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An Adaptation Strategies for Ground Water Sustainability in the Face of Climate Change in India

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ABSTRACT

As per key findings of climate change projections for India,the increase in the frequency of extreme precipitation,will also mean that much of the monsoon rain would be lost as direct run-off resulting in reduced groundwater recharge and increased ground water withdrawal ,which might further exasperate the present scenario of imbalanced development.adaptation strategies to enhance aquifer recharge,demand management through intelligent power rationing and conjunctive management have been examined . Mechanism to promote synergy amongst stakeholders for implementation has been spelt out .

The adaptation strategies proposed for mitigating the increasing stress on ground water resources due to climate change for enhancing recharge of groundwater aquifers, mandating water harvesting and artificial recharge in urban areas,ground water governance, incentivising to promote recharging of ground water, intelligent power rationing for irrigation ,optimizing water use efficiency, conjunctive management etc have been examined at great length in terms of the technical feasibility as well as social relevance of implementation in the light of extensive experience gained in the country.

As of now, managing the energy-irrigation nexus with sensitivity and intelligence is the principal tool for groundwater demand management as evident from the experiences with some states like Gujarat,Punjab and Andhra Pradesh having very high stage of ground water development. It is surmised that power rationing can be a simple and effective instrument for groundwater demand management.

The most critical response to climate change in India's water sector demands exploring synergies from a variety of players for a nation-wide groundwater recharge program. India's water policy has so far tended to focus on what governments and government agencies can do. Now, it needs to target networks of players, each with distinct capabilities and limitations by sensitizing them to the social relevance of technical decision on mitigation. The role and space for various stakeholders namely Farmers, NGOs, local communities, Canal system managers and Groundwater Recharge SPV, in groundwater recharge strategy as a major response to climate change is outlined.

Keywords: Managed Aquifer Recharge, Energy-Irrigation Nexus ,Intelligent Power Rationing,Synergy, Conjunctive Management.

INTRODUCTION

India's National Action on Climate Change (NAPCC), unveiled by the Prime Minister's Office in 2008, highlights the increasing stress on water resources due to climate change, and points to the need to increase efficiency of water use, explore options to augment water supply in critical areas, and ensure more efficient management of water resources"(MOWR11). It calls for measures to enhance recharge of the sources and recharge zones of deeper groundwater aquifers, mandating water harvesting and artificial recharge in relevant urban areas, incentives to promote recharging of ground water, optimize water use by increasing water use efficiency by 20%, regulation of power tariffs for irrigation and to augment storage capacities of surface water storage structures, including through the renovation of existing tanks.

Intergovernmental Panel on Climate Change (IPCC8) in its recent released report has reconfirmed that the global atmospheric concentration of carbon dioxide (CO_2) and greenhouse gases (GHGs) have increased markedly as a result of human activities since 1750. The global increase in CO_2 concentration is primarily due to fossil fuel use and land use change. These increases in GHGs have resulted in warming of the climate system by 0.74ºC between 1906 and 2005. The rate of warming has been much higher in recent decades. This has, in turn, resulted in increased average temperature of the global ocean, sea level rise, decline in glaciers and snow cover. There is also a global trend for increased frequency of droughts, as well as heavy precipitation events over most land areas and extreme events.

Projected Climate Change

Annual mean surface temperature rise by the end of century, ranging from 3 to5ºC under A2 scenario and 2.5 to 4ºC under B2 scenario of IPCC, with warming more pronounced in the northern parts of India, from simulations by Indian Institute of Tropical Meteorology (IITM), Pune. Indian summer monsoon (ISM) is a manifestation of complex interactions between land, ocean and atmosphere. The simulation of ISM's mean pattern as well as variability on inter-annual and intra-seasonal scales has been a challenging ongoing problem. Some simulations by IITM, Pune, have indicated that summer monsoon intensity may increase beginning from 2040 and by 10% by 2100 under A2 scenario of IPCC.

