भारत में भूजल के कृत्रिम पुनर्भरण सबंधी मास्टर योजना

Master Plan for Artificial Recharge to Ground Water in India

भारत सरकार

Government of India

जल संसाधन मंत्रालय

Ministry of Water Resources

केन्द्रीय भूमि जल बोर्ड

Central Ground Water Board

नई दिल्ली

New Delhi

2013

भारत में भूजल के कृत्रिम पुनर्भरण सबंधी मास्टर योजना

भारत में भूजल के कृत्रिम पुनर्भरण सबंधी मास्टर योजना

Master Plan
for Artificial Recharge to Ground Water in India

भारत सरकार
Government of India
जल संसाधान मंत्रालय
Ministry of Water Resources
केन्द्रीय भूमि जल बोर्ड
Central Ground Water Board
नई दिल्ली
New Delhi
2013

MASTER PLAN FOR
ARTIFICIAL RECHARGE TO GROUND WATER IN INDIA

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ध्रुव विजय सिंह
DHRUV VIJAI SINGH

सचिव
भारत सरकार
जल संसाधन मंत्रालय
श्रम शक्ति भवन
रफी मार्ग, नई दिल्ली-110001

SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES
SHRAM SHAKTI BHAWAN
RAFI MARG, NEW DELHI-1100 01

30th January, 2013

FOREWORD

Water sustains life. Ground water, due to its nature of occurrence at the place of utilization, has become the prime water source. The contribution of ground water in the green revolution has made India self-sufficient in food grain production. However, with increasing population and demand, ground water is facing stress leading to creation of various challenges in the management of ground water

.

In order to address quantity and quality related challenges, both supply and demand side management needs to be made. Artificial recharge of ground water by utilizing surplus rainfall runoff is one of the best supply side water management options for providing sustainability to ground water sources and augmenting depleted aquifer systems.

The present "Master Plan for Artificial Recharge of Ground Water" is an effort to assess the total recharge potential available in the country along with suitable designs of structures for such recharge. The Master Plan has been prepared by Central Ground Water Board in consultation with the State Governments, in view the technical and scientific aspects of recharge projects.

The efforts put in by Shri Sushil Gupta, Chairman and Dr. N. Varadaraj, Member, Central Ground Water Board along with several of their colleagues is worth appreciating. I am sure that this Master Plan would go a long way in helping and guiding the States in augmenting depleting ground water resources of the country.

(Dhruv Vijai Singh)

स्वच्छ सुरक्षित जल - सुन्दर खुशहाल कल

CONSERVE WATER - SAVE LIFE

Tel : 23715919, Fax : 23731553, E-mail : dvs@nic.in

सुशील गुप्ता
Sushil Gupta

अध्यक्ष
केन्द्रीय भूमि जल बोर्ड
भारत सरकार
जल संसाधन मंत्रालय

Chairman
Central Ground Water Board
Government of India
Ministry of Water Resources

Dt. 30.01. 2013

PREFACE

Ground water is the major source of water supply for various uses. The relentless pressure due to competitive demands and ever increasing needs of various sectors have resulted in over exploitation of ground water in many parts of the country.

Management of any natural resources needs long term planning to match supply and demand. Augmentation of the depleting water resources and protecting ground water quality is very essential for preservation of this precious resource. Harvesting of excess monsoon runoff, otherwise being lost to the sea, is the best option to achieve this objective. Central Ground Water Board has developed the methodology and techniques to augment ground water resources through various demonstrative artificial recharge studies in various hydrogeological conditions of the country. Based on this experience Central Ground Water Board had compiled a National Perspective Plan for Recharge to Ground Water by utilizing surplus monsoon runoff in 1996. The first Master Plan for Artificial Recharge to Ground Water was prepared in 2002.

Vast amount of database generated and experience gained by implementation of various schemes encouraged Central Ground Water Board to prepare the second Master Plan. The present Master Plan is an effort to bring out detailed district wise feasibility of artificial recharge, identifying the uncovered areas, deeper aquifers under stress and vulnerable areas for sea water ingress. The Master Plan will serve as a road map and implementation document of artificial recharge to ground water in the country. The present Master Plan prepared by the Board would be a useful document to the states in augmenting the ground water sources and increasing the sustainability of ground water abstraction structures and springs.

The Master Plan is the result of untiring efforts of the Regional Directors and officers of the Board and State Government organizations who have provided the required input for its preparation. I would however like to specially acknowledge and highly appreciate the efforts of Dr. N.Varadaraj, Member, Dr.K.M.Najeeb and Sri Manoj Srivastava, Regional Directors, Sri Sanjay Marwaha and Sri G.Sudarshan, Superintending Hydrogeologists, Dr. S.K.Gupta, Scientist-D, Dr. P.N. Rao, Scientist-D, Sri Y B Kaushik, Scientist-D, Sri S.K.Juneja, Scientist-D, Sri S.K. Sinha, Scientist-D, Sri G.Y. Setty, Scientist-C, Dr.S. Subramanian, Scientist-C, Sri M K Garg, Scientist-B and Sri P.Yadaiah, Asstt. Hydrogeologist.

(Sushil Gupta)

Bhujal Bhawan, NH-IV, Faridabad - 121001
Tel. : 0129-2419075, Fax : 0129-2412524, E-mail : chmn-cgwb@nic.in
Website : www.cgwb.gov.in, www.mowr.gov.in

स्वच्छ सुरक्षित जल - सुन्दर खुशहाल कल

CONSERVE WATER - SAVE LIFE

EXECUTIVE SUMMARY

India is a vast country with diverse geological, geomorphological and hydrometeorological conditions, which give rise to widely varying ground water situations. The hydrogeological units are broadly classified into unconsolidated, consolidated and semi-consolidated formations. Indo-Gangetic plains and coastal areas are occupied by unconsolidated formations. Almost two third of the country, mainly Peninsular India is covered by consolidated formations. Semi-consolidated formations occupy parts of both Peninsular and extra Peninsular India. Proliferation of ground water development by stakeholders of various sectors has resulted in water scarcity, quality deterioration and other related development problems in many areas of the country. As a result, substantial decline in ground water levels is being observed both in hard rock terrain as well as alluvial areas. Ground water quality in coastal area has also been affected due to excessive ground water development and resultant sea water ingress. Pollution of ground water due to unplanned disposal of industrial effluent and sewage is also on the rise. The ground water development in such areas needs to be watched and augmented through suitable recharge measures to provide sustainability and protection to ground water reservoir.

Central Ground Water Board (CGWB) prepared a “National Perspective Plan for Recharge to Ground Water by utilizing Surplus Monsoon Run-off” in 1996. The availability of non-committed surplus monsoon run-off in 20 River Basins of the country was analyzed vis-a-vis the sub-surface available space under different hydrogeological situations for saturating the vadose zone to 3m below ground level. It was estimated that it is possible to store 21.4 M.ha.m of surplus monsoon runoff in ground water reservoir, out of which 16.05 M.ha.m can be utilized. The plan presented a conceptual framework for utilization of surplus monsoon run-off for artificial recharge of ground water.

CGWB had prepared a Master Plan for Artificial Recharge to Ground Water earlier in the year 2002. The Master Plan envisaged the number of artificial recharge and water conservation structures in the country as 39 lakh at an estimated cost of Rs. 24,500 crores. Based on the above, various State Agencies and CGWB have taken up the construction of artificial recharge structures on a large scale under State/Central sector schemes.

Problems that may arise in coastal and hard rock aquifers and over-development in isolated pockets in “Safe” blocks are also to be addressed in coming years. The ground water quality issues also need to be focused on new areas of integrated approach in rain water harvesting and recharge to ground water. Considering this, some changes in the methodology in artificial recharge are proposed.

Based on the experience gained under demonstrative artificial recharge program and artificial recharge to ground water through dug well scheme, the need for identification of specific new areas in different States for additional artificial recharge to ground water was felt. To implement schemes in an effective manner, state-wise presentation of the base data on existing recharge structures and proposals in the pipeline is required. Also, the feasibility of diverting flood water or surplus run off from rainfall from one region to another region is examined. The new guidelines for taking up recharge schemes without affecting the existing surface water storage structures are also envisaged.

The Chairman, CGWB, constituted a Committee to prepare new guidelines for revision of Master Plan for artificial recharge to ground water for the country and the Committee submitted the report in September 2008. The committee recommended broad guidelines for selection of priority areas, schemes for different agroclimatic areas and use of transported water for recharge, creation of data base on existing recharge structures for planning any new schemes in a given time and other recommendations. The demand side management of ground water resources was given stress by the Committee.

Based on the recommendations of the Committee, the present revised Master Plan is prepared on the basis of hydrogeological parameters and hydrological data base available for each State. The identification of feasible areas for artificial recharge to ground water was made on the basis of depth and declining trend of ground water levels. The decadal average depth to water level for post monsoon period was taken to estimate the sub-surface storage space for recharge and volume of water needed to saturate the vadose zone to 3m below ground level. The quantification of surplus monsoon run-off was made for the identified areas/sub-basins. The computations for surface water available to harness in each identified areas were made to plan the feasibility of different artificial recharge structures. Based on the hydrogeological situation of each of the states the feasible number of different artificial recharge structures and their cost estimates were made.

A total area of about 9,41,541 sq.km. has been identified in various parts of country where artificial recharge to ground water is feasible. This also includes hilly terrain of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, North Eastern States & Islands where the structures are proposed to improve the sustainability of springs and freshwater.

It is estimated that annually about 85,565 MCM of surplus run-off is to be harnessed to augment the ground water. Most of the basins of the country, particularly in Peninsular India are having marginal/ negligible surplus runoff, where considerable space in underground reservoirs is available. Hence, surplus runoff is not available for recharge to ground water in various areas, which otherwise need artificial recharge. The surplus runoff available in North Eastern States, Himachal Pradesh and Islands is very high and due to limited space available underground for recharge, the surplus run off calculation is not separately given. However, for the stabilization of springs and improving the ground water scenario in existing localized ground water extraction areas, few recharge structures are identified and will be executed by considering the local ground slope and vulnerability of landslides, etc. in these areas.

In rural areas, suitable 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 arrest ground water flow through ground water dams has also been made in some states.

The revised Master Plan envisages construction of about 1.11crore artificial recharge structures in urban and rural areas at an estimated cost of about Rs. 79,178 crores. This comprises of around 88 lakh recharge structures/ facilities utilizing rain water directly from roof top and around 23 lakh artificial recharge and rain water harvesting structures for conserving surplus runoff and recharging ground water in aquifers. 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 shafts,1.08 lakh contour bunds,16235 injection wells and 23172 other structures which includes point recharge structures recharge tubewells, stop dams, recharge trenches, anicuts, flooding structures, induced recharge structures, weir structures etc. In North Eastern States, Andaman & Nicobar and Sikkim emphasis has been given to spring development and 2,950 springs are proposed for augmentation and development.

The areas having existing recharge structures are recommended to revisit for evaluating their performance and supplementing advanced techniques such as recharge shafts, recharge bores and tube wells for improving the overall efficiency of recharge structures.

The need for conservation of ground water has been emphasized in urban areas. The roof top rainwater harvesting is proposed both by augmenting the ground water storage as well as by storing it in specially built tanks. It is estimated that 88 lakh roof top rainwater harvesting structures are feasible in the country at an estimated cost of Rs. 16266 crores. The total cost of the revised Master Plan for Artificial Recharge to Ground water is estimated around Rs.79178 crores. The cost estimates have been computed on the basis of costs of various structures in the year 2011. The actual implementation of the plan is suggested to be taken up in a phased manner over a time period of 10 years. Part of the estimated cost of the order of Rs 15,000 crores may be utilized by Ministry of Water resources, Government of India to fund the recharge projects to states as central assistance and also for taking up action research program like construction of injection wells in identified deeper aquifers of the country.

The ongoing MGNREGA work will be also used to improve the existing rain water harvesting and recharge structures, creating specific supply channels and desilting of trenches, ponds etc. The community participation at Panchayat level for such work through concerned central ministries is estimated at Rs 20,000 crores for a period of 10 years.

The stakeholder industries (existing/new) would be involved in implementing rain water harvesting and recharge to ground water as part of Ministry of Environment & Forest directions with technical guidance of CGWB and state agencies. The expected contribution from industrial sector is estimated at Rs. 20,000 crores. The balance of about Rs. 24,178 crores would be spent by State/Central Government Departments under various programmes by involving the line Departments in the State, particularly Integrated Watershed Development Department, Forest Department, Public Works Department, Horticulture Department, Roads and Buildings Department, Agriculture Department and Water Supply Departments.

MASTER PLAN FOR ARTIFICIAL RECHARGE TO GROUND WATER IN INDIA

AT A GLANCE

1.	Area identified for Artificial Recharge		941541 sq. km.
2.	Volume of water to be recharged		85565 MCM
3.	Total number of structures proposed		(in lakhs)
	(i)	In Rural areas	22.83
	(ii)	In Urban areas	87.99
		Total	110.82
4.	Estimated Cost		(Rs. in crores)
	(i)	In Rural areas	61192
	(ii)	In Urban areas	17986
		Total	79178

MASTER PLAN FOR ARTIFICIAL RECHARGE TO GROUND WATER IN INDIA

1.0 INTRODUCTION

1.1 BACKGROUND

The rapid development of ground water resources for varied usage has contributed in expansion of irrigated agriculture, overall economic development and in improving the quality of life in India. Ground water, which is the source for more than 85 percent of rural domestic water requirements, 50 percent of urban water requirements and more than 50 percent of irrigation requirements of the country, is depleting fast in many areas due to its large-scale withdrawal for various sectors. The ground water development with time has changed the hydrogeological regime and as a result natural recharge components have altered to a great extent. Out of a total of 5723 assessment units (Blocks/Mandals/Talukas) in the country, 839 have been categorized as 'Over-exploited' as assessed on 31st March 2004, with ground water extraction in excess of the net annual recharge. There were also 226 'Critical' assessment units where the ground water draft is between 90 and 100 percent of the annual replenishment, apart from 30 blocks having only saline ground water. As per latest ground water resource estimation as on 31st March, 2009, the stage of ground water development of the country is worked out to be around 61%. Out of the 5842 assessment units, 802 units have been categorized as 'Over-exploited', 169 as 'Critical' and 523 units as 'Semi-Critical'. There are 71 saline units and 4277 'Safe' units. The annual replenishable ground water resource is 431 BCM and net ground water availability is 396 BCM. Categorization of Blocks/Mandals/Talukas is shown in Fig.1.1. The total annual ground water draft is 243 BCM and balance ground water resources available for further development is 153 BCM.

The revised ground water estimation indicated the improvement in the water levels due to the large scale artificial recharge activities and irrigation management practices as observed in Tamil Nadu and Andhra Pradesh. Over-development of the ground water resources results in declining ground water levels, shortage in water supply, intrusion of saline water in coastal areas and increased pumping lifts necessitating deepening of ground water structures. Geogenic contamination of ground water due to high concentrations of Arsenic, Fluoride and Iron in excess of limits prescribed for drinking purposes (BIS, 2004) has also been observed in many parts of the country. The development of ground water resource in such areas therefore needs to be regulated and augmented through suitable measures to provide sustainability. The National Water Policy, 2002 enunciates development and implementation of ground water recharge projects for augmenting the available supplies. It also envisages integrated and coordinated development of surface and ground water. Development of ground water needs to be kept under constant check near the coast to prevent ingress of sea water into fresh water aquifers. As such the ground water reservoir in different areas needs suitable management efforts for protection and augmentation.

To tackle the twin hazards of de-saturation of aquifer zones and consequent deterioration of ground water quality, there is an urgent need to augment the ground water resources through suitable management interventions. Artificial recharge has now been accepted world-wide as a cost-effective method to augment ground water resources in areas where continued overexploitation without due regard to their recharging options has resulted in various undesirable environmental consequences.

A 'Manual on Artificial Recharge of Ground Water' providing detailed guidelines on investigative techniques for selection of sites, planning and design of artificial recharge structures, monitoring and economic evaluation of artificial recharge schemes was brought out by Central Ground Water Board in 1994. It also included elaborate case studies and field examples of artificial recharge schemes from different parts of the world. The manual has been used extensively for planning and implementation of schemes for augmentation of ground water resources by various agencies.

