricated membrane such as tiles, shingles, or sheeting over an existing roof in order to increase a roof surface's SRI.

- **Tiled Cool Roof**. Tiled cool roof is made from high-reflective material like zirconium oxide, alumina silicate, or zirconium silicate and they reflect most of the solar heat absorbed during the day. Tiled cool roofs are mostly suited for terraces, pavements, and even open balconies. Tamil Nadu has been at the forefront of using cool tiles in India. This is due to the perpetual heat that existed in the state. Not surprisingly, most of the manufacturers and dealers of cool tiles are based in Tamil Nadu. Some of the top brands include ABC Ceramics, Roof Plus, Johnson Tiles, and Insulla.

Installing white cooling tiles on a roof of a building in Tamil Nadu

- **ModRoof**. ReMaterials, a startup based in Ahmedabad, Gujarat has developed an interlocking modular roofing system called ModRoof. ModRoof is made from waste, pulped cardboard, and natural fibers that were both sturdy and waterproof. The insulation, along with an air gap inside the panel, helps keep the heat out. ModRoof is especially targeted at low income home owners, most of whom lived in houses that have roofs made from thin corrugated metal sheets or thin cement. ModRoof can hold a weight of up to 180 kg, last for about 10 years, costs 50-60 per cent less than concrete slab roofs, and provide better insulation and it costs Rs. 190-200 per square feet.

Modular panel roofs are replacing metal sheeting and poor quality cement in a slum in Ahmedabad, Gujarat



Modular panel roofs are now the roof of choice in many low-income houses in Ahmedabad, Gujarat

Earthen Pots Insulation System. Use of earthen pots to keep roofs cool has been traditionally practiced in hot and dry areas of India. Locally available earthen clay pots are affordable and exhibits high thermal insulation property. Roofs (and sometimes even walls) are covered with upside down earthen pots and then cemented in place. That traps air between the original roof and the final surface and provides insulation. This method helps keep building cool in summer and warm in winter.

Demonstrating earthen pots insulation system on a roof in Surat, Gujarat

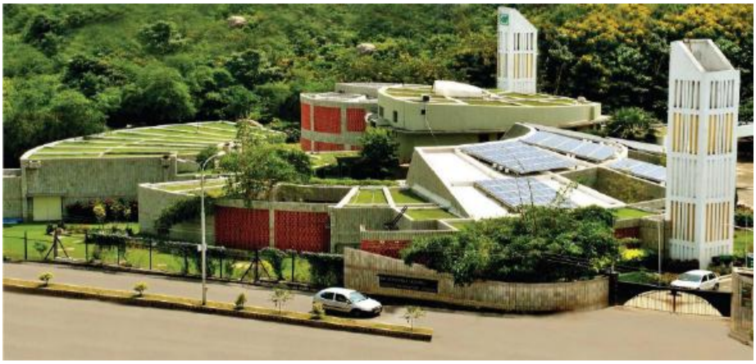
An earthen pots insulation system on a wall in Surat, Gujarat

III. Non-structural Measures: Nature-based Solutions

The International Union for Conservation of Nature (IUCN) defined nature-based solutions as "actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges (e.g. climate change, food and water security or natural disasters) effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits." Nature-based solutions have the potential to tackle both climate mitigation and adaptation challenges at relatively low-cost while delivering multiple additional benefits for people and nature. Measures such as green roofs, planting trees, vertical gardens, parks, creating bodies of water, etc. can help with urban cooling while storing carbon, mitigating against air pollution, and providing recreation and health benefits.

Green Roofs. Green roofs are roofs that are purposely fitted or cultivated with vegetation. They are also known as living roofs, eco-roofs or vegetated roofs. Green roofs provide shade, remove heat from the air, and reduce temperatures of the roof surface and surrounding air. The vegetation on a green roof cools the surrounding air through evapotranspiration, the process in which moisture in plant leaves evaporates into the air, essentially working like an outdoor air-conditioning system. In addition, the increased insulation and decreased need for air-conditioning means less overheated air is put back into the surrounding environment. The plants on green roofs also work like a giant sponge, soaking up water and therefore reducing the amount of rainwater that reaches street level, lowering the risk of flooding, minimizing sewer system overflow, and filtering dirty run-off.

ONGC corporate office in Dehradun



Confederation of Indian Industry's Sohrabji Godrej Green Business Centre (CII-Godrej GBC) in Hyderabad

A personalized "garden-auto" in New Delhi

Planting Trees. Tree canopy is considered to be the single-most effective natural solution to urban heat islands caused by streets and buildings absorbing and retaining heat. Trees cast cooling shadows and breathe water vapour out through their leaves, which cools the surrounding air. The water that a single tree transpires daily has a cooling effect equivalent to two domestic air conditioners for a day. According to a first-of-its-kind modelling of 93 European cities by an international team of researchers, increasing the level of tree cover from the European average of 14.9 per cent to 30 per cent can lower the temperature in cities by 0.4°C, which could reduce heat-related deaths by 39.5 per cent. Cities in India are well-endowed with trees. For example, Delhi is known for having "the best tree plantation along roads" among all the major cities of India. The city's roads are lined with structurally large trees with very tall, straight trunks that form excellent sprawling crowns. Also, the trees are indigenous species and are hardy, sturdy, and durable. However, trees in India's cities are increasingly threatened by development. It has been reported that an estimated 112,169 trees have been cut in Delhi from 2005 to February 2018 by the city's Public Works Department (PWD), Delhi Metro Rail Corporation (DMRC), the Railways, etc. Trees will become even more critical in helping people cope with heatwave especially in cities.

Trees along a road in Delhi

Trees along a road in Bengaluru

Trees along a road in Mumbai

Vertical Gardens. Vertical gardens, also known as green walls, are vertically suspended panel on which plants are grown using hydroponics. They can either be freestanding or attached to a wall and are a wonderful alternative to potted plants in the built environment. Potted plants provide flexibility in placement, but they take up space and require a great deal of maintenance. Vertical gardens take up very little, if any, floor space. Vertical gardens are more than just a trendy design feature. While they are installed primarily to improve air quality, the benefits of vertical gardens are many. They can also regulate the temperature through transpiration and cools home. Given these advantages, cities across India have now installed vertical gardens along major roads, buildings, and on the concrete pillars of flyovers and metro rail lines. Also, they have increasingly become a major feature of hotels and retail developments across India.

Vertical Garden on a metro pillar in Kolkata

A vertical garden inside the Kempegowda International Airport in Bengaluru

Vertical Garden along a road in Hyderabad

Parks. Urban parks are widely regarded as being highly effective in mitigating the urban heat island effect caused by extensive urbanization and high temperatures associated with climate change. They exerted a general cooling effect and can significantly reduce surrounding land surface temperature depending on the area of the green space and quality of green coverage. Studies on the cooling effect of urban parks in different regions have shown that large scale urban parks with areas over 10 hectares can have an average of 1°C to 2°C effect on surrounding areas that are an average of 350 meters (0.35 kilometer) away. In general, air temperature reductions in urban parks are typically up to 0.5°C to 4°C and may even cause up to 5°C to 7°C reduction. The number of accessible parks in many

Indian cities have declined as they have been converted into parking spaces. The lack of accessible and well-maintained parks could have a detrimental effect on people in times of soaring temperature.

The Yamuna Biodiversity Park in Delhi

Chhatrapati Shivaji Maharaj Park, the largest park in Mumbai

Kolkata's Maidan is the largest urban public park in India

Conservation of Forests. Role of forests as carbon sponges is well established. But comprehensive new data suggested that forests deliver climate benefits well beyond just storing carbon, helping to keep air near and far cool and moist due to the way they physically transform energy and water. Forests emit chemicals called biogenic volatile organic compounds (BVOCs) which create aerosols that reflect incoming energy and form clouds – both are cooling effects. Deep roots, efficient water use and so-called canopy roughness further enabled forests to mitigate the impact of extreme heat. These physical qualities allow trees to move heat and moisture away from the Earth's surface, which directly cools the local area, and influences cloud formation and rainfall – which has ramifications far away. India has a total forest cover of 7,13,789 square kilometer as of 2021. That is 21.71 per cent of the country's geographical area. Without its forests, India would be much hotter and the weather more extreme. Better protection, expansion, and improved management of forests therefore is critical.

The Western Ghats

Restoring Wetlands in and around Cities. A wetland is an area of land that is either covered by water or saturated with water either permanently (for years or decades) or seasonally (for weeks or months). It included lakes, ponds, marshlands, and swamps. India has large and diverse wetland classes, some of which are unique. In 2011, the Indian Space Research

Organisation (ISRO) mapped a total of 7,57,060 wetlands across India covering 15.26 million hectares or 4.63 per cent of the geographic area of the country. Of these wetlands, 75 of them covering 13,266.77 square kilometers are designated as Wetlands of International Importance (Ramsar Sites). Wetlands can exert a cooling affect on cities.

A Wetland in Mumbai

However, a number of wetlands in India's cities have disappeared owing to encroachment. A 2021 report by the Comptroller and Auditor General (CAG) of India observed that whereas Bengaluru had 1,452 water bodies during early 1800s, it has only 194 by 2016. Similarly, Chennai once had more than 474 wetlands but more than 85 per cent of them has degraded. The Chennai Municipal Corporation has now prioritized the restoration of 200 wetlands as part of its Smart Cities Initiative and disaster mitigation efforts.