Climate projections for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) made using the newly developed representative concentration pathways (RCPs) under the Coupled Model Inter-comparison Project 5 (CMIP5) by Rajiv Kumar Chaturvedi et al 4 of Indian Institute of Science, Bangalore ,provides multi-model and multi-scenario temperature and precipitation projections for India for the period 1860–2099 based on the new climate data. They found that that CMIP5 ensemble mean climate is closer to observed climate than any individual model. The key findings of this study are: (i) under the business-as usual (between RCP6.0 and RCP8.5) scenario, mean warming in India is likely to be in the range 1.7–2ºC by 2030s and 3.3–4.8ºC by 2080's relative to pre-industrial times; (ii) all-India precipitation under the business-as-usual scenario is projected to increase from 4% to 5% by 2030s and from 6% to 14% towards the end of the century (2080's) compared to the 1961–1990 baseline; (iii) while precipitation projections are generally less reliable than temperature projections, model agreement in precipitation projections increases from RCP 2.6 to RCP 8.5, and from short- to long-term projections, indicating that long term precipitation projections are generally more robust than their short-term counterparts and (iv) there is a consistent positive trend in frequency of extreme precipitation days (e.g. > 40 mm/day) for decades 2060s and beyond.

CMIP5 model-based time series of temperature and precipitation anomalies (historical and projections) from 1861 to 2099 relative to the 1961–1990 baseline for the RCP scenarios are given in Fig.1. Shaded area represents the range of changes projected by the 18 models for each year. The model ensemble averages for each RCP are shown with thick lines. The observed temperature and precipitation trend from CRU is shown by the green line and the solid black

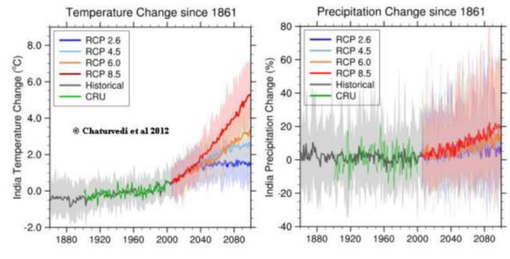

Figure1 .CMIP5 model-based time series of temperature and precipitation anomalies (historical and projections) from1861 to 2099 relative to the 1961–1990 baseline for the RCP scenarios. (After, Rajiv KumarChaturvedi*et al* ,2012)

line 'historical' refers to model ensemble values for historical simulations. Projected change in the frequency of extreme rainfall days for future decades relative to the 1861–1870 baseline is given in Fig 2.

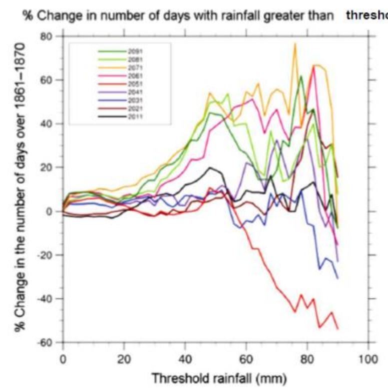

Figure 2. Projected change in the frequency of extreme rainfall daysfor future decades relative to the 1861–1870 baseline (After, Rajiv KumarChaturvedi*et al* ,2012) .

Climate Change and Water Resources

The importance of climate change impacts on water resources has been well brought in the Third Assessment Report of the Intergovernmental Panel on climate Change (IPCC) 8 , which says " Climate Change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources, affecting both ground and surface water supply. Rising global temperatures are expected to raise sea level and change precipitation and other local climate conditions.

Changing regional climate could affect forests, crop yields, and water supplies. It could also threaten human health, and harm living beings and the ecosystem. Changing climate is expected to influence both evaporation and precipitation in most of the areas. In those areas where evaporation increases more than precipitation, soil will become drier, water level in lakes will drop and rivers will carry less water. Lower river flows and lower lake levels could impair navigation, hydroelectric power generation, water quality and reduce the supplies of water availability for agricultural, domestic and industrial uses. Melting snow provides much of the summer water supply; warms temperatures could cause the snow to melt earlier and this reduce summer supplied even if rainfall increased during the spring.

Various studies carried out in India in different basins to assess the impact of Green House Gases (GHG) and global warming including development of simulation models (SWAT) revealed that under GHG scenario the conditions may deteriorate in terms of severity of droughts in some basins and enhanced intensity of flood in other basins of the country. However, there is a general overall reduction in the available runoff, which has direct bearing on ground water recharge. This may have considerable implications on Indian agriculture and hence on our food security and farmers livelihood. The strategies may range from change in land use, cropping pattern, to water conservation flood warning system.