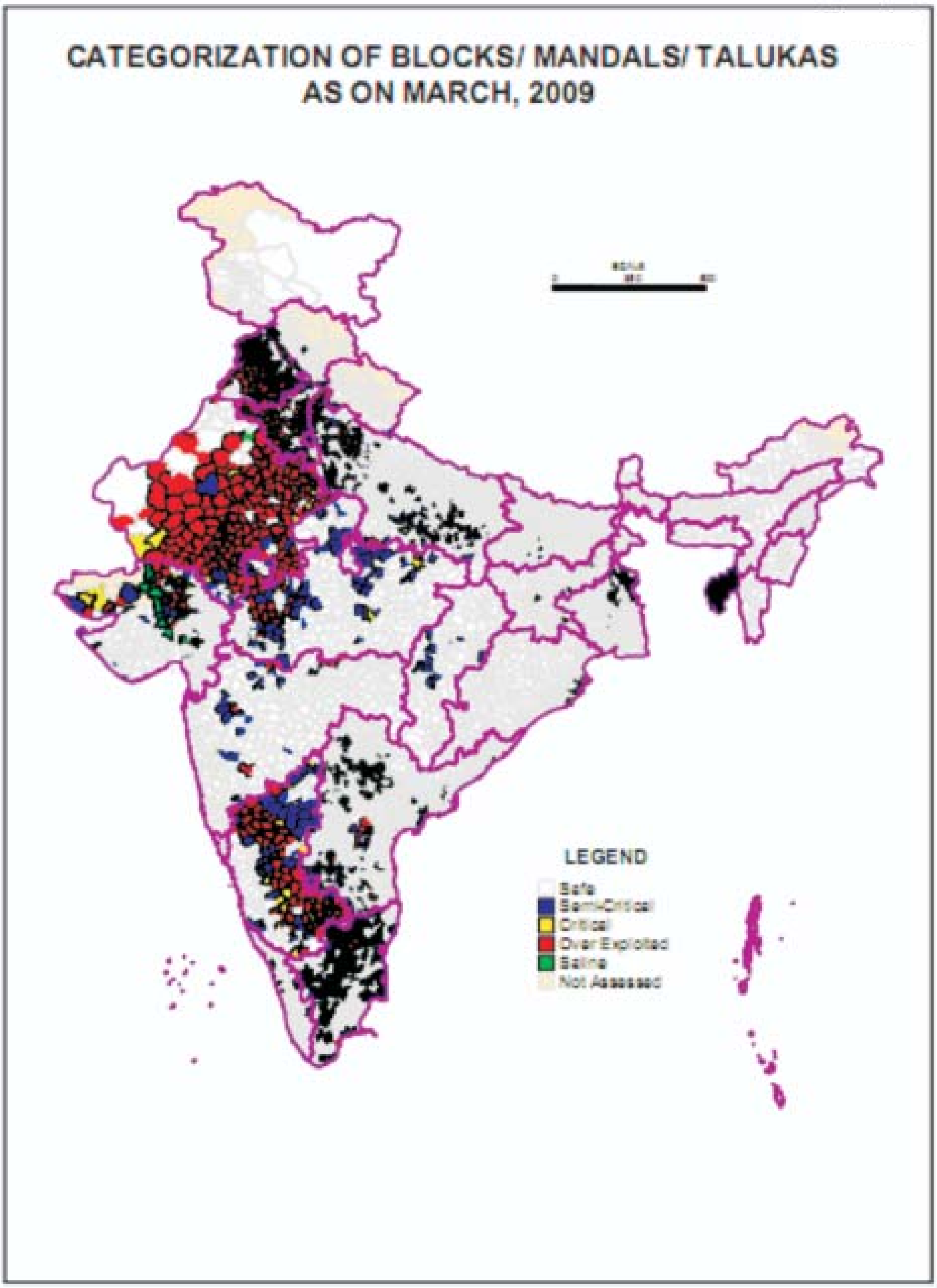


Fig. 1.1. Categorization of Blocks/Mandals/Talukas as on March 2009

Subsequent to the publication of the manual, Central Ground Water Board has brought out publications on the topic in an attempt to disseminate the experiences gained during various ground water augmentation projects implemented by the Board in the country.

These are:-

1) Manual on Artificial Recharge of Ground Water (1994)

2) National Perspective Plan for Recharge to Ground Water by Utilizing Surplus Monsoon Runoff (1996)

3) Guide on Artificial Recharge to Ground Water (1998)

4) Guide on Artificial Recharge to Ground Water (2000)

5) Master Plan for Artificial Recharge to Ground Water (2002)

6) Manual on Artificial Recharge of Ground Water (2009)

7) Select Case Studies on Rain Water Harvesting and Artificial Recharge (2011)

Apart from these, Central Ground Water Board has also published technical brochures on various aspects of artificial recharge through its Regional Directorates, in its local vernacular languages, which served as guidelines to various governmental and non-governmental agencies and the general public. Some of the State Departments have also brought out manuals and guidelines on artificial recharge to ground water, which dealt with specific areas in most cases. There were also many projects implemented at state and national level with people's participatory approach in executing recharge projects. It is felt that there is a need for convergence of data and information on ongoing recharge and rain water harvesting projects as well as the optimization of the number of structures.

1.1.1 SALIENT FEATURES OF MASTER PLAN -2002

The preparation of master plan for artificial recharge to ground water in different states, prepared by Central Ground Water Board in 2002, aims at providing area specific artificial recharge techniques to augment the ground water reservoir based on the twin important requirements of source water availability and capability of ground water reservoir to accommodate it. The specific problems in different areas in the states like excessive ground water development resulting in ground water decline, water scarcity due to inadequate recharge in arid areas, low ground water retention in hilly areas despite substantial rainfall, urban areas with limited ground water recharge avenues and related problems of urban pollution, etc., have been considered while preparing the master plan. To fully utilize the available surplus monsoon runoff in rural areas, emphasis has been given for adoption of artificial recharge techniques based on surface spreading like percolation tanks, nala bunds, etc. and sub surface techniques of recharge shaft, well recharge, etc. In urban areas, hilly areas and coastal regions priority has to be given to rain water conservation measures through roof top harvesting techniques etc.

The Master Plan while bringing out the areas suitable for artificial recharge to ground water reservoir, prioritizes the areas wherein schemes need to be implemented as a first priority to ameliorate the water scarcity problems. The proposals and schemes recommended are not the ultimate ones but are the first stage of implementation. These need to be further extended in other areas depending on the availability of infrastructure, finances and future problems.

The master plan envisaged the number of artificial recharge and water conservation structures in the country as 39 lakh at an estimated cost of Rs. 24,500 crores.

Experiments on artificial recharge to aquifers started in India from1970 onwards by Central and State Government Departments and individually by some NGOs in different parts of the country where early signs of overexploitation of ground water were noticed. The Central Ground Water Board under took artificial recharge experiments through injection well around Kamliwala in Central Mehsana, Gujarat where sufficient water was available from Saraswati River during monsoon period. A detailed injection recharge experiment was carried out at the Kamliwala site by injecting water from the source well in Saraswati River bed to the injection well by 5cm dia. siphon of galvanized pipe, at a rate of 225 m^3/day for 250 days. There was a building of 5 meters piezometric head in the injection well and 0.6 to 1.0 m in wells in areas of 150 m away. These experiments indicated feasibility of ground water recharge through injection wells in the area. Subsequently several such studies were taken up in different states of the country. The details of demonstrative artificial recharge studies taken up by CGWB during different five year plans are furnished in table 1.1.

Table 1.1 Artificial Recharge Studies taken by CGWB during different Five Year Plans

Plan	Status	Cost (crores)
VIII (1992-97)	Maharashtra, Karnataka, Andhra Pradesh, Delhi, Kerala, Madhya Pradesh, Tamil Nadu, West Bengal & Chandigarh (Total States/UT – 9)	3.23
IX (1997-2002)	Andhra Pradesh, Arunachal Pradesh, Assam, Andaman & Nicobar, Bihar, Chandigarh, Gujarat, Haryana, Himachal Pradesh, Jammu & Kashmir, Jharkand, Karnataka, Kerala, Lakshdweep, Madhya Pradesh, Maharashtra, Meghalaya, Mizoram, Nagaland, Delhi, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttrakhand and West Bengal (Total States/UT – 27)	33.10
X (2002-2007)	Andhra Pradesh, Karnataka, Madhya Pradesh & Tamil Nadu (Total States – 4)	5.60
XI (2007-2012)	Andhra Pradesh, Arunachal Pradesh, Bihar, Chhattisgarh, Chandigarh, Delhi, Gujarat, Himachal Pradesh, Jammu & Kashmir, Jharkhand, Kerala, Karnataka, Maharashtra, Madhya Pradesh, Nagaland, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal (Total States/UT – 21)	99.87

Over exploited, critical, coastal and urban aquifers as well as ground water quality issues were given focus in the above schemes and some suggestions were also received for revision of the Master Plan. A separate scheme on Dug well recharge was prepared for Tamil Nadu, Gujarat, Madhya Pradesh, Karnataka, Maharashtra, Rajasthan and Andhra Pradesh states at the estimated cost of Rs. 1871 crores covering 4.455 Million irrigation dug wells covering 1155 blocks in seven participating states. The Scheme is being implemented through NABARD, CGWB and identified nodal agencies in the state. Under this scheme, farmers were given fund directly for the construction of recharge pits near the dug well at a average cost of Rs 4000/- which varies from Rs.3600/- (Maharashtra) to Rs.5700/- (Andhra Pradesh). As on March 2012, 1,14,205 dug well recharge structures were completed under this scheme.

The earlier Master Plan prepared by the Government of India also needs updating of physical and financial targets to account the executed work and to arrive at a base for further implementation with the involvement of state and other stake holders at grass root level.

1.2 PRESENT ENDEAVOUR

It is decided to revise and update the Master Plan of Artificial Recharge (2002) as on March 2011, by incorporating the actual progress made in the targets up to 2010-11 and also reassessing the new areas of recharge to make use of the experience already gained and the input received from the impact assessment of select schemes executed by Central Ground Water Board through state agencies under central sector and centrally sponsored schemes.

1.3 CONSTITUTION OF GROUP

Realizing the necessity to revise the earlier Master Plan for Artificial Recharge to Ground Water for different States and Union Territories of the country, CGWB has constituted a committee vide letter no.13-15/MSML/AR/District plan/09-465- dated 26th April 2011.

The composition of the committee is as follows:

1. Dr. N.Varadaraj, Regional Director, CGWB, SR, Hyderabad - Chairman
2. Sh. Manoj Srivastava, Regional Director, CGWB, WR, Jaipur - Member
3. Dr K.M. Najeeb, Regional Director, CGWB, SWR, Bangalore - Member
4. Sh. Sanjay Marwaha, Suptdg. Hydrogeologist, CGWB, NR, Lucknow - Member Coordinator

A Group was constituted earlier by the Chairman, CGWB to prepare new guidelines for revision of Master Plan for Artificial Recharge to Ground Water for the country with Sh. Sushil Gupta, then Regional Director, NWR, and Dr N.Varadaraj, then Regional director, SECR along with Sh. Sanjay Marwaha and Dr S.Suresh, Scientists. The group submitted the report in September 2008 and recommended broad guidelines for selection of priority area, schemes for different agro-climatic areas and use of transported water for recharge, creation of data base on existing recharge structures for planning any new schemes in a given time and other recommendations. (Annexure I-A to I-C). The demand side water management was given stress by the committee. Based on the concept note prepared during the year 2008, by Sh. Sushil Gupta, Member (SML), Dr. N.Varadaraj, Regional Director under the guidance of Dr. S.C.Dhiman, Chairman, CGWB, the approach for revision of the Master Plan was finalized. Regional Directors of CGWB have collected the required input from various states and facilitated the revision of the Master Plan. The group members held meetings to discuss the various issues and prepared a model physical and financial outlay for eliciting desired information from different States. The Regional Directors of CGWB were requested to send the details on the various ongoing schemes of artificial recharge as well as additional requirement in consultation with concerned state agencies. The data made available by the Regional offices were utilized in preparing the revised Master Plan for Artificial Recharge.

2.0 NATIONAL SCENARIO OF GROUND WATER

2.1 HYDROGEOLOGICAL SET UP

India is a vast country with varied hydrogeological situations resulting from diversified geological, climatological and topographic set up. The rock formations, ranging in age from Archaean to Recent, control occurrence and movement of ground water. Physiography varies widely from rugged mountainous terrains of Himalayas, Eastern Ghats, Western Ghats and Deccan Plateau to the flat alluvial plains of the river valleys and coastal tracts, and the Aeolian deserts in western part. Similarly rainfall pattern also shows region wise variations.

Various rock types occurring in the country have been categorized as follows to describe the ground water characteristics.

1. Porous rock formation

   (a) Unconsolidated formations.

   (b) Semi-consolidated formations

2. Hard rock/ consolidated formations

The proper understanding of the characteristics of rock types help in site selection and designing artificial recharge structures. The area recording high yield is obviously having more storage potential and hence there is scope for more recharge to ground water.

2.1.1 POROUS ROCK FORMATIONS

2.1.1.1 Unconsolidated Formations

The sediments comprising newer alluvium, older alluvium and coastal alluvium are by and large the important repositories of ground water. These are essentially comprised of clay, sand, gravel and boulders, ferruginous nodules, kankar (calcareous concretions), etc. The beds of sand and gravel and their admixtures form potential aquifers. The aquifer materials vary in particle size, roundness and sorting. Consequently, their water yielding capabilities vary considerably. The coastal aquifers show wide variations in the water quality both laterally and vertically.

The piedmont zone of the Himalayas extending from Jammu and Kashmir in the west to Tripura in the east, offers suitable locations for artificial recharge. The hydrogeological conditions and ground water regime in Indo-Ganga-Brahmaputra basin indicate existence of large quantities of fresh ground water down to 600.5 m or more below land surface. Bestowed with high rainfall and good recharge conditions, the ground water gets replenished every year in these zones. The alluvial aquifers to the explored depth of 600 m have transmissivity values from 250 to 4000 m^2/day and hydraulic conductivity from 10 to 800 m/day.

2.1.1.2 Semi-consolidated Formations

The semi-consolidated formations mainly comprise shales, sandstones and limestones. The sedimentary deposits belonging to Gondwana and Tertiary formations are included under this category. The sandstones form highly potential aquifers locally, particularly in Peninsular India. Elsewhere they have only moderate potential and at places they yield meagre supplies. These sediments normally occur at narrow valleys or structurally faulted basins. Though these formations have been identified to possess moderate potential, the physiography of the terrain, normally restricts development. Under favorable situations, these sediments give rise to artesian conditions as in parts of Godavari Valley, Cambay basin and parts of West Coast, Puducherry and Neyveli in Tamil Nadu. Potential aquifers particularly those belonging to Gondwanas and Tertiaries have transmissivity values from 100 to 2300 m^2/day and the hydraulic conductivity from 0.5 to 70 m/day. Generally the well yields in productive areas range from 10 to 50 lps. Lathi and Nagaur sandstone in Rajasthan and Tipam sandstone in Tripura state also form productive aquifers.

2.1.2 HARD ROCK FORMATIONS

2.1.2.1 Consolidated Formations

The consolidated formations occupy almost two thirds of the country. From the hydrogeological point of view, the consolidated rocks are broadly classified into the following three types:

a) Igneous and metamorphic rocks excluding volcanic and carbonate rocks

b) Volcanic rocks

c) Carbonate rocks

These formations control the ground water availability and scope for augmentation and artificial recharge. The nature, occurrence and movement of ground water in these formations are described as follows:

2.1.2.2 Igneous and Metamorphic Rocks

The most common rock types are granites, gneisses, charnockites, khondalites, quartzites, schist and associated phyllite, slate, etc. These rocks possess negligible primary porosity but are rendered porous and permeable due to secondary porosity by fracturing and weathering.

Ground water yield and capability to accept recharge also depend on rock types. Granite and gneiss are better repositories than Charnockites. The ground water studies carried out in the crystalline hard rocks reveal the existence of lineaments along deeply weathered and fractured zones, locally forming potential aquifers. These lineament zones are found to be highly productive for construction of bore wells. These in turn offer good scope for recharge through suitable techniques.

In areas underlain by hard crystalline and meta-sedimentaries viz; granite, gneiss, schist, phyllite, quartzite, charnockites, etc., occurrence of ground water in the fracture system has been identified down to a depth of 100 m and even up to 300 m locally. In most of the granite/ gneiss area, the weathered residuum serves as an effective ground water repository. It has been observed that the fracture systems are generally hydraulically connected with the overlying weathered saturated residuum. The yield potential of the crystalline and meta-sedimentary aquifers show wide variations. Bore wells tapping the fracture systems generally yield from less than 1.0 lps to 10 lps. The transmissivity values vary from 10 to 500 m^2/day and the hydraulic conductivity values vary from 0.1 to 10 m/day.

