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Climate Resilience in Water Resource Management in India

A Conceptual Framework for Action

Authors

Neha Lakhwan, Dr Girija K Bharat & Dr S K Sarkar

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This Discussion Paper presents the findings and recommendations based on the available data in public domain during the study period. The authors recognize the complexity of data availability and its dynamic nature with time and hence the recommendations should be read as the indicative information serving as a guiding platform for formulating specific action with further updated knowledge and data.

For more information

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1.0 Introduction

The complex landscape of water resources of India is characterized by extreme variability. The two major sources of water for the country are the monsoon rains which bring most of the annual precipitation and the groundwater reserves. However, both the sources are not sustainable given the unpredictability of monsoon and over-abstraction of groundwater beyond its recharge capacity. Additionally, the looming spectre of climate change brings in more complexity, further stressing the water resources of the country.

The signatures of climate change on global water resources have been evident. The urgency is growing for developing countries such as India, where the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC, 2022) highlights the accelerating intensity and frequency of extreme weather events in India, impacting water availability and quality. It is thus important to understand the threat posed by the changing climate which has multi-faceted and far-reaching impact on the water resources of India. Some of these key threats include - rising temperature- which leads to increasing evapotranspiration, changes in precipitation pattern, accelerated glacial melt causing glacial lake outburst flood (GLOF); erratic monsoon which intensify both floods and droughts; sea level rise which is a threat for coastal areas of India (MOES, 2022)(IISC, 2020). These threats significantly impact water security, thus posing immense challenges for agriculture, industry, domestic, environmental needs and takes a toll on the public health, livelihoods, and essential ecosystem services.

For a sustainable future, climate resilient water management strategies are not just an option but an imperative. Building a climate resilient future requires adoption of multi-pronged approach inclusive of principles of integrated water resources management (IWRM), nature-based solutions (NbS), evidence-based decision making, use of advance technologies and Internet of things (IoT) for providing best of solutions, demand management strategies, building capacity and awareness of stakeholders.

While most of these are climate change adaptation strategies, there is also a need to work on mitigation options such as energy efficiency in water and wastewater sector by optimizing pumping and treatment processes to reduce energy consumption, implementing energy recovery systems (e.g., biogas, hydropower) in water infrastructure. A few other options include – protecting and restoring natural wetland ecosystems that act as carbon sinks and use of climate smart agriculture techniques such as drip irrigation (IPCC, 2014). By implementing both adaptation and mitigation strategies, the water sector can comprehensively address the challenges posed by climate change. Adaptation measures help build resilience and ensure water security in the face of immediate impacts, while mitigation strategies contribute to long-term sustainability by reducing greenhouse gas (GHG) emissions and slowing down the progression of climate change.

By embracing innovative solutions, fostering partnerships, encouraging community participation and evidence-based decision making, India can build a climate-resilient water future. This would not only ensure water security for India but also facilitates achievement of the Sustainable Development Goal (SDG-6) and several aligned SDGs (Bharat & Dkhar, 2018).

2.0 Impact of Climate Change on Water Resources

India is a diverse land with different agro-climatic zones having varying characteristics. India has the Himalayas in the north, a long coastal line from West Bengal in the east to Gujarat in the west, dry deserts and one of the wettest places of the world, making it highly vulnerable to a changing climate. Himalayas on one side are witnessing glacial melt, while coastal areas are having the risk of sea level rise, and other parts of India are vulnerable to erratic rainfall and drought.

Increased Greenhouse gas (GHG) emissions have been linked to climate change, which in turn impacts precipitation patterns. Extreme events, such as heavy floods and prolonged dry spells, are becoming more frequent and intense due to climate change (Mohammed, 2023) (Kumar & Aujard, 2023). These changes indicate a higher risk for water resources and highlight the need for proper water resources planning and management. A study by Mall et al., 2023 indicates that important river basins in India have shown increased susceptibility to flooding and drought events, which are expected to become more frequent and severe in the future.

Some of the key extreme events that have been observed in India and are linked to climate change:

1. **Heatwaves**: These are becoming more frequent and intense, and many parts of the country are affected due to rising temperatures mainly attributed to climate change. These heatwaves also impact human health and have led to several deaths in the recent past. India has experienced an increasing number of intense and prolonged heat waves in recent decades, particularly in northern and central parts of the country (IITM, 2021).
2. **Erratic Monsoons**: One of the most common impacts of climate change is visible on monsoons. Climate change is causing alterations in the monsoon patterns, resulting in more erratic rainfall distribution across different regions of India. This is impacting agriculture, which affects the lives and livelihoods of a large population in the country.
3. **Droughts**: Due to erratic precipitation pattern and increase in evaporation rates due to higher temperatures, drought conditions are exacerbated in various regions of India. These droughts have severe consequences on water scarcity, crop failures, livestock deaths, and socio-economic challenges, particularly in rural areas where agriculture is a primary source of livelihood. Climate change has contributed to an increase in the frequency and severity of droughts in India, particularly in arid and semi-arid regions (IISC, 2019).
4. **Floods**: Floods, as mentioned earlier, are a common outcome of climate change induced intense rainfall events, often associated with cyclones and monsoon disturbances. Floods can cause loss of lives, displacement of populations, damage to infrastructure, and contamination of water sources. Climate change has led to an increase in the frequency and intensity of extreme rainfall events, resulting in severe flooding in various parts of India (MOES, 2020).
5. **Cyclones and Storm Surges**: Frequency and intensity of extreme events like cyclones and tropical storms is also increasing. These events bring strong winds along with heavy rainfall, which often leads to coastal erosion, inundation of low-lying areas, and damage to coastal infrastructure. The

Indian subcontinent has witnessed an increase in the intensity and frequency of cyclones and storm surges due to rising sea surface temperatures and sea levels (IMD, 2022).

6. **Glacial Retreat and Avalanches**: The Himalayan region is an important source of perennial rivers and with changing climate, the rates of glacial lake outburst floods (GLOF) and glacial avalanches have also increased. It largely impacts downstream communities, water resources and livelihoods.

Compound extremes, which are the worst events caused by a combination of multiple factors, have also been observed in India. The impacts of these extreme events are significant, affecting both human lives and the environment (Joo, K., 2023).

Several studies have been conducted to understand the climate change impact on precipitation and temperature in the past through trend analysis and for future projections. These studies indicate a grim future under various climate change scenarios over different parts of the country.

Assessment of Climate Change

A study by Indian Institute of Tropical Meteorology (IITM) (Kulkarni et al., 2020) highlights that in terms of precipitation, there has been a decline in the June-September rainfall by about 6% during 1951-2015, with notable decreases over the Indo-Gangetic plains and the Western Ghats. The frequency of daily precipitation extremes with rainfall intensities exceeding 150 mm per day increased by about 75% over central India. Both the frequency and spatial extent of droughts have increased significantly during 1951–2016, with the dry spells being 27% more frequent during 1981–2011 compared to 1951–1980. Climate model projections indicate an increase in the frequency, intensity and area under drought conditions by the end of the 21st century. Flash droughts due to unusually high incoming solar radiation and winds pose new challenges.

Impact on the Himalayas

Impacts of climate change are significant in the Himalayan region which is also known as the 'Third Pole' and is the source of many perennial rivers in India. According to a study by the Indian Space Research Organization (ISRO), glaciers in the Himalayan region have retreated by an average of 13% between 1976 and 2006 (Kulkarni & Karyakarte, 2014). Spatial variation in the rate of warming and precipitation pattern has a direct influence on melting of glaciers which in turn affect the hydrological cycle of these perennial rivers. The meltwater from the glaciers and snow has significant contribution to the discharge of perennial rivers in northern India, predominantly during the summer season. As glaciers melt, the volume of meltwater feeding these rivers is expected to decrease in the long run, leading to alterations in river flow patterns (Lutz et al., 2014) and this would have severe consequences for the demand in all the sectors especially downstream agriculture sector in Indo-Gangetic plains which is highly dependent on the water from these rivers. This may further increase the conflict between upper and lower riparian states. According to studies, significant impact is expected like shift in the seasonal discharge in the future (Grover et al., 2022). This impacts the glacial lakes with frequent outburst flooding leading to heavy loss of lives and properties.

Impact on wetlands

India is home to a diverse range of wetland ecosystems, which are also known as kidneys of the Earth. They play a vital role in maintaining ecological balance, providing valuable ecosystem services, and supporting the livelihoods of many communities. India has 49 designated Ramsar sites (wetlands of

international importance), covering an area of over 1.09 million hectares. These include the Sundarbans in West Bengal, Chilika Lake in Odisha, Wular Lake in Jammu and Kashmir, and Keoladeo National Park in Rajasthan. These wetlands are spread across different agro-climatic regions of India and are witnessing variable impacts of climate change. Changes in precipitation pattern and temperature are the common causes and lead to deleterious impacts such as loss of biodiversity, loss of ecosystem services, etc. Conservation of wetlands is important to ensure both adaptation and mitigation interventions to climate change. Wetlands accommodate the largest carbon stocks among terrestrial eco-systems, storing twice as much carbon as forests. Some of the key roles of wetlands in the context of climate change include carbon sequestration and storage; GHG regulation; flood control, drought mitigation and water purification; biodiversity conservation, protection and restoration; and ecosystem-based solutions.