IV. Non-structural Measures – Policy

Policy plays an important role in climate change adaptation. Climate change policy encompasses policies formulated specifically to tackle climate change and it can be local, national or international in scope. Climate change policies fall into two broad categories: those that are designed to minimise the extent of climate change or climate change mitigation and those that are intended to minimise risks and seize upon new opportunities or climate change adaptation. In the context of heatwave in India, the following policy measures aimed at minimising risks has been formulated.

Heat Action Plan (HAP). HAPs are designed as adaptation plans with suggested preventive measures and protocols to battle increasing occurrences of heatwaves and escalating temperatures. Such plans focuses on implementation of early warning systems and interagency coordination; capacity building/training programs for health professionals; public awareness and community outreach; and cooperation with non-governmental organizations and civil society. India has established a national framework for heat action plans through the National Disaster Management Authority (NDMA). NDMA coordinated a network of state disaster response agencies and city leaders to prepare for soaring temperatures and ensure that everyone is aware of heatwave "Do's and Don't's." And along with the India Meteorological Department (IMD), NDMA is currently working to develop HAPs in 23 states.

Indian Cooling Action Plan (ICAP). Access to cooling can be an effective means of preventing fatalities caused by extreme heat stress. The vast majority of Indians however do not have access to cooling. Given this, the challenge for India is this: how should it provide access to cooling to its citizens without warming the planet. In order to address this, the country launched ICAP in March 2019. ICAP aimed to reduce, by 2037-2038, cooling demand across sectors by 20-25 per cent, refrigerant demand by

25-30 per cent, and cooling energy requirements by 25-40 per cent. It also aimed to recognize "cooling and related areas" as a thrust area of research and train and certify 100,000 servicing sector technicians by 2022-2023. It is believed that in the coming years, ICAP will enable India to deploy alternative and innovative energy efficient technologies for keeping spaces cool.

Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA). Enacted in 2015, MGNREGA is a labour and social security law that aimed to enhance the livelihood security of people in rural areas by guaranteeing 100 days of wage employment in a financial year to a rural household whose adult members volunteer to do unskilled manual work. Development works undertaken under MGNREGA has provided critical climate change adaptation co-benefits as the bulk of works carried out under it are related to Natural Resource Management (NRM). Not surprisingly, a 2021 study by the New Delhi-based Centre for Science and Environment (CSE) concluded that MGNREGA is the "world's biggest adaptation programme as it harnesses the labour of people to invest in building the wherewithal to fight drought and build resilience." It also deemed MGNREGA to be India's "largest water conservation exercise" that improved resilience to climate risks in drought-prone regions of the country.

National Action Plan on Climate Change (NAPCC): NAPCC was released on 30 June 2008. It outlined a national strategy aimed at enabling India to adapt to climate change while maintaining a high growth rate that is essential for increasing the living standards of its vast population. The plan included eight "National Missions" and 24 other initiatives that are implemented by the respective nodal ministries in the central government. The eight "National Missions" include National Solar Mission, National Mission for Enhanced Energy Efficiency, National Mission on Sustainable

Habitat, National Water Mission, National Mission for Sustaining the Himalayan Eco-system, National Mission for a Green India, National Mission for Sustainable Agriculture, and National Mission on Strategic Knowledge for Climate Change.

State Action Plan for Climate Change (SAPCC). In 2009, the Government of India directed all State governments and Union Territories to prepare SAPCC that is consistent with the strategy outlined in the NAPCC. SAPCC included climate profile of a State, a strategy of intended actions, and outline of specific implementation activities. It sought to address the following: prevention of flood, drought and famine; protection of soil erosion and degradation; deforestation and afforestation; water conservation; energy conservation; transport; urbanization; health; protection of coastal erosion; degradation of mountain system; technology development; education; outreach programmes; employment; poverty alleviation; human resources, etc. All states of India now has an SAPCC and they are working to integrate climate change concerns into mainstream government planning processes.

National Adaptation Fund for Climate Change (NAFCC). NAFCC was established in 2015 to finance concrete adaptation projects and programmes in the states and UTs of India that are particularly vulnerable to the adverse effects of climate change. The National Bank for Agriculture and Rural Development (NABARD) is the implementing agency for these projects. As of February 2022, NAFCC have sanctioned 30 projects totaling Rs. 847.5 crore in 27 States and UTs. On the whole, grants released under NAFCC has fallen from Rs. 115.36 crore in 2017-2018 to Rs. 42.94 crore in 2020-2021, and Rs. 27.76 crore (till December 2021).

Nagar Van Yojana. Launched in 2020, this scheme aimed to develop 400 urban forests (*nagar van*) and 200 urban gardens (*nagar vatika*) across India within the next five years. These forests and gardens will be developed on land that has been marked as forest lands but do not have any trees. It will also be created on any other vacant land offered by local urban local bodies. Urban forests and gardens can help reduce temperature and carbon emissions, remove air pollutants, prevent soil erosion, recharge groundwater, and stabilize soil. They can also help conserve biodiversity in cities. Between 2020 and 2022, a total of 270 projects have been approved.

Amrit Dharohar: Announced in 2023, this scheme aimed to protect vital wetlands which sustain aquatic biodiversity. The scheme also encouraged optimal use of wetlands, enhancement of biodiversity, eco-tourism, income generation for local communities, etc. It will be implemented over the next three years

Floods

Floods are the single most frequent hazards faced by India. In 1980, Rashtriya Barh Ayog (the National Commission on Floods) assessed the total area liable to flooding in the country at 40 million hectares (400,000 square kilometers). That constituted 12.5 per cent of India's total geographical area. Meanwhile, the Planning Commission estimated the maximum area affected by floods in any given year during 1953-2010 at 49.815 million hectares. Meanwhile, a 2021 report by NITI Aayog estimated that 7.17 million hectares of land in India are affected by floods every year. On average, floods damaged 1.2 million houses and claimed the lives of 1,654 people and 6,18,248 cattle every year. Furthermore, the average annual loss in monetary terms was estimated at Rs. 5,649 crores.

A 2020 report by the New Delhi-based Council on Energy, Environment and Water (CEEW) found that, in the last 50 years, the frequency of flood events in India have increased almost eight times. More specifically, between 1970 and 2004, three extreme flood events occurred per year on an average. However, after 2005, the yearly average rose to 11. Also, the yearly average for districts affected by flood until 2005 was 19. But after 2005, it jumped to 55. The study also found that 97.51 million people in 55 or more districts are exposed to extreme flood events in India annually.

Cities are uniquely vulnerable to flooding because of the proliferation of impervious surfaces. In a completely uninhabited landscape, rainfall integrates into the natural water cycle by four different ways: it either soaks all the way to the ground and becomes groundwater; runs down valleys into bodies of water and finds its way to the sea; is taken up by plants; or just evaporates. In cities with paved roads, highways, and parking lots, water has nowhere to go, so every heavy rain can turn into devastating flood. Thus, as India urbanise, so does storm water runoff problems.

Adaptation measures	
Structural Measures: Traditional	Chang ghar, Kaso pithiya, Check dam.
Structural Measures: Modern	Dams, Barrage, River channelization, Embankment, Drainage improvement.
Non-structural Measures: Nature-based solutions	Planting trees, Hydroseeding, Planting vetiver grass, Floodplain widening, Restoring wetlands, Afforestation.
Non-structural Measures: Flood Forecasting and Warning	Flood forecasting and warning.
Non-structural Measures: Policies	Nagar Vana Udyan Yojana (NVUY), National Water Policy, Flood Management and Border Areas Programme (FMBAP), Flood Plain Zoning, National Plan for Conservation of Aquatic Eco-systems (NPCA).

I. Structural Measures: Traditional

Chang Ghar. The *Mishing* community of Assam, an indigenous community of who inhabited the Brahmaputra River valley, adapted to floods by building unique and traditional flood-resilient houses called *chang ghar*. *Chang ghar* is a type of house that is perched above the ground on bamboo stilts. A wooden ladder called *jokhola* leads to the raised entrance of the house. The walls of the house are made of interwoven bamboo or cane. The floor of the house too is lined with long and thick bamboo strips. During the wet season, the house's elevation protects those living in it from floods. However, frequent flooding have often caused the bamboo stilts to rot. New designs have been introduced in recent years. Constructed with sturdy, locally available species of bamboo, the house rests on rubberised bamboo columns set in a concrete base. A flexible joinery system allows homeowners to raise the floor higher if necessary, while cross-bracing bamboo supports make the structure capable of withstanding movement caused by floods and earthquakes.

A Chang Ghar belonging to the Mishing tribe in Majuli Island in Assam

Another example of Chang Ghar in Assam

Kaso Pithiya. *Kaso Pithiya* is a traditional man-made mound or highland upon which people in flood affected areas of Assam built their houses. The mound is generally built in the shape of a semi-circle and it resembles the shell of a turtle rising above the floodwater. During a flood, land that is temporarily immersed in water can become waterlogged. *Kaso Pithiya* prevented houses and those living in them from the ravages of floods and waterlogging. Many communities in Assam even build these 'highlands' as a refuge for wildlife. Many animals often climbed on top of them to escape floodwater.

A house built atop Kaso Pithiya in Assam

Check Dam. A check dam is a small dam constructed across a drainage ditch, swale, or channel to lower the velocity of flow. Reduced runoff velocity reduces erosion and gullying in the channel and allows sediments to settle out. Built using stones, sandbags filled with pea gravel, or logs, check dams are one of the most popular low-cost methods of controlling floods in India.