2.1.2.3 Volcanic Rocks

The basaltic lava flows are mostly horizontal to gently dipping. Ground water occurrence in these hard rocks is controlled by the contrasting water bearing properties of different lava flows. The topography, nature and extent of weathering, jointing and fracture pattern, thickness and depth of occurrence of vesicular basalts are the important factors which play a major role in the occurrence and movement of ground water in these rocks. Basalts or Deccan Traps usually have medium to low permeability depending on the presence of primary and secondary porosity. Pumping tests have shown that under favourable conditions, bore wells yield about 3 to 6 lps at moderate drawdown. Transmissivity and the hydraulic conductivity values of these aquifers are generally in the range of 25 to 100 m^2/day 0.05 to 15 m/day respectively.

2.1.2.4 Carbonate Rocks

Carbonate rocks include limestone, marble and dolomite. Among the carbonate rocks, limestones occur extensively. In carbonate rocks, solution cavities lead to widely contrasting permeability within short distances. Potential limestone aquifers are found to occur in Rajasthan and Peninsular India in which the yields range from 5 to 25 lps. Large springs exist in the Himalayan Region in the limestone formations. The distribution and potential of the major hydrogeological units are presented in table-2.1 and Fig. 2.1.

Table 2.1: Distribution of Hydrogeological Units in India and their Ground Water Potential

Geologic Age		Rock Formations	Hydrogeological Characters
UN-CONSOLIDATED FORMATIONS			
Pleistocene to Recent	a)Fluvio-glacial deposits b) Glacio lacustrine deposits	a) Mixed Boulders, Cobbles, Sands and Silts b) Conglomerates, Sands Gravels, Carbonaceous shales and blue Clays.	The morainic deposits occupy valleys and gorges in interior Himalays. Karewas (Kashmir Valley) are lacustrine deposits displaying cyclic layers of clayey, silty and coarser deposits with intervening boulder beds. Locally significant hydrogeological potential.
	c) Pediment, Himalayan and foot hill regions	c) Boulders, Cobbles, Pebble beds, Gravels, Sands, Silt and Clays	The Bhabhar piedmont belt contains many productive boulder-cobble-gravel-sand aquifers. The water table is deep. Forms recharge zone for deeper aquifers of alluvial plains in south. Tarai belt is down-slope continuation of Bhabhar aquifers display flowing artesian conditions. Shallow water table yields upto 28 lps.
	d) Alluvial Plains (Older & Newer Alluvium)	d) Clays & Silts, Gravels and Sands of different mix. Lenses of Peat & Organic matter. Carbonate and Siliceous Concretions (Kankar)	Occur widespread in the Indo-Ganga-Brahmaputra alluvial plains. Form the most potential ground water reservoirs with a thick sequence of sandy aquifers down to great depths. The unconfined sand aquifers sometimes extend down to moderate depth (125 m). Deeper aquifers are leaky-confined/confined. The older alluvium is relatively compact. The unconfined aquifers generally show high storativity (5 to 25% and high). Transmissivity (500 to 3,000 sq.m/day). The deeper confined aquifers generally occurring below 200 to 300 m depth have low Storativity (0.005 to 0.005) and Transmissivity (300 to 1000/sq.m/day). Highly productive aquifers yield upto 67 lps and above). The potentials of peninsular river, alluvium are rather moderate with yield upto 14 lps. But the alluvial valley fill deposits of Narmada, Tapi, Purna basins, 100m thick, sustain yield upto 28 lps. The quality of ground water at deeper levels is inferior. Storativity ($4x10^{-6}$ to $1.6x 10^{-2}$) and Transmissivity 100 to 1,000 sq.m./day. The alluvial sequences in deltas of major rivers on the eastern coast and in Gujarat estuarine tracts have & hydrogeological potential limited by salinity hazards.

	e) Aeolian deposits	e) Fine to very fine sand and slit	The aeolian deposits occurring in West Rajasthan, Gujarat, Haryana, Delhi, Punjab have moderate to high yield potentials; are well sorted and permeable; lie in arid region; natural recharge is poor and water table is deep.
SEMI-CONSOLIDATED FORMATIONS			
Tertiary		Nummulitic Shales and Limestones Carbonaceous Shales Sandstones Shales Conglomerates Ferrugineous Sandstones Calcareous Sandstones Pebble Beds and Boulder-Conglomerate Sands Clay	The hydrogeological potential of these formations is relevant only in the valley areas. Lower Siwaliks and their equivalents in Himachal Pradesh, Jammu & Kashmir, Assam, Punjab, Haryana, Uttar Pradesh, Sikkim generally do not form potential aquifers. The Upper Siwaliks have moderate ground water potential in suitable topographic locations. Tertiary sandstones of Rajasthan, Gujarat, Kutch, Kerala, Odisha, Tamil Nadu, Andhra Pradesh, West Bengal and North Eastern States have moderate to moderately good yield potential upto 28 lps. Possess moderate primary porosity and hydraulic conductivity.
Upper Carboniferous to Jurassic	Gondwana Jurassic of Kutch and Rajasthan Baghbeds Lametas and Equivalents	Boulder-Pebble Beds Sandstones Shales Coal Seams Sandstones Calcareous sandstone Shales Quartzites Limestones	Occur in Bihar, Maharashtra, Andhra Pradesh, Odisha, Madhya Pradesh, Gujarat, Rajasthan and Tamil Nadu. These formations do not have wide regional distribution, possess moderate primary porosity and hydraulic conductivity. Karstified limestones are good water yielders. Friable sandstones in Barkaras and Kamthis (Lower Gondwana) and their equivalent formations possess moderately good potential yield upto 14 lps.
CONSOLIDATED FORMATIONS			
Jurassic/ Upper Cretaceous to Eocene	Rajmahal Traps, Deccan Traps	Basalts, Dolerties Diorites and other acidic derivatives of Basaltic magma	Occur in West Bengal, Bihar, Madhya Pradesh, Gujarat, Maharashtra, Andh ra Pradesh, Karnataka. Hydrogeological characteristics almost same as above. Fractured and Vesicular basaltic layers and inter-trappean sedimentaries are productive. Yield upto 5 lps, Storativity: 1 to 4%. Hydraulic conductivity 5 to 15 m/day. Unconfined shallow aquifers and leaky confined/confined deeper aquifers.
Pre-Cambrian	Cuddapahs Delhi & Equivalent Systems	Consolidated Sandstones Shales, Conglomerates, Limestones, Dolomites Quartzites, Marbles Intrusive Granites & Malani Volcanics.	Occur in all States. These formations are devoid of primary porosity. Weathering & denudation, structural weak planes and fractures impart porosity and permeability in the rock mass. Solution cavities (caverns) in carbonate rocks at places, give rise to large ground water storage/ Circulation. The ground water circulation is generally limited within 100m depth. Storativity value of unconfined aquifer is generally low (0.2% to 3%). Hydraulic conductivity areas widely depending on fracture incidence (2 to 10m/day). Leaky confined/confined aquifers may be present in layered formations. Granites and granite-gneisses are the most productive aquifers. Yield range 2 to 10 lps and more.

2.2 GROUND WATER QUALITY

The ground water in most of the areas in the country is fresh. Brackish ground water occurs in the arid zones of Rajasthan, close to coastal tracts in Saurashtra and Kutch, and in some zones in the east coast and certain parts of Punjab, Haryana, Western Uttar Pradesh, etc., which are under extensive surface

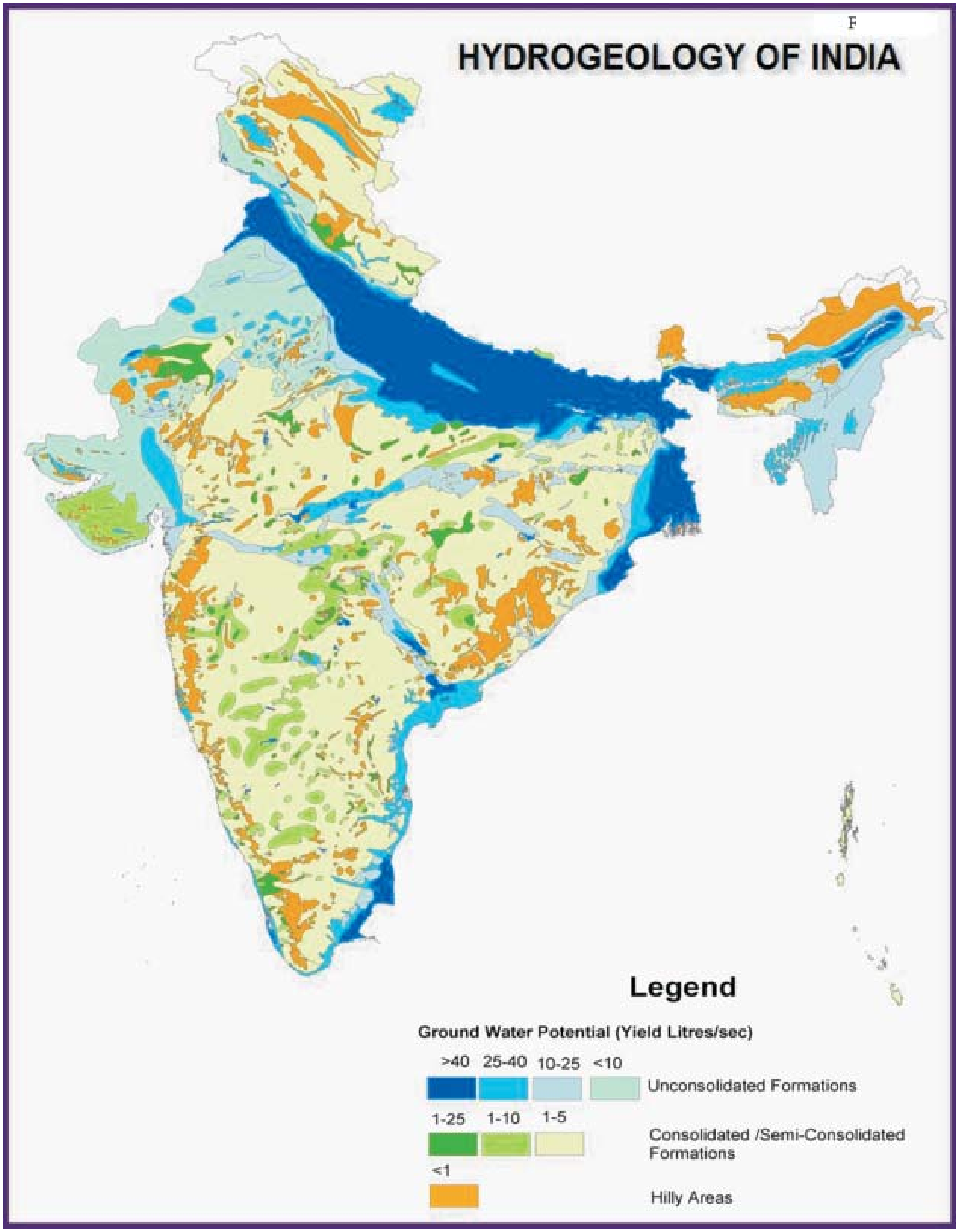


Fig. 2.1 Hydrogeology of India

water irrigation. The fluoride levels in the ground water are considerably higher than the permissible limit in vast areas of Andhra Pradesh, Haryana and Rajasthan and in some parts of Punjab, Uttar Pradesh, M.P., Karnataka and Tamil Nadu. In the north-eastern regions, ground water with iron content above the desirable limit occurs widely. Pollution due to human and animal wastes and fertilizer application has resulted in high levels of nitrate and potassium in ground water in some parts of the country. Ground water contamination in pockets of industrial zones is observed in localized areas. The over-exploitation of the coastal aquifers in the Saurashtra and Kutch regions of Gujarat has resulted in salinisation of coastal aquifers due to sea water ingress. The excessive ground water withdrawal near the city of Chennai has led to seawater intrusion into coastal aquifers. The artificial recharge techniques can be utilized in improving the quality of ground water and to maintain the delicate fresh water-salt water interface in coastal zone.

2.3 GROUND WATER RESOURCE POTENTIAL

The annual precipitation including snowfall in India is of the order of 4000 BCM and the natural runoff in the rivers is computed to be about 1869 BCM. The utilizable surface water and replenishable ground water resources are of the order of 690 BCM and 431 BCM respectively. Thus, the total water resources available for various uses, on an annual basis, are of the order of 1121 BCM. Although the per capita availability of water in India is about 1869 cubic meters/year as in 1997 against the benchmark value of 1000 Cu m/year signifying 'water-starved' condition (Fig.2.2), there is wide disparity in basin-wise water availability due to uneven rainfall and varying population density in the country. The availability is as high as 14057 cu m/year per capita in Brahmaputra/ BarakBasin and as low as 307 cu m/year/person in Sabarmati basin. Many other basins like Mahi, Tapi and Pennar are already water stressed.

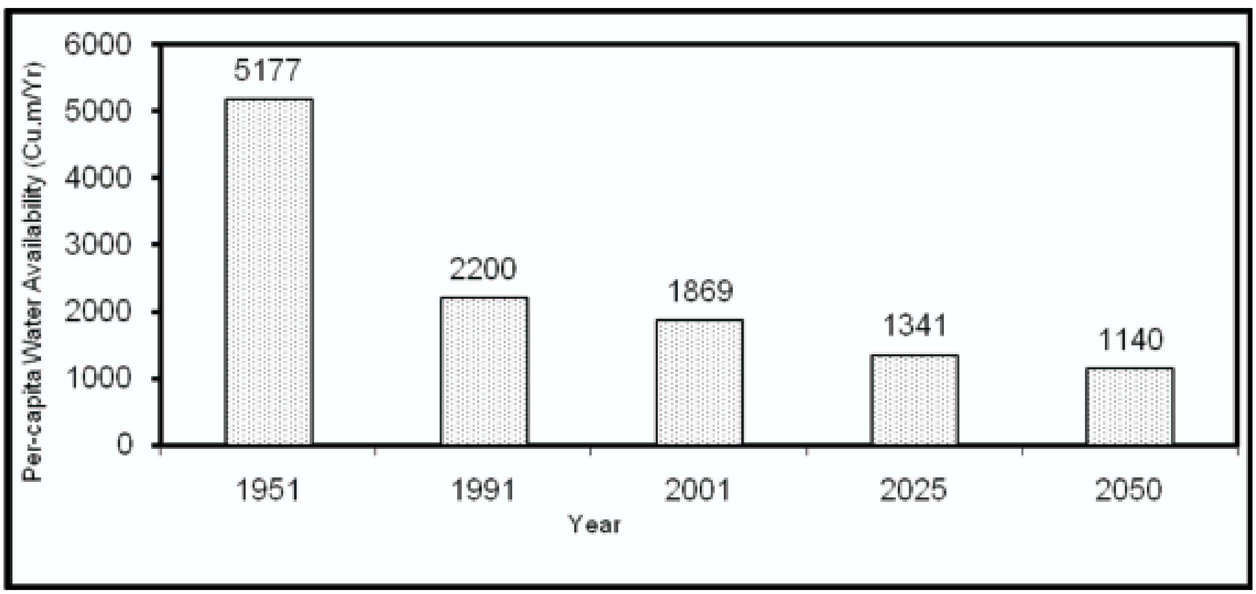


Fig. 2.2 Per Capita Water Availability in India.

2.4 GROUND WATER DEVELOPMENT SCENARIO

During the past four decades, there has been a phenomenal increase in the growth of ground water abstraction structures due to implementation of technically viable schemes for development of the resource, backed by liberal funding from institutional finance agencies, improvement in availability of electric power and diesel, good quality seeds, fertilizers, government subsidies, etc. During the period 1951-2001, the number of dug wells increased from 3.86 million to 9.62 million that of shallow tube wells from 3000 to 8.35 million and deep tube wells from negligible to 0.53 million. There has been a steady increase in the area irrigated from ground water from 6.5 Mha in 1951 to 44.98 Mha in 2001. The ground water abstraction structures are projected to be in the order of 27 million as on March, 2011.

Such a magnitude of ground water development with sub optimal planning has resulted in creating deleterious effects in terms of ground water depletion and quality deterioration. These multiple challenges emerging in different parts of country need a suitable ground water management approach. Augmentation and artificial recharge to ground water reservoir offers a positive approach to overcome the problems of ground water depletion and affected quality. The revision of Master Plan for Artificial Recharge is an effort in this direction.

3.0 CONCEPT OF ARTIFICIAL RECHARGE TO GROUND WATER

The artificial recharge to ground water aims at augmentation of ground water reservoir by modifying the natural movement of surface water utilizing suitable civil construction techniques. Artificial recharge techniques normally address to the following issues:

- To enhance the sustainability in areas where over-development has depleted the aquifer.
- Conservation and storage of excess surface water for future requirements, since these requirements often change within a season or a period
- To improve the quality of existing ground water through dilution.