Future Projections

A study by Woo et al. 2019 highlighted that under Representative Concentration Pathway (RCP)-4.5, the precipitation projection indicated an increase in seasonal summer precipitation over northwest India, south peninsular India, and west peninsular India in the range of 4–19% from the near-to-far futures, and a decrease of about 5% in precipitation is expected over the northeast India. While under RCP 8.5, the increase is quite higher for south peninsular India and west peninsular India while it projects decrease for northwest India. Precipitation projection shows a high spatial-temporal uncertainty. With respect to projected temperature, a study by (Salunke et al., 2023) suggests that in future, temperature will increase over the entire Indian landmass, relatively more over the north-western part of the country. It also highlights that the rate of warming would be more in winter as compared to summer.

These alterations in temperature and precipitation pattern impact the hydrological cycle. As expected, temperatures would increase, and warmer climate may lead to intensification of the hydrological cycle which in turn will cause higher rates of evaporation and increase of precipitation. Precipitation on the other hand would exhibit uncertainty both in terms of spatial and temporal patterns. These disturbances to the hydrological cycle would affect the overall water resources of the country.

3.0 Status of Water Resources in India

Climate change is projected to have significant impacts on water availability in India. Decreased glacier melt and snowfall in the Himalayan region are expected to reduce the flow of major rivers like the Ganga, Indus, and Brahmaputra, affecting water availability (Immerzeel, et al., 2010). Sea-level rise and saltwater intrusion pose threats to coastal aquifers and groundwater resources, impacting water quality and availability for coastal communities (Gopalakrishnan., K., et al., 2024).

India's water resources are unevenly distributed, and the challenges posed by climate change are exacerbating the stress on this vital resource with each passing day.

3.1 Availability of Water Resources

India has diverse water resources in the form of rivers, lakes, and groundwater aquifers, but faces significant challenges in managing and utilizing them sustainably. The country is endowed with several major river systems like the Ganga, Brahmaputra, Indus, Godavari, Krishna, and Cauvery. Groundwater is a critical resource, meeting a significant portion of the country's irrigation and domestic water needs. However,

India's growing water stress is a major concern that threatens the country's economic development, food security, and overall sustainability.

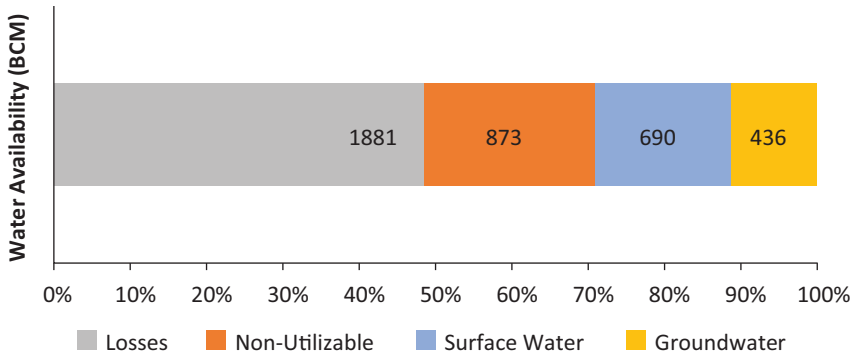

Figure 1: Water availability from total precipitation

According to the Central Water Commission (CWC, 2015), India's per capita surface water availability has decreased from around 1,816 cubic meters in 2001 to 1,545 cubic meters in 2011. Groundwater depletion is also a significant issue, with the Central Ground Water Board (CGWB, 2019) reporting that more than 30% of the country's districts are categorized as "semi-critical" or "critical" in terms of groundwater availability. Subsequent section discusses the status of various water resources in India.

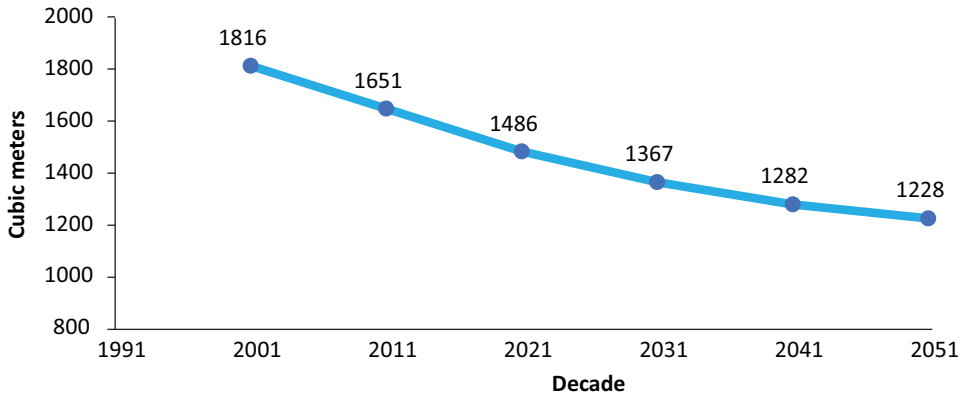

Figure 2: Change in per capita water availability over the decades

*Source: Government of India, 2009 (NCIWRD Report, 1999), *projected from 2011 census*

India receives 3880 BCM of annual precipitation, of which only 1999 BCM is available after losses. Out of 1999 BCM utilizable water is estimated to be at 1126 BCM, which includes 690 BCM of surface water and 436 BCM of replenishable groundwater (Vohra & Saurabh, 2024). The availability of water resources in India is highly dependent on the monsoon season, with around 75% of the annual rainfall occurring during the monsoon months (June to September) (MOEFCC, 2019). Out of the total rainfall, just 8% rainwater is stored in the country. As of 2021, the gross storage capacity created is only 325.455 BCM (PIB, 2021). The total storage capacity is less than 45% of the total available surface water resources potential in the country (NITI Aayog, 2021).

Water bodies and storage tanks also play an important role in ensuring water availability during non-monsoon period. The First Census of Water Bodies 2023 mentions that 38,496 water bodies (mostly small ones) have been encroached upon in India (MoJS 2024). It has been reported that India's tank irrigated

area in 1960-61 was 46.30 lakh hectares (lha), which declined to 22.05 lha in 2021-22, mostly due to encroachment and giving way to urbanization. Conserving these small to medium storage structures would help store rainwater and will also attenuate the peak discharge thereby reducing impact of flash floods.

A report by India's Fifth Minor Irrigation Census (2013-14) states that of a total of 5.92 lakh tanks and small water bodies in India, 72,853 are defunct due to poor maintenance. These all are important sources of water which have been neglected in the past (MoJS, GoI, 2017).

Another major source of water in India is groundwater, accounting for around 63% of the total irrigated area and 85% of the rural and urban domestic water requirements (CGWB, 2019). The overall stage of extraction of ground water has increased from 58% in 2004 to 63% in 2017 (CAG, 2021). In major parts of north-western and western states, the depth to the water table is generally deeper than 40 meters below ground level, indicating significant groundwater stress (CGWB, 2023). The CGWB's "Ground Water Year Book 2020-21" reports that around 63% of the monitoring wells in India showed a decline in groundwater levels compared to the previous year.

NITI Aayog has identified an indicator for SDG 6.4, which is the 'percentage annual groundwater withdrawal against net annual availability.' According to the NITI Aayog, the national target value for this indicator for the year 2030 should be 70%. Currently, there are 8 states/UTs and 202 districts in India where this indicator is already above 70%. In these 202 districts across India, the percentage of groundwater extraction ranges from 71% to 385%, indicating a wide variation in the stage of extraction (CAG, 2021).

According to the Falkenmark Water Stress Indicator, a per capita availability of less than 1,700 cubic meters indicates water stress, while below 1,000 cubic meters indicates water scarcity. India is among 31 countries facing water stress, projected to worsen by 2050. Around 600 million of the Indian population faces high to extremely high water stress[1] (WRI, 2015).

3.2 Water Quality

Concerns also exist regarding water pollution, with 351 polluted river stretches across the country due to untreated municipal and industrial wastewater discharge. The Central Pollution Control Board (CPCB) reported that around 63% of the monitored rivers in India were found to be polluted (**CPCB, 2021**). Disposal of domestic sewage from cities and towns is the biggest source of pollution of water bodies in India. According to a report by the Central Ground Water Board (CGWB), about 60% of the districts in India have issues with groundwater contamination, primarily due to the presence of fluoride, arsenic, nitrate, iron, and salinity (CGWB, 2023). Another study by the CPCB in 2018 found that 68% of the groundwater samples across India were contaminated with one or more pollutants (CPCB, 2018). NITI Aayog's Composite Water Management Index (CWMI) 2018 report states that India was placed at the rank of 120 amongst 122 countries in the water quality index, with nearly 70% of water being contaminated. Thus, both groundwater and surface water resource of India are facing water quality issues which mostly of anthropogenic origin or in some cases geogenic. Water contamination also contributes to global emissions; the contaminated effluents such as untreated sewage emits Green House Gases (GHGs) (Dohee, K., et al., 2019).