Construction of a check dam following a flood in Wayanad district in Kerala in 2019

II. Structural Measures: Modern

Dams. A dam is a structure built across a river or stream to hold back water. Dams can be used to store water, control flooding, and generate electricity. By regulating water flow, dams generally alter the frequency, duration, and timing of annual flooding events. According to the National Register of Large Dams, there are currently 5,264 completed large dams and 437 large dams are under construction in India. In theory, these dams can help moderate floods in the downstream areas. But that depended on the amount of space it has to store water. The lack of space to store more water often necessitated the release of all the water inflows into downstream rivers. As a result, dams can end up increasing the magnitude of flood disasters. Floods caused by dams are sudden, and given its intensity and the unpreparedness of people living in surrounding areas, its impact tended to be more destructive to lives and properties.

Cheruthoni Dam and the Idukki reservoir in Kerala

Barrage. Barrage is a concrete structure consisting of a series of large gates that can be opened or closed to control the amount of water that flows through them. This allows the structure to adjust and stabilize the elevation of the upstream water for irrigation and other systems. The valves are positioned between the pillars that have the task of supporting the water load of the pool created. The most well known barrage in India is the Farakka Barrage. The Farakka Barrage was constructed in 1975 across the

Ganga River to divert part of its flow to its tributary, the Hooghly.

Farakka Barrage in West Bengal

River Channelization. Channelization is a method of river engineering that widens or deepens rivers to increase the capacity for flow volume at specific sections of the river. As a result, during flood, watercourses can move more efficiently and facilitate more water, which results in less damage to banks. River channelization typically involves dredging to remove sedimentation at the base of the river to increase the flow rates of water. Besides controlling flood, channelization provides erosion control and the rehabilitation of watercourses. River channelization has now been deployed as a solution to control flood in rivers such as the Gomti in Lucknow, Mithi in Mumbai, and Brahmaputra in Assam. River channelization however can cause damage further downstream where efforts to widen or deepen the river have not been undertaken.

Channelization of the Gomti River in Uttar Pradesh


Dredging the Mithi River in Mumbai

Embankments. Embankments are artificial banks built along banks of a river to protect adjacent land from inundation by a flood. It is usually earthen and parallel to the course of a river. The embankments or 'bunds' vary in nature and function under a variety of situations. Some embankments are made from compacted soil, but many are made from readily available sand and stones dug from riverbeds. Large embankments are often buttressed with spurs (projections that slow the flow of water), gabion boxes filled with boulders, and sandbags. Embankments confine the flood flows and prevent spilling, thereby reducing the damage from flood. They are generally cheap, quick, and most popular methods of flood protection and have been constructed extensively. As of 2020, a total of 3,790 kilometers of embankment have been built on 13 rivers in Bihar. Meanwhile, Assam has 4,473.82 kilometers of embankments as of 2022. The effectiveness of embankment however has been questioned increasingly.


Embankment along the Brahmaputra River in Assam

Drainage Improvement. India has been undergoing rapid urbanization. That has led to an increase in impermeable surfaces such as roads, pavements, and driveways. As a result, surface water run-off has also increased. Well-designed drainage systems therefore are critical as it allow for effective discharge of stormwater, reducing property losses and expenditures on recovery. In many cities across India, many of the urban wastewater and stormwater systems were designed with limited capacity and have become overwhelmed by flow increases spurred by hydrologic change and urban growth. Besides, open drains on the edge of pavements often are clogged with silt, plastics, and other solid waste block drains and waterways during the rainy season, resulting in water spilling over roads. Cities like Chennai has now embarked on an ambitious project of constructing new stormwater drains across the city for flood mitigation.

Stormwater drain project in Chennai, Tamil Nadu

III. Non-structural Measures: Nature-based solutions

Planting Trees. Trees help to reduce flooding in a number of ways. Rain hits the ground at higher speeds where there is a lack of tree cover. A canopy of leaves, branches and trunks slows down the rain before it hits the ground simply by getting in the way. This action can spread the effect of a rain storm over a longer time period. This allows some of the water to evaporate back into the atmosphere directly from the canopy without ever reaching the ground. Also, root systems help water penetrate deeper into the soil at a faster rate under and around trees. This means less surface run-off and more water storage in the soil. In rural areas, the removal of trees and hedges and changes in cropping have increased run-off from fields. Planting trees and hedges can be effective in increasing water infiltration, and reducing and slowing run-off on farmland. In towns and cities, the rise in impermeable surfaces such as roads, pavements, and driveways has led to increased surface water run-off. An increase in green space could drastically reduce run-off in built-up areas.

Trees along a road in Delhi

Hydro-seeding. Hydroseeding, also known as hydro-mulching, hydraulic planting, hydraulic mulch seeding, and hydra-seeding, is an accelerated grass planting technique that involves spraying a slurry of seed, mulch, fertiliser, and bonding agents on the ground where they germinate quickly. The roots of the vegetation hold topsoil together and stabilize slopes. In doing so, it prevents soil erosion and landslides especially in hilly regions. Since hydroseeding involves spraying 'liquid' seed using high powered sprayers, it is much easier, faster, cheaper, and more reliable than conventional methods of planting grass. In Tamil Nadu, hydroseeding was employed along highways in Nilgiris district to stabilize slopes and prevent soil erosion and landslides. As of 2021, as much as 4,170 locations across Tamil Nadu have been identified as vulnerable to landslides. Of these, 284 are in the Nilgiris district out of which 49 are located close to highways. Hydroseeding has been found to be cost effective, saving 50 per cent of the cost compared to developing revetments or concrete structures on vulnerable hill slopes.

Hydroseeding along a road in India

Planting Vetiver Grass. Vetiver is a fast-growing non-invasive plant with an extensive, dense and deep root system and strong stems with adaption to large range of climates. It was first developed by bioengineers for the World Bank in India in the 1980s, when they learned that vetiver grass forms a horizontal mat of roots that can grow to four metres below ground level, binding the soil together. This can reduce soil erosion by up to 90 per cent and rainwater runoff by up to 70 per cent. Vetiver grass is increasingly seen as a solution to soil erosion. The grass forms a dense, permanent hedge that prevents soil loss from runoff, thereby improving soil fertility and water quality. Vetiver is now widely used and has proven to be effective, efficient, economical, and sustainable erosion control systems.

Vetiver Grass in Udhagamandalam in the Nilgiri Hills, Tamil Nadu

Planting Vetiver Grass on the bank of the Ganga River in Uttar Pradesh

Floodplain Widening. A floodplain is a generally flat area of land next to a river or stream. It stretches from the banks of the river to the outer edges of the valley. Floodplains are natural flooding outlets for rivers. When a river floods, water spreads across the floodplain and slows down. Without floodplains, rivers would rise and move faster. Restoring floodplains to give rivers more room to accommodate large floods is the best way to keep communities safe. Giving rivers more room also provide a number of other benefits including clean water, open space for agriculture, recreation and trails, and habitat for fish and wildlife. Following Chennai's devastating flood in 2015, efforts are now undertaken to widen the floodplain of the Adyar River. Work has been completed on about 22 kilometers section of the river. Authorities have also commissioned a study on further widening of the Adyar River.

Widening the Adyar River's floodplain in Chennai

Restoring Wetlands. A wetland is an area of land that is either covered by water or saturated with water either permanently (for years or decades) or seasonally (for weeks or months). They consisted of lakes, ponds, marshlands, and swamps. India has large and diverse wetland classes and some of them are unique. Wetlands, variously estimated to be occupying one to five per cent of the geographical area of the country, supports about a fifth of the known biodiversity. In 2011, the Indian Space Research Organisation (ISRO) mapped a total of 7,57,060 wetlands in India covering 15.26 million hectares or 4.63 per cent of the geographic area of the country. Of these wetlands, 75 of them covering 13,266.77 square kilometers are designated as Wetlands of International Importance (Ramsar Sites). These wetlands can play a critical role in reducing the frequency and intensity of floods by acting as natural buffers, soaking up and storing a significant amount of floodwater. A number of wetlands in cities however have disappeared owing to encroachment. A 2021 report by the Comptroller and Auditor General (CAG) of India observed that whereas Bengaluru had 1,452 water bodies during early 1800s, it has only 194 by 2016. Similarly, Chennai once had more than 474 wetlands but more than 85 per cent of them has degraded. The Chennai Municipal Corporation has now prioritized the restoration of 200 wetlands as part of its Smart Cities Initiative and disaster mitigation efforts.

Loktak Lake in Manipur is the largest freshwater lake in Northeast India

A Wetland in Chennai, Tamil Nadu

A lake in Bengaluru

Afforestation. Forests can soak up excess rainwater and prevent run-offs and damage from flooding. By releasing water in the dry season, forests can also help provide clean water and mitigate the effects of droughts. The volume of water retained by forests can depend on characteristics such as forest cover area, the length of vegetation growing season, tree composition and density, as well as the age and the number of layers of vegetation cover. Water retention by forests affects the amount and timing of the water delivered to streams and groundwater by increasing and maintaining infiltration and storage capacity of the soil. India is currently implementing three major schemes for the development of forest areas namely National Afforestation Programme (NAP), Green India Mission (GIM), and Forest Fire Prevention and Management (FFPM). While NAP is being implemented for afforestation of degraded forest lands, GIM is implemented to protect, restore, and enhance India's forest cover and FFPM is implemented for the purpose of forest fire prevention and management.

Afforestation in Uttarakhand

IV. Non-structural Measures: Flood Forecasting and Warning

Flood forecasting and warning is key to reducing vulnerabilities and flood risk. In India, flood forecasting and warning programme commenced in 1958 for the Yamuna River. The programme now covers most of the flood prone inter-state river basins of the country. In 2021, the Central Water Commission's (CWC) flood forecasting services were extended to 331 stations (199 level forecast stations and 132 inflow forecast stations). In all, CWC's flood forecasting services covered 22 states and three union territories. Flood forecasting activities of the CWC are performed from May to December each year through its 36 Field Divisions which issued flood forecasts and warnings to central as well as state authorities.