3.1 GROUND WATER RESERVOIRS

The rivers and rivulets of the Indian sub continent are mainly monsoon fed with 80 to 90 percent runoff generated during the monsoon. The principle source for ground water recharge is also monsoon precipitation. The country receives more than 75% monsoon rainfall from June to September except in the eastern coast. Annually the rainy days vary from 12 to 100, and actual rainfall time varies from a few hours to over 300 hours. Incidences of up to 60 percent annual rainfall within a few days duration in a year are common in many parts of the country, causing excessive runoff, taking a heavy toll of life, agriculture and property. Harnessing of excess monsoon runoff in ground water storage/reservoir will not only increase the availability of water to meet the growing water demands, but also help in controlling damages from floods.

The sub surface reservoirs are technically feasible alternatives for storing surplus monsoon runoff and store substantial quantity of water. The sub surface geological formations may be considered as "warehouse" for storing water that come from sources located on the land surface. Besides suitable lithological condition, other considerations for creating sub surface storages are favorable geological structures and physiographic units, whose dimensions and shape will allow retention of substantial volume of water in porous and permeable formations.

The sub surface reservoirs located in suitable hydrogeological situations will be environment friendly and economically viable for artificial recharge. The sub surface storages have advantages of being free from the adverse effects like inundation of large surface area, loss of cultivable land, displacement of local population, substantial evaporation losses and sensitivity to earthquakes. No gigantic structures are needed to store sub-surface water. The underground storage of water also has beneficial influence on the existing ground water regime and abstraction structures. The deeper water levels in many parts of the country either of natural occurrence or due to excessive ground water development, may be substantially raised, resulting in reduction on lifting costs and energy saving. The quality of natural ground water would substantially improve in brackish and saline areas. The conduit function of aquifers can further help in natural sub-surface transfer of water to various needy centres, thereby reducing the cost intensive surface water conveyance system. The effluence resulting from such sub-surface storage of various surface intersection points in the form of spring line, or stream emergence, would enhance the river flows and improve the degraded eco-system of riverine tracts, particularly in the outfall areas. The structures required for arresting surface runoff and recharging to ground water reservoirs are of small dimensions and cost effective such as check dams, percolation tanks, surface spreading basins, pits, sub-surface dykes, etc. and these can be constructed with local knowhow.

3.2 BASIC REQUIREMENTS

The basic requirements for recharging the ground water reservoir are:

- Availability of non-committed surplus monsoon run off in space and time.
- Identification of suitable sites for creating sub-surface reservoir in suitable hydrogeological environment through cost effective artificial recharge techniques.

3.2.1 SOURCE WATER AVAILABILITY

The availability of source water, one of the prime requisites for ground water recharge, is basically assessed in terms of non-committed surplus monsoon run off, which as per present water resource development scenario is going unutilized. This component can be assessed by analyzing the monsoon rainfall pattern, its frequency, number of rainy days, and maximum rainfall in a day and its variation in space and time. The variations in rainfall pattern in space and time, and its relevance in relation to the scope for artificial recharge to sub-surface reservoirs can be considered for assessing the surplus surface water availability.

3.2.2 HYDROGEOLOGICAL ASPECTS

Detailed knowledge of geological and hydrological features of the area is necessary for adequately selecting the site and the type of recharge structure. In particular, the features, parameters and data to be considered are geological boundaries, hydraulic boundaries, inflow and outflow of waters, storage capacity, porosity, hydraulic conductivity, transmissivity, natural discharge of springs, water resources available for recharge, natural recharge, water balance, lithology, depth of the aquifer, and tectonic boundaries. The aquifers best suited for artificial recharge are those aquifers which absorb large quantities of water and do not release them too quickly. Theoretically this will imply that the vertical hydraulic conductivity is high, while the horizontal hydraulic conductivity is moderate. These two conditions are not often encountered in nature.

The evaluation of the storage potential of sub-surface reservoir is invariably based on the knowledge of dimensional data of reservoir rock, which includes their thickness and lateral extent. The availability of sub-surface storage space and its replenishment capacity further govern the extent of recharge. The hydrogeological situation in each area needs to be appraised with a view to assess the recharge capabilities of the underlying hydrogeological formations. The unsaturated thickness of rock formations, occurring beyond three meters below ground level should be considered to assess the requirement of water to build up the sub-surface storage by saturating the entire thickness of the vadose zone to 3 meter below ground level. The upper 3 m of the unsaturated zone is not considered for recharging, since it may cause adverse environmental impact e.g. water logging, soil salinity, etc. The historical water level behaviour gives an idea of the maximum saturation existed in a given area and the present endeavour should also aim for restoration of the maximum saturation for a given hydrogeological set up. There are few states like Rajasthan where the water level is very deep in the historical past also. Similarly, the states with undulating terrain will have steep hydraulic gradient and the saturation up to 3 m below ground level is not logical. The post-monsoon depth to water level represents a situation of minimum thickness of vadose zone available for recharge which can be considered vis-à-vis surplus monsoon run off in the area. In view of the above, depth below 3 m from ground level is taken for estimation of thickness of available unsaturated zone in post monsoon period for most of the states. For states like Bihar (7m), Rajasthan (8m), Gujarat (6m), Kerala (6m), Maharashtra (5m) and Sikkim (5m) deeper levels are considered for estimating the available average volume of unsaturated mass. However, shallow level is considered in coastal and island aquifers, where the head above mean sea level should be raised to a maximum possible extent to keep the fresh water-salt water interface at safe level. Depth to water level map for post monsoon period of 2010 is presented in Fig. 3.1.

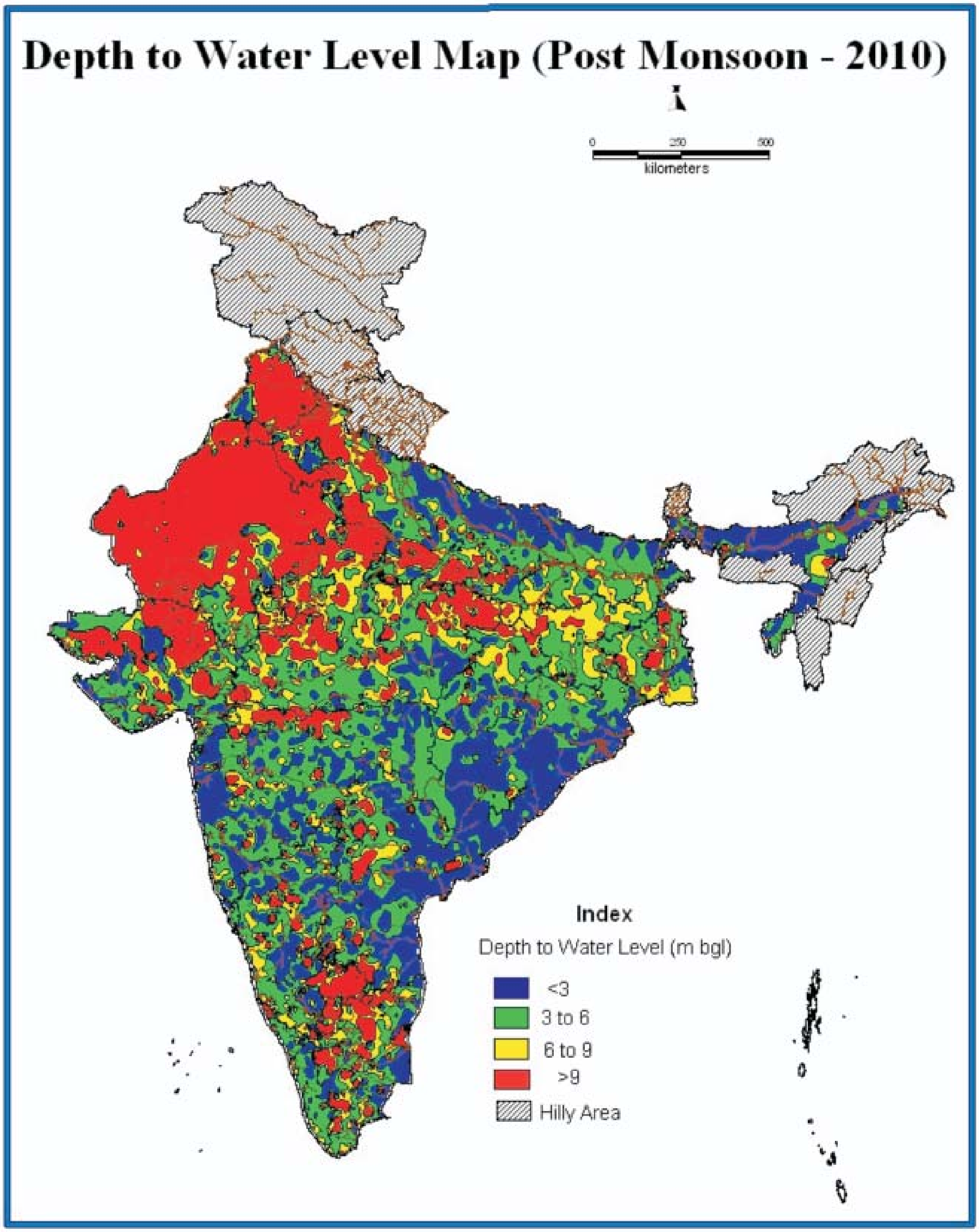


Fig.3.1 Depth to Water Level Map (Post Monsoon -2010)

The artificial recharge techniques inter-relate and integrate the source water to ground water reservoir. This results in rise in water level and increment in the total volume of the ground water reservoir.

3.3 NATIONAL PERSPECTIVE PLAN

Central Ground Water Board in year 1996 prepared National Perspective Plan for utilization of surplus monsoon run off for augmentation of ground water resources. This Plan was a broad policy frame of the artificial recharge schemes for implementation in the country. The Plan envisaged in situ conservation of surplus monsoon run off through artificial ground water recharge techniques. However, presently the transported water is proposed to be utilized for artificial recharge structures in the absence of insitu-surplus runoff and availability of thick unsaturated zone.

3.3.1 Salient features of National Perspective Plan

The surplus monsoon run off available for sub surface ground water storage in twenty river basins of the country has been estimated as 87.19 million hectare meters.Saturating the vadose zone to 3 meters depth below ground level will create sub surface storage potential of 59.06 M.ha.m. Of this, the retrievable storage potential works out to be 43.65 M.ha.m. The availability of monsoon run off is, however, not uniform in all the basins, resulting in surplus and deficit of monsoon run off vis-à-vis the water required to recharge the vadose zone. Hence, the above potential is further modified.

On the basis of availability of monsoon run off and storage potential of vadose zone, the feasible ground water storage has been estimated as 21.42 M.ha.m, of which 16.05 M.ha.m can be utilized.

The sub surface storages created would be free from environmental hazards and interstate controversies, since the surface structures created for recharge would be of small dimensions and would be within the basin/ watershed.

The creation of sub surface storage will help in:

(i) Equitable distribution of water resources, especially in the water scarcity hilly areas, since the augmentation of ground water resources will commence from the first order streams.

(ii) Ensuring sustainability of existing ground water abstraction system for major parts of the year due to extended recharge period of 3 to 4 months, thereby mitigating drinking water scarcity in problematic villages.

(iii) Mitigating hazards of flash floods, soil erosion, and silting of major reservoirs or river channels, thereby increasing the lift of the reservoirs, as also navigability of the river channels.

4.0 NEED FOR ARTIFICIAL RECHARGE TO GROUND WATER

Artificial Recharge is the process by which the ground water reservoir is augmented at a rate exceeding that under natural conditions of replenishment. Any man made scheme or facility that adds water to an aquifer may be considered to be an artificial recharge system.

Natural replenishment of ground water reservoir is slow and unable to keep pace with the excessive continued exploitation of ground water resources in various parts of the country. This has resulted in declining ground water levels and depleted ground water resources in some areas of the country. In order to augment the natural supply of ground water, artificial recharge of ground water has become an important and frontal management strategy in the country. The artificial recharge efforts are basically augmentation of natural movement of surface water into ground water reservoir through suitable civil structures. The artificial recharge techniques interrelate and integrate the source water to ground water reservoir and are dependent on the hydrogeological situation of the area.

In India, there are numerous ways of rain water harvesting and the traditional wisdom of local people can be seen from various practices in vogue in the country. The select situations are given in Table 4.1. However, with speedy ground water development in the last few decades, the necessity for changing practices is felt.

Table - 4.1. Traditional Artificial Recharge Practices in India

Sl. No.	Region	Structure	Description	Areas
1	Trans Himalayan Region, Jammu & Kashmir	Zings	Small tank like structures used to collect melted glacier water with a network of guiding channels	Ladakh & Kargil area
2	Western Himalayan Region	Kul	Water channels lined with rocks, to collect melted glaciers water	Spiti Valley and Jammu region
		Naula	Small ponds /wells to collect water from the streams by making stone wall	Hilly areas of Uttrakhand
		Khatri	10 x12 x 12 size carved structure in hard rock mountain.	Hamirpur, Kangra and Mandi (HP)
	Kashmir Valley to Uttarakhand region	Kuhl	Surface channels diverting water from natural flowing streams	Jammu & Kashmir Himachal Pradesh Uttrakhand
3	Eastern Himalayas Sikkim, Arunachal Pradesh & Darjeeling (WB)	Apatani	The slope of the valley is terraced in to plots separated by earth dams supported by bamboo frames.	Lower Subansiri (Arunachal Pradesh)
4	Northern Hill Regions	Zabo	Pond like structures located on high ridges runoff water from hill top passes through terraces and collected in ponds	Nagaland
	Assam, Nagaland, Manipur, Mizoram, Meghalaya & Tripura	Bamboo drip irrigation	Bamboo pipes are used to divert perennial spring water from hill top to irrigation field in the lower reaches	Khasi & Jaintia hills

5	Brahmaputra Valley	Dungs	Small irrigation channels linking paddy fields	Assam
6	Indo- Gangetic Plains	Dighi Baolis	Square/circular reservoir with steps Step wells	
7	Thar Deserts Western Rajasthan, Kutch region of Gujarat, Parts of Punjab and Haryana	Kundi Kuis/Beris Baoris/ Bers Jhalaras Nadis Tobas Tankas Khadin Vav/Vavdi/ Bavoli/ Bavadi Virdas Paar	Looks like an upturned cup nestling in a saucer 10-12 m deep pits dug near tanks to collect the seepage water Community wells used for drinking needs Rectangular Tanks having steps used for Religious rites Ponds storing water during rainy season Natural catchment with ground depression Lined circular holes made in the ground Built across the lower hill slopes Traditional step wells with a sluice constructed at the rim Shallow wells in low depressions A common water harvesting place, rain water flows from the catchment and percolates into the sandy soil	Western Rajasthan and some parts of Gujarat Rajasthan Rajasthan Jodhpur city Jodhpur city Bikaner Jaisalmer Rajasthan and Gujarat Rann of Kutch, Gujarat Western Rajasthan
8	Central high lands, Rajasthan, Gujarat, Madhya Pradesh	Talabs/ Bandhis Saza Kuva Johads Naada Pat Rapat Chandela tanks Bundela tanks	Human made/natural lakes Open well with multiple owners Earthern check dams A small stone check dam across a stream or gully Structures to store the water by diverting swift flowing hill streams Percolation tank with a bund to impound rain water flowing through a watershed Constructed by stopping run off in rivulet flowing between hills by erecting massive earthen embankment Similar to Chandala tank constructed with steps	Bundelkhand region Rajasthan and Madhya Predesh
9	Eastern high lands, Bihar, Madhya Pradesh, Odisha	Katas/ Mundas/ Bandhas	Strong earthen embankment curved at either end built across drainage line.	
10	Maharashtra, Karnataka and parts of AP	Cheruvu Kohlis Bandharas Phad Kere Ramtek model	Lake like structure Water tanks Small check dams/diversion weirs built across river Community managed irrigation system Check dam like structures built across streams for irrigation Network of ground water and surface water bodies connected through surface and underground canals	Chittoor, Kadapa districts of AP Maharashtra Maharashtra North West Maharashtra Karnataka Ramtek, Maharashtra

The rainfall occurrence in India is limited to about three months period ranging from around 10 to 100 days. The natural recharge to ground water reservoir is restricted to this period only. The artificial recharge techniques aim at increasing the recharge period in the post-monsoon season for about 3 more months providing additional recharge. This result in providing sustainability to ground water development during the lean season. In arid areas of the country rainfall varies between 150 and 600 mm/year with even less than 10 rainy days. Majority of the rain occurs in 3 to 5 major storms lasting only a few hours. The rates of potential evapo-transpiration (PET) are exceptionally high in these areas which range from 300 to 1300 mm. The average annual PET is much higher than the rainfall and at times as high as ten times the rainfall. The entire annual water resource planning has to be done by conserving the rainfall by either storing on surface or in sub-surface reservoir. The climatic features are not favorable for creating surface storage. Artificial recharge techniques have to be adopted which help in diverting most of the surface storage to ground water storage within shortest possible time.