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[1] Baseline stress= withdrawals/ available supply; high stress = 40% -80%; extremely high stress>80% 3 Maps Explain India's Growing Water Risks
https://www.wri.org/insights/3-maps-explain-indias-growing-water-risks

3.3 Water Demand

Increasing water demand is another cause of concern for dwindling water resources and only supply-side strategies of augmenting the resource would not be enough to tackle the grim future situation. There is an urgent need to manage the demand side by adopting some demand management strategies including enhancing water use efficiency and wastewater management.

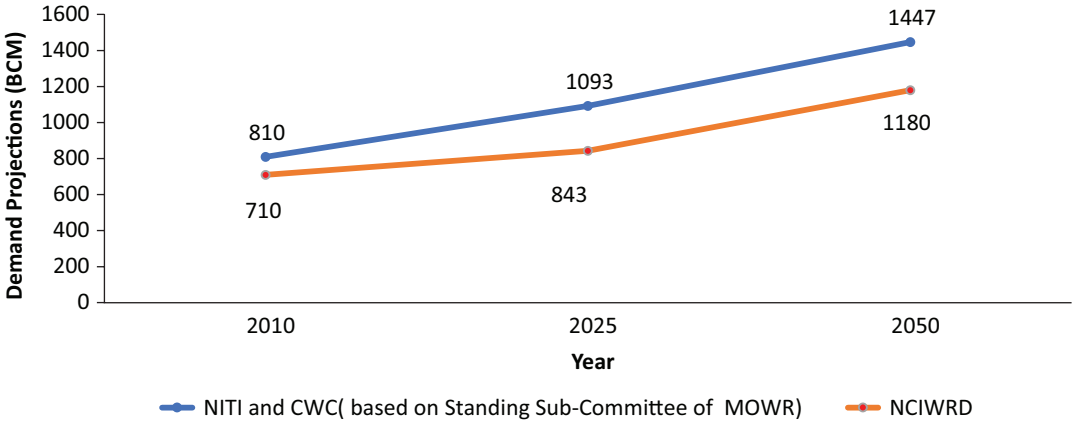


Figure 3: Projected water demand

According to a report by CWC and NITI Aayog, the total water demand in India is projected to increase from 634 BCM in 2000 to 1,093 BCM in 2025, and further to 1,447 BCM in 2050 (CWMI, 2019). NITI Aayog's CWMI 2018 report highlights that country's water demand to be twice the available supply by 2030, implying severe scarcity for hundreds of millions of people and an eventual loss in the country's GDP.

The report of Parliamentary standing sub-committee on "Assessment of Availability & requirement of Water for Diverse uses-2000" presents projected water demand in India by various demand sectors (Table 1). It is important to note here with climate change this demand is subjected to change and hence a new assessment based on latest technologies like remote sensing and Artificial Intelligence could give us a better hydrological unit-wise projections. This would further aid in regional water management strategies.

Table 1: Projected Water Demand in India (By Different Use)

Sector	Water Demand in BCM (Billion Cubic Meter)								
	Standing Sub-Committee of MOWR[2]			NCIWRD[3]					
	2010	2025	2050	2010		2025		2050	
				Low	High	Low	High	Low	High
Irrigation	688	910	1072	543	557	561	611	628	807
Drinking Water	56	73	102	42	43	55	62	90	111

[2] Report of the Standing Sub-Committee on "Assessment of Availability & requirement of Water for Diverse uses-2000"

[3] NCIWRD: National Commission on Integrated Water Resources Development

Sector	Water Demand in BCM (Billion Cubic Meter)								
	Standing Sub-Committee of MOWR[2]			NCIWRD[3]					
	2010	2025	2050	2010		2025		2050	
				Low	High	Low	High	Low	High
Industry	12	23	63	37	37	67	67	81	81
Energy	5	15	130	18	19	31	33	63	70
Other	52	72	80	54	54	70	70	111	111
Total	813	1093	1447	694	710	784	843	973	1180

Source: MOSPI, 2016

Climate change is expected to exacerbate the water supply and demand gap in India due to factors such as changes in precipitation patterns, increased evapotranspiration, and melting of glaciers. Overall, India faces complex challenges in managing its water resources, requiring sustainable practices and efficient management to address water scarcity, pollution, and unsustainable extraction practices.

4.0 Existing Policies, Programs in Water Sector viz.-a-viz. Climate Change

4.1 Policies and Regulatory Frameworks

4.1.1 Constitutional Rights

Over the years, the Hon'ble Supreme Court (SC) through various key judgments have elaborated on Right to clean drinking water under Article 14 and Article 21. In the case of *M K Ranjitsinh & Ors versus Union of India (2024)*, SC held that the people have a right to be free from the adverse effects of climate change within the ambit of Fundamental Rights (Article 14 and Article 21) (DTE, 2024). The court noted that "*Despite governmental policy and rules and regulations recognising the adverse effects of climate change and seeking to combat it, there is no single or umbrella legislation in India which relates to climate change..*". Similarly, the Directive Principles via 39(b), Article 47 puts responsibility on the state for providing access to water and related infrastructure.

4.1.2 Federal Structure

Water being a State subject, initiatives for augmentation, conservation and efficient management of water resources are primarily undertaken by the respective State Governments. In order to supplement the efforts of the State Governments, Central Government provides technical and financial assistance to them through various schemes and programmes. However, it is crucial to note that while the Union List explicitly mentions 'interstate water,' the State List uses the term 'water' without specifying 'intra-state'. Consequently, states possess full legislative authority over matters in Entry 17 of List II, even if the river source or tributaries extend into another state (ORF, 2024). Due to climate change the demand and supply gap for different sectors in water would increase leading to conflict between upper and lower

riparian states. The Inter-State River Water Disputes Act (1956), amendment to which is passed in lower house in 2019, replace the multiple tribunals set up under the 1956 Act for inter-state water dispute adjudication with a single tribunal and a set of strict timelines for decisions. The Bill is still to be tabled in the Upper House.

Under Article 243, the local governments take into account minor irrigation, water management, and watershed development as included in the list of subjects in the Eleventh Schedule, which can be transferred to *Panchayats* if the State Government so notifies in terms of the State legislation, as several States have done.

4.1.3 National Water Policy

The Central Government also formulates National Water Policy to direct activities for water management. In 1987 the National Water Resource Council (NWRC) chaired by the Hon'ble Prime Minister implemented the first National Water Policy (NWP) since then three NWP have been implemented (NWP 1987, 2002, 2012). These water policies worked in agreement with the other National Plans at the time. The first NWP in 1987 prioritised on meeting irrigation demands aiming at food security and thus focused on groundwater utilisation. The NWP 2002 prioritised on water allocations for purposes of drinking, irrigation, hydropower, ecology, industries, navigation, and other uses in that order (Kale et al., 2022). NWP 2012 introduced the concept of 'ecological needs' and this was given a high priority. The policy aimed at conservation, development, and improved management of water resources, commitment to IWRM and other environment related concerns. However, the policy also lacked in implementation on various grounds such as delay in creating River Basin Agencies/Authorities/Organizations; inadequate implementation of policy recommendations; over-optimistic estimates regarding India's annual water availability; lack of consideration for ancient water cultures, the irrigation energy nexus, etc. It also avoided on listing priorities and not due importance to diversity in geographic conditions.

In 2016, to suggest reforms in the existing water resources management administrative set-up, two bills were proposed (the Draft National Water Framework Bill and the Model Bill for the Conservation, Protection, Regulation, and Management of Groundwater), and a report titled 'A 21st Century Institutional Architecture for India's Water Reforms' was published. These Bills further develops on the water resource management keeping in view the effects of climate change.

Independent regulatory agencies (IRA) in water sector were introduced in India. It came after the urging of the World Bank and other International Financial Institutions (IFI) to insulate the water sector from unnecessary government interventions and ensure its autonomy. There are merely 4 states – Maharashtra, Haryana, Punjab and Jammu and Kashmir (now a UT) that have a water regulatory authority and only 11 states have enacted the Water Regulatory Act thereby limiting the potential of water reuse and recycling as a sustainable mechanism.

4.1.4 National Water Framework Bill, 2016 and Model Bill for the Conservation, Protection, Regulation, and Management of Groundwater, 2017

The National Water Framework Bill mentions that the impacts of ongoing climate change on the global water cycle must be addressed pro-actively. It also focuses on planning and management of water infrastructure, such as dams, flood embankments, tidal embankments, among others (IELRC, 2016).

