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Sustainable Water Resource Management in Arid Regions: Challenges and Solutions in the Indian Context

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Abstract:

Sustainable water resource management in arid regions is critical for ensuring long-term water security, especially in a country like India where climatic variability, rapid population growth, and intensive agricultural practices place severe pressure on limited water resources. Arid and semi-arid regions such as Rajasthan, parts of Karnataka, Telangana, and western India face acute water scarcity due to low precipitation, high evaporation rates, groundwater over-extraction, and declining surface-water availability. Groundwater depletion, deteriorating water quality, institutional fragmentation, and inadequate infrastructure further complicate effective management. Climate change has intensified extreme events such as droughts and floods, disrupting hydrological cycles and reducing the reliability of traditional water systems. Sustainable solutions therefore require integrated approaches such as demand management, improved irrigation efficiency, artificial groundwater recharge, rainwater harvesting, conjunctive use of surface and groundwater, and nature-based solutions for ecosystem restoration. Community-led initiatives, technological interventions, and policy frameworks such as Integrated Water Resources Management (IWRM) offer promising pathways for enhancing resilience. Case studies from Rajasthan, Karnataka, Telangana, and western India demonstrate that coordinated planning, decentralised governance, and scientific monitoring can significantly improve water availability. Strengthening institutions, expanding infrastructure, and adopting climate-adaptive strategies remain essential for achieving sustainable water management in India's arid regions.

Keywords: Sustainable water management; Arid regions; Groundwater depletion; Climate variability; Integrated Water Resources Management; Rainwater harvesting; Water scarcity.

Introduction

Simply stated, sustainable water resource management means managing water resources without compromising the ability of future generations to meet their water needs. But the term arid, though frequently used in public discourse, lacks a universally accepted definition (Sheriff Hemoh & Shenbei, 2014). It generally refers to a climate whose potential evaporation exceeds its precipitation due to its distance from oceans and low winter temperatures. India's arid regions are characterized by average annual precipitation of less than 250 mm and include the world's largest desert, the Simpson Desert on the continent of Australia. By a more practical measure—precipitation scarcity, calculated as the ratio of total annual precipitation to potential evaporation—India's arid regions fall under either the hyper-arid (less than 10 percent) or semi-arid (10 to 25 percent) category. The Third Assessment Report of the Intergovernmental Panel on Climate Change states that approximately 14 percent of the world's land mass, supporting about 12 percent of the human population, is classified as arid or semi-arid (M. Singh et al., 2013). According to the Aqueduct Water Risk Atlas, which indicates water scarcity relative to demand, only California and the twelve southwestern states of the United States currently have a water scarcity situation as severe as that of Rajasthan. Although much of Rajasthan is arid, it supports a population density of 200 people per square kilometer.

The Arid Context in India

India is a million square-mile landmass that straddles the boundary between roughly arid and tropical climates. The northern section occupies the mid-latitude northern hemisphere where conditions are more continental (low humidity) and tropical monsoon conditions dominate in the southern portion. As a continent-sized region the climatic conditions, water resources, and socio-economic circumstances vary across the country. At the global level large areas of southeastern Europe and northeastern Africa fall into the arid region classification. These vast land regions exhibit a widespread and telling socio-economic condition called "water poverty." Water poverty is recognized, for example, as either (1) a shortage of water resources for drinking, sanitation and growing food for it originated in a parched climate environment or (2) excess invest and social cost to manage water so that the desired services can be delivered (Koundouri & Karousakis, 2006).

India has long been viewed as endowed with a plentiful supply of water being endowed with an abundant supply of fresh-water rivers, glaciers-based resources, monsoon rains, and a wide groundwater aquifer system. During the past six decades, however, the discourse has shifted considerably; northern India is classified as a water-scarce region, excluding the southern half of the country (Sheriff Hemoh & Shenbei, 2014). Since water has a very high socio-economic value, the diverse situation across the country has led to considerable confusion. Without accurate water indicators it is impossible to evaluate a shortage situation and hence identify the best solution or remedy.