Ground Water Scenario:

Ground water is one of the most precious natural resource and has played a significant role in maintenance of India's economy, environment and standard of living. Besides being the primary source of water supply for domestic and many industrial uses, it is the single largest and most productive source of irrigation water. India is a vast country having diversified geological, climatological and topographic set-up, giving rise to divergent groundwater situation in different parts of the country. The prevalent rock formations, ranging in age from Achaean to Recent, which control occurrence and mocement of groundwater, are widely varied in composition and structure. Broadly two groups of water bearing rock formations have been identified i.e. (i) Porous rock formations which can be further classified into unconsolidated and semi consolidated formations having primary porosity; and (ii) Fissured rock formations which mostly have secondary or derived porosity. Similarly, there are significant variations of landforms from the rugged mountainous terrains of the Himalayas, Eastern and Western Ghats to the flat alluvialplains of the river valleys and coastal tracts, and the aeolian deserts of Rajasthan. The rainfall patterns too show similar region-wise variations. The topography and rainfall virtually control run-off and groundwater recharge. The entire country has been broadly divided into five distinct ground water regions considering the characteristic physiographic features as well as occurrence and distribution of ground water.

Mountainous Terrain and Hilly areas:

This region is occupied by varied rock types including granite, slate, sandstone and limestone. The yield potential of aquifers ranges from 1 to 40 letres per second (lps). However, because of high conductivity and hydraulic gradient, it offers very little scope; for ground water storage. The valley fills in mountains function as underflow conduits and act as the major source of recharge. Springs are main source of water supply. Indo-Gangetic-Brahmaputra Alluvial Plains: Indo-Gangetic- Brahmaputra alluvial plains, occupy the States of Punjab, Haryana, Uttar Pradesh, Bihar, Assam and West Bengal. The plain is underlain by thick pile of sediments. Thickness of the sediments increases from north to south. At places, the thickness of the alluvium exceeds 1000m. The thick alluvial fill constitutes the most productive ground water reservoir in the country. In the present scenario the ground water development in this region is at low level except the western parts in the States of Haryana and Punjab. The deeper aquifers in these areas offer good scope for further exploitation of ground water. In Indo-Gangetic-Brahmaputra plain, the deep wells yield in the range of 25-50 lps.

Peninsular shield Area:

The area is located south of Indo-Gangetic plain and consists mostly of consolidated sedimentary rocks, Deccan basalts and crystalline rocks in the states of Karnataka, Maharashtra, and Tamil Nadu. Occurrence and movement of ground water in these rock formations are restricted to weathered material and interconnected fractures at deeper levels. These have limited ground water potential. Ground water occurs within depth 50m, occasionally down to 150m, and rarely beyond 200m depth. Ground water development is largely through dug well and borewells. The yield of borewells tapping deep fractured zones in hard rocks varies from 2-15 lps.

Coastal Area: Coastal areas have a thick cover of alluvial deposits and form potential multi-aquifer systems covering states of Gujarat, kerala, Tamil Nadu, Andhra Pradesh and Orissa. However, inherent quality problems and the risk of seawater ingress impose severe constrains in the development of these aquifers. In addition, the ground water development in these areas is highly vulnerable to up-coning of saline water. The yield of tubewells varies from 20-25 lps.

Central Alluvial Areas: This region has been grouped separately owing to its peculiarity in terms of presence of three discrete fault basins, the Narmada, the Purna and Tapti, all of which contain extensive valley-fill deposits. The alluvial deposit ranges in thickness from about 50 to 150m. Ground water occurrence in the area is restricted to deep aquifer systems tapping fossil water. For example, in parts of Purna valley the ground water is extensively saline and unfit for various purposes. The yield potential of tubewells varies from 1-10 lps.

The Hydrogeological map of India is depicted in Plate – I showing ground water potential of the broad groups of water bearing formations.

Ground Water Availability : Rainfall is the major source of ground water recharge, which is supplemented by other sources such as recharge from canals, irrigated fields and surface water bodies. The rainfall is unevenly distributed. The average rainfall in country is around 117cm. It is below 75 cm in the northwestern part covering parts of the states of Rajasthan, Gujarat, Haryana and the southern part, covering the states of Karnataka and Tamil Nadu. The amount of ground water withdrawal and situation of low rainfall are the factors which decides the overall stress on ground water and accordingly the assessment units are being categorized as over-exploited & critical blocks.