For integrated river basin management, it suggests that the Central Government shall establish a River Basin Authority for each inter-state river basin or sub-basin, ensuring sustainable development with participation from all basin states. Each authority will create a Master Plan for the basin, updated every five years, considering national economic and social development, land use, rural and urban development, river and aquifer rejuvenation, environmental protection, and climate change. The plan will emphasize regional agro-climatic factors and incorporate Water Security Plans. The Master Plan will be public, available online, and coordinated with other planning agencies and stakeholders.

Model Groundwater Bill 2017 (Kaushik, 2016) recognizes that groundwater is the sole most important source of water for all purposes and is pivotal for water food and livelihood security in rural as well as urban areas. Considering the existing and worsening groundwater crisis due to excessive overdraft and groundwater contamination, the bill calls for equitable and environmentally sound regulation of groundwater. The bill considers ground water as a "common pool resource" and "common heritage of the people" held in public trust and is subject to reasonable restrictions to protect the fundamental right to water for life.

So far, 15 States and 6 UTs have adopted and implemented the ground water legislation on the lines of Model Bill. However, the Model Groundwater Bill 2017 is actually not as sound as the National Water Framework Bill in treating groundwater and surface water as a single, interconnected resource (Srinivasan, 2016). The water security plans in the two Bills are not in consonance with each other. The Model Groundwater Bill though a roadmap for states to develop their own Bills do not comprehensively address the climate change issues. For instance, in model groundwater bill climate change is mentioned once. The term river is mentioned twice and the term basin is not at all mentioned. This shows a poor inter-linkage between river basin and groundwater in the Bill. Also the institutional structure so suggested would create parallel silos thus they should be subsumed under the river basin authority proposed in the National Water Framework Bill.

4.1.5 Mihir Shah Committee 2016

A report titled 'A 21st Century Institutional Architecture for India's Water Reforms' (PRS, 2016) was published to provide structural reforms for water management. Since all water is interconnected by hydrology, it is important that the institutions dealing with different water sources work in synergy. Thus, the committee recommended the restructuring and unification of CWC and CGWB to form a new National Water Commission (NWC), aimed at ensuring sustainable water resource management. It also proposed the creation of an Irrigation Reform Division to assist states with irrigation projects and enhance water management, recognizing agriculture as the largest consumer of water. Additionally, the committee suggested establishing a Water Data Management and Transparency Division to maintain a transparent and accessible system for water data, enabling decentralized decision-making. It advised setting up a Water Security Division to address water security challenges and a Water Quality Division to develop and implement programs for controlling water pollution. The proposed NWC was recommended to have regional offices covering all river basins in the country, equipped with interdisciplinary expertise for effective river basin management. However, the Government is yet to take a final decision on Mihir Shah Committee recommendations.

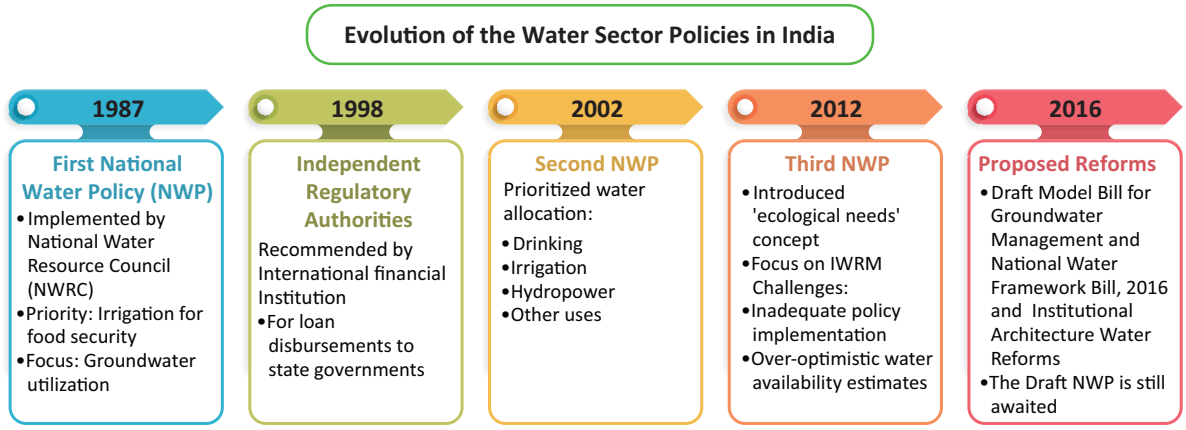


Figure 4: Projected water demand the evolution of water sector policies in India

4.1.6 National Action Plan on Climate change (NAPCC), 2008

Government of India has committed "To better adapt to climate change by enhancing investments in development programmes in sectors vulnerable to climate change, particularly agriculture, water resources, Himalayan region, coastal regions, health and disaster management" in Intended Nationally Determined Contributions (INDC) under United Nations Framework on climate change (UNFCCC) agreement. However, there are no specific targets.

To focus on climate change and its impact on various sectors, in 2008, the then Prime Minister launched the National Action Plan on Climate change (NAPCC). It outlined a national strategy that aims to enable the country to adapt to climate change and enhance the ecological sustainability of India's development path. National Water Mission is one of the eight National Missions under NAPCC. The main objective of NWM is "conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within States through integrated water resources development and management". NWM has identified five goals as below:

1. Provide comprehensive water data base in public domain and assessment of the impact of climate change on water resource;
2. Promotion of citizen and state actions for water conservation, augmentation and preservation;
3. Focused attention to vulnerable areas including over-exploited areas;
4. Increase water use efficiency by 20%; and
5. Promotion of basin level integrated water resources management

The NWM should lay clear goals and targets for improving resilience to climate change for energy, food, ecology sustainability.

The Bureau of Water Use Efficiency (BWUE), established in October 2022 under the National Water Mission, aims to improve water use efficiency by 20% across sectors, facilitating and regulating efficient water use in irrigation, industry, and domestic spheres. Concurrently, India is implementing State Action Plans on Climate Change (SAPCCs) across 28 states and 8 union territories, representing a comprehensive

sub-national climate action initiative with water management as a key focus area, providing a framework for state-level responses to climate change impacts. However, the Government has not given legal sanctity to this BWUE. Further, SAPCC being prepared by the States hardly cover climate resilience steps since, water is a state subject.

4.1.7 National Adaptation Fund for Climate Change (NAFCC)

As an adaptation measure, NAFCC was established to support adaptation activities in the States and Union Territories (UTs) of India that are vulnerable to the adverse effects of climate change. It is implemented in project mode. However, the funding has seen a drastic cut from Rs 118 Crore in 2015-2016 to Rs 20 Crore in 2022-2023 (The New Indian Express, 2023). In 2023-24, NAFCC and the funding for the Climate Change Action Plan, among others, were discontinued (India spend, 2023). This will have impact on efforts for climate change adaptation.

4.2 Programs and Schemes

4.2.1 Water Sharing and River Interlinking

It is anomalous that while some regions of the country face severe drought, others experience frequent floods. Keeping this in view the National Perspective Plan (NPP) of Interlinking of Rivers (ILR) was proposed in 1980 to transfer water from surplus basins to deficit areas. The National Water Development Agency identified 30 links under this project. However, the success of river interlinking projects depends on consensus on water sharing between participating states.

4.2.2 Aquifer Mapping and Recharge

For efficient water resource utilisation, water resource planning is important. The National Aquifer Mapping and Management program (NAQUIM) aims to map aquifers, characterize them, and develop Aquifer Management Plans for sustainable groundwater management. NAQUIM outputs are shared with States/UTs for suitable interventions. The Master Plan for Artificial Recharge to Groundwater- 2020 has been prepared by the CGWB in collaboration with States/UTs providing a broad outline of the project and expected investments. The Master Plan envisages construction of about 1.42 crore Rainwater Harvesting and artificial recharge structures in the country to harness 185 Billion Cubic Metre (BCM) of water. The Master plan has been shared with States/UTs for suitable interventions (PIB, 2023).

Additionally, the *Atal Bhujal Yojana* focuses on sustainable groundwater management in *Gram Panchayats* through community participation and demand-side interventions by preparing a water budget and water security plan for the *Panchayat*. Sustainable groundwater management can help to tide over climate change related crisis.

4.2.3 Water Conservation and Harvesting

The National Water Mission launched the "***Catch the Rain***" campaign in 2021, to encourage states and stakeholders to create rainwater harvesting structures before the onset of monsoon. The campaign had five focused interventions, including rainwater harvesting, water conservation, enumerating water bodies, setting up *Jal Shakti Kendras*, intensive afforestation, and awareness generation. These interventions help to enhance water security of the region and are one of the best adaptation strategy for climate change impact. Ministry of Housing & Urban Affairs (MoHUA) has formulated Model Building Bye Laws (MBBL),

where all buildings having a plot size of 100 Sq.m. or more shall mandatorily include the complete proposal of rainwater harvesting. 36 States/ UTs have adopted the features of the Bye Laws.