Hydrological Foundations and Water Demand

Globally shared water resources are limited, and India is no exception to this reality. The water resource management problem is further exacerbated by growing urbanization, industrialization, and demand for water from different agricultural crops (D Clark, 2019). India has a total surface storage capacity of ~220 Billion Cubic Meter (BCM) among ~5000 large and medium reservoirs. The conservation storage among these is ~42 BCM. The average annual inflow into major reservoirs is ~234 BCM out of which ~100 BCM is retained within the reservoirs providing an assured supply. The average annual observed seasonal inflow into major reservoirs bifurcated by month ranges from 4.6 to 48.06 BCM providing for the peak irrigation season in April-May to the Rabi season in Nov-Dec. The peak average observed inflow month into major reservoirs is July, with an inflow of ~75 BCM (M. Singh et al., 2013).

Groundwater Dynamics: Groundwater comprises a significant portion of the world's freshwater and significantly influences regional hydrology and ecology (Venu Menon, 2007). Factors such as limited recharge, overexploitation, and groundwater quality deterioration contribute to groundwater depletion, negatively affecting food and livelihood security and public health through contamination. Groundwater is an important water source mainly for irrigation, domestic, and industrial purposes. India is the largest groundwater user, and many parts of India draw a significant percentage from the groundwater resource. Accepting more groundwater than what is being replenished can lead to an unsustainable situation. North-western and southern states of India extract more than 100% of the replenishment. Six Indian states Andhra Pradesh, Gujarat, Madhya Pradesh, Rajasthan, Tamil Nadu, and Uttar Pradesh—

account for 60% of the total groundwater extraction in the country. The over-exploitation of water tables becomes a big concern in this area. One of the difficulties confronting the sustainability of water resources is groundwater depletion in arid and semi-arid regions. Extraction by public and private wells is too high in these areas, illustrated through the declining water-table indication in the areas. Groundwater depletion can have a huge impact on infrastructure, agriculture, and ecosystem services. Surface irrigation networks are not widespread in arid and semi-arid regions.

Surface Water Resources: India has a vast network of rivers; 14 major river systems comprise 12% of land area and contribute to 40% of river flows. Furthermore, India has large reservoirs providing storage for surface water. The river system is seasonal, with most precipitation occurring for 3–4 months. Total annual runoff is estimated at 1850 km^3, but workable potential is only 690 km^3 due to evaporation and other losses. Storage per capita is low by world standards. Spatial variability in rainfall, river flows, and watershed boundaries hampers inter-basin transfers. The Ganga, Brahmaputra, and Indus river basins are snow-fed, but climate change is likely to alter flows. River basin governance is fragmented among central, state, and local government institutions (M. Singh et al., 2013).

Sectoral Water Demand: Water resources in India are unevenly distributed across the three main sectors of the conomy (agriculture, municipalities, and industry). The agriculture sector consumes around 89% of the total water supply, with only one-third of the sown area irrigated by surface water and the rest depending on groundwater; efficiency in the sector is around 40%. The municipalities and industry account for around 9% and 3% of the total water, showing consumption patterns inclined towards domestic use (compared with East Asia), but with growing public concerns about drinking-water security. Meanwhile, the water-market sector, supported by both the central and state governments, is showing increasing demand that has close connection with the socio-economy (M. Singh et al., 2013).

Challenges to Sustainable Management

Despite groundwater being an important source for drinking and irrigation in southern Africa's arid regions, it is poorly managed. Climate change and increasing populations threaten already limited resources, heightening the need for sustainable management. Lack of integrated frameworks, limited infrastructure, and inadequate capacity hinder progress. A sustainable integrated management framework has been developed for Africa's arid regions, offering tools for governments and stakeholders to improve planning and management (Sheriff Hemoh & Shenbei, 2014). Adequate water resources remain a distance away for people in many arid and semi-arid parts of Africa. Africa receives 8.5% of the world's fresh water and only 0.5% is available for economic development and human consumption. Groundwater, representing only 0.3% of the continent's renewable water resources, supplies closer to 50% of urban drinking water and 95% of rural supplies. It is the most accessible resource but still not adequately managed.