Large development of ground water resources in the country takes place from the unconfined / shallow aquifers, which hold replenishable ground water resource. Central Ground Water Board has assessed the replenishable ground water resource in the country in association with the concerned State Government authorities (CGWB2) .The annual replenishable ground water resources have been assessed as 431bcm. Keeping an allocation for natural discharge, the net annual ground water availability is 396 bcm. The annual ground water draft (as on 31st March, 2009) is 243 bcm. The Stage of ground water development works out to be about 61%. The development of ground water in different areas of thecountry has not been uniform. Highly intensive development of ground water in certain areas in the country has resulted in over – exploitation leading to decline in ground water levels and sea water intrusion in coastal areas. Out of 5842 assessment units (Blocks/Mandals / Talukas) in the country, 802 units in various States have been categorized as 'Over-exploited' i.e. the annual ground water extraction exceeds the net annual ground water availability and significant decline in long term ground water level trend has been observed either in pre-monsoon or post- monsoon or both. In addition 169 units are 'Critical' i.e. the stage of ground water development is above 90 % and within 100% of netannual ground water availability and significant decline is observed in the long term water level trend in both pre-monsoon and post-monsoon periods.There are 523 semi-critical units, where the stage of ground water development is between 70% and 100% and significant decline in long term water level trend has been recorded in either Pre-monsoon

or Post-monsoon.4277 assessment units are Safe where there is no decline in long term ground water level trend. Apart from this, there are 71 blocks completely underlain by saline ground water.

In addition to annually replenishable ground water, extensive ground water resources occur in the confined aquifers in the Ganga-Brahmaputra alluvial plains and coastal – deltaic areas. These aquifers have their recharge zones in the upper reaches of the basins. The resources in these deep-seated aquifers are termed as 'In-storage ground water resources'. In alluvial areas, these resources are normally renewable over long periods of time, except in case of sedimentary rock aquifers in Rajasthan, which comprise essentially non-renewable fossil water.

Proposed adaptationstrategies

In view of the clear evidences of change in global surface temperature, rainfall pattern, evapotranspiration and extreme events and its possible impact on the hydrological cycle, it is pertinent to reassess the availability of water resources. It is critical for formulating relevant national and regional long-term development strategies in a holistic way. The various mitigation measures within the constraints imposed by the possible climate change and hydrologic regimes and future research needs are discussed in following paragraphs.

Rainwater harvesting and Artificial Recharge: Extreme climate events such as aridity, drought, flood, cyclone and stormy rainfall are expected to leave an impact on human society. They are also expected to generate widespread response to adapt and mitigate the sufferings associated with these extremes. Societal and cultural responses to prolonged drought include population dislocation, cultural separation, habitation abandonment, and societal collapse. A typical response to local aridity is the human migration to safer and productive areas. However, climate and culture can interact in numerous ways. Historical societal adaptations to climate fluctuations may provide insights on potential responses of modern societies to future climate change that has a bearing on water resources, food production and management of natural systems. Decentralized rainwater harvesting from roof catchments in cities has the potential to supplement centralised water supply strategies to create an overall more resilient urban water supply. This result highlights the importance of implementing a diverse range of water sources and conservation for urban water management. The efficiency of translation of rainfall runoff into recharge is highly dependent on strategy and location.

The immediate priority for augmentation of ground water are the areas already overexploited resulting into severe decline in ground water level, coastal areas affected by sea water ingress due to haphazard and unscientific development of ground water and the areas infested with pollution due to various reasons. While prioritizing the areas, the possible impact of climate change needs to be dovetailed. As a long term measure an attempt has been made to provide a conceptual framework for utilization of surplus monsoon runoff for artificial recharge of ground water and consequently a "National perspective plan for recharge to ground water by utilizing surplus monsoon runoff" has been prepared by CGWB1. The report provides availability of non-committed surplus monsoon runoff in 20 river basins of the country vis-a vis the subsurface available space under different hydrogeological situations for saturating the vadose zone to 3 m below ground level. It was estimated that it is possible to store 21.4 Mham in the ground water reservoir through out the country out of which 16.05 Mham can be utilized.

As per the the Master Plan (2013)3 for artificial recharge to ground water, out of the geographical area of 32,87,263 sq. km of the country, an area of about 9,41,541 sq.km. has been identified in various parts of country which need artificial recharge to ground water. This includes the hilly terrain of Himalayas also where the structures are basically proposed to increase the fresh water recharge and improve the sustainability of springs. It is estimated that annually about 85,565 MCM of surplus surface run-off can be harnessed to augment the ground water.