4.2.4 Irrigation Development

One of the growing challenges is the increasing gap between irrigated potential created (IPC) and irrigation potential utilized (IPU) (DTE, 2019). The efficiency of surface water irrigation is around 35-40% and groundwater is around 65-70%. To enhance water use efficiency in agriculture, the National Water Mission's "*Sahi Fasal*" campaign encourages farmers in water-stressed areas to cultivate crops that are both water-efficient and economically viable, thereby addressing the issue of water scarcity.

Likewise, the "Per Drop More Crop" component of the *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY) aims to boost water use efficiency by promoting micro-irrigation systems. The *Command Area Development & Water Management (CADWM)* programme seeks to increase irrigation potential and enhance agricultural production through Participatory Irrigation Management (PIM).

4.2.5 National River Conservation Plan

National River Conservation Plan works on reviving rivers by preventing the pollution of rivers. Launched in 1995, the program is implemented with 70:30 sharing of the burden of all costs between the Centre and the states. 10% of the minimum total cost is from the public. The National River Conservation Directorate (NRCD) was set up to undertake activities for conservation of rivers, lakes and wetlands in the country and improving the water quality which covers stretches of 40 rivers in 190 towns spread over 20 States.

5.0 International and National Case Studies

There have been some very innovative interventions implemented by various countries including India (Bharat et. al., 2021)(Namami Gange and NIUA, 2020) to adapt to changing climate and better manage their water resources. Some of the case studies which reflect successful integration of climate adaptation and sustainable water management are presented below:

5.1 Integrated Urban Water Management Strategies through Regulatory Reforms in Australia

Many national, state and local governments are taking proactive measures through regulatory reforms that encourage efficient water use and help cities become water secure in the future.

State governments in Australia are attempting to drought proof their cities by adopting strategies like grey water recycling, water efficient labelling on appliances, providing incentives to households conserving water, and putting water restrictions in place that are enforced by fines. The city of Perth is avoiding the situation of water crisis by adopting multiple strategies which help in water conservation, developing alternate sources of water and ways to recycle stormwater and wastewater. Perth's Water Corporation has strongly engaged with the users in sensitizing them about their current water usage and options to reduce their consumption. They also engage with plumbers and landscapers to encourage homeowners to adopt water efficient fixtures. Perth's long-term strategy for sourcing water and managing its use is called 'Fresh Water Thinking'. It includes direct outreach and education to the users on aspects of their

current water usage and potential avenues for saving water. Additionally, the government is operating two large scale desalination plants which cater to half of Perth's water supply (Core, L. N., 2020). Perth came up with its first action plan which was developed based on the ideas and actions suggested by over 200 stakeholders from diverse sectors including Government; Communities; Finance; Local Government, Sport and Cultural Industries; Planning, Lands and Heritage; the Water Corporation.

5.2 Effective Water Demand Management Plan for Cape Town

The Government in South Africa implemented a robust water demand management plan for Cape Town. With water-saving efforts of citizens, the city's water demand reduced to 550 million liters per day (in 2018) from 900 million liters per day before the drought. Effective governance and holistic management of the integrated water cycle have facilitated Cape Town transition to a water-sensitive city (Cape Town Water Strategy, 2019). The city government also ensures access to potable water through delivery by both centralized and decentralized infrastructure. In addition to this, to improve the existing urban water cycle, the city has undertaken steps to integrate stormwater treatment with the landscape. The city has been effective in managing its water resources even before the 2018 water crisis and is continuing its efforts in effective network management. Some of the key activities undertaken include proactive leak detection, pipe and meter replacement, comprehensive asset management system, and smart pressure controller.

5.3 Nature-based Solutions (NbS) for Increased Climate Resilience in China

Most cities in China do not have a drainage system that is at par with its national flood prevention safety standards. This led to urban flooding and contamination of the water supply in several areas. In response to its urban water management challenges, the Government of China launched the "Sponge City Programme" in 2013. Wuhan is leading the way for the exemplary "nature-based" approach implemented in the city. NbS helps in protecting, restoring and managing the ecosystems, which can be easily applied in cities transforming them to an urban system that is regenerative and accessible. The city has green infrastructure such as rain gardens, absorptive roads, permeable pavements, rainwater reuse facilities, etc. The city's nature-based approach has cost around USD 600 million (Oates et al., 2020) which is still low-cost compared to the alternative grey infrastructure-based approach (like upgrading the city's drainage system) to improve the city's resilience to flooding.

5.4 Active, Beautiful, Clean (ABC) Waters Program of Singapore

Singapore's long-term vision, adoption of innovative technologies and stakeholder engagement efforts has led Singapore to become one of the most talked about example in water sector. Singapore's National Water Agency, Public Utility Board (PUB) has taken many worth mentioning initiatives. One such initiative is the Active, Beautiful, Clean (ABC) Waters program (PUB, 2014), which demonstrated how Singapore has incorporated sustainable city planning with stormwater management. The program was launched in 2006 and ensured that there is inter-connection of green and blue spaces. The goal was to create community spaces around reservoirs and canals, giving these assets a recreational function. Further, to build resilience to the current flood protection scheme, PUB, has adopted a "Source-Pathway-Receptor" strategy, which seeks to develop catchment-wide solutions. This is a holistic approach where flexibility

and adaptability to the entire system is ensured, addressing not just the stormwater drains and canals (the pathways for water) but also areas that generate stormwater runoff (source) and where floods may occur (receptor).

5.6 Converting Wastewater as a Resource in Israel

Mediterranean water crisis is known to everyone and so is the remarkable achievement of Israel (*OECD, n.d.*) in the water sector. Israel holds a world record of 85% reclaimed effluents reused in agriculture and is a global champion in the development and the production of efficient water saving irrigation systems. The country uses around 21% of treated wastewater in total water consumed by the industries and around 45% in agriculture sector. Some of the key steps undertaken by the Government included:

- In 2010, new and stringent quality standards for effluents were legislated with 37 different quality parameters. The standards enable to use the effluents without any limits for all purposes and thus the Ministry of Health allocates permits for unlimited cultivation of crops.
- Secondly, Water and Sewerage Corporations Law in 2001 transferred water and sewerage services from the municipalities to corporate entities. This was the first step in the transformation of the administratively managed water sector to a more commercially oriented one. It helped to bring finance for infrastructure investments, and the assurance of high-quality services.

Use of both economics (closed market) and environmental (stringent standards) principles helped in development of an advanced wastewater reuse system in Israel.

5.7 Women as Champions of Pond Rejuvenation in Rajasthan, India

The Bal Rashmi Society in Rajasthan, India has taken up rehabilitation of ponds work in parched and rural areas of Rajasthan that have not been desilted for 10 years (Jayalakshmi D., 2003). Earlier, women were facing the plight of water stress where they had to walk 5 to 6 km for fetching drinking water. Women contributed 90 % of the labour in the rehabilitation work. Mahila mandals were entrusted with the maintenance of the ponds by way of *shramdhan*. This led to a significant impact where in 56 villages were benefited; 67 ponds deepened; storage capacity has risen by 5-7 ft; more drinking water has been provided for cattle; run-off water has been stored; green belt and cooler surroundings were developed. This also is an adaptation strategy towards climate change. Women can play a pivotal role like this in enhancing water security of the region through their involvement and management which can help community stride over water stress situation and combat deleterious impacts of climate change. it also resonates with the Government flagship program 'Jal Jeevan Mission' where the focus is on participation and empowerment of women for safe water access programs.

5.8 State Level Initiatives in Rajasthan

In Rajasthan, the project '*Mukhya Mantri Jal Swavlamban Abhiyaan* (MJSA)' (Chief Minister's Water Self-reliance Mission) for Climate Change Adaptation and Water Harvesting in various districts was implemented by the State Department of Watershed Development & Soil Conservation. In phase I (2015-18), interventions were implemented in 12000 villages. The key objectives were to:

a. Develop 'self-reliant' villages in terms of water requirement;
b. Enhance adaptation and improve resilience;

c. Improve groundwater management;
d. Improve drinking water availability;
e. Increase crop production.

It resulted in a rise in groundwater table and brought additional lands under cultivation and irrigation. This helps community to tide over drought or extreme heat and dry conditions.

5.9 River Cities Alliance in India

The River Cities Alliance (RCA) is a joint initiative of the Department of Water Resources, River Development & Ganga Rejuvenation under the Ministry of Jal Shakti (MoJS) & the Ministry of Housing and Urban Affairs (MoHUA), with a vision to connect river cities and focus on sustainable river centric development. It has 110 member cities including one international member city from Denmark. RCA is envisaged as a facilitatory platform for initiating river-sensitive planning and development. The platform would allow cities to discuss, learn from each other the best practices (PIB, 2022).