V. Non-structural Measures: Policies

National Water Policy. The first National Water Policy was adopted in September, 1987. It was reviewed and updated in 2002 and later in 2012. India's national Water Policy aimed to govern the planning and development of water resources and their optimum utilization. The policy called for conservation of rivers, river corridors, water bodies, and infrastructure. It also called for an integrated management of storage capacities of water bodies and water courses and/or associated wetlands, floodplains, etc. It also observed that encroachments and diversion of water bodies (like rivers, lakes, tanks, ponds, etc.) and drainage channels (irrigated area as well as urban area drainage) must not be allowed and wherever it has taken place, it should be restored to the extent feasible and maintained properly.

Flood Management and Border Areas Programme (FMBAP). FMBAP was created for the period 2017-2020 with an outlay of Rs. 3,342 crore. The programme was an amalgamation of the erstwhile Flood Management Programme (FMP) and the River Management Activities and Works Related to Border Areas (RMBA) scheme. FMBAP is being implemented throughout India for effective flood management, erosion control, and maintaining peace along India's border. FMBAP was further extended till 2026 owing to demands from flood prone states that the Indian government continue to provide them financial assistance. The proposed outlay of FMBAP for the period 2021-2026 therefore was Rs. 15,000 crores.

Flood Plain Zoning. Floodplain zoning aimed to demarcate zones or areas likely to be affected by floods of different magnitude or frequencies and probability levels, and specify the types of permissible developments in these zones, so that whenever floods actually occur, the damage can be minimised. In other words, it aimed to prevent encroachment on river floodplains. A model draft bill for floodplain zoning legislation titled "Model Bill for Flood Plain Zoning, 1975" has already been circulated by the Indian government to all the states. Only Manipur, Rajasthan, Uttarakhand, and the erstwhile state of Jammu and Kashmir have enacted the legislation till date. But they are yet to delineate and demarcate floodplains. Meanwhile, Uttar Pradesh, Bihar, West Bengal, Assam, and Odisha - all major flood-prone states – have not enacted any legislation. Experts have warned of dire consequences if floodplain zoning is not undertaken in view of the rise in the frequency and intensity of floods due to climate change.

National Plan for Conservation of Aquatic Eco-systems (NPCA): NPCA was launched in 2015. It aimed to holistically conserve and restore wetlands in India in order to achieve the desired water quality enhancement, besides improving biodiversity and ecosystems. It also aimed to promote mainstreaming of wetlands in developmental programming with States by supporting formulation and implementation of integrated management plans, capacity development and research.

Water Scarcity and Drought

India faces a dire water situation. The country has 18 percent of the world's population, but only four per cent of its water resources, making it among the most water-stressed in the world. A 2018 report by NITI Aayog titled 'Composite Water Management Index' underlined the country's grave water situation. It observed that "India is suffering from the worst water crisis in its history" and that 600 million Indians currently faced high to extreme water stress. The report further observed that about 200,000 people die every year due to inadequate access to safe water. Groundwater is one of the most important sources for irrigation as well as for rural and urban domestic water supply. However, overexploitation of this valuable resource has led to its depletion. NITI Aayog's report further warned that India's water crisis will get worse. It projected the country's water demand to be twice the available supply by 2030. That would lead to severe water scarcity for hundreds of millions of people. It will also lead to six per cent decline in the India's GDP. Climate change is likely to further exacerbate India's water crisis. Sustainable water management therefore acquired critical importance.

Adaptation measures	
Structural Measures: Traditional	Ahar Pyne, Dobha, Pukhri, Bamboo drip irrigation, Dong, Zabo, Beri, Taanka, Johad, Baoli, Virda, Zing, Kuhl, Baudi, Naula, Panam keni, Suranga, Eri, Ooranga.
Structural Measures: Modern	Bore well, Tube well, Water recycling, Seawater desalination, Cloud seeding.
Non-structural Measures: Nature-based Solutions	Wetland restoration, Afforestation.
Non-structural Measures: Policies	National Water Policy (NWP), Jal Shakti Abhiyan (JSA), Jal Jeevan Mission (JJM), Atal Mission for Rejuvenation & Urban Transformation 2.0 (AMRUT 2.0), Atal Bhujal Yojana (ABY), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), National River Conservation Plan (NRCP), Namami Gange, National Plan for Conservation of Aquatic Eco-systems (NPCA), Amrit Dharohar.

I. Structural Measures: Traditional

Traditional water harvesting systems are multi-functional in nature and they provide a variety of ecosystem services that contribute to the overall wellbeing of people. India has a rich history of managing water that extended over several millenniums. Every region in the country has their own unique traditional water harvesting systems based on local geography, climate, and culture. Water experts across the country have now espoused the benefits of reviving traditional water harvesting systems in India. This is critical because a growing number of traditional water harvesting systems in the country have fallen into disrepair and neglect.

Eastern India

Ahar Pyne. *Ahar Pyne* is a traditional floodwater harvesting system that is indigenous to southern Bihar. *Ahars* are low-lying fields with embankments on three sides that act as water reservoirs. *Pynes* are diversion channels carrying water from swollen rivers into the *ahars*. Some of these *pynes* such as the *Jamune Dasain Pyne* and *Barki Pyne* are more than 100 kilometers long. As water flowed through these *pynes* on their way to the *ahars*, they irrigated numerous farmlands.

Ahar Pyne floodwater harvesting system in Bihar

This combined irrigation and water conservation system which reaches even remote countryside dates back to the Mauryan Empire, the first pan-Indian empire that was founded around 321 B.C.E. There is now a growing interest in *ahar pynes* and efforts are being made to revive them.

Dobha. In Jharkhand, rainwater is harvested for use during the dry season in ponds locally referred to *Dobhas*. *Dobhas* are dug in low-lying areas where rainwater could accumulate. Each *dobha* can store up to 25,000 to 30,000 liters of rainwater. The harvested water is used for irrigation and it help reduce farmer's dependence on monsoons and allow them to diversify their crops.

Digging Dobha in Jharkhand

Pukhri. In Manipur, rainwater is harvested for use during the dry season in ponds locally referred to as *Pukhris*. Water from *pukhris* was originally used for drinking and other household uses, but over the years, people also breed fish in them for personal consumption, and also to earn additional income.

A household Pukhri in Manipur

Pukhris can be either privately owned or community-owned. Community-owned *pukhris* are much larger in size than privately owned ones, and they often have retaining walls built into them. A number of small- to medium-sized community ponds exist in most parts of Manipur. However, *pukhris* in urban areas have fallen into neglect and some have even disappeared.

Bamboo Drip Irrigation. Farmers in Meghalaya have long used traditional bamboo drip irrigation systems to irrigate their plantation crops. This system of irrigation involve the diversion or transportation of water from perennial springs located high up on the hills to the foothills through bamboo pipes. This technique was further refined by constructing rainwater harvesting ponds/tanks on the hilltop itself.

Bamboo drip irrigation in Meghalaya

Layout of modified bamboo drip irrigation system in Meghalaya

That ensured water availability even during the dry season. The water that are harvested in the ponds/tanks is then transported directly to farms through a series of interconnected bamboo pipes which then irrigates high value field crops grown in specified row to row and plant to plant spacing. To ensure efficient utilisation of water, the speed of the water dripping from the bamboo pipes is managed by a woollen thread tied to the holes of the lateral bamboo pipes.

Dong. *Dong* is a traditional irrigation method practiced by the *Bodo* community of Assam. *Bodos* are an ethno-linguistic group who live primarily on the north bank of the Brahmaputra River below the foothills of Bhutan and Arunachal Pradesh. *Dong* consisted of one main earthen canal that is 12 feet wide and three to 10 feet deep. This main canal diverts water from rivers. Water flowing through the canal is again diverted to villages through a network of sub-canals known as *shakas* and *prashakas*. The flow of water in these sub-canals is regulated by dams made from tree branches, stones, and boulders. Water is released from the main canal to the sub-canals at a fixed time, usually twice a day. The water thus released from the main canal to the sub-canals reaches villages and fields. Building and maintaining *dongs* is a community effort.

Dong in Assam

Zabo. *Zabo* is a traditional farming method practiced in Nagaland. It combined agriculture and forestry with built-in water-harvesting systems and conservation measures. Protected forests that are located high up in the hills serve as the water catchment area. Gravitational flow and manmade channels directed water from the catchment area to water harvesting ponds that are located further downhill. The sides and bottom of these ponds are rammed and compacted to reduce seepage. Finally, water from the ponds is channelled to terraced paddy fields and fishery ponds that are located further downhill from the ponds. The ponds not only serve as a water reservoir for irrigation but they are also a source of drinking water for cattle and other animals of the village. Animal husbandry activities are usually located near and above the water-harvesting pond.

Zabo in Kikruma village, Nagaland

Western India

Beri. *Beri* is a pitcher-shaped shallow well that is typically found in Rajasthan. It is about half a metre wide at the top and three to four meters wide at the bottom and can hold up to 500,000 liters of water. People also build raised concrete platform and cover it with a slab to prevent dust and surface runoff contamination.

Beri in Rajasthan

Taanka. *Taanka* is a rainwater harvesting tank indigenous to the Thar Desert region of Rajasthan. It comprises of covered, underground, impermeable cistern on shallow ground for the collection of rainwater. The cistern is generally constructed out of stone or brick masonry, or concrete, with lime mortar or cement plaster. Rainwater or surface run-off from rooftops, courtyards, or artificially prepared catchments (locally called *agor*) flows into the tank through filtered inlets in the wall of the pit. Once completely filled, water stored in a *taanka* can last throughout the dry reason.