In rural areas, suitable civil structures like percolation tanks, check dams, nala bunds, gully plugs, gabion structures etc. and sub-surface techniques of recharge shaft, well recharge etc. have been recommended. Provision to conserve ground water flow through ground water dams has also been made. It is envisaged to construct of about 1.11crore artificial recharge structures(11 Million) in urban and rural areas at an estimated cost of about Rs. 79,178 crores(US $ 15835 Million) . This comprises of mainly around 88 lakh structures utilizing rain water directly from rooftop and more than 23 lakh artificial recharge structures utilizing surplus run-off and recharging ground water in various aquifers across the country. The break-up includes around 2.90 lakh check dams, 1.55 lakh gabion structures, 6.26 lakh gully plugs, 4.09 lakh nala bunds/cement plugs. 84925 percolation tanks, 8281 sub-surface dykes, 5.91 lakh recharge shaft, 1.08 lakh contour bunds, 16235 injection wells and 23172 other structures which includes point recharge structures, recharge tube wells, stop dams, recharge trenches, anicuts, flooding structures, induced recharge structures, weir structures etc. In hilly terrain of Himalayas emphasis has been given for spring development and 2950 springs are proposed for augmentation and development.

Assuming the importance of artificial recharge and rain water harvesting, the Model Bill on Ground water prepared and circulated by Ministry of Water Resources has been amended in 2006 to accommodate the this important aspect and all the state Governments have been asked to formulate their own rule and law for better governance of ground water adopting suitable augmentation measures where ever required or else impose regulatory measures to ensure sustainability of this vital resource.

An increase in precipitation in the basins of Mahanadi, Brahmani, Ganga, Godavari and Cauvery is projected under climate change scenario. Unless remedial measures are implemented to control the runoff, frequency of floods in these areas are unavoidable. During and after the floods, ground water plays a significant role as alternative source of drinking water. The construction of " Sanctuary wells " in such areas at suitable locations or near the shelters houses may provide a solution for solving the drinking water crisis during the flood times. Preferably the Sanctuary wells may be constructed tapping the deeper aquifers which are less vulnerable to contamination because of inundation.

Conjunctive Management: Conjunctive management will play crucial role as a mitigatory measure since climate change will lead to extreme situation of water level rise in some areas and water level decline in other areas. In such event Conjunctive management need to be adopted so as

- To evolve a suitable plan for controlling the problem of rising water levels by adopting the technique of conjunctive use of surface and ground water, and proper drainage.
- To prepare sector/ block-wise plans for development of ground water resource in conjunction with surface water based on mathematical model results.
- To test the sustainability of the present irrigation pattern with respect to conjunctive use of water resources and suggest improvement for future.
- To evaluate the economic aspect of groundwater development plan with respect to Cost benefits ratio, internal rate of return and pay back period etc.

In areas of India with massive evaporation losses from reservoirs and canals but high rates of infiltration and percolation, the big hope for surface irrigation systems—small and large—may be to reinvent them to enhance and stabilize groundwater aquifers that offer water supply close to points of use, permitting frequent and flexible just-in-time irrigation of diverse crops. Already, many canal irrigation systems create value not through flow irrigation but by supporting well irrigation. In the Mahi Right Bank system in Gujarat, with a command area of about 250,000 ha, it is the more than 30,000 private tube wells—each complete with heavy-duty motors and buried pipe networks to service 30 to 50 ha—that really irrigate crops; the canals merely recharge the aquifers. An elaborate study by Central Groundwater Board (1995) lauded the Mahi irrigation system as a "model conjunctive use project" in which 65 percent of water was delivered by canals and 35 percent was contributed by groundwater wells. However, what conjunctive use was occurring was more by default than by design as the enterprising farming community of the area have taken the initiative and realized fully the advantages of adopting the conjunctive use techniques for reaping optimal benefits.

Further, there is an urgent need to adopt participatory Irrigation management ensuring participation of stakeholders since inception of the conjunctive use projects. Due to variations in rainfall and runoff in different basins of the country, it is expected that imbalances in availability of surface and ground water may aggravate the conditions of water logging at one end and scarcity at other end. The major irrigation command areas are more vulnerable to such extreme events and hence there is an urgent need to implement conjunctive use practices in field conditions so as to control rising water level scenario, water logging and even water shortages in tail end areas.

Intelligent management of energy-irrigation nexus : As of now, managing the energy-irrigation nexus with sensitivity and intelligence is the region's principal tool for groundwater demand management. The current challenge is twofold. First, diesel-based groundwater economies of the Indo-Gangetic basin are in the throes of an energy squeeze; some recent studies (Shah 2007, 2009)13, show that, further rise in diesel prices, will undermine the potential benefits of conjunctive use of ground and surface waters in water abundant areas of Ganga basin. Electrification of the groundwater economy of these regions combined with a sensible scheme of farm power rationing may be the most feasible way of stemming distress outmigration of the agrarian poor. In the electricity-dependent groundwater economy of western and peninsular India, the challenge is to transform the current degenerate electricity-groundwater nexus into a rational one. Tariff reform has proved a political challenge in many of these states; but other 'hybrid' solutions need to be invented. Gujarat's experience under the Jyotigram scheme illustrates a 'hybrid' approach based on intelligent rationing of power supply (Shah and Verma14; Shah et al 15). But other states in the region too are moving in the direction of demand management by rationing power. Punjab has effectively used stringent power rationing in summer to encourage farmers to delay rice transplantation by a month and in the process significantly reduced groundwater depletion. Andhra Pradesh gives farmers free power but has now imposed a seven-hour ration. It is surmised that power rationing can be a simple and effective instrument for groundwater demand management.