Based on these international and national best practices, it is recommended that national and state level governments should enact regulatory reforms that promote efficient water use and support cities in becoming water secure. Adoption of these initiatives such as setting standards and guidelines for water conservation (Australia); investing in Nature-based Solutions (NbS) (China, Singapore) to bolster climate resilience; establishing stringent quality standards for effluents and promoting reuse of treated wastewater in agriculture, industry, and other sectors (Israel, Singapore); actively engaging communities (Cape town, India) can yield substantial long-term benefits in the water sector. These measures collectively contribute to sustainable water management practices, ensuring the efficient use of water resources, mitigating the impacts of climate change on water availability and quality, and fostering community ownership and participation in conservation efforts.

Compendium of Best Practices- Policy led Initiative

The compendium of best practices by NITI Aayog also has suggested the following learnings from policy led interventions:

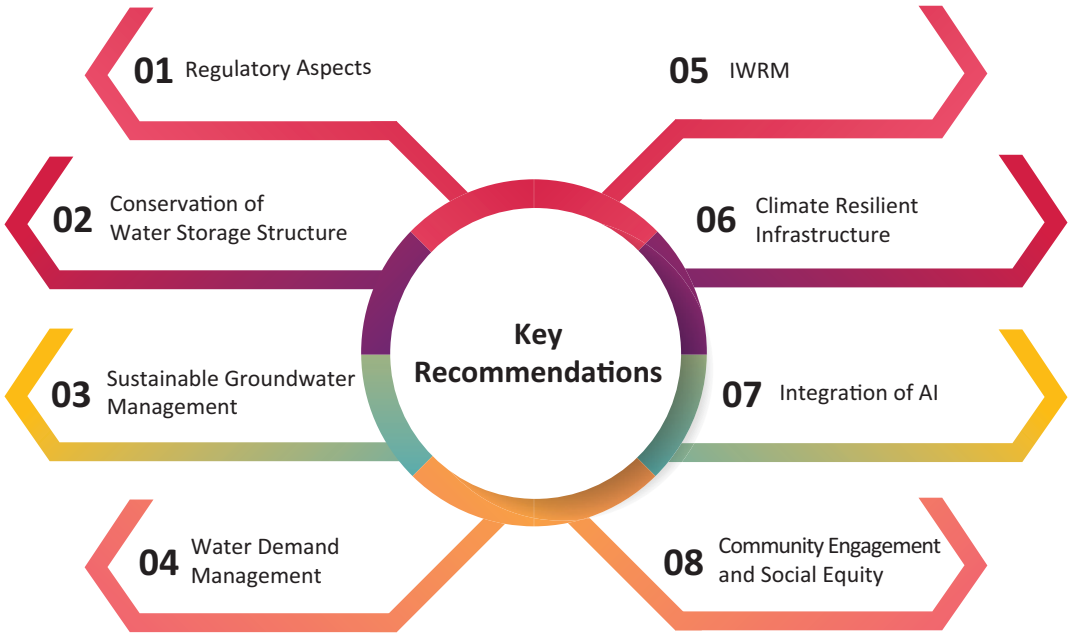
- Policy led interventions are instrumental in effective water management at village or district level.
- Tanks, check dams, farm ponds are conventional methods of water conservation with which local communities strongly associate. Hence, community participation will lead to ownership and help in long-term sustainability of the intervention.
- Water budgeting as adopted in *Mukhyamantri Jal Swavlamban Abhiyan* of Rajasthan proved to be an effective measure of optimizing water consumption.
- Use of information technology with smart metering helps in data capturing which can be used by the operators as a tool for decision making.

6.0 Issues and Recommendations

Initiatives such as the National Water Mission, judicial reinforcement of climate rights, and proposals for integrated management frameworks act as enablers, the lack of overarching legislation, institutional fragmentation, centre-state coordination challenges, and inadequate devolution of powers hinder India's ability to comprehensively address water scarcity and climate change impacts on its water resources. However, a more holistic approach and changes are needed at all scales- regulatory, technical, financial and social front which could help to drive the needed reforms (Vijay Kumar & Bharat, 2014) in the water sector.

6.1 Regulatory Changes

Issue: The challenges within regulatory and policymaking spheres primarily stem from some key factors such as the absence of comprehensive climate change legislation coupled with a fragmented institutional framework.



Inadequate enforcement of existing policies exacerbates these issues. The proliferation of multiple institutions with overlapping roles and ambiguous responsibilities complicates matters further, often resulting in a neglect of advancements within the water sector. Additionally, in spite of the National Water Policy 2012 suggesting for autonomous water regulatory authorities, only 11 states have enacted the Water Regulatory Act and merely 4 states—Maharashtra, Haryana, Punjab and Jammu and Kashmir (now a UT) have a water regulatory authority. These authorities have no uniformity in their framework. This highlights poor enforcement of recommendations. The following recommendations would aid in further streamlining it.

Recommendations:

- The National Water Policy, 2012 needs to be updated and adopted at the earliest with emphasis on climate resilient sustainable water management, equitable distribution, conservation, IWRM, multi-stakeholder partnership, rejuvenation of traditional water bodies, and integration of advanced technology.
- A National Climate Change Act needs to be enacted, which provides a legal framework for addressing climate change impacts, mandates adaptation and mitigation measures, and defines clear roles and responsibilities for various stakeholders, including water sector. Under this act, develop a comprehensive national framework for climate-resilient water management, with clear guidelines, targets, and accountability measures for different stakeholders.
- As recommended by the Mihir Shah Committee, a dedicated National Water Commission should be established as an apex body for IWRM, subsuming existing institutions like CWC and CGWB, with regional offices covering all river basins. This authority can mandate the inclusion of climate change adaptation strategies and regular monitoring and evaluation mechanisms in all water management plans and projects at national, state, and local levels.
- River Basin Authorities for each major river basin needs to be constituted that are responsible for developing and implementing basin-level master plans, coordinating with stakeholders, and ensuring sustainable development considering climate change impacts. These authorities should have representatives from state governments, local bodies and users. The role of which can be substantial in preparing water accounts from basin level to watershed level, with targets for water neutrality.
- The Indian Easements Act, 1882 needs to be revised and modified, particularly Section 7/ Clause (g)3 and related sub-clauses, to recognize water as a common property resource and not confer exclusive private domain over it.
- To work on mission mode, the National Water Resource Council headed by the Hon'ble Prime Minister, should meet regularly and frequently. This would also provide coordination between states and reduce riparian states' conflicts. Similarly, there should be State Water Resource Council established at state level to coordinate efforts between local bodies, forest communities and state government.
- At the state level—the Water Regulatory Acts needs to be enacted and enforced through a Model Framework facilitated by the Central Government by establishing independent regulatory authorities to oversee water allocation, pricing, and conflict resolution within each state. These authorities should also be made responsible for undertaking third party independent audit of industries for water neutrality[4] as defined in the NITI Aayog and CII(Report on Water Neutrality for Indian Industries) report. As India has put net zero target for GHG emissions, we should also establish clear goals and targets for water neutrality in cities for working on a mission mode.
- The State governments should be empowered to enact and enforce state-level water policies and regulations aligned with national goals and priorities for climate-resilient water management. It should be ensured that each state has a state action plan for climate change. The Central government and institutions can aid by providing centralised updated water availability, demand and gap data

[4] UNESCO-IHE 2008 Research Report described water neutrality as reducing an activity's water footprint as much as reasonably possible while offsetting the negative externalities of the remaining water footprint.

to prepare water budget keeping in future scenarios and sector-wise demand. Financial incentives should be provided for implementation of same.

- River Reservation Zone Policy to protect natural ecosystem alongside river and its tributaries (Our Rivers Have Rights, 2023).
- Legal sanctity to be provided to the Bureau of Water Use Efficiency.
- The CWMI Report produced by NITI Aayog provides comprehensive 28 indicators for assessing and monitoring water management in the country. This report should become a biennial report to assess the targets set for water neutrality. Additionally, this report can be a guiding tool for the Finance commission for providing financial incentives or grants provided to states based on the performance in the water sector.

Issue: Traditional water storage structures across the country face decline amid encroachment challenges. As urbanization expands, these vital reservoirs are threatened by encroaching development, disrupting natural water flow patterns and diminishing storage capacities. Without swift intervention, communities risk losing critical water sources essential for agriculture, livestock, and daily consumption. With variation in surface water resources and depletion of groundwater resources, these traditional water bodies are going to be the saviour during dry periods. Urgent action is needed to preserve these heritage structures and address encroachment issues to ensure water security for future generations.