In hilly areas, even though the rainfall is high, the scarcity of water is felt in the post-monsoon season. Due to the steep gradients, major quantity of water flows in the low lying areas as surface run-off. Springs which are the major source of water in hilly areas are also depleted during the post monsoon period. There is thus a need to provide sustainability to these springs. This can be done by increasing the recharge period during and after rainy season. Small surface storages above the spring level provide additional recharge and help in sustaining yield of springs.

Roof top rain water harnessing can also be adopted to meet domestic water requirements. The roof top rain water can be stored in specifically constructed surface or sub-surface tanks. Dependence on ground water has increased many folds and the natural recharge to ground water has decreased, due to urbanization, construction of buildings and paved area. The over-development of ground water is resulting in decline of ground water levels and to counter this artificial recharge has to be adopted. In urban areas water falling on roof tops can be collected and diverted to the open wells/ tube wells/ bore wells by providing a filter bed.

There is thus a need to prepare a systematic plan for augmenting ground water resources under various hydrogeological situations. The revised Master Plan prepared by CGWB provides an overview of the possibilities for storing surplus monsoon run-off in sub-surface reservoirs in major basins of the country. This covered all the areas to saturate vadose zone up to 3 m depth bgl. based on available surplus monsoon run-off and specific areas of coastal aquifers and island aquifers. However specific emphasis needs to be given to the areas where ground water levels are declining and water scarcity is being felt. Keeping this need in view, an attempt has been made, to prepare a Master Plan for each state where artificial recharge can be taken up in identified water scarcity areas. In this Plan emphasis has been given to the areas with declining and deep ground water levels. The Plan also includes roof top rain water harvesting in urban and rural areas for recharging the specific aquifer that ensures prevention of rain water wastage by letting into drains along with sewage water.

5.0 METHODOLOGY FOR PREPARATION OF MASTER PLAN

The Master Plan for Artificial Recharge has been prepared considering the hydrogeological parameters and hydrological data base. The following aspects were considered for preparation of the plan:

(i) Identification and prioritization of need based areas for artificial recharge to ground water. Estimation of sub surface storage space based on the water table behaviour and quantity of water needed to saturate the unsaturated zone (up to a depth of 3 to 8 m bgl depending on the prevailing hydraulic conditions and zone of fluctuation in the state, to fully utilize the unsaturated zone without allowing water logging condition)

(ii) Quantification of local surplus annual run off availability as source water for artificial recharge in each sub basin/watershed and possibility of transporting surplus run off from adjoining watersheds/sub-basins also to be considered.

(iii) Areas of poor chemical quality of ground water and scope of improvement by suitable recharge measures.

(iv) Working out design of suitable recharge structures, their numbers and type; storage capacity and efficiency considering the estimated storage space and available source water for recharge.

(v) Cost estimates of artificial recharge structures required to be constructed in identified areas.

5.1 DATA PREPARATION

Depth to water table map for post monsoon period based on decadal average of depth to ground water levels was prepared with contour intervals of 2 or 3 meters. The data of ground water levels was taken from National Hydrograph Network Stations of CGWB. Similarly a long term (decadal) post monsoon water level trend map was prepared. This map brought out the ranges of water level rise and fall on long term basis. These two maps were superimposed to bring out depth to water table variations along with the trends of water levels over the last decade. The special problem areas like deeper pressure head in deeper aquifers under exploitation and coastal aquifers under stress were demarcated and special recharge programmes aresuggested in the plan. The water logged areas close to water scarcity areas are also identified for diverting the surface run off.

5.2 IDENTIFICATION OF FEASIBLE AREAS

The areas feasible for artificial recharge have been demarcated into different categories as follows in most of the states:

- Areas showing post monsoon water levels deeper than 3 m bgl and declining trend of more than 10 cm/year in plains.
- Post monsoon Water level above 4 to 8 m in undulating/ hilly terrain and poor rainfall with deep water table zones.
- Areas with deeper pressure head in known principal aquifers.
- Areas having less fresh water lenses in coastal/island aquifers.

However, in few states, the categorization of area was done to suit the local situations. Depending upon data availability and specific ground conditions, the areas of above categories were demarcated and identified as feasible areas for planning and implementation of artificial recharge to ground water. Based on the severity of decline of ground water levels and ground water scarcity situation, prioritization for implementation of plan was decided. The availability of funds needed for the implementation, surveys, investigations, preparation of design and cost estimates for the structures, capability of the implementing agencies, land acquisition in case of scheme involving submergence etc. are some of the important aspects which need to be considered for implementation of the plan.

5.3 ESTIMATION OF AVAILABLE STORAGE SPACE

The thickness of available unsaturated zone (below 3 m bgl) described earlier is estimated by considering the different ranges of water level. The different ranges of DTW(depth to water level) are averaged to arrive at thickness of unsaturated zone. The total volume of unsaturated strata is calculated by considering the above categories and unsaturated thickness of different ranges. This volume was then multiplied by average specific yield on an area specific basis to arrive at volume of water required to saturate the aquifer to 3 m bgl.

5.4 SOURCE WATER REQUIREMENT

After assessing the volume of water required for saturating the vadose zone, the actual requirement of source water is to be estimated. Based on the experience gained in the pilot/demonstrative recharge projects implemented in different hydrogeological situations, an average recharge efficiency of 75% of the individual structure is considered. The volume of source water required for artificial recharge was calculated by multiplying a factor of 1.33 (i.e. reciprocal of 0.75). In few cases different values are taken depending upon the regional scenario prevailing thereupon.

5.5 SOURCE WATER AVAILABILITY

The surface water resources available in various basins and sub basins utilized for preparation of plan were based on information mostly provided by State Government. In few cases information from other Government Agencies were considered. The data availability for source water availability for each sub basin includes committed run off, provision for future planning and surplus water available. The availability of source water per annum was worked out by adding the amount of surface water provided for future planning and surplus available. This availability so worked out is for the entire sub basin and not exclusively for the requirement of the areas identified for artificial recharge. The source water availability for areas identified for artificial recharge was apportioned from total water availability in the basin.

5.6 CAPACITY OF RECHARGE STRUCTURES

The capacity of recharge structures was worked out based on the findings of various artificial recharge studies under taken in different states and the same was used for planning the recharge structures. Maximum storage capacity (single filling) and gross capacity due to multiple fillings during rainy season were taken into consideration for designing percolation tanks, cement plugs, check dams and other surface storage structures. The number of rainy days and the possible number of fillings to the proposed recharge structure (2 to 3 fillings for check dams, 3 to 5 fillings for ponds etc) is also taken into consideration.

5.7 NUMBER OF RECHARGE STRUCTURES

The numbers of recharge structures required to store and recharge the ground water reservoir have been worked out as follows: -

$$\text{No. of Structures} = \frac{\text{Total surplus Surface Water runoff Considered}}{\text{Average Gross Capacity of Water Spreading Recharge Structures (Considering Multiple Fillings)}}$$

The type and design of different types of structures like percolation tanks, check dams, recharge shafts etc. in a particular block/watershed would be guided by prevailing hydrogeological situation, existing density and number of structures, land availability etc. The planning of type and design of proposed structures should accordingly be decided. The allocation of source water for recharge through specific type of artificial recharge structures should be done considering these aspects. In case of deeper aquifers, injection wells are recommended on the basis of thickness of aquifer and status of ground water withdrawal and the feasibility of gravity injection at safe rate obtained from trial tests at Neyveli aquifer in Tamil Nadu. Few structures are based on conceptual projection, which can be fine-tuned by more site specific field studies during preparation of Detailed Project Reports (DPRs).

6.0 DESIGN OF ARTIFICIAL RECHARGE STRUCTURES

A wide spectrum of techniques are in vogue which are being implemented to recharge the ground water reservoir. Similar to the variations in hydrogeological framework, the artificial recharge techniques feasible too, would vary accordingly. The artificial recharge structures, which are feasible in varied hydrogeological situation, are described as follows:

6.1 PERCOLATION TANKS

Percolation tank is an artificially created surface water body, submerging in its reservoir highly permeable land areas, so that the surface run off is made to percolate and recharge the ground water storage. The percolation tank should have adequate catchment area. The hydrogeological condition of site for percolation tank is of utmost importance. The rocks coming under submergence area should have high permeability. The degree and extent of weathering of rocks should be uniform and not just localized. The purpose of percolation tank is to conserve the surface run off and diverts the maximum possible surface water to the ground water storage. Thus the water accumulated in the tank after monsoon should percolate at the earliest, without much evaporation losses.

The size of a percolation tank should be governed by the percolation capacity of the strata in the tank bed rather than yield of the catchment. For, in case the percolation rate is not adequate, the impounded water is locked up and wasted more through evaporation losses, thus depriving the downstream area of the valuable resource.These are the most prevalent structures in India as a measure to recharge the groundwater reservoir both in alluvial as well as hard rock formations. The efficacy and feasibility of these structures is more in hard rock formation where the rocks are highly fractured and weathered. In the States of Maharashtra, Andhra Pradesh, Madhya Pradesh, Karnataka and Gujarat, the percolation tanks have been constructed in plenty in basaltic lava flows and crystalline rocks. The percolation tanks are, however, also feasible in mountain fronts occupied by talus scree deposits. The percolation tanks can also be constructed in the Bhabar zone. Percolation tanks with wells and shafts can also be constructed in areas where shallow or superficial formations are highly impermeable or clayey.

6.1.1 Site Characteristics and Design Guidelines

A detailed analysis of rainfall pattern, number of rainy days, dry spells and evaporation rate and detailed hydrogeological studies to demarcate suitable percolation tank sites, is necessary. In Peninsular India with semi arid climate, the storage capacity of percolation tank is designed such that the water percolates to ground water reservoir by January/February. The submergence area should be in uncultivable land as far as possible. Percolation tank be located on highly fractured and weathered rock for speedy recharge. In case of alluvium, the bouldary formations are ideal for locating percolation tanks. The aquifer to be recharged should have sufficient thickness of permeable vadose zone to accommodate recharge. The benefited area should have sufficient number of wells and cultivable land to develop the recharged water. Detailed hydrological studies for run off assessment be done and designed capacity should not normally be more than 50 percent of total quantum of rain fall in catchment. Waste weir or spillway is suitably designed based on single day maximum rain fall to allow flow of surplus water after the tank is filled to its maximum capacity. Cut off trench be provided to minimize seepage losses both below and above nala bed. To avoid erosion of embankment due to ripple action stone pitching be provided upstream up to highest flood level (HFL).

6.2 CHECK DAM CEMENT PLUG/ NALA BUND

Check dams are constructed across small streams having gentle slope and are feasible both in hard rock as well as alluvial formation. The site selected for check dam should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within short span of time. The water stored in these structures is mostly confined to stream course and the height is normally around 2 m. These are designed based on stream width and excess water is allowed to flow over the wall. In order to avoid scouring from excess run off, water cushions are provided at down streamside. To harness the maximum run off in the stream, series of such check dams can be constructed to have recharge on a regional scale. The peak flow should not create bank erosion and damage to structures.

A series of small bunds or weirs are made across selected nala sections such that the flow of surface water in the stream channel is impeded and water is retained on pervious soil/ rock surface for longer period Nala-Bunds are constructed across bigger nala or second order streams in areas having gentler slopes. A nala bund acts like a mini percolation tank with water storage confined to stream course.

6.2.1 Site Characteristics and Design Guidelines

For selecting a site for check dams/ nala bunds the following aspects may be observed :

- The total catchment of the nala should normally be between 40 to 100 hectares though the local situations can be guiding factor for this.
- The rain fall in the catchment should be less than 1000 mm/annum.
- The width of nala bed should be at least 5 meters and not exceed 15 meters and the depth of bed should not be less than 1 meter.
- The lands downstream of check dam/ nala bund should have land under well irrigation.
- The rock strata exposed in the ponded area should be adequately permeable to cause ground water recharge through ponded water.
- The structures should not block the flow of water during the rainfall totally and hence the sufficient carrying capacity of nala/stream should be ensured.

6.3 GABION STRUCTURE

This is a kind of check dam being commonly constructed across small stream to conserve stream flows with practically no submergence beyond stream course. The boulders locally available are stored in a steel wire. This is put up across the stream to make a small dam by anchoring it to the streamside. The height of such structures is around 0.5 m and is normally used in the streams with width of about 10 to 15 m. The excess water overflows this structure leaving some storage water to serve as source of recharge. The silt content of stream water is deposited in the interstices of the boulders in due course to make it more impermeable. These structures are common in the states of Maharashtra, Madhya Pradesh, Andhra Pradesh, etc.

6.4 MODIFICATION OF VILLAGE TANKS AS RECHARGE STRUCTURE

The existing village tanks which are normally silted and damaged can be modified to serve as recharge structure in case these are suitably located to serve as percolation tanks. In general, no “Cut Off Trench”

(COT) and Waste Weir is provided for village tanks. Desilting, coupled with providing proper waste weir and COT on the upstream side, the village tanks can be converted into recharge structure. Several such tanks are available which can be modified for enhancing ground water recharge. Studies, however, are needed to ascertain whether the village tanks are suitably located to serve as recharge structures. Some of the tanks in Maharashtra and Karnataka have been converted into percolation tanks.

6.5 DUG WELL RECHARGE

In alluvial as well as hard rock areas, there are thousands of dug wells which have either gone dry or the water levels have declined considerably. These dug wells can be used as structures to recharge ground water. The storm water, tank water, canal water, etc. can be diverted into these structures to directly recharge the dried aquifer. By doing so the soil moisture losses during the normal process of recharge, are reduced. The recharge water is guided through a pipe to the bottom of well, below the water level to avoid scoring of bottom and entrapment of air bubbles in the aquifer. The quality of source water including the silt content should be such that the quality of ground water reservoir is not deteriorated. In rural areas the rain water runoff can be channelized and recharged to dug wells through a filter.

6.6 RECHARGE SHAFTS

In areas where phreatic aquifer is overlain by poorly permeable strata, the recharge to ground water storage by water spreading method becomes ineffective or has very low efficiency. This situation also occur in ponds/depressions where due to siltation an impermeable layer or lens is formed which affects hydraulic connection of surface water and phreatic aquifers. Recharge shaft is an artificial recharge structure which penetrates the overlying impervious horizon and provides affective access of surface water for recharging the phreatic aquifer. These structures are ideally suited for areas with deep water levels. In areas where low permeable sandy horizon is within shallow depths, a trench can be excavated to 3 m depth and back filled with boulder and gravel. The trench can be provided with injection well to effectively recharge the deeper aquifers.

6.6.1 Site Characteristics and Design Guidelines

The following are the site characteristics and design guidelines:

- To be dug manually if the strata is of non-caving nature.
- If the strata are caving, proper permeable lining should be provided.
- The diameter of shaft should normally be more than 2 m to accommodate more water and to avoid eddies in the well.

In the areas where source water is having silt, the shaft should be filled with boulder, gravel and sand from bottom to have inverted filter. The upper most sandy layer has to be removed and cleaned periodically. When water is put into the recharge shaft directly through pipes, air bubbles are also sucked into the shaft through the pipe which can choke the aquifer. The injection pipe should therefore, be lowered below the water level, to avoid this.

6.7 INJECTION WELL

The aquifer to be replenished is generally one which is already over exploited by tube well pumpage and the declining trend of water levels in the aquifer has set in. Because of the confining layers of low permeability the aquifer cannot get natural replenishment from the surface and needs direct injection through recharge wells. Artificial Recharge of aquifers by injection well is also done in coastal regions to arrest the ingress of sea water and to combat the problems of land subsidence in areas where confined aquifers are heavily pumped.

In alluvial areas, injection well recharging a single aquifer or multiple aquifers can be constructed in a fashion similar to normal gravel packed pumping well. The only difference is that cement sealing of the upper section of the well is done in order to prevent the injection pressures from forcing leakage of water through the annular space of borehole and well assembly. In hard rock areas casing and well screens may not be required. An injection pipe with opening against the aquifer to be recharged may be sufficient. However, in case of number of permeable horizons separated by impervious rocks, a properly designed injection well may be constructed with slotted pipe against the aquifer to be recharged. In practice the injection rates are limited by the physical characteristics of the aquifer. In the vicinity of well, the speed of ground water flow may increase to the point that the aquifer is eroded, especially if it is made up of unconsolidated or semi-consolidated rocks. In confined aquifer confining layers may fail if too great pressure is created under them. If this occurs, the aquifer will become clogged in the vicinity of the borehole and/or may collapse.