Institutional and Regulatory Measures : One of the most important mitigation measure is strengthening of institutional as well as regulatory framework of the country in relation to ground water. In spite of the fact that water is a state subject and it need to be regulated at the state level, there are several states in which there is no independent department or set up to look after the ground water governance. Hence, there is an urgent need of institutional strengthening at appropriate level and adoption of regulatory measures in strict sense.

In this connection the implementing agencies for regulatory measure may be decided by the Central and State government. The implementation may be through the State Ground Water Department/PHED or local development board or authority. The implementation should be entrusted to one single department in the state and not to a number of departments with a view to better implementation, monitoring of the progress etc. If the programme has to be implemented in more than one department in the state due to unavoidable and certain special consideration, one of the departments should be designated as Nodal Department for coordinating the all the activities related mitigatory measure related climate change and ground water and sending consolidated progress to the Central Government. The Panchayati Raj Institution should also be involved in the implementation of the schemes, particularly in selecting the location of stand post spot sources, operation and maintenance. Planning Commission12 in its report of the Expert Group on " Ground Water Management and Ownership " has discussed the requirement of certain institutional changes and suggested that the mandate of Central Ground Water Board to be shifted to a facilitator rather than a regulator to assist better implementation of management options.For effective implementation of ground water management plan a three tier institutional arrangements involving Central, State and Districts level agencies needs to be formulated.

Increasing Ground Water Use Efficiency: Water use efficiency programs, which include both water conservation and water recycling, reduce demands on existing water supplies and delay or eliminate the need for new water supplies for an expanding population. These effects are cumulative and increasing. Water conservation savings have increased each year due to expansion of and greater participation in these water conservation programs. Water recycling, or the use of treated wastewater for non-potable applications, is used in a variety of ways, including for irrigation and industrial processes. This in turn will provide environmental benefits as well as significant aesthetic and human health benefits. A reduction in water-related energy demand due to water conservation and water recycling reduces the air pollutants and allows to respond to the water supply challenges posed by global climate change. Water conservation and water recycling programs clearly save energy and reduce air pollutant emissions.

Broadening the limits of the quality of water used in agriculture can help manage the available water better in areas where scarcity of water is due to salinity of the available ground water resources. Cultivation of salt tolerant crops in arid/semi-arid lands, dual water supply system in urban settlements - fresh treated water for drinking water supply and brackish ground water for other domestic uses are some such examples. Recycling of water after proper treatment for secondary and tertiary uses is another alternative that could be popularized to meet requirements of water in face of the scarcity of resource in the cities. It has been estimated that parts of Haryana, Punjab, Delhi Rajasthan, Gujarat, Uttar Pradesh, Karnataka and Tamil Nadu have inland saline ground water of the order of about 1164 BCM. Yields of many crops, vegetables and fruit plants e.g. barley, dates and pomegranate, when irrigated with saline or brackish water are not significantly affected. Saline/ brackish water can be successfully used to irrigate such plants and fresh or good quality water can be saved for use by other sensitive crops or for other uses. Brackish water can also be utilized forpisciculture / aquaculture. Therefore, additional resource of 1164 BCM of saline/brackish ground water resource would be available for use. Studies are required to be undertaken on use and disposal of brackish / saline ground water.

Studies have shown that that substantial quantity of water could be saved by the introduction of micro irrigation techniques in agriculture. Micro irrigation sprinklers and drip systems can be adopted for meeting the water requirement of crops on any irrigable soils except in very windy and hot climates. These water conservation techniques would provide uniform wetting and efficient water use.