Recommendations:

- Conduct a comprehensive national census and geo-mapping of traditional water storage structures (e.g., tanks, ponds, stepwells) and water bodies, identifying encroachments and prioritizing their restoration and maintenance.
- Set up one dedicated authority to take cognizance of riverbed exploitation, river banks encroachment, lakes, ponds, natural stormwater drain encroachment, wetlands destruction etc. Developing and implementing comprehensive guidelines for infrastructure development around water bodies is of utmost importance. Enact and enforce strict regulations to prevent encroachment and unauthorized construction around water bodies, with heavy penalties for violations. This can be done with allocating more roles, responsibilities and power to NRCD.
- Allocate dedicated funds and responsibilities to urban local bodies and *Gram Panchayats* for the conservation, maintenance, and management of small water bodies within their jurisdictions. This could be promoted and implemented through community-led approaches, involving women's groups and local stakeholders, for the restoration and sustainable management of traditional water storage structures, fostering a sense of ownership and cultural preservation, which would create opportunities for eco-tourism.
- Promote the adoption of nature-based solutions (NbS) and blue-green infrastructure for water storage and management, such as constructed wetlands, bio-swales, and rainwater harvesting systems these will act decentralised solutions for water management in peri-urban areas.
- To ensure sustainable management of water supply and demand, it's crucial to diversify urban water sources. Relying on a single water source makes cities vulnerable to shortages and environmental changes. By integrating multiple sources, such as rainwater harvesting, recycled wastewater, desalination, and groundwater recharge, cities can create a resilient water system that meets the needs of growing populations. This approach not only enhances water security but also reduces the environmental impact and supports long-term urban sustainability.

Issue: Unsustainable groundwater extraction and water pollution in India pose severe challenges to water security. Over-extraction depletes aquifers, threatening agricultural productivity and drinking water supplies.

Recommendations:

- The Model Bill for the Conservation, Protection, Regulation, and Management of Groundwater (2017) at the state level needs to be enforced, ensuring the regulation and sustainable management of groundwater resources. This should align with river basin management to establish synergy between the two.
- The adoption of advanced techniques like remote sensing, GIS, and groundwater modelling for monitoring and regulating groundwater extraction to be mandated, with real-time data sharing and transparency.
- The large-scale adoption of water-efficient irrigation techniques, such as micro-irrigation systems and precision agriculture, water sensors to plan irrigation timing and duration, water efficient crops and techniques, through financial incentives, awareness campaigns, and capacity-building programs.
- Agriculture based on agro-climatic zone should be promoted.
- There is a need of empowering Farmer Producer Organisations (FPOs) to focus on adopt and adapt water use efficient techniques in agriculture. The Water Use Authorities which became defunct due to lack of funds need to be revived.
- Integrating sub-soil water management with groundwater management is essential for sustainable irrigation practices. This approach requires enhancing source augmentation for irrigation and expanding the scope and coverage of the *Atal Bhujal Yojana*. Effective implementation can improve groundwater recharge through the construction of check dams, trenches, and other water conservation structures.

Issue: Surface water pollution in India pose severe challenges to water security. Industrial effluents, agricultural runoff, and untreated sewage contaminate water sources, endangering public health and ecosystems.

Recommendations:

- By focusing on both surface and sub-surface water management, we can enhance water availability, reduce dependency on depleting groundwater resources, enhance water security and promote climate resilient agricultural practices.
- Watershed management is crucial for climate change adaptation as it helps protect and sustain water resources, which are increasingly vulnerable to extreme weather events. By managing land use, preserving natural vegetation, and restoring ecosystems within a watershed, we can reduce the impacts of floods, droughts, and soil erosion. Effective watershed management ensures the long-term availability of clean water, supports biodiversity, and enhances the resilience of communities to climate-related challenges, making it a vital component of climate adaptation strategies. Watershed management improves sub-soil management by reducing erosion, enhancing groundwater recharge and maintaining soil moisture and fertility.
- Strengthening the implementation of pollution control measures, such as the National River Conservation Plan, by increasing monitoring, enforcement, and stakeholder participation, with heavy

penalties for non-compliance. The roles and responsibilities of NRCD should be increased.

- Encouraging the adoption of circular economy principles in industries and urban areas, promoting wastewater treatment, recycling, and reuse to reduce freshwater demand and pollution.
- Legislation to be effectively implemented that has stringent water quality standards for discharge of effluents into the natural environment and/or reuse for fit-for-purpose end uses.
- At present, CPCB monitors surface water quality, CGWB groundwater quality and CWC also monitors water quality (NCIWRD, 1999). It is necessary to have a single organisation with a single dashboard to monitor real-time water quality.

6.2 Promoting Water Demand Management Strategies

***Issue*:** It is important to address demand side water management. With growing population and urbanization, water demand is increasing manifolds but there is limited intervention in demand side. The data currently available for demand side assessment is not updated. It is hence essential for prepare a sector-wise demand side assessment for each basin. This would help in better demand side management using water accounting and water budgeting tools.

Recommendations:

- The Mihir Shah committee has suggested a Water Data Management and Transparency Division to maintain a transparent and accessible system for water data (supply and demand side data with water quality), enabling decentralized decision-making.
- Comprehensive basin-level water demand assessments needs to be conducted for different sectors (agriculture, domestic, industrial), considering future projections, climate change impacts, and socio-economic factors. This data should be easily accessible in public domain. This will aid in developing a rationale and fair water sharing arrangement between water surplus and deficit areas.
- Water demand management strategies, including water accounting based on demand and water availability assessment, water budgeting, pricing mechanisms, and targeted awareness campaigns for different sectors and stakeholders for each hydrological unit needs to be developed and implemented.
- For Urban areas it is important to have hydrological footprint for the cities. This will help analyse the requirements of water for different locations and thus take measures to meet the demand.
- Ambitious and achievable targets for water use efficiency improvements across sectors should be set. There needs to have regular monitoring and incentives for achieving the targets.
- Adoption of water-efficient technologies and practices should be promoted along with water labelling on fixtures across sectors through financial incentives, regulations, and capacity-building programs.
- Adoption of circular economy principles and water recycling and reuse practices in industries, agriculture and urban areas should be promoted so as to reduce freshwater demand.

6.3 Promoting Integrated Water Resources Management in India

IWRM promotes the coordinated development and management of water, land, and related resources to maximize economic and social welfare equitably without compromising the sustainability of vital ecosystems (GWP, 2000). CWC states that IWRM addresses water management as a resource and provides a framework for water services to all users, addressing both water quantity and quality. The basin or sub-basin is recognized as the basic unit for planning and management, ensuring firm societal commitment and public participation. (GWP, 2000; CWC, Government of India).

Issue: The National Water Policy (2012) emphasizes the adoption of IWRM practices, decentralized water governance, and participatory decision-making for strengthening SDG 6, SDG 8. However, India is yet to fully embrace the transition to IWRM. Despite policy initiatives, challenges remain in implementing IWRM principles at the ground level. Issues such as inadequate institutional capacity, weak enforcement mechanisms, lack of stakeholder participation, and limited financial resources hinder effective water governance and management. Policies and projects often have a hydro-technocratic focus, overlooking the long-term sustainability of projects. While hydro-technocratic approaches have their merits in addressing immediate water challenges, they must be complemented with long-term sustainability considerations to ensure the resilience, equity, and effectiveness of water management interventions.

Recommendations:

- For effective IWRM it is important to develop the *principle of cooperative federalism* where planning and implementation meets the requirement of the administrative unit and state and central government facilitate this. This can be achieved by ensuring decentralised decision making by implementing Article 243L and Forest Rights Act (2006), providing necessary skill, training, resources, financial incentives and data for effective implementation of schemes and programmes.
- Mandate the adoption of IWRM principles and the integration of NbS in water management plans and policies at the national, state, and local levels, with clear guidelines and implementation frameworks.
- Invest in capacity-building programs to enhance the knowledge, skills, and technical expertise and preparedness of government agencies, water professionals, and stakeholders in implementing IWRM and NbS.
- Promote the use of decision support systems (DSS), modelling tools, and geospatial technologies for integrated water resources planning and management at the river basin level.
- Foster international collaborations and knowledge-sharing platforms to learn from successful IWRM and NbS implementations in other countries and adapt best practices to the Indian context.
- Learning from Saudi Arabia's National Water Strategy 2030 which is based on IWM approach, India should also undertake restructuring of water sector to increase efficiency, setting regulation, building capacity and increasing reliability.
- It is also necessary to focus on data, research and development for adapting international best practices for Indian context leading to planning at the watershed level. Further, integrated water management at the scale of the river basin needs to consider the adaptation capacity of the basin ecosystem, given the pressures created by climate change.
- It is also necessary to ensure that tourism is sustainable and tourism industry is climate resilient. Therefore, promoting integration of eco-tourism into IWRM ensures that tourism development is aligned with the sustainable management of water resources, benefiting both people and the environment. It can help achieve the sustainable use and protection of water resources, engage local communities, promote conservation, and provide economic benefits that support broader water management goals.
- The recently launched, Green Credit Program (GCP) is an innovative market-based mechanism designed to incentivize voluntary environmental actions across diverse sectors, by various stakeholders like individuals, communities, private sector industries, and companies. In its initial phase, the GCP focuses on two key activities: water conservation and afforestation. Afforestation

not only mitigates climate change through carbon sequestration, but also enhances resilience to flash floods and landslides by improving resilience to droughts, resilience of coastal infrastructure and habitation by reducing coastline erosion due to storm surges and sea-level rise, soil retention. It reduces vulnerability to extreme heat by reducing ambient temperatures, and supports native wildlife and biodiversity. It is recommended that any water conservation intervention if done through NbS to be given more credits than the conventional way of water conservation.