Taanka in Rajasthan

Johad. *Johad* is a crescent-shaped dam of earth and rocks, built to intercept rainfall runoff in Rajasthan. It serves two functions. On the surface, it held water for livestock. Also, by holding water in place, it allowed it to percolate down through the soil and recharge the aquifer below, as far as a kilometer away. Stored underground, the water could not be lost to evaporation. In the midst of the dry season, without pipes or ditches to deliver water, villagers could always count on water from their wells.

Johad in Rajasthan

Baoli. *Baolis* are step-wells built to provide water for drinking and agriculture. They have existed for over 1,000 years and were constructed in towns and alongside *serais* (travellers' inns), across the Thar Desert and into Delhi. *Baolis* exist in all shapes and sizes and are essentially reservoirs built into the earth. Groundwater is pulled up from a circular well at the bottom and rainwater is collected from above.

Panna Meena ka Kund in Jaipur, Rajasthan

A set of steps – on one or more sides of the structure – lead down to the water level, which fluctuates depending on the amount of rain.

More recently, electric pumps have been installed in many *baolis* to help retrieve the water. *Baolis* are a great example of how a centuries-old water conservation technique can survive and find relevance down the ages. However, many *baolis* have now fallen prey to rapid urbanisation and neglect.

Virda. *Virda* is a well that is found all over the Banni grasslands in the Great Rann of Kutch region of Gujarat. It was dug by the nomadic *Maldharis* who used to roam the grasslands. The topography of the grasslands are undulating and is pockmarked by depressions. By studying the flow of water during the monsoon, the *Maldharis* identified these depressions and dug *virdas* there. After rainwater infiltrated the soil, it gets stored in the *virdas*. A structure was then built to access the water.

Virda in Gujarat

Northern India

Zing. In Ladakh, melting glacier water is collected in a small tank called *Zing*. A network of guiding channels transported water from the glacier to the tank. A trickle in the morning, the melting waters of the glacier turn into a flowing stream by the afternoon. The water, collected by evening, is used in the fields on the following day. A water official called a *Chirpun* is responsible for the equitable distribution of water in this dry region that relies on melting glacial water to meet its farming needs.

Zing in Ladakh

Kuhl. *Kuhl*, found in Himachal Pradesh, is a shallow surface channel that divert water from naturally flowing streams or springs, to cultivated fields. *Kuhl* is usually two meters wide and two meters deep, and it can stretch from 100 meters to even a kilometer. It enable farmers to move beyond subsistence farming and into commercial production of vegetables and plantation of fruit trees. Wasteland has also been converted into productive land for cultivating, expanding the number of hectares under cropping and increasing farmer's income.

Kuhl in Himachal Pradesh

Baudi: Also found in Himachal Pradesh, *baudi* is a deep stoned pit, which is dug where water percolates naturally from the Earth's surface. It is circular/ square in shape and gently slopes towards the pit in the center. While constructing *baudi*, the masons placed stones in a particular sequence to have continuous percolation of water from the ground. *Baudi* is sometimes provided with an outlet and is covered with roof to protect the water. Water from a *baudi* is primarily used for drinking.

Baudi in Himachal Pradesh

Naula. *Naula* is a stone-lined tank that catches dripping water from springs. It is primarily found on the hill slopes in the lesser Himalayan region of Kumaon in Uttarakhand. Water from a *naula* is used to meet the domestic water needs of the local communities. *Naula* looked like a temple from the outside and is equally regarded as such.

Naula in Uttarakhand

This is evident in the fact that a number of traditional customs like weddings and *namkaran* (naming ceremony) are linked with it. For example, in Kumaon, a new bride on reaching her husband's home will first offer a ritual prayer at the village *naula*. *Naula* have small entrance to prevent animals from entering it and also to ensure that only one person entered it at a time.

Southern India

Panam Keni. *Panam keni* is a type of well used by the *Kuruma* tribes of Wayanad in Kerala. Wooden cylinders are made by soaking the lower stems of the native toddy palms in water for a long time. As the core of the palm rots away, only the hard outer layer remains. The resultant palm cylinder, measuring four feet in diameter as well as depth, is then immersed in groundwater springs located in fields and forests. *Panam keni* is used by the community as a source of drinking water. Being a shallow well, it does not require a rope, pulley or pump to lift the water out. One can just scoop the water out from the well with utensils.

Panam Keni in Kerala

Suranga. *Suranga* is a narrow horizontal tunnel, barely two-and-a-half feet wide and just over five-and-a-half feet high, dug into laterite hills until a water spring is found. It is found primarily in northern Kerala and southern Karnataka. A typical *suranga* can run from anywhere between 30 meters to 300 meters into a hill. As water percolates through rock and flows into the tunnel, it is carefully channelised in a narrow stream to a small mud reservoir, built near the tunnel. *Surangas* have been losing popularity as borewells are much cheaper to dig. As their popularity waned, a growing number of *suranga* have been abandoned and some of them have even caved in over time.

Suranga in Karnataka

Eri and Oorani. *Eris,* which dates back to the time of the Cholas, are a series of cascading tanks or reservoirs contained behind earthen bunds or embankments. They are found primarily in Tamil Nadu and are used for irrigation. Each *eri* is designed to allow excess water to flow out after reaching full capacity. As such, excess water flows from one *eri* to the next one in the series. Many *eris* are still in existence today. As compared to *eris*, *ooranis* are much smaller and shallower. And unlike *eris*, rainwater harvested in *ooranis* are used primarily for drinking.

Eri in Tamil Nadu

Oorani in Tamil Nadu

II. Structural Measures: Modern

Borewells and Tubewells. These are vertical drilled wells bored into an underground aquifer to extract water for various purposes. Borewell is now perhaps the most common source of water in urban India. It typically draws water from "confined deep aquifers," i.e. rock layers deep underground where water is trapped under pressure between the cracks of rocks. These aquifers are formed over many years, sometimes even centuries, due to water percolating down the rock layers. In cities, heavy machinery is used to dig borewells up to depth of 1,800 feet. India now has around 33 million borewells, making the country the largest user of groundwater in the world.

A borewell in Chitradurga in Karnataka

Rice farmers irrigating from a shallow well to complement irrigation water from the Nagarjuna irrigation scheme in Krishna river basin, Andhra Pradesh

Water Recycling. Water recycling, also known as water reclamation, is the process of treating wastewater and reusing it. The wastewater will undergo different filtration processes depending on the purpose. Modern water recycling units use a combination of membrane filtration for the removal of solids, and biological treatment for removing organic and oxidisable matter, combined into a single system called a Membrane Bioreactor (MBR). Water recycling has generated growing interest in India. A 2022 report by NITI Aayog observed that India's urban areas generated 72,368 million litres per day (MLD) of wastewater as of 2021. Of this, only 20,236 MLD or 28 per cent are treated by the country's 1,093 operational sewage treatment plants (STPs). In other words, 72 per cent of India's urban wastewater remained untreated and they are discharged into rivers, ponds, lakes, etc. As such, there is an urgent need to scale up India's urban wastewater recycling capacity especially in the face of growing urban population and water scarcity. The country's urban population was 483 million or 35 per cent of its total population in 2020. This was projected to increase to 675 million or 43 per cent of the country's population by 2035. And by 2050, India's urban population could reach 877 million or 50 per cent of the country's population. Meeting the daily water requirements of this growing urban population requires an increase in India's wastewater recycling capacity.

The 318 MLD capacity Coronation Pillar sewage treatment plant in New Delhi

The 45 MLD Tertiary Treatment Reserve Osmosis (TTRO) plant in Chennai

Seawater Desalination. Seawater desalination is a process in which salt and other constituents are removed to produce pure water. The principal desalination methods fall into two categories: thermal processes and membrane processes. Thermal treatment uses heat to evaporate the water, leaving behind the dissolved salts, or waste stream, and separating it from pure water. Membrane processes use reverse osmosis and high pressure to force saltwater through very fine, porous filters that retain the salts, leaving pure water on one side of the membrane and the waste stream on the other side. Tamil Nadu is at the forefront of deploying desalination plant in India. India's first desalination plant, the 100 MLD Minjur desalination plant, opened in Chennai in 2010. The plant costs Rs. 500 crore to build. Since then, Chennai has increased the number of desalination plants in the city and construction of a fourth plant having 400 MLD capacity is currently underway. Meanwhile, Gujarat has also opened a 100 MLD plant at Dahej in 2021. And at least four more plants are in the pipeline at Kutch (100 MLD), Dwarka (70 MLD), Gir-Somnath (30 MLD), and Bhavnagar (70 MLD).

The 100 MLD seawater desalination plant in Dehej, Gujarat

The 100 MLD Minjur desalination plant in Chennai, Tamil Nadu

Cloud Seeding. Cloud seeding is a weather modification technique aimed at enhancing precipitation from clouds. It involves manipulating existing clouds to try and help them produce more rain or snow. This is done by firing small particles (usually silver iodide) into clouds. Water vapour gathers around the particles and eventually falls as precipitation. India has been experimenting with this technique at least since the 1950s. The experiments are carried out primarily by the Pune-based Indian Institute of Tropical Meteorology (IITM). In recent years, a number of states in India have shown interests in pursuing cloud seeding to address their water problems. Karnataka for example has carried out cloud seeding exercise in 2017 under a programme called *Varshadhare*. The exercise was deemed to be successful and was repeated several times since.