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Adopting the Concept of Virtual Water: Virtual water is defined as water embedded in commodities. It is said that the largest exported commodity in the world is 'Water', which is in terms of virtual water contained in the food grains. As a thumb of rule, a grain crop transpires about 1 cubic meter of water in order to produce 1 kilogram of grain. Thus exporting or importing 1 kilogram of grain is approximately equivalent to exporting 1 cubic meter of water. The best example of virtual water in Indian context can be thought in terms of producing fodder in the water surplus areas of Indo Gangetic plains and transported to the water stressed areas of Gujarat, Rajasthan, Punjab etc. this way water used for fodder production in these states can be reduced and water saved can be fruitfully utilized for other priority sectors. Thus the concept of Virtual Water can help in combating the impact of climate change on ground water by planning the suitable cropping pattern depending upon the availability of ground water.

Coastal Aquifer Management: Recent studies on the likely impact of sea level rise to the tune of one meter along Indian coast provide an idea about the land which could be inundated and the population that would be affected provided no protective measures are taken. The ingress of salinity in the coastal aquifers with respect to sea level rise and ground water abstraction is most likely in the event of climate change. Most vulnerable areas along the Indian coastline are the Kutch region of Gujarat, Mumbai and South Kerala. Deltas of rivers Ganges (West Bengal), Cauvery (Tamil Nadu), Krishna and Godawari (Andhra Pradesh) and Mahanadi (Orissa). The future studies should be focused on developing efficient monitoring mechanism, Filling the data gap through ground water exploration, hydrochemical and modeling studies.

Capacity Building and Training Needs: As per an estimate within the country about 10,000 professionals, 20,000 sub-professionals and nearly 1, 00,000 skilled personnel are employed in the work of ground water investigation, development and management. Many of the sub professionals like drillers etc. have no formal training in ground water which is very essential for getting optimum benefits for its sustainable development. In view of the increasing importance of ground water and anticipated climate change there is a need to create exclusive infrastructure to cater the need of training requirements of ground professional in the country.

The country had so far not been able to create the requisite training facilities. The professionals being assigned to the work usually possessed a Master's Degree in Geology / Geophysics / Chemistry or Bachelors Degree in Engineering. Though the Universities and Technical institutes are well equipped to carry out academic teaching programmes in the mother disciplines like geology, Geophysics they have limited facilities for training the field professional on specialized aspects of ground water assessment, management application of advanced tools like modeling , GIS etc.

In the context of water resources, training in the form of capacity building is indispensable for

(a) strengthening the enabling institutional environment which takes the organizations in the right directions.

(b) optimizing the available water resources which is becoming more and more critical with the passage of time.

(c) establishing responsibility and accountability at all appropriate levels of hierarchy to usher in the needed efficiency.

(d) understanding and appreciating value of water as a social and economic good.

(e) developing and encouraging reliable information on policies, programmes, and projects, and systems of sharing this information to bring in transparency.

(f) keep finding innovative solutions to problems, technical or otherwise, facing the sector to manage the resource sustainably.

Synergy amongst stake holders:

Sustainable development of ground water resources and various mitigation programmes required in the event of possible climate change in the country can be accomplished only with the help and active cooperation of all stakeholders such as the Ministries of Government of India for Water Resources, Environment & Forests, Rural Development, Agriculture, Science & Technology and the institutions working under them; State Governments & their organizations; Associations of Industry, Non-Government Organizations, District Administrations and Panchayati Raj Institutions and the individuals users. To be successful in this mission we also have to create conditions for complete synergy in the activities of all the stakeholders.In this regard Ministry of Water Resources has taken a step forward by constituting the "Advisory Council on Artificial Recharge to Ground Water " involving members from all walks of life. However, the stakeholders in grass root levels need to be sensitized to the social relevance of technical decision on mitigation.

Although the groundwater agencies at central and state level are the custodians of our groundwater resource, in reality, multiple agencies in public and private sectors are involved as major players in India's groundwater economy. As climate change transforms groundwater into a more critical and yet threatened resource, there is dire need for coordinating mechanisms to bring these agencies under an umbrella framework to synergize their roles and actions. Even as governments evolve groundwater regulations and their enforcement mechanisms, more practical strategies for groundwater governance need to be evolved.

In hard-rock regions of the country, together with intelligent management of the energy-irrigation nexus, mass-based decentralized groundwater recharge offers a major short-run supply-side opportunity. Public agencies are likely to attract maximum farmer participation in any programs that augment on-demand water availability around farming areas. Experience also shows that engaging in groundwater recharge is often the first step for communities to evolve norms for local, community-based demand management.