Water remains abundant, yet less than 1% of total supply is reliably available for human consumption. Water-related illnesses cause an estimated 25,000 deaths daily in the developing world. Water issues have gained international concern, with conferences calling for innovative assessment, development, and management of freshwater resources. Agencies like the World Bank, FAO, UNDP, WHO, UNICEF, WMO, UNESCO, and UNEP emphasize the scarcity and value of water, warning that growing water scarcity and misuse threaten sustainable development. Competition among agriculture, industry, and cities for limited water supplies constrains development efforts, especially as populations and economies grow. Water mismanagement is widespread, with surface water quality deteriorating from urban and industrial waste, groundwater polluted from surface sources, and overexploited aquifers losing capacity, leading to land subsidence (M. Singh et al., 2013).

Resource Depletion and Quality Concerns: Groundwater resources in India, especially in arid and semi-arid regions, are facing unprecedented depletion, posing dire challenges to the economic foundation of many states (M. Singh et al., 2013). Urban, industrial, and agricultural water demands, compounded by pumping for irrigation, have contributed to water scarcity. Consequently, livelihood losses have proliferated, with 60 million dryland farmers predominantly dependent on groundwater (Venu Menon, 2007). Anticipating rising demand and erratic supply linked to climate change, the focus accordingly shifts to sustainability, calling for rejuvenation strategies that rejuvenate groundwater while promoting social inclusivity. Apart from depletion, groundwater quality concerns have intensified, particularly salinity from seawater intrusion and contamination from industrial effluents, agricultural chemicals, and peri-urban discharges.

Depletion of aquifers and declining water tables, induced chiefly by excessive irrigation pumping, have led to delayed and staggered half-yielding of wells, casting doubts over irrigation reliability. Many districts now confront supply deficits, threatening both livelihoods and food security. After decades of uninterrupted socio-economic growth, groundwater reservoir exploitation reaches critical momentum. Nationwide, India extracts annually from aquifers over 50 percent of the theoretical renewal capacity. Commercially and technically proven in 1975, the now-mature technique of drilling bore wells has taken a disruptive turn. Increasing urbanisation triggers uncontrolled rural-urban migration of services and capital to mega cities. Globalisation fuels mechanisation, intensive use of chemical fertilisers, and large-scale tankers for surface-water supply. Amid soaring rural-urban water transfers designed to satisfy municipal needs, irrigation and livestock provisioning sustain the agrarian economy, food security, and rural livelihood expectation. Urban water demands spiral ever-higher, far outpacing prevailing water supply and governance infrastructure.

Climate Variability and Extremes: Extreme weather phenomena, such as droughts and floods, have increased in incidence over the last century due to changing climate patterns (P Sishodia et al., 2018). The period 1901–2000 saw a rise in frequency of all-India droughts from 3 to 4 years per decade, while flash floods increased from 3 to 4 events per decade. Global mean temperature is projected to rise by 1.1 to 2.6 °C by 2100 under business-as-usual emissions scenarios (Ghosh et al., 2016). The projected rise in mean temperature will intensify the hydrological cycle, increasing the severity and uncertainty of India's climate. By 2020, the Intergovernmental Panel on Climate Change expects a reduction in summer monsoon (June–September) rainfall by 7% and an increase of 20% in the intensity of rainfall during extreme events. Consequence on surface water resources, flood damage, urban drainage infrastructure, and groundwater recharge remain a major concern. Most existing water resources systems were designed to adapt to climate normal between 1951–1980, thus severe socio-economic repercussions foreseen from change of hydrology regimes on inter-state river operations, optimal conjunctive use of surface-ground-water, and water allocation. Limited adaptive capacity drives high vulnerability to climate change in India especially in arid and semi-arid regions.