6.8 GROUND WATER DAMS OR SUB SURFACE DYKES OR UNDERGROUND BANDHARAS (UGB)

These are basically ground water conservation structures and are effective to provide sustainability to ground water structures by arresting sub surface flow. A ground water dam is a sub surface barrier across stream which retards the natural ground water flow of the system and stores water below ground surface to meet the demands during the period of need. The main purpose of ground water dam is to arrest the flow of ground water out of the sub-basin and increase the storage within the aquifer. This helps in rising of water levels in upstream part of ground water dam rise, thus saturating the otherwise dry part of aquifer.

6.9 ROOF TOP RAIN WATER HARVESTING

In urban areas, the roof top rain water can be conserved and used for recharge of ground water. This approach requires connecting the outlet pipes from roof top to divert the water to either existing wells/ tube wells/ bore well or specially designed wells. The urban housing complexes or institutional buildings have large roof area and can be utilized for harvesting roof top rain water and recharging.

7.0 MONITORING MECHANISM

The monitoring of water levels and water quality is of prime importance in any scheme of artificial recharge to ground water. The monitoring data speaks for the efficacy of structures constructed for artificial recharge and greatly helps in taking effective measures for ground water management on scientific lines. As such the plan for artificial recharge should have the monitoring mechanism inbuilt with the scheme.

7.1 WATER LEVEL MONITORING

The monitoring of surface water and ground water levels during feasibility studies greatly help in identifying the method of artificial recharge. Network of observation wells is used to study the ground water flow pattern and temporal changes in potentiometric head in the aquifer.

The observation well network during feasibility stage is generally of low density, spread over a large area with the primary aim of defining the boundary zonation of the aquifer to be recharged and to know the hydraulic characteristics of the natural ground water system. After identification of the feasible ground water structures, the observation well network is redefined in a smaller area with greater well density. The objective of monitoring system is to study the effect of artificial recharge on the natural ground water system. Depending on the method of artificial recharge and the hydrogeology of the area, the observation well network has to be designed.

The monitoring system of observation well network should be designed specially to monitor impact of individual structures which can further be extended and dovetailed to monitor the impact of group of such structures in the artificial recharge scheme area. The network of observation wells should be

a) adjacent to the recharge facility

b) at a sufficient distance from the recharge facility to observe composite effects and

c) near the limit of hydrological boundaries.

If the recharged aquifer is overlain by confining/ semi-confining layer, piezometers should be installed to monitor the water levels of overlying and underlying aquifers which helps in the study of leakages etc. Where the surface water bodies are hydraulically connected with the aquifers which are being recharged, it is advisable to monitor the water level profiles of both surface water and ground water.

The periodic monitoring of water levels can demarcate the zone of benefit. In this method a network of observation wells is established in the area likely to be benefitted to study the following:

- In the zone benefitted, the water levels be observed as to whether the well hydrographs have a flat apex during the time when there is water in the recharge structure (tank, pit, etc.)
- Wells situated outside the zone of influence normally show an angular apex for the period when the recharge is taking place, while those situated within the zone of influence have a flatter area.
- The recession limbs of hydrograph wells close to a recharge structure normally have a gentle gradient as compared to those located far off. Crops in the zone of influence will be healthy compared to those outside such an area. Furthermore, in the zone of influence there is a tendency by the farmers to grow crops with high water requirements. Well yields in the zone of influence are generally being greater

than those outside it. The wells in benefitted zones may have more sustainability in lean period than those outside.

The above criteria can be used to define the zone of influence and thereby, a real and temporal demarcation of the effectiveness of recharges structures.

7.2 TRACER TECHNIQUE FOR DEMARCATING ZONE OF BENEFIT

Tracers are useful in demarcating the area benefitted by artificial recharge, Tritium; Rodhomine B, fluorescent dye and environmental isotopes, etc. are quite useful in assessing the extent of recharge and efficiency of recharge structures.

7.3 WATER QUALITY MONITORING

The monitoring of water quality during the implementation of artificial recharge schemes is essential to maintain the quality standards for specified uses of the augmented resource. In case of injection wells, the composition of native water in the aquifer and the recharged water is important to know prevent clogging of well and aquifer due to excessive precipitation of salts. The data on the chemical quality of native water and the changes which may take place during the implementation of artificial recharge schemes should be collected by regular sampling from observation well network. Where treated wastewater is used for recharge a careful monitoring is required to detect any possibility of contamination through a network of monitoring wells. Thus, the type of water quality monitoring programme depends on the specific problem being studied i.e. changes in ground water quality; effect of soil salinisation and prevention of any contamination etc. The samples to be collected will also depend on the purpose and are generally categorized into:

(1) Indicative: The indicative samples are collected at 1 to 4 months intervals and used to ascertain the presence of injected effluent.

(2) Basic: Basic samples are taken at monthly intervals for wells already influenced by recharge to determine the effect of recharge effluent on ground water quality and the purification provided by flow through the soil and aquifer system.

(3) Comprehensive: Comprehensive samples are taken at intervals of 6 months to 1 year for observation wells to determine water quality with respect to specific standards for intended water use.

7.4 IMPACT ASSESSMENT

The impact assessment of artificial recharge schemes can generally be enumerated as follows:

- Conservation and harvesting of surplus monsoon run off in ground water reservoir which otherwise was going un-utilized outside the watershed/ basin and to sea. Rise in ground water levels due to additional recharge to ground water. In case where continuous decline of ground water level was taking place, a check to this and/or the intensity of decline subsequently reduces. The energy consumption for lifting ground water from abstraction structures also reduces.

- The ground water structures in the benefitted zone of artificial recharge structures gain sustainability and the wells provide water in lean month. The domestic wells will become sustainable and many of the areas depending on water supply through tankers are benefitted.

- The cropping pattern in the benefitted zone may undergo marked change due to augmentation of ground water. Due to the increase in soil moisture, green vegetation cover may be increased and so are the number of ground water abstraction structures in the zone of influence.
- The quality of ground water may also improve due to dilution. Besides, the artificial recharge schemes will generate indirect benefit in terms of decrease in soil erosion, improvement in fauna and flora, influx of migratory birds, etc. The social and economic status of farmers would be substantially improved due to increase in crop production.

8.0 STATE WISE MASTER PLAN FOR ARTIFICIAL RECHARGE

8.1 ANDHRA PRADESH

Andhra Pradesh State with a geographical area of 2,75,068 sq km has three distinct regions viz; Coastal Andhra, Rayalaseema and Telangana and is administratively divided into 23 districts and 1125 Mandals. The state is characterized by diverse climatic, physiographic and hydrogeological conditions. It has semi-arid type of climate with normal rainfall of 940 mm. It receives rainfall during south- west monsoon (June-Oct) and north-east monsoon (Nov-Dec), out of which south-west monsoon contributes 67% of total rainfall. The distribution of rainfall is highly variable from 561 mm to 1113 mm from south and south western parts of the state to north and north eastern parts of the state.

Agriculture is the lifeline of State's economy. Increased water demand, vagaries of rainfall coupled with near total utilization of surface water resources resulted in increase in dependency on ground water as the major source for irrigation, domestic and industrial sectors. This led to declining water levels, reduction in well yields, well commands and increase in pumping lifts in considerable part of the state particularly in Rayalaseema and Telangana regions. As on March, 2009, the stage of ground water development in the state is 46%. Out of 1108 Assessment units (basins) in the state, 84 units are over exploited, 26 are critical, while 93 are semi-critical. In these basins, there is a need to take up steps for augmentation of ground water resource through appropriate techniques for sustainable development. The state is having three major river basins i.e. Krishna, Godavari and the Pennar. The total estimated surplus water availability at 75% dependency, in the state of Andhra Pradesh is about 6,141 MCM.

8.1.1 IDENTIFICATION OF AREA

Artificial recharge is feasible in areas having surplus monsoon run-off and in areas where the aquifer is capable of storing water when the natural recharge process is augmented. Both declining trend and depth to water levels have been taken into consideration for taking up artificial recharge schemes. The area characterized by depth to water level of more than 3 m bgl during the post-monsoon period and area with declining decadal water level trend is considered as area requiring artificial recharge. The areas which are categorized as Semi-critical, Critical or Over-exploited (2008-09) meet such criteria. Hence these areas are identified for artificial recharge. Apart from these, urban areas, coastal areas prone to salinity ingress and areas with deep water levels in deeper aquifers in sedimentary terrain also need special attention. Hence, all municipal areas in the state (except shallow water level areas) and identified specific areas are taken into consideration while preparing the present plan.

8.1.2 SUBSURFACE STORAGE SPACE

The thickness of unsaturated zone for each category of depth to water level is arrived and 3 m is subtracted to get the unsaturated thickness available for recharge in the regional level. The state is covered by crystalline formations, having specific yield in the range of 1-3% are considered.

8.1.3 SOURCE WATER AVAILABILITY

Monsoon rainfall run off is the only source water for artificial recharge in the state. The runoff yield in each unit is estimated from monsoon rainfall of respective unit (Mandal) using Strangers table for average catchment type. From the data used in ground water resource estimation and field experience, 25 % of runoff potential is taken as existing storage and the remaining as surplus runoff. The utilizable surplus runoff is assumed as

50 % of surplus, considering riparian and other practical considerations for construction of artificial recharge structures.

8.1.4 NEED FOR MODERNIZING OF EXISTING STRUCTURES

Govt. of Andhra Pradesh is one of the pioneering States in realizing the importance of soil and conservation activities and accordingly watershed development programmes have been given considerable importance. Initially launched in 12 drought prone districts, the programmes are now extended to all the districts of the state. In all 44091 percolation tanks, 28328 check dams, 47438 farm ponds, 248693 gully plugs, 12201 nala bunds and 206789 other structures were constructed apart from desilting in 1311 tanks as on 2008. It has been observed that desired results are not achieved due to poor maintenance; as a result many structures were either defunct or not fully operational. Hence there is a need to repair and renovate technically feasible structures so as to make them fully operational at low cost. The work may be under taken by Panchayati Raj Institutions in association with water user groups and beneficiary committee by integrating the MGNREGA work also. Considering this, it is proposed to take up about 50% of existing structures having large storage (percolation tanks & check dams) for providing additional structures and rectification of the damages in the structures as a major rehabilitation program at a cost Rs. 1.0 lakh for each structure for repair, and Rs. 1.0 lakhs for providing additional structures. In all 34,000 structures with an average cost of Rs. 2.0 lakhs and a total cost of Rs. 680 crores is proposed. The detailed area wise proposal is given in the table 8.1.1

Table-8.1.1 Cost estimate for different kinds of Artificial Recharge Structures in Andhra Pradesh

S. N.	Item	Structure	Total No.of Structures	Unit cost (Rs. in crores)	Total Cost (Rs. in crores)
1	Artificial Recharge in Over Exploited, Critical and Semi-Critical Mandals	Check Dam with Recharge Shaft	28787	0.05	1439.35
		Percolation Tank with Recharge Shaft	3838	0.10	383.80
2	Repair, Renovation & strengthening of existing structures with shafts/recharge bores	Recharge shafts /bore well	34000	0.02	680.00
3	Rooftop harvesting in urban areas	RTRWH(H) RTRWH(G&I)	712500 37500	0.0012 0.01	1230.00
4	Recharge to deeper aquifers	Recharge tubewells	2000	0.10	200.00
	Total Cost				**3933.15**

8.1.5 PLANNING OF SUITABLE ARTIFICIAL RECHARGE STRUCTURES AND THEIR NUMBER

Considering past experience of the effective recharge rate from various structures, check dams and percolation tanks in combination with recharge shafts are proposed for faster inflow into the system. The available surplus run off has been accounted in equal proportions for new check dams and percolation tanks at appropriate locations. In all, 3838 percolation tanks along with recharge shafts and 28,787 check dams along with recharge shafts or bore wells are proposed for artificial recharge, based on the storage capacity of the recharge structures. There are many existing recharge structures and village ponds and irrigation tanks with poor connectivity to the fractures available at 20 to 60 m depth. The massive sheet rocks are prevalent in major part of hard rocks and hence the structures created for recharge purpose are often found to be less effective which can be improved by providing additional structures like recharge shafts or bore wells. Depending upon hydrogeological conditions, the exact locations of structures can be decided after field investigations. As many rain water harvesting and recharge structures were constructed in the past, stress on restoration and renovation of existing structures was also need to be taken up.

8.1.6 OTHER SPECIFIC AREAS IDENTIFIED FOR ARTIFICIAL RECHARGE

Roof top rain water harvesting structures in all urban areas and major villages in rural areas are also proposed with recharge pits around existing bore wells. Areas of semi consolidated rocks in coastal districts have overexploited aquifers like Rajahmundry sandstone in West Godavari and East Godavari districts, where the pressure head is lowering at alarming rate and there is a need to recharge these aquifers with local or transported surplus water from adjoining watersheds through existing net work of canals and system tanks. For the construction of recharge tube wells, deeper aquifers under high level of exploitation as well as areas vulnerable for sea water ingress are identified with provision of supply channel and local surface storage for collecting the run off in monsoon/ canal water in non monsoon and allow a long term recharge provision. In all, recharge well fields / tube wells of 100 to 200 m depth in cluster (unit cost of Rs. 10 lakhs) at 2000 locations are proposed to be taken in feasible artificial recharge areas by State level agencies.

8.1.7 ROOF TOP RAINWATER HARVESTING

It has been assessed that roof top rainwater harvesting can be adopted in ~7.5 lakh houses, govt buildings, institutes etc. in urban and municipal area of the state suitable for artificial recharge in the first phase. It will harness 120.53 MCM rain water to augment groundwater resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a buildings having roof and paved areas of ~ 200 sq.m has been assessed to be Rs. 12,000/- and for bigger building having more than 1000 sq.m will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 1,230 crore in the first phase considering 5% of the total buildings having larger roofs.

8.1.8 COST ESTIMATES

The unit cost of each percolation tank with shaft is taken as Rs.10 lakhs, while the cost for check dam along with recharge shaft is considered as Rs. 5 lakhs. The district wise estimate for the above two structures are given in table 8.1.2 and the area proposed under the same is given in Fig-8.1.1. The recharge tube well with storage and filter unit is taken as Rs. 10 lakhs. The total outlay is estimated at about Rs. 3,933.15 crores to take up the artificial recharge structures including Roof Top Rain Water Harvesting.

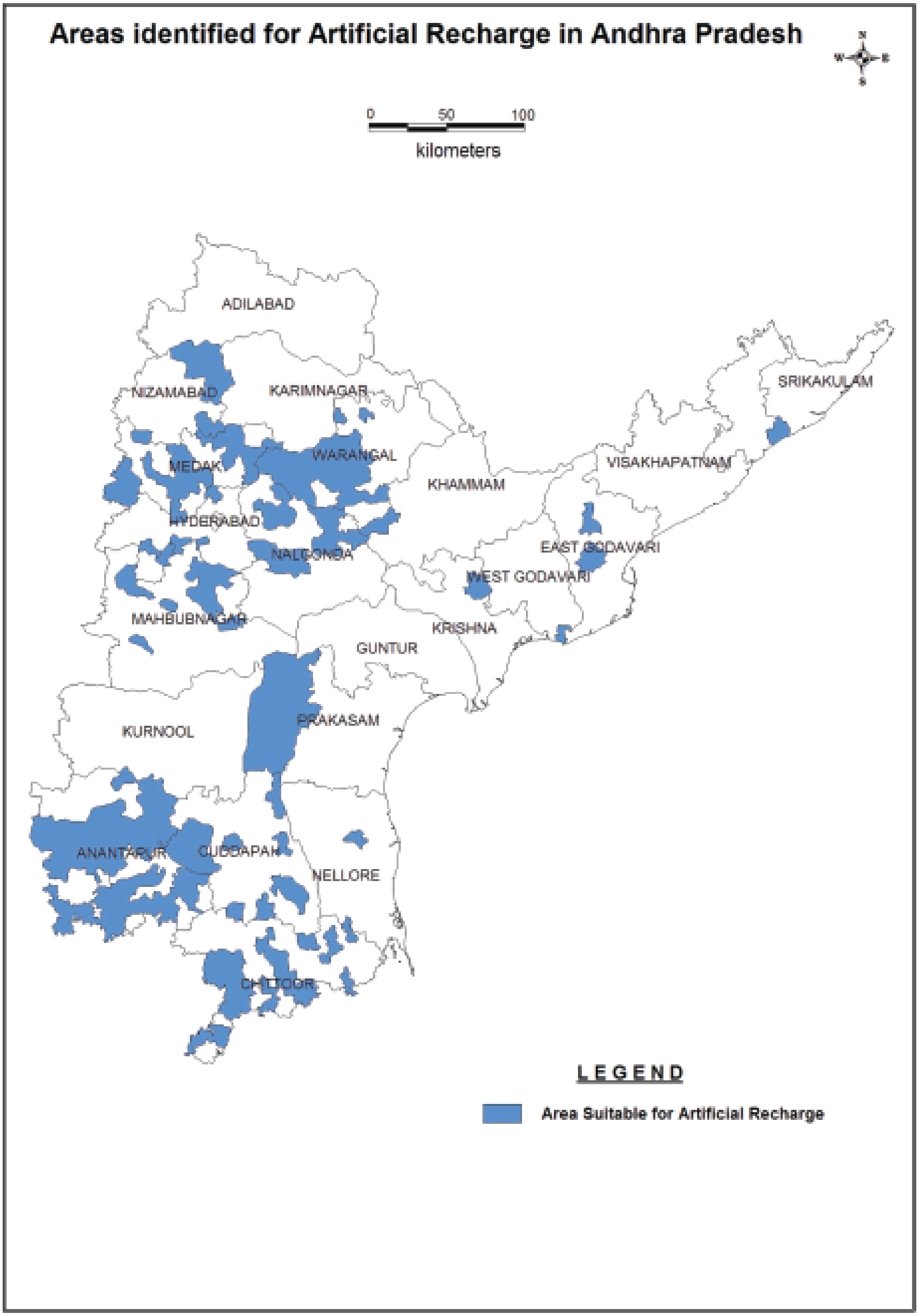


Fig 8.1.1 Areas identified for Artificial Recharge in Andhra Pradesh.