Table1. Fluoride, Iron and Nitrate concentrations in Punjab (Source: CGWB, India)

Sr. no.	District	Concentration range (mg/l)		
		Fluoride	Iron	Nitrate
1	Amritsar	1.58-1.99	-	95-286
2	Bhatinda	1.93-4.70	1.02-25.00	54-621
3	Faridkot	2.64-3.67	1.86-3.10	60-287
4	Fatehgarh Sahib	1.54	1.00-2.58	52-85
5	Firozepur	1.63-3.46	1.82	69-241
6	Gurdaspur	3.55	1.37-3.62	55-521
7	Hoshiarpur	-	1.00-1.36	64
8	Jalandhar	-	-	105
9	Kapurthala	-	-	105
10	Ludhiana	-	-	57-104
11	Mansa	1.58-8.33	1.76-1.82	70-348
12	Moga	1.96	-	45
13	Muktsar	5.36	-	83-944
14	Nawanshahr	-	-	77
15	Patiala	2.05-2.80	-	47-52
16	Rupnagar	-	1.07-3.40	60-64
17	Sangrur	1.71-11.30	1.07-1.37	110-1180

In alluvial aquifer areas, conjunctive management of rain, surface water, and groundwater is the big hitherto under-exploited opportunity for supply-side management. Massive investments being planned for rehabilitating, modernizing, and extending gravity-flow irrigation from large and small reservoirs need a major rethink in India. In view of the threat of Climate Change, indeed, we need to rethink our storage technology itself. Over the past 40 years, India’s landmass has been turned into a huge underground reservoir, more productive, efficient, and valuable to farmers than surface reservoirs. For millennia, it could capture and store little rainwater because in its predevelopment phase it had little unused storage.

The pump irrigation revolution has created 250 km3 of new, more efficient storage in the subcontinent. Like surface reservoirs, aquifer storage is good in some places and not so good in others. To the farmer, this reservoir is more valuable than surface reservoirs because he has direct access to it and can obtain water on demand.

Therefore, he is far more likely to collaborate in managing this reservoir if it responds to his recharge pull. Indeed, he would engage in participatory management of a canal if it served his recharge pull. This is best illustrated by the emergence of strong canal water user associations of grape growers in the Vaghad system in Nasik district of Maharashtra. Vineyards under drip irrigation in this region need to be watered some 80 to 100 times a year, but canals are useless: they release water for a maximum of just 7 times. Yet grape growers have formed some of the finest water user associations in the region for proactive canal management here mostly because they value canals as the prime source of recharging the groundwater that sustains their high-value orchards (Shah17).

By far the most critical response to climate change in India’s water sector demands exploring synergies from a variety of players for a nation-wide groundwater recharge program. India’s water policy has so far tended to focus on what governments and government agencies can do. Now, it needs to target networks of players, each with distinct capabilities and limitations. If groundwater recharge is to be a major response to hydro-climatic change, the country needs to evolve and work with an integrated groundwater recharge strategy with role and space for various players to contribute as outlined in the table 2 below.

Table 2. Outline of an Integrated Groundwater Recharge Strategy for India

Key actors	Arid alluvial aquifer areas	Hard rock aquifer areas	Roles that need to be played by CGWB, Recharge SPV, other public agencies
Farmers	Dug wells, farm ponds, roof-water harvesting; other private recharge structures	Dug wells, farm ponds, roof-water harvesting; other private recharge structures	Vigorous IEC[a] campaign to promote recharge to dynamic waters through dug wells & farm ponds
			Technical support in constructing recharge pits, silt-load reduction, periodic desiltation of wells
			Financial incentives and support to recharging farmers
communities	surface dykes; stop dams and delayed-action dams on streams		construction and maintenance
			Supportive policy environment and incentive structures
			Support for building local institutions for groundwater recharge
Canal system managers	Conjunctive management of surface and groundwater		Operate surface systems for extensive recharge
			Where appropriate, retrofit irrigation systems for piped conveyance and pressurized irrigation
			Where appropriate, retrofit irrigation systems for use of surplus floodwaters to maximize recharge
			Where appropriate link canals through buried pipelines to dug wells/recharge tubewells for year-round recharge
Groundwater recharge SPV	Recharge canals to capture flood flows for recharge (e.g., Ghed canal in Saurashtra) or transport surplus flood waters for recharge in groundwater-stressed areas (e.g., *SujalamSufalam* in North Gujarat)		Create a Special Purpose Vehicle to execute, operate and maintain large-scale recharge structures
			Build and operate large-scale recharge structures in upstream areas of confined aquifers. e.g. at the base of Aravalli's in North Gujarat
	Large recharge structures in recharge zones of confined aquifers		Build and operate large earthen recharge canals along the coasts

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