Governance, Institutions, and Policy Gaps: In India, sustainable water resource management is hindered by institutional fragmentation at multi-level governance structures, inter-sectoral conflicts, and contradictory policy frameworks. At the national level, the Constitution and corresponding legislative clauses at regional and state levels often remain ineffective due to weak enforcement mechanisms. The temporal mismatch between water availability and demand often leads to misuse of the resource by affluent users, further aggravating inequities in access to water, with severe consequences for large sections of the population. Insufficient investments in public infrastructure and maintenance, coupled with an absence of reliable water-quality data, hamper the implementation of solutions to improve supply, combat climate variability, or expand infrastructure. Regulations, guidelines, and comprehensive local water-market data to assess groundwater abstraction are lacking; these are necessary to issue permits for new wells or implement suitable quota systems (M. Singh et al., 2013).

Financial and Technical Constraints: The Indian Water Sector has suffered from chronic underinvestment and preferential treatment to certain sectors like irrigation balancing limited investments in water supply and sanitation infrastructure (Sheriff Hemoh & Shenbei, 2014). Operation and maintenance (O&M) of assets remain deficient (Schultz & De Wrachien, 2002). Cities often cannot provide quality water for more than a couple of hours a day due to frequent outages. Elected representatives are unlikely to devote sufficient time and attention to upkeep. Simple technical solutions to upgrading facilities do exist, but few engaged experts are available, limiting investment and maintenance prospects. Monitoring of water quantity and quality—essential for producing credible water balance and statistical analysis—is scarce. Consequently, reliable information on water resources and associated indicators needed for planning is not available.

The majority of water supply utilities lack the technical expertise needed for adequate groundwater estimation. Industrial establishments are exempt from water supply restrictions. Weak local organizations providing environmental services, especially maintenance, stem from societal perception of these services as State prerogative. Infrastructural deficiencies have been aggravated by negligence or disrepair, leading to soft structural soil losses, siltation, and enlargements of flat systems poorly equipped for vegetation removal. Staff and technical associates working on long-term planning and service level enhancement miss an integrated framework of long-term future envisioning and urgent short-term needs assessment.

Strategies for Sustainable Management

Demand management and improved efficiency constitute an elementary, generally acceptable principle. Reducing water that actually requires treatment benefits the provision of potable water for human consumption, minimizes waste, optimizes the use of already invested capital, alleviates the need for water supply and wastewater treatment investments, and may even enhance environmental flows (Sheriff Hemoh & Shenbei, 2014). Metering, construction of effective volumetric charging systems, changes to crop patterns to lower water requirements, and extensive public education constitute complementary demand management techniques. A programme of supply augmentation and new infrastructure also appears desirable. Water supply shortages continue to impede the economy's growth, especially during drought periods, and consistently lower the overall quality of life wherever such shortages occur. Systematic improvements to storage and conveyance offer significant potential, particularly for surface water; dramatically better rainwater harvesting and reuse systems currently exist and could also contribute.

Integrated water resources management constitutes a related concept of substantial interest. Improved all-round system design and operation that combines sectoral interfaces, sets explicit water use allocation guidelines, encourages stakeholder involvement, and improves cross-sectoral planning according to a wider range of principles should also be beneficial. Optimizing groundwater management represents another dimension of potential action. Various approaches exist. Community reaction to excessive private use in large areas of rural India suggests that considerable demand could remain with little additional supply; pump-and-treat technologies might nevertheless be necessary for urban centres, and urban services either could simultaneously expand or develop entirely anew according to local preferences. Public opinion counselling and efforts to strengthen cooperatives on ownership, recharge, and technological spread might also possess merit.

Demand Management and Efficiency: Arid regions typically experience water scarcity characterized by significant spatial and temporal variability in both surface and groundwater resources. Demand management, which directly influences efficient water use and augments sustainability, forms a crucial part of a comprehensive water management strategy. The major consumer of fresh water in India, agriculture contributes a significant proportion of income and employs a large part of the workforce in rural areas despite rising share of water demand by industrial, domestic, and commercial sectors. Public awareness campaigns could alter inefficient and traditional crop patterns that are high-water demanding. Metering and proper pricing could be established to increase awareness of water scarcity. Intensive irrigation management through automation could address rising competition on surface water.