Cloud seeding plane in Karnataka

III. Non-structural Measures: Nature-based Solutions

Wetland Restoration. Wetland restoration is the manipulation of a former or degraded wetland's physical, chemical, or biological characteristics to return its natural functions. Restoration practices include re-establishment or the rebuilding a former wetland; and rehabilitation or repairing the functions of a degraded wetland. In addition to restoring compromised wetlands, voluntary protection of naturally occurring wetlands is a valuable part of voluntary wetland restoration and protection. Besides protecting surrounding areas from flooding by absorbing a significant amount of water and temporarily storing it, wetlands are also valuable sources of water during periods of drought. In 2019, India identified 130 wetlands for priority restoration over the next five years. The highest number of such identified wetlands are in Uttar Pradesh (16) followed by Madhya Pradesh (13), Jammu & Kashmir (12), Gujarat (8), Karnataka (7), and West Bengal (6). Each of these wetlands will be restored under the National Plan for Conservation of Aquatic Ecosystems (NPCA).

Cleaning the Ansupa Lake, the only freshwater lake of Odisha

Afforestation. Every tree in the forest is a fountain, sucking water out of the ground through its roots and releasing water vapor into the atmosphere through pores in its foliage. In their billions, they create giant rivers of water in the air – rivers that form clouds and create rainfall hundreds or even thousands of kilometers away. But continued deforestation risk drying up these aerial rivers and the lands that depend on them for rain. A growing body of research suggests that this hitherto neglected impact of deforestation could in many continental interiors dwarf the impacts of global climate change.

Afforestation programme in Manipur

India is currently implementing three major schemes for the development of forest areas namely National Afforestation Programme (NAP), Green India Mission (GIM), and Forest Fire Prevention and Management

(FFPM). While NAP is being implemented for afforestation of degraded forest lands, GIM is implemented to protect, restore, and enhance India's forest cover and FFPM is implemented for the purpose of forest fire prevention and management.

IV. Non-structural measures: Policies

National Water Policy (NWP). NWP is formulated by the Ministry of Water Resources of the Government of India to govern the planning and development of water resources and their optimum utilization. The first NWP was adopted in September, 1987. It was reviewed and updated in 2002 and later in 2012. The objective of the NWP 2012 gave a number of recommendations for conservation, development, and improved management of water resources in India.

Jal Shakti Abhiyan (JSA). Launched in 2019 in 1,592 water stressed blocks in 256 districts, JSA is a campaign to promote water conservation and water resource management by focusing on accelerated implementation of five targeted interventions namely water conservation and rainwater harvesting, renovation of traditional and other water bodies, reuse of water and recharging of structures, watershed development, and intensive afforestation. These water conservation efforts are supplemented with special interventions including the development of Block and District water conservation plans, promotion of efficient water use for irrigation, and better choice of crops.

Jal Jeevan Mission (JJM). Launched in 2019, JJM aimed to provide functional household tap connection to every rural household by 2024. As of 21 December 2022, more than 10.76 crore (55.62 per cent) of rural households in 125 Districts and 1,61,704 villages have been provided with tap water connection in adequate quantity and of prescribed quality on regular basis. Every rural households in four states - Goa, Telangana, Gujarat, Haryana - and three Union Territories - Puducherry, Daman & Diu and Dadra & Nagar Haveli, Andaman & Nicobar Islands – now has provision of tap water supply. Meanwhile, Punjab (99.93 per cent), Himachal Pradesh (97.17 per cent), and Bihar (95.76 per cent) were on the verge of doing so.

Atal Mission for Rejuvenation & Urban Transformation 2.0 (AMRUT 2.0). Launched in 2021, AMRUT 2.0 aimed to provide universal coverage of water supply through functional taps to all households in all the statutory towns in India and coverage of sewerage/septage management in 500 cities covered in first phase of the AMRUT scheme. AMRUT 2.0 also aimed to promote circular economy of water through the development of City Water Balance Plan (CWBP) for each city. CWBP focuses on recycle/reuse of treated sewage, rejuvenation of water bodies and water conservation.

Atal Bhujal Yojana (ABY). Launched in 2019. The scheme aimed to improve the management of groundwater resources in select water stressed areas in identified states namely Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh.

Pradhan Mantri Krishi Sinchayee Yojana (PMKSY). Launched in 2015. The scheme aimed to achieve convergence of investments in irrigation at the field level; expand cultivable area under assured irrigation; improve on-farm water use efficiency to reduce wastage of water; enhance the adoption of precision-irrigation and other water saving technologies (More crop per drop); enhance recharge of aquifers and introduce sustainable water conservation practices by exploring the feasibility of reusing treated municipal waste water for peri-urban agriculture and attract greater private investment in precision irrigation system.

National River Conservation Plan (NRCP). Launched in 1995. The plan aimed to reduce the pollution load in rivers through implementation of various pollution abatement works, thereby improving their water quality.

Namami Gange. Launched in 2014. Namami Gange aimed to rejuvenate the Ganga River and its tributaries. The scheme was extended till 31 March 2026.

National Plan for Conservation of Aquatic Eco-systems (NPCA). Launched in 2015. The scheme was the result of a merger between the National Wetlands Conservation Programme (NWCP) that was launched in 1986 and the National Lake Conservation Plan (NLCP) that was launched in 2001. It aimed to conserve and restore wetlands to improve their water quality, biodiversity, and ecosystems.

Amrit Dharohar. Announced in 2023. The scheme aimed to protect vital wetlands which sustain aquatic biodiversity and will be implemented over the next three years.

Sea-level Rise

According to the Intergovernmental Panel on Climate Change (IPCC), global mean sea level is rising and accelerating due to a combination of melt water from glaciers and ice sheets and thermal expansion of seawater as it warms. Global mean sea level has risen from 0.05 inch per year during 1901-1990 to 0.08 inch per year during 1970-2015 to 0.12 inch per year during 1993-2015, and to 0.14 inch per year during 2006–2015. In all, global mean sea level has risen about 8-9 inches since 1880. Projections indicated that even on the pathway with the lowest possible greenhouse gas emissions and warming i.e. 1.5°C, global mean sea level would rise at least 12 inches above 2000 levels by 2100. Sea level rise matters to India. The Ministry of Earth Sciences (MoES) estimated in a 2020 report that the North Indian Ocean has risen by 0.04-0.06 inch per year during 1874-2004. But that has accelerated to 0.12 inch per year from 1993-2017. Continued increase in the level of the North Indian Ocean did not portent well for India's coastal states and cities.

A 2018 assessment by the Chennai-based National Centre for Coastal Research (NCCR) found that from 1990 to 2006, about 33 per cent of India's coastline experienced varying degree of coastal erosion. West Bengal remained the worst affected states in India as 63 per cent of its coastline has experienced varying degree of erosion. The state was followed by Puducherry (57 per cent), Kerala (45 per cent), and Tamil Nadu (41 per cent) respectively. Furthermore, a 2022 analysis by RMSI, a global risk management firm, revealed that by 2050, sea level rise will affect a number of critical infrastructures in Mumbai, Kochi, Mangalore, Chennai, Vishakhapatnam, and Thiruvananthapuram. That translated to 998 buildings and 24 kilometers of road in Mumbai. And during the high tide, that number could increase to 2,490 buildings and 126 kilometers of road. In Chennai, five kilometers of road and 55 buildings will be affected. In Kochi, 464 buildings will be affected and the number will increase to 1,502 during high tide. In Thiruvananthapuram, 349 buildings will be affected by sea-level rise by 2050 and that number will increase to 387 during high tide. In Visakhapatnam, 206 buildings and 9 kilometers of road network are likely to be affected.

Adaption Measures	
Structural Measures: Modern	Seawalls, Groynes, Geotextile tube.
Non-structural Measures: Nature-based solutions	Mangrove plantation, Seagrass preservation.
Non-structural Measures: Policies	Coastal Regulation Zones (CRZ); Mangrove Initiative for Shoreline Habitats and Tangible Incomes (MISHTI).

I. Structural Measures: Modern

Seawall. Seawalls are hard engineered structures that are built parallel to the shore. They are designed to resist storm surges, coastal flooding, and coastal erosion. The physical form of seawalls are highly variable – they can be vertical or sloping - and they are constructed from a wide variety of materials such as concrete, masonry, sheet piles, etc. In India, seawalls are increasingly seen as a solution to myriad problems such coastal erosion, coastal flooding, storm surges, etc. A number of coastal states have For example, Kerala has begun constructing a seawall along a section of its coast. Chellanam, a coastal fishing village located on the outskirt of Kochi, has long bore the brunt of erosion. In August 2022, Pinarayi Vijayan, the Chief Minister of Kerala, inaugurated a Rs. 344 crore project to save coastline of Chellanam. The project will cover 10 kilometer of shoreline in two phases. The first phase measuring 7.2 kilometers has been completed.

Tetrapod seawall in Kerala

Seawall in Puducherry

Seawall in Mumbai

Groynes. Groynes are narrow, shore-perpendicular hard structures designed to interrupt longshore sediment transport by trapping a portion of the sediment that would otherwise be transported alongshore. By doing so, groynes help to build and stabilize the beach environment. Groynes are normally built on exposed and moderately exposed sedimentary coastlines to address erosion hazards. They can be constructed from a wide variety of materials including rock armour, concrete, dolos, tetra-pods, steel piling and hardwood timber. Fosters beach widening, which helps maintain an attractive beach environment that is valuable for recreation and tourism. This is particularly the case when applied along with beach nourishment.