Table 8.1.2 – District-wise Master Plan for Artificial Recharge, Andhra Pradesh

S. No.	Name of the District	Area suitable for Artificial Recharge (sq.km.)	Volume of water required for artificial recharge (MCM)	Surplus Runoff (MCM)	Existing storage utilized (MCM)	Surplus runoff available (MCM)	Utilizable Surplus runoff (MCM)	No. of Percolation Tanks feasible	No. of Check Dams with recharge wells feasible	Unit Cost @ Rs. 10.0 lakhs per Percolation Tank (Rs. in crores)	Unit Cost @ Rs. 5.0 lakhs per Check Dam with recharge wells (Rs. in crores)	Total cost (Rs. in crores)
1	ANANTAPUR	10925	2614	556.27	139.07	417.20	208.60	348	2608	34.80	130.40	165.20
2	CHITTOOR	5171	1634	959.29	239.82	719.47	359.73	600	4497	60.00	224.85	284.85
3	EAST GODAVARI	261	253	78.22	19.55	58.66	29.33	49	367	4.90	18.35	23.25
4	KADAPA	4103	681	510.80	127.70	383.10	191.55	319	2394	31.90	119.70	151.60
5	KHAMMAM	220	1	26.31	6.58	19.73	9.87	16	123	1.60	6.15	7.75
6	KRISHNA	442	252	107.70	26.92	80.77	40.39	67	505	6.70	25.25	31.95
7	MEDAK	4415	1361	803.06	200.77	602.30	301.15	502	3764	50.20	188.20	238.40
8	MAHABUB NAGAR	2596	797	230.66	57.66	172.99	86.50	144	1081	14.40	54.05	68.45
9	NALGONDA	3319	268	439.21	109.80	329.41	164.70	275	2059	27.50	102.95	130.45
10	NIZAMABAD	2332	680	598.45	149.61	448.84	224.42	374	2805	37.40	140.25	177.65
11	PRAKASAM	2832	742	321.78	80.45	241.34	120.67	201	1508	20.10	75.40	95.50
12	RANGA REDDY	1230	246	163.52	40.88	122.64	61.32	102	767	10.20	38.35	48.55
13	SRIKA KULAM	344	22	81.61	20.40	61.20	30.60	51	383	5.10	19.15	24.25
14	WARANGAL	5553	663	1264.38	316.09	948.28	474.14	790	5927	79.00	296.35	375.35
	STATE TOTAL	**43743**	**10215**	**6141**	**1535.31**	**4605.94**	**2302.97**	**3838**	**28787**	**383.80**	**1439.35**	**1823.15**

8.2 BIHAR

The state of Bihar has an area of 94,163 sq.km. As per the 2011 census, the population of Bihar is 10.38 crore The average annual rainfall is 1205 mm. The river Ganga forms the major river basin in this state.

8.2.1 IDENTIFICATION OF AREA

The identification of the area suitable for artificial recharge has been done on the basis of depth of mean post-monsoon water level. The areas where the average water level of last 10 years is more than 7 mbgl in post-monsoon period (November) has been considered suitable for artificial recharge. Suitable areas for artificial recharge were identified in 2 districts viz; Gaya and Jamui (Fig.8.2.1). An area of 760.30 sq.km is found suitable for large scale artificial recharge in the state while the other parts of the State have very localized pockets suitable for recharge.

8.2.2 SUBSURFACE STORAGE AND WATER REQUIREMENT

The storage space for recharge has been assessed for the areas where the mean post monsoon water levels are deeper than 7 m bgl. The storage space available for artificial recharge is considered as a slice of unsaturated zone occurring between 3 m and 7 m bgl and the mean post-monsoon depth to water level exceeding 7 m bgl. The difference between 3 m bgl and average post monsoon depth to water level is then multiplied with the area to arrive at the volume of unsaturated zone possible for recharging. The district wise breakup of the volume of the aquifer likely to be recharged was worked out for two needy districts and the specific yield of rock formation has been utilized to arrive at the total volume of water required for saturating the phreatic aquifer. The gross volume of surface water required for artificial recharge is estimated on the basis of 75% efficiency of the artificial recharge structures.

8.2.3 SOURCE WATER AVAILABILITY

The basin wise surface water availability with 75% dependability has been taken from Bihar State Irrigation Commission report. The amount of overland flow from the Kiul, Ajay and Badua, Belhara river basins, available during monsoon for area falling in Jamui district has been worked out as 68.96 MCM. For the area falling in Gaya district, the amount of overland flow available from the Morhar river basin has been worked out as 14.18 MCM. The total overland flow in parts of Gaya and Jamui district identified as suitable for artificial recharge is 83.14 MCM. The district wise distribution of surplus surface water resource generated within the identified districts is given in table-8.2.1.

Table-8.2 .1: Requirement of Surface Water Resources for Artificial Recharge to Ground Water in Bihar

S. N.	Name of District	Area identified for Artificial Recharge (sq.km.)	Volume of water required (MCM)	Surface Water required at 75% efficiency (MCM)	Total surplus runoff available (MCM)
1.	Gaya	115.0	43.12	57.30	14.18
2.	Jamui	645.3	119.25	158.60	68.96
	Total	760.3	162.37	215.90	83.14

Fig-8.2.1 Areas identified for Artificial Recharge in Bihar

8.2.4 RECHARGE STRUCTURES

For consideration of suitability of artificial recharge structures, the state has been divided into

(i) Hard rock area of Jamui district and
(ii) The marginal alluvial area of Gaya district.

In hard rock areas the suitable artificial recharge structures are:

(i) Percolation Tank
(ii) Nala Bunding

In marginal alluvial areas the suitable artificial recharge structures are:

(i) Nala/Contour Bunding
(ii) Recharge Shaft
(iii) Percolation Tank

Emphasis has been given on the renovation of old contour bunding (Ahar System) which is very common in the area. Such system has been in existence since long and occasional repairs are undertaken by the local farmers. These structures if revitalized would assist in water conservation as well as some degree of recharge.

The volume of surface water considered for planning the artificial recharge is based on the surplus runoff availability and the space available for recharge. Based on the field situation it has been considered that 50% storage will be through percolation tanks and 50% through nala bunding in hard rock areas.

However, for marginal alluvial areas, 25% resources may be recharged through percolation tank and 25% through recharge shaft and rest 50% through nala bunding (check dams)/ contour bunding. The single filling capacity of percolation tank is 75 TCM. Considering 200% of multiple filling, the gross storage is 150 TCM. For Nala Bunding of 10 TCM capacity the actual storage will be 25 TCM based on 250% of multiple filling. The nala bunds should be concrete structures in lower order streams. The entire surface water diverted through recharge shaft is likely to be utilized for recharging. Contour bunding has 50 TCM storage capacities. The contour bunds are of 300 to 400 m length depending upon the local slope and availability of land.

Number of structures has been worked out at district level based on gross storage capacity of individual structure. The proposed plan envisages utilization of 83.14 MCM of total volume of surface water for recharge purpose through different structures.The district wise number of different types of artificial recharge structures is given in table 8.2.2

Table- 8.2 .2: District-wise feasibility of Artificial Recharge Structures in Bihar

S. No.	Name of District	Area identified for Artificial Recharge (sq.km.)	Volume of water required (MCM)	Surface Water required at 75% efficiency (MCM)	Total surplus runoff available (MCM)
1.	Gaya	115.0	43.12	57.30	14.18
2.	Jamui	645.3	119.25	158.60	68.96
	Total	**760.3**	**162.37**	**215.90**	**83.14**

8.2.5 COST ESTIMATES

Based on experiences gained by CGWB, the unit cost of structures has been work out and given in Table 8.2.3.

Table-8.2.3: Unit Cost of Structures in Bihar

S.No.	Structure	Unit cost (Rs. in Lakhs) (approx.)
1.	Percolation Tank (P)	27.00
2.	Nala Bunding (NB)	3.0
3.	Recharge Shaft (RS)	3.5

The district wise cost estimates for different types of structures are given in table 8.2.4

Table 8.2.4- District-wise details of artificial recharge structures in Bihar

S. No	District Name	Area of District (sq.km)	Average post monsoon Depth to water (mbgl)	Area Feasible for Artificial Recharge (sq.km)	Volume of Un - saturated zone available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of surplus water available for recharge (MCM)	Type & No. of Artificial Recharge Structures Feasible	Unit Cost (Rs. in lakh)	Total cost (Unit Cost *Number) **(Rs.in crore)**
1	Gaya	4985.86	7.0	115	431.2	43.12	14.18	P- 47 NB- 284 RS- 118	P- 27.0 NB- 3.0 RS- 3.5	P- 12.69 NB- 8.52 RS- 4.13
2	Jamui	3098.26	9.16	645.3	3975	119.25	68.96	P- 230 NB- 1379	P-27.0 NB- 3.0	P- 62.10 NB-41.37
	Total									128.81

8.2.6 ROOF TOP RAIN WATER HARVESTING

It has been assessed that roof top rainwater harvesting can be adopted in 1,00,000 houses, govt buildings, institutes etc. in urban and municipal area of the state suitable for artificial recharge in the first phase. It will harness 23.13 MCM rain water to augment groundwater resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a buildings having roof and paved areas of ~ 200 sq.m has been assessed to be Rs. 12,000/- and for bigger building having more than 1000 sq.m will be Rs. 1,00,000/-. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 164 crore in the first phase considering 5% of the total buildings having larger roofs.

8.2.7 TOTAL COST

Total cost of the artificial recharge schemes and roof top rain water harvesting is Rs. 292.81 crores (approx) for the State of Bihar. Due to deficit rainfall during the last two years in the state of Bihar drying of phreatic aquifers up to 6-9 m has been reported from the several parts of seventeen districts falling in south Bihar plain. In these areas revival of traditional water conservation structures (ahar-pyne system) would help facilitate indirect recharge of phreatic aquifers.

8.3 CHHATTISGARH

Chhattisgarh, the newly formed State of India after bifurcation of Madhya Pradesh on 1st November, 2000, covers an area of 1,36,034 Sq. km. The population of the state is 25.54 million (Census 2011) with density of population being 189 per sq.km. The average annual rainfall of the state is 1356 mm. The state has 3 administrative divisions, 18 districts and 146 development blocks. There are 19,744 populated villages and 8 major cities in the state. About 59,285.27 sq.km. area of the state is covered by forests. The agricultural land and irrigated land in the state is 5.8 million ha and 1.21 million ha respectively. The state comprises Mahanadi and Godavari basins with small parts of Ganga, Narmada and Swarnarekha basins. These basins can be subdivided into 74 major watersheds 8 watersheds of Son and Narmada falls partly in the adjoining Madhya Pradesh state.

8.3.1 IDENTIFICATION OF THE AREA

Based on data of National Hydrograph Stations established by CGWB, a trend analysis was carried out for the decade between 2000 and 2009. A total area of 22,401.40 sq.km. shows declining trend in ground water levels. 39 major watersheds have been identified in Chhattisgarh in which declining trend of more than 0.1 m/yr was recorded (Fig-8.3.1). These watersheds have been identified for construction of suitable artificial recharge structures for augmenting the available ground water resources.

8.3.2 SUB-SURFACE STORAGE SPACE AND WATER REQUIREMENT

To estimate the sub surface storage space available, a map was prepared on the basis of average post monsoon depth to water level for period 2000-2009. The decadal post monsoon average depth to water level is predominantly in the range of 3 to 6 m below ground level. Based on this map the volume of unsaturated zone available for recharge (Vadose zone to 3 m below ground level) was calculated for each of the 39 identified watersheds. A total 85343.578 MCM volume of unsaturated zone was estimated for the Chhattisgarh state. The requirement of water to fully saturate the vadose zone up to 3 m below ground level was worked out for each watershed at 75% efficiency considered for recharge structures. The total requirement of water for creating the sub-surface storage works out to 2902.72 MCM for the entire state.

8.3.3 SOURCE WATER AVAILABILITY

The availability of surplus monsoon runoff was estimated for 39 identified watersheds mainly on the basis of NWDA data and State Irrigation Department. The total availability of source water for recharge works out to 37,783.48 MCM, which far exceeds the total requirement to create the sub-surface storage. However, for each watershed the requirement vis-a-vis the availability was seen and the least of the two was considered as available source water for harnessing in artificial recharge structures. The total quantum of source water which can be utilized for creation of sub-surface storage works out to 2902.72 MCM for all the 39 identified watersheds (table 8.3.1).

8.3.4 RECHARGE STRUCTURES AND COST ESTIMATES

The suitable artificial recharge structures in the state are gully plugs, gabion structures, contour bunds in the upper reaches of the watersheds, percolation tanks, nala bunds in the runoff zones and recharge shafts, gravity head wells in downstream areas. The main artificial recharge structures proposed are given below along with the estimated number of feasible structures and their cost.

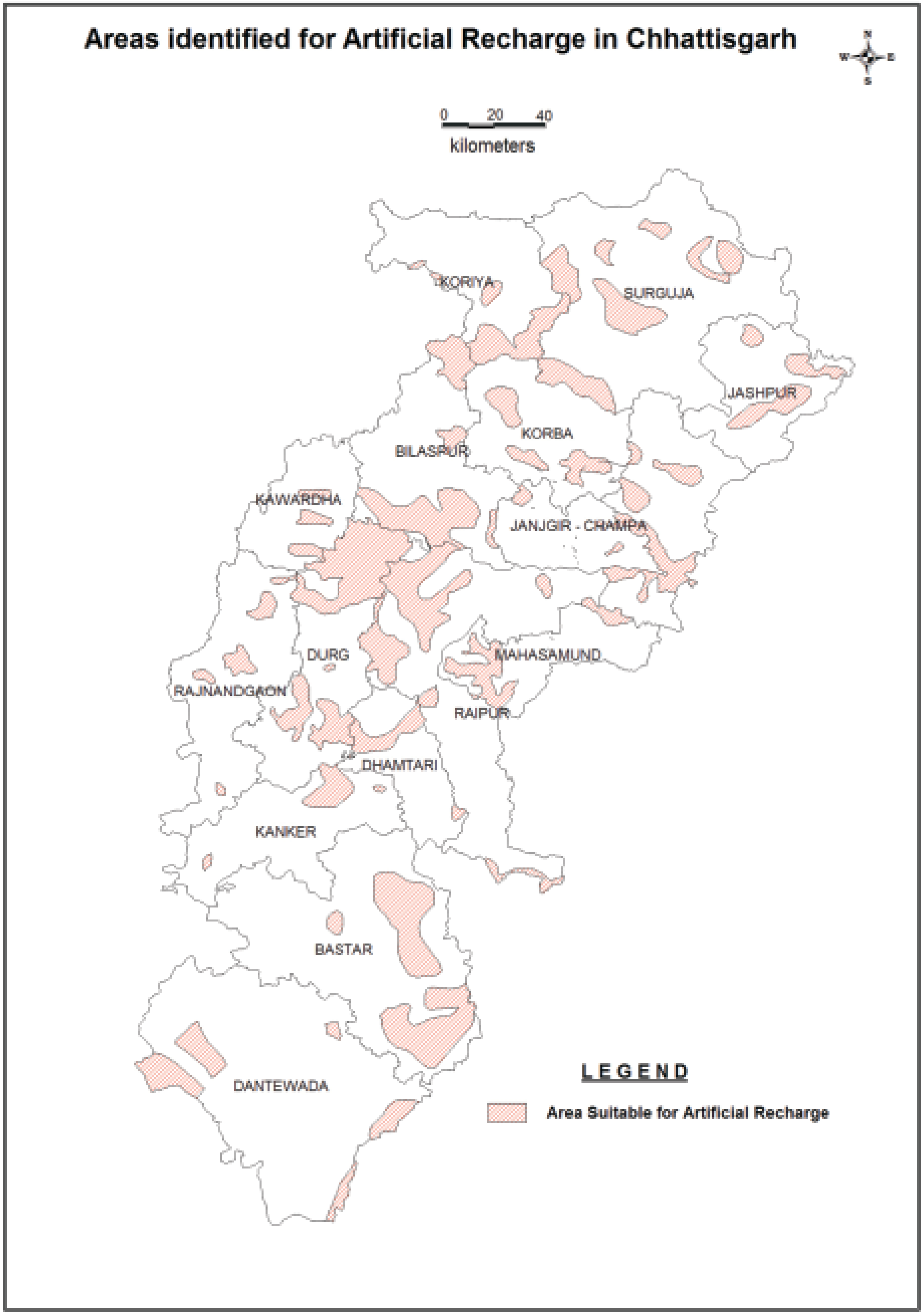


Fig. 8.3.1 Areas identified for Artificial Recharge in Chhattisgarh

a) Percolation Tanks

Percolation tank is the main artificial recharge structure proposed for effective utilization of the surplus monsoon runoff. In hard rock areas only 50% of the total estimated surplus surface water resources have been considered for storage in the percolation tanks. As per the hydrogeological conditions in Chhattisgarh an average percolation tank has filling capacity of 0.1525 MCM. It can actually store 200% of its capacity due to multiple filling during the monsoon. Thus an average gross storage capacity of 0.305 MCM has been considered. The average cost of such structure has been considered as Rs. 20 lakh. The number of feasible percolation tank in each identified watershed has been calculated and presented in table 8.3.1. The total percolation tanks feasible in Chhattisgarh are 4729 costing Rs. 945.8 crore.