Rapidly rising water demand due to rising population, urbanization, and changing life-styles could take precedence if efficient, sustainable, and equitable management of mineral and energy resources is not adopted during the ever-increasing construction of infrastructure projects on a large scale (M. Singh et al., 2013). Repeated down-grading of the priorities on optimal water management after each five year plan during successive decades has transformed initial efficient water management practices for future generations too (K. Jha et al., 2020).

Supply Augmentation and Infrastructure: Supply augmentation through new sources, storage, distribution, rainwater harvesting, and recycling complements demand management. Strategies under consideration respond to current and projected shortages, population growth, and hydrological variability. Proposals remain aspirational, lack systematic assessment, and often motivate infrastructure investments outside fragile arid environments. Additional supply extends straight-line analyses of drought exposure by shifting focus from demand-driven depletion to basin-wide availability. Water use across India exceeds biomass-linked estimates (M. Singh et al., 2013). Investments in silos and distribution for inter-state transfer, balancing agency amalgamation, and dam regulation to unclog rivers remain unimplemented. Surface systems lack monitoring networks, flood-drought climate projections, and deficiency-based planning. Major urban-industrial development ignores availability and future flows (P Sishodia et al., 2018).

Facility siting requires regional hydrological modelling. Preferences across supply options and infrastructure investments warrant economic appraisal to tease out supply priority and assess resource security in the context of rising demand and diminishing availability. Probing metering encourages conservation by building base-load demand profiles; modulating reuse-savvy, ground-based systems arrested further exploration. Supply-extension-based surface-water resources are overdrawn in multiple states, irrevocably disrupting flow continuity; underground systems too probe across nine states and three-hundred sites punctuating water-logging.

Integrated Water Resources Management: Integrated Water Resources Management (IWRM) was introduced to facilitate a better understanding of water as a finite renewable resource in a catchment/basin and to address degradation of quality caused by agricultural runoff, effluents, solid waste, and municipal sewage. Following the 1992 International Conference on Water and Environment held in Dublin, Ireland, the subsequent International Conference on Water and Sustainable Development held in Bonn, Germany, and the 2nd World Water Forum held in The Hague, Netherlands, the Agenda for a Water-Secure World and the resolution adopted for IWRM at the 2004 International Conference of Water for Sustainable Development held in Bonn have further emphasized the need for IWRM.

India established its first national policy on water in 2002 and emphasized the need for IWRM but IWRM was not widely understood. In order to propagate the concept and approach of IWRM at the national level, the Government of India with the assistance of UNDP developed the document “National Water Policy 2002 (Draft): Operational Guidelines on IWRM” and organized workshops in different parts of the country. Subsequently the approach has been adopted by several states and union territories in India.

Integrated Water Resources Management in Several North African Countries focuses on the need for a systematic and integrated analysis of water and land resources in a river basin to take full advantage of good potential while sustaining resources for future generations The comprehensive water policy has started to encourage the provision of efficient water saving technologies in agricultural irrigation systems and for urban and industrial water supply in association with recycling and reuse. Integrated Quaternary Water Systems ˜he approach may be regarded as a strategy to reconcile conflicting demands for water between agriculture, urban supply, and other sectors, aiming therefore at a balanced sustainable development that will be beneficial, economically, and environmentally in the short and long term Even though practical applications may differ from one region to another, the strategy is of paramount importance in most of the countries to achieve a better management of water resources.