Groyne in Tamil Nadu

Geo-textile Tube. Geotextile tubes are large, tube-like bags made of high-strength and permeable woven geotextiles and they are used in many civil engineering and erosion control projects like embankments, retaining walls, reservoirs, bank protection and stabilization, as well as coastal erosion control. Geotextile tubes are typically filled with sand and sometimes covered with gabions - a wire box filled with small rocks – and are placed along shorelines and beaches and they are considered good alternatives for the conventional hard coastal structures. A number of coastal states in India including Andhra Pradesh, Orissa, and Kerala have deployed geotextile tubes to prevent coastal erosion.

Installing geotextile tube along Odisha's coast

II. Non-structural Measures: Nature-based Solutions

Mangrove Plantation. Mangroves are a group of trees and shrubs that live in the coastal intertidal zone i.e. the shore between high and low tide where land and sea meet. Mangroves reduce waves and storm surges, and serve as a first line of defense against flooding and erosion. The aerial roots of mangrove forests retain sediments thereby stabilizes the soil of intertidal areas and reduces erosion. Studies have shown that mangroves can reduce up to 66 per cent of wave energy in the first 100 meters of forest width. According to *India State of Forest Report 2021*, the current mangrove cover in the country is estimated at 4,992 square kilometer or 0.50 per cent of the country's total geographical area. "Very Dense Mangrove" comprises

1,481 square kilometer (29.67 per cent) of the total mangrove cover. "Moderately Dense Mangrove" is 1,481 square kilometer (29.67 per cent) while "Open Mangroves" constitute and area of 2,036 square kilometer (40.78 per cent). There has been a net increase 17 square kilometers of India's total mangrove forest as compared to 2019. This increase however is marginal given that India has lost 40 per cent of its mangrove forest in the last century.

Mangrove forest in the Sundarbans

Mangrove forest in Karnataka

Seagrass Preservation. Seagrasses are flowering plants with long ribbon-like leaves that often grow in the sea in lush underwater meadows. These plants protect coastal areas from erosion and flooding by dissipating the hydrodynamic energy through their submerged canopies or structural complexity. They also absorb carbon from the atmosphere up to 35 times faster than tropical rainforests, stores 10 per cent of the annual ocean carbon storage across the globe and locks up that carbon in sediments. Seagrasses also provides sanctuary to many marine wildlife. Seagrasses occur all along the coastal areas of India. The main coastal areas with rich seagrass meadows are Palk Bay and Gulf of Mannar (14 species), Andaman and Nicobar Islands (12 species), Lakshadweep Islands (10 species), Odisha (8 species), and Gujarat (8 species). Greater protection of these seagrasses will enable India's coastal areas to adapt to the impact of climate change such as sea level rise and storm surges better.

Seagrass off the Andaman and Nicobar Islands

III. Non-structural Measures: Policies

Coastal Regulation Zones (CRZ). Under Section 3 of the Environment Protection Act of 1986, India issued its first CRZ notification in February 1991 in order to regulate anthropogenic activities in the coastal areas. Specifically, the notification demarcated an area of up to 500 metres from the high tide line (HTL) all along the coast as CRZ. CRZ is further classified it into four categories (CRZ I, CRZ II, CRZ III and CRZ IV) depending on their land use or sensitivity and regulated developmental activities in the areas. Two more notifications are promulgated in 2011 and 2019 respectively. These notifications aimed to classify the coastal areas into different zones and to manage the activities in an integrated manner.

Mangrove Initiative for Shoreline Habitats and Tangible Incomes (MISHTI). Announced in 2023. Although details about the scheme remained sketchy, it will aim to promote mangrove plantation along the coastline and on salt pan lands.

Agricultural Systems

India is one of the world's leading agricultural nations. The country's agricultural land as a share of total land area is 60.2 per cent as of 2020. India has two major cropping seasons - *Kharif* and *Rabi*. *Kharif* crops are sown in the summer during the monsoon rainy/season and are harvested in September and October. Rice, coarse cereals, maize, pulses, groundnut, soyabean, cotton, sugarcane, etc. are the major *Kharif* crops. *Rabi* crops on the other hand are sown during winter and are harvested in spring. Wheat, mustard, barley, gram, peas, chickpea, etc. are the major *Rabi* crops. Agriculture is a key sector for India's economy. According to the *Economic Survey 2021-22*, an annual document of the Ministry of Finance, Government of India, 232.7 million out of India's total workforce of 535.3 million are engaged in the agriculture sector as of 2020. In other words, around 44 per cent of India's total workforce is engaged in the agriculture sector. The agriculture sector also accounted for 20.2 per cent of India's GDP in 2021. Most notably, from 1 April 2021 to 31 March 2022, India's agriculture exports reached a historic high of USD 50 billion. During that period, India recorded its highest ever exports for staples like rice (USD 9.65 billion), wheat (USD 2.19 billion), sugar (USD (4.6 billion), and other cereals (USD 1.08 billion). Export of marine products, at USD 7.71 billion, was also the highest ever. However, agricultural production in India is becoming increasingly vulnerable to climate change. In an attempt to mitigate the impact of climate change on its agricultural sector, India has undertaken the following measures.

Adaption Measures	
Traditional	Natural farming, Traditional flood-tolerant rice variety (pottiya)
Modern	Climate-Smart Agriculture (CSA) - Solar-powered irrigation system; Direct Seeding of Rice (DSR); System of Rice Intensification (SRI); Heat tolerant variety of wheat, flood tolerant rice variety (Ranjit Sub-1, Bahadur Sub-1, Swarna Sub-1), Heat-tolerant wheat variety (DBW 187, DBW 222), Flood-tolerant rice variety (Ranjit Sub-1, Bahadur Sub-1, and Swarna Sub-1); Salt water tolerant rice variety (CSR 30, CSR 36), Salt water tolerant wheat variety (KRL 1, KRL 2, KRL 3, KRL 4, KRL 19, KRL 210, KRL 213), Salt water tolerant mustard variety (CS 54, CS 56, CS 58); Hydroponics.
Policy	Bharatiya Prakritik Krishi Paddhati Programme (BPKP), Paramparagat Krishi Vikas Yojana (PKVY).

I. Natural Farming

Natural farming is a chemical-free/traditional farming method. It is also known by various other names including Zero Budget Natural Farming, *Prakrithik Krishi*, Cow-based Natural Farming, *Shashwat Kheti*, Chemical Free Agriculture, etc. It has been reported that just 5.9 million hectares or four per cent of the India's net-sown area is currently under organic and natural farming. And there are 4.43 million organic farmers. Efforts are now underway to upscale the practice.

One such effort is the Bharatiya Prakritik Krishi Paddhati Programme (BPKP). BPKP is a sub-component of the Paramparagat Krishi Vikas Yojana (PKVY), a centrally sponsored scheme that was launched in 2015. BPKP aimed to promote traditional indigenous farming practices that reduce externally purchased inputs. It is largely based on on-farm biomass recycling with major stress on biomass mulching, use of on-farm cow dung-urine formulations, periodic soil aeration, and exclusion of all synthetic chemical inputs. BPKP programme has been adopted by various states including Andhra Pradesh, Karnataka, Himachal Pradesh, Gujarat, Uttar

Pradesh, and Kerala. Studies have reported the effectiveness of natural farming in terms of increase in production, sustainability, saving of water use, improvement in soil health and farmland ecosystem. It is considered as a cost-effective farming practices with scope for raising employment and rural development.

Manure is a key component of natural farming

II. Climate-Smart Agriculture (CSA)

Climate change's negative impacts are already being felt across agricultural systems worldwide in the form of increasing temperatures, weather variability, shifting agroecosystem boundaries, invasive crops and pests, and more frequent extreme weather events. That has reduced crop yields and the nutritional quality of major cereals. It has also lowered livestock productivity. Substantial investments in adaptation will therefore be required to maintain current yields and quality of food crops. CSA is an approach for transforming and reorienting agricultural systems to support food security under the new realities of climate change. CSA, as it is currently practiced in India, include the following:

Solar-powered Irrigation System. As of 2022, India has over 30 million agricultural irrigation pumps of which 20.3 million are grid-connected, 2.7 million are solar pumps, and 8.8 million are diesel pumps. Unreliable electric supply and high fuel costs have made solar irrigation pumps an attractive alternative to grid-connected and diesel ones. Solar irrigation can enable uninterrupted supply of clean electricity and curb rising electricity demand from the agricultural sector. Also, grid-connected solar can become an additional source of revenue for farmers if they can get attractive buy-back tariffs. A scheme launched in 2019, PM Kusum Yojana, aimed to increase the deployment of solar agricultural irrigation pumps across India by 2022. Specifically, component A of the scheme aimed to install 10,000 MW of solar capacity; component B aimed to install two million standalone solar-powered agricultural irrigation pumps; and component C aimed to convert 1.5 million grid-connected agricultural irrigation pumps into solar ones. However, the pace of implementation of the scheme has been affected significantly by the COVID-19 pandemic. As such, the scheme was extended till 31 March 2026.

A farmer in India with solar-powered irrigation system

Direct Seeding of Rice (DSR). DSR is the sowing of rice seeds directly into the field, as opposed to the traditional method of growing seedlings in a nursery and then transplanting them into flooded fields. Compared to the conventional Puddled Transplanted Rice (PTR) technique, DSR delivers faster planting and maturing, conserves scarce resources like water and labour, is more conducive to mechanization, and reduces emissions of greenhouse gases that contribute to climate change. Mechanized DSR also creates avenues for employment through new service provisions and is less labour intensive and free from drudgery, hence more attractive to youth and women farmers. States like Punjab aimed to bring around 30 lakh acres of agricultural lands under DSR technique, as compared to the 15 lakh acres that are currently sown using DSR technique in the state. To encourage farmers to sow paddy through DSR, the state government has already decided a Rs. 1,500 per acre incentive to farmers. A sum of Rs. 450 crore has been earmarked to provide incentive to farmers for promotion of less water-consuming and cost-effective DSR technology.