6.4 Investment in Climate Resilient Infrastructure

Investment in infrastructure is a continuous process for a country. With large scale population to address, water sector in India is investing in infrastructure and technology. However, there is a need to invest mindfully in climate-resilient water infrastructure and technologies that enhance water storage, distribution, and treatment capacity, while minimizing vulnerability to climate hazards such as floods, droughts, and sea-level rise. Increasingly frequent cloudbursts and flooding in the era of climate change needs urban planning to shift focus to river sensitive urban design perspectives, with much greater emphasis on cloudburst masterplans based on low-cost blue-green infrastructure that connects urban hydrological functions (blue) with vegetation systems (green) for climate buffers in our system.

Issue: India faces significant challenges due to insufficient investment in climate-resilient water infrastructure. Aging systems, inadequate asset management, inadequate funding, and limited technological advancements hinder the country's ability to manage water resources effectively amid climate change.

Recommendations:

- Detailed vulnerability assessments and climate risk analysis for existing water infrastructure (dams, reservoirs, distribution networks, treatment plants) should be conducted and investments for upgradation or replacement needs to be prioritized.
- The incorporation of climate change projections, risk assessments, and adaptation measures in the design, construction, and operation of all new water infrastructure projects needs to be mandated.
- Development and adoption of innovative, climate-resilient technologies, such as advanced monitoring systems, smart water management systems, water recycling and desalination technologies, and green infrastructure solutions to be promoted.
- Implementation of nature-based solutions (NbS) for water infrastructure, such as restoring wetlands and floodplains for flood control, and implementing green roofs and permeable pavements for stormwater management in urban areas.
- Public-private partnerships (PPPs) to be encouraged for innovative financing mechanisms, such as green bonds and climate finance, to mobilize resources for climate-resilient water infrastructure projects.
- When dealing with water scarcity by sustainable use of water resources, it is necessary to look beyond water-energy-food nexus to water-energy-food-disaster nexus.

6.5 Integrating Artificial Intelligence (AI) into Climate Change Adaptation and Water Resource Management

Integrating AI into climate change adaptation and water resource management can significantly enhance the ability to monitor, predict, and manage these critical areas.

Issue: Integration of AI into climate change adaptation and water resource management in India is still in a nascent stage.

Recommendations:

- Machine learning algorithms can improve the accuracy of climate models by analyzing large datasets of historical climate data. AI integration would predict extreme weather events such as floods, droughts, and hurricanes more accurately, allowing for better preparedness and response.
- AI-powered sensors and IoT devices need to be deployed to continuously monitor water quality parameters (e.g., pH, temperature, contaminants) in real-time. Machine learning algorithms would detect anomalies and potential pollution events in water bodies, enabling prompt intervention.
- AI-driven irrigation systems should be developed that optimize water usage by analysing soil moisture data, weather forecasts, and crop water needs. AI can forecast water demand based on historical usage patterns, population growth, and climate conditions, ensuring efficient resource allocation.
- AI needs to be utilized to enhance early warning systems for floods and droughts by analysing meteorological data and predicting the likelihood of such events in various regions, helping policymakers and planners to develop targeted mitigation strategies.
- Machine learning models can predict river flows, reservoir levels, and groundwater recharge rates based on historical data and climate projections. AI can simulate various climate scenarios and their impacts on water resources, aiding in long-term planning and decision-making.
- AI algorithms can be implemented to predict the maintenance needs of water infrastructure, such as dams and pipelines, reducing the risk of failures and ensuring operational efficiency.
- AI could manage and optimize the distribution of water resources through smart grid systems, balancing supply and demand effectively.
- Data from various sources (e.g., weather stations, satellite imagery, IoT sensors) can use AI to analyse to gain insights into climate patterns and water resource availability. This would be an very useful Decision Support Systems (DSS) tool providing actionable insights for water resource management and policy-making.
- AI-powered platforms and applications can be created that educate and engage communities about water conservation practices and climate resilience strategies. AI can also analyse behavioral data and design targeted campaigns to promote sustainable water usage and climate-friendly practices.

6.6 Community Engagement and Social Equity

Issue: Often, local communities, especially marginalized groups, indigenous communities are excluded from decision-making processes, leading to projects that don't meet their needs or address inequities. Effective water management requires inclusive participation, ensuring all voices are heard and benefits are equitably distributed.

Recommendations

Government has been working with the local communities for many of its projects. However, the focus now should be to involve and build capacity of indigenous peoples, and vulnerable groups including women to participate in decision-making processes, planning, and implementation of climate-resilient water management initiatives. Some specific recommendations are:

- Monitoring and forecasting technologies need upgradation to capture essential elements of climate change through high-speed internet networks, cloud computing, enhancement of virtual storage capabilities, wireless sensors for monitoring water consumption and remote water metering and big data analytics for improved water management. This combined with citizen science and "crowd-sourcing can provide early warning systems (EWS) and validate flood forecasting models.
- Mechanisms need to be established for meaningful community engagement, particularly involving indigenous peoples, women, youth and other vulnerable groups, in the planning, decision-making, and implementation of water management initiatives. For this, the rights of communities on community forests should be strengthened reducing administrative blockages. Also, *Gram Panchayats* should be involved in skill building and knowledge sharing under rural development programmes.
- Development of useful to usable (U2U) (Prokopy et al., 2017) research and application agenda for effective on-ground decision tools for adapting to climate change. This will help promote capacity-building and awareness-raising programs to empower local communities in water conservation, management, and climate change adaptation practices, leveraging traditional knowledge and local wisdom.
- Prioritized investments and targeted programs in marginalized and at-risk communities to enhance their access to water services, adaptive capacity, and socio-economic resilience to climate change impacts.
- Encouraging the formation of community-based organizations and water user associations (WUAs), with representation from diverse stakeholders, to facilitate participatory decision-making and sustainable water resource management.
- Implementing mechanisms for benefit-sharing and equitable distribution of water resources, ensuring that the needs of marginalized communities and ecosystems are adequately addressed.

7.0 Conclusion

The examination of climate resilience in water resource management in India has highlighted several critical issues and provided essential recommendations for addressing these challenges. The key issues identified include the increasing variability and unpredictability of water resources due to climate change, the inadequate infrastructure for water storage and distribution, and the insufficient integration of climate resilience into water management policies.

Establishing robust systems for the continuous monitoring of water resources and climate data by upgrading meteorological and hydrological stations and utilizing advanced technologies such as remote sensing and GIS for better data accuracy would be vital for resilient water infrastructure. Constructing new storage facilities, repairing existing ones, and implementing modern irrigation techniques to optimize water use. It is vital to strengthen institutional frameworks by ensuring that water management policies

incorporate climate resilience principles by revising existing policies, enhancing coordination between different governmental agencies, and involving local communities in decision-making processes.

Adoption of sustainable water management practices across various sectors is an important step by promoting water-saving technologies in agriculture, improving industrial water use efficiency, and increasing public awareness about water conservation. Fostering research and innovative solutions for water management under changing climate conditions by exploring new methods for water conservation, purification, and efficient use would strengthen climate resilience in the water sector.

Implementation of IWRM principles would foster collaboration among various sectors, including agriculture, industry, and urban development, to create a cohesive water management strategy that optimizes resource use and reduces conflict. Enhancing data collection and monitoring systems by deploying advanced technologies such as remote sensing, GIS, and IoT-based sensors to improve the accuracy and reliability of water and climate data. These could be presented on centralized databases and platforms for real-time data sharing among stakeholders, ensuring informed decision-making processes.

Building the capacity of stakeholders at all levels through training and education programs would help sustain effective water management practices. Alongside, it is important to engage in international collaborations to share knowledge, technologies, and best practices for climate-resilient water management. This would lead to the development of comprehensive strategies that address both local and national water challenges.

By integrating Climate Action (SDG 13) into the governance will ensure accessibility, availability and affordability of clean water (SDG 6) can help achieve various SDGs like - reducing poverty (SDG 1), eliminate hunger (SDG 2) by ensuring food security, ensure good health and wellbeing (SDG 3) by reducing incidence of water borne diseases, promote gender equality (SDG 5), lead to sustainable cities and communities (SDG 11) thereby reducing conflicts related to water and promote healthy ecological biodiversity on land (SDG 15) and life below water (SDG 14).

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