An integrated strategy is forward-looking. It has to be integrated with the institutional development of the country, because time is required to formulate the new laws and to establish new institutions for water management. Integrated Water Resources Management, the sustainable use and development of water resources, increasingly remains relevant today. The overall aim is to reverse the declining trend of water resources in the region and to prepare for future global climate changes or other external scenarios. A guideline is provided for smooth implementation of IWRM in arid and semi-arid region establishing the basic and important link between management and physical/hydrological components. It emphasizes the holistic approach indicating the guidelines are equally applicable for silted water bodies; urban areas, point sources; river systems connecting neighboring countries; inter-basin; and blue/green architecture. (Sheriff Hemoh & Shenbei, 2014)

Groundwater Regulation and Recharge: The value of groundwater is difficult to overstate, allowing sustenance of agriculture, livestock, urban livelihoods, and sanitation in circumstances of rainfall failure or insufficient surface-water supplies. Strategies aimed at sustainable groundwater management frequently involve measures intended either to regulate extraction or to augment recharge. Compulsory regulation of extraction through permits or volumetric caps is hypothesized as feasible only in dense urban areas. The United Nations estimates that every year around 112 million people are likely to be displaced because of catastrophic floods. Rajasthan ranks atop the list among states where groundwater extraction has disturbed the equilibrium of replenishment in aquifers. The issues have aggravated owing to uncontrolled extraction caused by the onset of climate change and exasperated by sudden floods.

Artificial recharge schemes Pilot programs for artificial recharge conducted in several places throughout the country have yielded appreciable benefits and demonstrated their potential for expansion (Venu Menon, 2007). Simple recharge measures such as recharge pits and trenches, roof-water harvesting and recharge, selection ponds, rainwater harvesting and recharge, and recharge through clogged percolation tanks have proven effective. Availability of site-specific hydro-geo-morphological and hydrometeorological information is essential for the success of such schemes. Under the Southern Region Hydrogeology Project, that was initiated in several states including Rajasthan, an artificial recharge scheme was designed and the possibility of large-scale artificial recharge identified. For this purpose, suitable dug wells were selected for artificial recharge with “suitable material” for filtration.

Nature-Based Solutions and Ecosystem Services: India is endowed with a diverse range of ecosystem services provided by its forests, wetlands, grasslands, coastal resources, and arid and semi-arid areas, but the degradation of these ecosystems places a severe strain on the water resource management system of the country. The 2018 National Water Policy recognizes the strong linkages between water, ecosystem health, and human well-being and emphasizes the need to restore degraded ecosystems and develop holistic approaches to sustainable water resource management (M. Singh et al., 2013). Nature-based solutions (NbS) are increasingly being recognized as one of the means to find a solution to challenges of water resource management. NbS refers to actions that work with nature in order to simultaneously address societal challenges and promotes the conservation, restoration, and sustainable management of ecosystems in order to deliver multiple benefits to humans and nature. NbS can control floods, monitor and prevent drought conditions, improve resilience to climate change, maintain water quality, recharge aquifers, control soil erosion, maintain biodiversity, and protect against pollution. NbS can also complement technical systems, making investments more durable and efficient.

Case Studies from Indian Arid Contexts

Sustainable water resource management (SWRM) is crucial for the sustainable development and livelihoods in arid regions such as India, where precipitation is low and the variability is high (Koundouri & Karousakis, 2006). In recent years, several initiatives aimed at SWRM have been implemented in India; three of these case studies are presented here. The first, in Rajasthan, centres on groundwater management through community-led recharge efforts, supported by an innovative state policy. The second focuses on the semi-arid regions of Karnataka and Telangana, where measures to optimise canal irrigation are complemented by urban water security initiatives. The third involves a state-led programme in western India that supports groundwater management through the establishment of monitoring networks and coordination across institutions.

Rajasthan and Thar Desert Initiatives: Rajasthan, the largest state in India, is characterized by aridity, limited water availability, fragile ecosystems, high poverty levels, and socio-economic exclusion. The Thar Desert, located in western Rajasthan, is characterized by extreme climatic variability, low groundwater recharge, and limited surface water supplies. Rural poverty and dependence on agriculture are prevalent. Consequently, a policy approach is needed which provides multiple solutions at scale. Four important initiatives within the state have provided substantial insights into improving groundwater management in arid regions (Spross, 2015). First, the Rajasthan government launched the National Watershed Development Project for Rain-Fed Areas in 2005, with support from the World Bank, to improve surface and groundwater levels and enhance agricultural production. Second, the state government implemented a pilot groundwater recharge project in 2007 in the Jaisalmer District. Third, the Ground Water Management Programme was initiated in Rajasthan in late 2005 to improve groundwater management and access in semi-arid regions. Lastly, the community-led campaign Jal Shakti Abhiyan commenced in 2019 to encourage water conservation, rainwater harvesting, and groundwater recharge.