DSR Machine

DSR in Punjab

System of Rice Intensification (SRI). SRI, which originated in Madagascar in the 1980s, is an agro-ecological methodology for increasing the productivity of irrigated rice. It involves early transplanting of young single seedlings (8-15 days old) wide apart (often at 25 centimetersx25 centimeters) instead of the conventional method of transplanting multiple mature seedlings close together. SRI does not depend on continuous flooding of rice fields as it only requires the fields to be wet.

The application of biomass (compost, manure, green manure, etc.) to build healthy and productive soils is also a recommended practice. SRI has resulted in increased grain yields; better grain filling and grain quality; better resistance to drought, storm damage and flooding due to larger/healthier root structure; improved pest/disease resistance; reduced seed requirements; water conservation; reduced production costs; reduced need for pesticides and agrochemicals; reductions in methane and arsenic levels achievable through reduced flooding of rice fields, etc. In addition to irrigated rice, SRI principles have been also applied to rainfed rice and other crops such as wheat, sugarcane, finger millet, pulses, etc. When SRI principles are applied to other crops, it is referred to as System of Crop Intensification (SCI). SRI is now adopted widely in India.

In SRI, seedlings are planted in lines further apart than in traditional methods

Heat Tolerant Wheat Variety. India's wheat production is vulnerable to rising temperature. The record-breaking heatwave that struck northwest India in 2022 has caused wheat crops to shrivel and that has adversely affected production. As a result, India imposed a ban on all wheat exports that year. To mitigate against rising temperature, India has developed heat tolerant variety of wheat. For example, the Haryana-based Indian Institute of Wheat and Barely Research (IIWBR) has developed heat tolerant wheat varieties including DBW 187 and DBW 222. During the 2021-2022 cropping season, these wheat varieties have demonstrated heat tolerance with yield gains of 3.6 per cent and 5.4 per cent respectively. To promote their use, IIWBR has signed 250 Memorandum of Agreements (MoAs) for DBW 187 and 191 MoAs for DBW 222 with private companies for seed production. IIWBR has also distributed more than 2,500 quintal seeds of DBW 187 and 1,250 quintal seeds of DBW 222 during the 2021-2022 cropping season.

Heat tolerant rice variety

Flood Tolerant Rice Variety. Flood-prone states like Assam faced the risks of declining food production and hence food insecurity due to floods. An estimated 4,75,000 hectare or 16.9 per cent of the state's net sown area are chronically flooded every year. Farmers who plant traditional varieties of rice therefore struggled with low yields and crop damage. To mitigate against the impact of flood on rice production, scientists at the Assam Agricultural University (AAU) has developed flood tolerant varieties of rice such as Ranjit Sub-1, Bahadur Sub-1, and Swarna Sub-1. That has helped farmers in Assam cope with the impact of flooding. Meanwhile, in Odisha, farmers have resorted to planting a flood-tolerant traditional rice variety called *pottiya*. *Pottiya* can reportedly withstand floods for up to two months. Even though these rice varieties have been cultivated for generations, farmers have increasingly shifted away from it in favour of hybrid rice varieties as they promised higher monetary returns. However, with the monsoon becoming more unpredictable, the high input cost of hybrid varieties and their inability to tolerate floods have made their cultivation increasingly risky. Hence the shift towards traditional rice varieties.

Flood tolerant of rice variety

Salt Water Tolerant Crop Variety. A soil may be rich in salts because the parent rock from which it was formed contains salts. Sea water is another source of salts in low-lying areas along the coast. A very common source of salts in irrigated soils is the irrigation water itself. Most irrigation waters contain some salts. After irrigation, the water added to the soil is used by the crop or evaporates directly from the moist soil. The salt, however, is left behind in the soil. If not removed, it accumulates in the soil. Salty groundwater may also contribute to salinization. When the water table rises (e.g., following irrigation in the absence of proper drainage), the salty groundwater may reach the upper soil layers and, thus, supply salts to the rootzone. Most crops do not grow well on soils that contain salts. One reason is that salt causes a reduction in the rate and amount of water that the plant roots can take up from the soil. Also, some salts are toxic to plants when present in high concentration. It has been estimated that salinity, sodicity, and associated problems diminished the productivity of nearly 6.73 million hectares of agricultural lands in India resulting in an annual loss of about 17 million tonnes of food grains, oilseeds, and cash crops valued at Rs. 23,000 crore. Salt tolerant varieties of rice, wheat, and mustard crops are therefore currently being grown on about 1.19 million hectares of agricultural lands every year in India. Examples of such crops include rice (CSR 30, CSR 36), wheat (KRL 1, KRL 2, KRL 3, KRL 4, KRL 19, KRL 210, KRL 213), mustard (CS 54, CS 56, CS 58), etc.

Salt tolerant rice variety

Salt tolerant wheat variety

III. Hydroponics

Hydroponics is the technique of growing plants using a water-based nutrient solution rather than soil, and can include an aggregate substrate, or growing media, such as vermiculite, coconut coir, or perlite. Hydroponics has been recognized as a viable method of producing vegetables including tomatoes, lettuce, cucumbers and peppers, and ornamental crops such as herbs, roses, freesia, and foliage plants. Given the need for more sustainable agriculture, there has been a rise in eco-friendly start-up companies in India that uses hydroponic technology to produce crops on a large scale with a technique known as "vertical farming." Vertical farms are buildings filled with countless levels of hydroponic systems (or nutrient film style planters), growing different crops in an indoor, controlled temperature environment. They include Nutrifresh (Pune), Urban Kisaan (Hyderabad), Varshney Hydrofarms, Ela Sustainable Solutions (Cochin), Brio Hydroponics (Ahmedabad), etc. While hydroponic technology may never replace conventional farming, it is breaking the paradigm of food production; we may see a new generation of modern farmers building green walls inside their houses or community centers to feed families with fresh produce grown all year round.

Urban Kisaan's hydroponic farm in Hyderabad

Urban Kisaan's hydroponic farm in Hyderabad

Conclusion

Adaptation against climate change is increasingly becoming critical. While mitigation involve cutting the pace of global greenhouse gas emissions and slowing down warming, adaptation is essential to save lives and livelihoods in the short to medium term. Adaptation also helps in building long-term resilience to the impacts of climate change. India's climate is highly diverse. It ranges from the subfreezing Himalayan winters up north to the tropical climate of the south. Also while states in eastern India like Assam and West Bengal experienced extremely damp, rainy, and humid conditions, those in the western part of the country like Rajasthan and Gujarat are part of the arid Great Indian Desert. The extraordinary variety of climatic regions in India has resulted in multiplicity of extreme weather events including heatwave, flood, drought, and tropical cyclone. As a result of this, communities across India have developed long and rich traditions of adaptation. This is evidenced in the numerous types of vernacular architecture, water conservation systems, agricultural practices, etc. These traditional adaptation methods are developed over the centuries and are often transmitted orally from generation to generation. Overtime, they become an integral part of the cultural heritage of many communities in India. The transmission of traditional knowledge across generations is fundamental to resilience in the face of climate change. Traditional knowledge can thus make a significant contribution to adaptation and they should be revived where feasible.

However, in the current times, much of the adaptation measures involve 'hard' or 'grey' infrastructure. Gray infrastructure is built structures and mechanical equipment such as dams, reservoirs, embankments, water treatment plants, canals, sea walls etc. However, the limitations of such infrastructure in mitigating against the impact of extreme weather events has been demonstrated time and time again. The failure of embankments and even dams in controlling floods in vulnerable states like Assam and Bihar is a case in point. That has led to growing interests in green infrastructure. Green infrastructure refers to the natural vegetative systems and green technologies that collectively provide society with a multitude of economic, environmental, health, and social benefits. This includes urban forests, wetlands, green roofs and green walls, parks, gardens, urban agriculture, floodplains, mangroves, sea grass, etc. Green infrastructure in turn is an integral part of nature-based solutions. A hybrid approach that combine long-standing traditional Indian knowledge, green infrastructure, and gray infrastructure could enable India to adapt to extreme weather events brought about by climate change.

About the VIVEKANANDA INTERNATIONAL FOUNDATION

The Vivekananda International Foundation is an independent non-partisan institution that conducts research and analysis on domestic and international issues, and offers a platform for dialogue and conflict resolution. Some of India's leading practitioners from the fields of security, military, diplomacy, government, academia and media have come together to generate ideas and stimulate action on national security issues.

The defining feature of VIF lies in its provision of core institutional support which enables the organisation to be flexible in its approach and proactive in changing circumstances, with a long-term focus on India's strategic, developmental and civilisational interests. The VIF aims to channelise fresh insights and decades of experience harnessed from its faculty into fostering actionable ideas for the nation's stakeholders.

Since its inception, VIF has pursued quality research and scholarship and made efforts to highlight issues in governance, and strengthen national security. This is being actualised through numerous activities like seminars, round tables, interactive dialogues, Vimarsh (public discourse), conferences and briefings. The publications of VIF form lasting deliverables of VIF's aspiration to impact on the prevailing discourse on issues concerning India's national interest.

VIVEKANANDA INTERNATIONAL FOUNDATION
3, San Martin Marg, Chanakyapuri, New Delhi – 110021
Phone: +91-11-24121764, 24106698
Email: info@vifindia.org,
Website: https://www.vifindia.org
Follow us on twitter@vifindia