Semi-Arid Regions of Karnataka and Telangana: Irrigation practices in semi-arid areas of Karnataka and Telangana rely heavily on canal systems derived from major rivers that originate in neighbouring states. Historically, irrigation projects promoted large-scale construction and investment in infrastructure, which has since yielded substantial returns. However, increasing agricultural water demand due to irrigation expansion and intensified cropping—especially of paddy in areas ill-suited for it—combined with diminishing returns from conventional investments, now threaten sustainability. Moreover, many perennial canals across India remain underutilized for irrigation, an opportunity partly addressed in Karnataka through Water Supply and Sanitation (WSS) improvements to enhance urban water security and partly through the Optimal Canal Water Management (OCWM) pilot scheme. Urban demand projections for 2025 and 2050 indicate that water supply will become a severe constraint throughout the region, necessitating adjustments to supply, demand, and quality issues in co-mingled systems serving mixed communities.

Canal-water efficiency varies significantly across states: 25–40% in Tamil Nadu, < 30% in Andhra Pradesh, 38–60% in Karnataka, 23% in Gujarat, < 45% in Maharashtra, and a mere 20% in Telangana. In Telangana, the OCWM pilot scheme aims to increase irrigation efficiency, improve intra- and inter-region timing, and extend system life by relating canal management to crop patterns. Scheduled canal periods have reportedly been maximized under existing institutional arrangements, and formal public-private partnerships remain uncommon.

Inhibitory factors include excessive investments elsewhere on the command network, variability in canal schedules due to unaccounted usage, and misaligned cropping patterns with partner references. Following 2005, Wal-mart initiated CANAL 1 X:1 Project (Pathak et al., 2006) (Koundouri & Karousakis, 2006; Sheriff Hemoh & Shenbei, 2014).

Western India Groundwater Management Programs: The innovative framework developed by the World Bank has been widely adopted throughout the arid and semi-arid India due to its importance in the State. The framework focuses on developing Groundwater Management Action Plan, implementing Decentralized Groundwater Development and Management (DGDM) approach and setting up Groundwater Regulation and Management system as policy measures. Under DGDM, funds are transferred to the Districts through Watershed Development Programme so that District specific solutions can be identified and implemented by involving local professionals and the community in the planning and implementation process. Sustainable development of groundwater is further enhanced with installation of volumetric flow meters in the pump sets. Department of Groundwater Resources has initiated plans to develop and operationalize real time monitoring system for water levels and rainfall over the State (Venu Menon, 2007). Further, water balance modelling was also carried out to quantify groundwater availability from all sources and assess stress (N. Bhanja et al., 2017).

Conclusion

Sustainable water resource management in arid regions remains a significant challenge throughout the world, especially in India. Analysis of the Indian situation reveals a complex and interwoven mix of policy, institutional, technical, and financial issues that severely undermine sustainable management of water resources in arid regions. Nevertheless, the growing recognition of these challenges, along with the government's active pursuit of ambitious reform strategies and some promising initiatives at the ground level, signals a potential way forward toward sustainable water resource management in the Indian arid context. A key insight emerges from the Indian experience. Integrated water resource management that seeks to improve water-use efficiency and reduce supply vulnerability through an interconnected combination of demand and supply measures within a governance framework that encourages active stakeholder participation offers considerable promise for addressing sustainability challenges. Integrating consideration of both groundwater and surface water across sectors and geographical units into an overarching framework helps highlight the significance and interdependence of these natural resources. Systematic attention to citizen water requirements across domestic, agricultural, commercial, and industrial domains and the articulation of government financing that prioritises water services facilities undergird attention to temporal, spatial, and sectoral dimensions of supply availability.

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