b) Nala Bunds

There is a large scope for constructing nala bunds/cement plugs in various second order streams of the state. About 25% of surplus monsoon runoff can be utilized by recharge through these structures. The average capacity of nala bunds/cement plugs has been considered as 0.45759 MCM. The average cost of each structure has been taken as Rs.1 lakh. It is estimated that 15,862 nala bund/ cement plugs can be constructed in the state at the cost of 158.6 crore (table 8.3.1).

c) Recharge Shafts & Gravity Head Recharge Wells

These structures are feasible in villages and urban pockets. About 10% of the surplus monsoon runoff can be utilized through these structures. The average recharge capacity through recharge shafts, gravity head recharge through dug wells during an operational period of 60 days in monsoon and post monsoon period is considered as 0.01525 MCM. The average cost of structure may be taken as Rs.2.5 lakhs. The number of structures and their cost for each identified watershed is calculated and presented in table 8.3.1. For the entire State the feasible structures are 28,549 costing Rs.713.725 crore.

d) Gully Plugs, Contour Bunds, Gabion Structures

These are mainly soil conserving structures to increase the soil moisture with limited recharge to ground water. It is estimated that 15% of total water available for recharge can be utilized through these structures, which have an average storage capacity of 0.007626MCM. The average cost of each structure is taken as Rs 10,000/-. The structures feasible in each identified watershed has been estimated and presented in table 8.3.1. For the entire State the feasible structures will total up to 38,062 costing Rs 38.062 crore.

8.3.5 ROOF TOP RAIN WATER HARVESTING:

It has been assessed that roof top rainwater harvesting can be adopted in ~2,00,000 houses, govt buildings, institutes etc. in urban and municipal area of the state suitable for artificial recharge in the first phase. It will harness 52.07 MCM rain water to augment groundwater resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a building having roof and paved areas of ~ 200 sq.m has been assessed to be Rs. 11,000/- and for bigger building having more than 1000 sq.m will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 309 crores in the first phase considering 5% of the total buildings having larger roofs.

8.3.6 COST ESTIMATES AND BENEFITS

The main artificial recharge structure in the 39 identified watershed are percolation tanks, nala bund/ cement plugs, recharge shaft / gravity head recharge wells and water conservation structures like gully plug, contour bund and gabion structures. The total cost of these artificial recharge structures works out to Rs 1856.21crore. For urban areas, the roof top rainwater harvesting will have a total cost of Rs. 309.0 crore. The total cost estimations of the proposed Master Plan are Rs. 2165.21crore (Say 2165 crores).

The benefits from the proposed plan would be in terms of creation of additional irrigation potential in rural areas and supplementing drinking water needs in urban areas. An additional irrigation potential of 2,06,188.76 ha would be created.

Table 8.3.1 District-wise details of Artificial Recharge Structures in Chhattisgarh

S.No.	District name	Area of district (sq.km)	Average post monsoon depth to water (mbgl)	Area feasible for artificial recharge (sq.km)	Volume of unsaturated zone available for recharge (MCM)	Volume of sub surface potential to be recharged (MCM)	Surface Water Require ment (MCM)	Volume of non commit ted surplus run off available for recharge (MCM)	Type of Structure	Types of artificial recharge structures feasible and their numbers	Unit cost (Rs in crores)	Total costs (unit cost x number) (Rs in crores)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	Bastar	11018	6.03	3210.96	14912.38	594.8452	594.8452	5000.93	P	976	0.2	195.20
									NB & CD	3252	0.01	32.52
									RS	5853	0.025	146.325
									G	7803	0.001	7.803
2	Bijapur	8889	4.5	1133	2590.75	103.4408	103.4408	1913.09	P	169	0.2	33.8
									NB & CD	565	0.01	5.65
									RS	1017	0.025	25.425
									G	1356	0.001	1.356
3	Bilaspur	7476	5.78	1927.09	8173.863	217.4284	217.4284	1854.1	P	356	0.2	71.2
									NB & CD	1188	0.01	11.88
									RS	2139	0.025	53.475
									G	2851	0.001	2.851
4	Dantewara	8301	4.5	589	1348.1	52.7345	52.7345	3719.07	P	59	0.2	11.8
									NB & CD	294	0.01	2.94
									RS	529	0.025	13.225
									G	705	0.001	0.705
5	Dhamtari	3414	6.18	643.52	3125.091	87.57984	87.57984	1005.27	P	144	0.2	28.8
									NB & CD	479	0.01	4.79
									RS	862	0.025	21.55
									G	1149	0.001	1.149

1	2	3	4	5	6	7	8	9	10	11	12	13
6	Durg	8708	5.14	3191	10405.84	270.7511	270.7511	1996.25	P	444	0.2	88.8
									NB & CD	1480	0.01	14.8
									RS	2663	0.025	66.575
									G	3551	0.001	3.551
7	Janjgir-Champa	4155	4.5	124	283.65	10.74973	10.74973	1196.99	P	18	0.2	3.6
									NB & CD	59	0.01	0.59
									RS	106	0.025	2.65
									G	141	0.001	0.141
8	Jashpur	6710	5.08	627	1987.838	76.01881	76.01881	1792.44	P	125	0.2	25.0
									NB & CD	415	0.01	4.15
									RS	748	0.025	18.7
									G	997	0.001	0.997
9	Kanker	7238	7.07	548	2399.225	129.1792	129.1792	2588.92	P	212	0.2	42.4
									NB & CD	706	0.01	7.06
									RS	1271	0.025	31.775
									G	1694	0.001	1.694
10	Kawardha	3416	4.61	220	539.85	19.75516	19.75516	501.67	P	32	0.2	6.40
									NB & CD	108	0.01	1.08
									RS	194	0.025	4.85
									G	259	0.001	0.259
11	Korba	7090	5.24	880	3005.775	115.6103	115.6103	1424.92	P	190	0.2	38.00
									NB & CD	632	0.01	6.32
									RS	1137	0.025	28.425
									G	1516	0.001	1.516
12	Koriya	5314	5.66	1165	4728.263	166.1745	166.1745	1377.93	P	272	0.2	54.4
									NB & CD	908	0.01	9.08
									RS	1635	0.025	40.875
									G	2179	0.001	2.179

1	2	3	4	5	6	7	8	9	10	11	12	13
13	Narayanpur	3619	7.5	42	97.6	4.0565	4.0565	91.00	P	6	0.2	1.2
									NB & CD	21	0.01	0.21
									RS	38	0.025	0.95
									G	51	0.001	0.051
14	Mahasamund	5154	4.5	1041	2381.228	87.33645	87.33645	1749.02	P	143	0.2	28.6
									NB & CD	477	0.01	4.77
									RS	859	0.025	21.475
									G	1145	0.001	1.145
15	Raigarh	6275	6.17	1510	7301.70	246.98	246.98	1877.93	P	405	0.2	81.00
									NB & CD	1350	0.01	13.50
									RS	2429	0.025	60.725
									G	3239	0.001	3.239
16	Raipur	12707	6.56	2333	12675.04	396.1172	396.1172	4273.39	P	649	0.2	129.80
									NB & CD	2165	0.01	21.65
									RS	3896	0.025	97.4
									G	5195	0.001	5.195
17	Rajnandgaon	8631	4.87	571	1626.413	59.91451	59.91451	1241.15	P	98	0.2	19.6
									NB & CD	327	0.01	3.27
									RS	589	0.025	14.725
									G	786	0.001	0.786
18	Sarguja	16885	4.68	2645.82	6730.615	262.7192	262.7192	4179.41	P	431	0.2	86.2
									NB & CD	1436	0.01	14.36
									RS	2584	0.025	64.6
									G	3445	0.001	3.445
State Total		**136034**		**22401.4**	**85343.575**	**2902.721**	**2902.721**	**37783.48**		**87202**		**1856.206**

8.4 DELHI (NATIONAL CAPITAL TERRITORY)

National Capital Territory, Delhi occupies an area of 1483 sq. km. Out of this about 145 sq. km is the ridge area comprising of weathered quartzite rock. The present population of Delhi is about 125 lakhs. Administratively, the state has 6 blocks namely Alipur block, City block, Mehrauli Block, Najafgarh block, Kanjhawala block & Shahdara block. In Alipur block, Kanjhawala block, Najafgarh block & part of Mehrauli block the area is cultivable. Due to increase in population, the water demand is increasing and ground water is also used for irrigating the cultivable land. Due to over-exploitation of groundwater resources the ground water levels have been declining especially in southern and south western parts of the State.

8.4.1 IDENTIFICATION OF AREA

Feasible areas for artificial recharge to ground water have been identified on the basis of depth to water level (> 3 m.bgl) areas showing declining trend of water level and having surplus surface water availability. The area identified for artificial recharge to ground water is 699.86 sq. km in NCT Delhi (Fig-8.4.1).

8.4.2 SOURCE WATER AVAILABILITY

The average annual rainfall of the state is 611.8 mm, of which 533.1 mm occurs during monsoon period (June to September). Delhi mostly being urban area, 142 sq.km of roof area, 69 sq.km of paved area and balance 485 sq.km is open area. Considering 80 % runoff coefficient for roof area, 60% for paved area and 30 % for open, the runoff availability for Delhi state is assessed as 175 MCM. The surplus monsoon runoff available from Yamuna is 282 MCM. Thus a total of 457 MCM surplus runoff is available for recharge to ground water. As the areas proposed for recharge are at higher elevations, the surplus water of Yamuna River cannot be diverted under gravity to these areas. Hence only the available surface runoff from the recharge areas i.e. 175 MCM out of which 52 MCM is estimated to be utilized by existing structures and balance 123 MCM is available for recharge in feasible area. Out of this only 20% i.e. 24.39 MCM may be utilized for recharge to ground water as most area is urban and entire rainwater cannot be harvested due to outflow into sewers and other losses.

8.4.3 RECHARGE STRUCTURES

In order to harness the net available runoff, two types of structures are considered i.e recharge shaft with injection well in urban area and check dams in ridge area. The artificial recharge structures are given in table-8.4.1 along with cost estimates. Total number of feasible structures are 17,850 recharge shaft with injection well and 8 number of check dams costing Rs. 892.90 crore.

8.4.4 ROOF TOP RAIN WATER HARVESTING

It has been assessed that roof top rainwater harvesting can be adopted in 1.25 lakh houses, govt buildings, institutes etc. in urban and municipal area of the state suitable for artificial recharge in the first phase. It will harness 14.69 MCM rain water to augment groundwater resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a buildings having roof and paved areas of ~ 200 sq.m has been assessed to be Rs. 12,000/- and for bigger building having more than 1000 sq.m will be Rs. 1 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 205 crore in the first phase considering 5% of the total buildings having larger roofs.

8.4.5 TOTAL COST

The total cost of Artificial Recharge Structures and Roof Top Rain Water Harvesting in NCT Delhi is estimated to be Rs. 1097.90 crores.

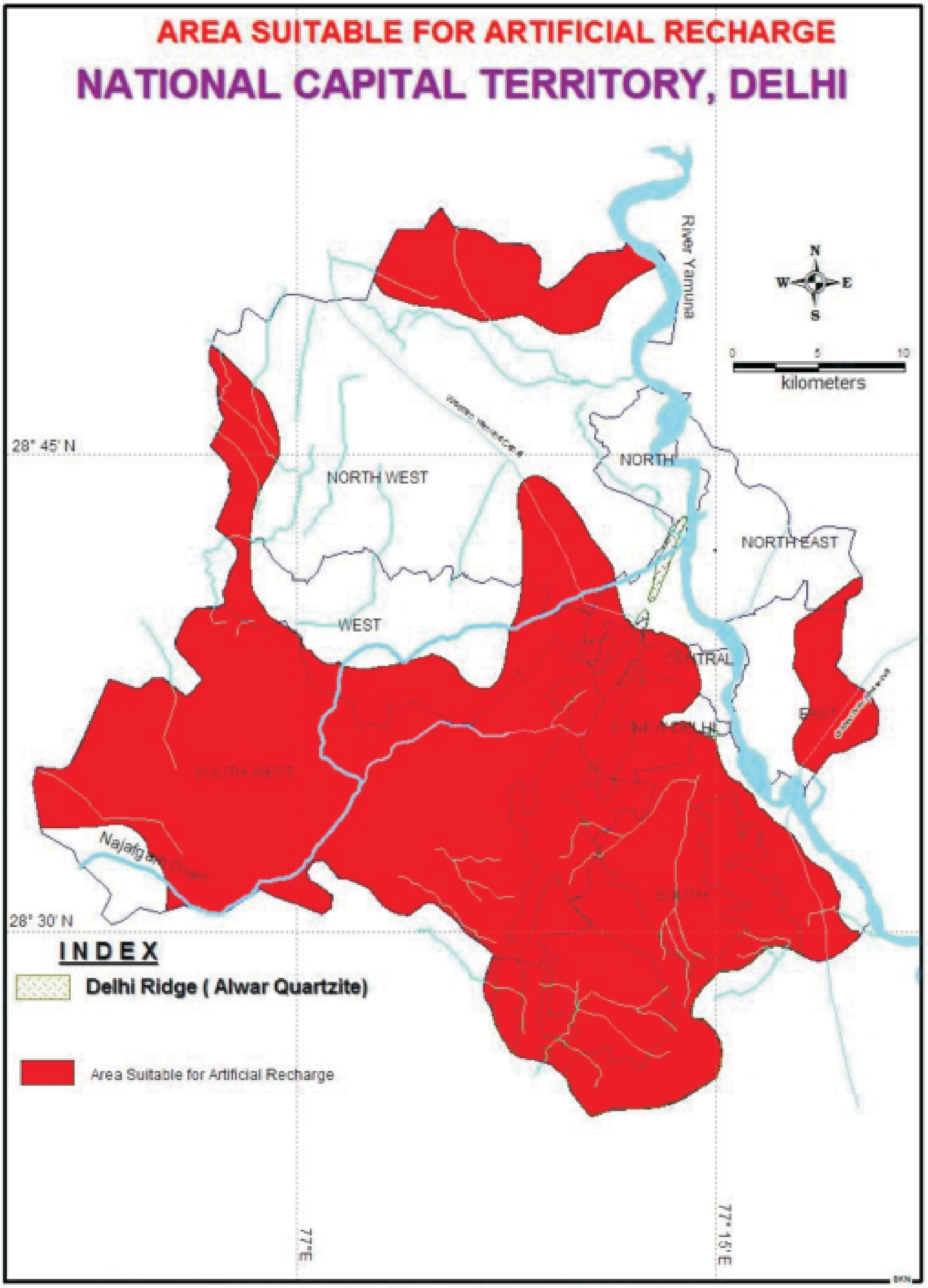


Fig. 8.4.1 Areas suitable for Artificial Recharge in Delhi

Table 8.4.1 District-wise details of Artificial Recharge Structures in Delhi

S. No.	District name	Area of district (sq.km)	Average post mon-soon depth to water (bgl)	Area feasible for artificial recharge (sq.km)	Volume of unsaturated zone available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of surplus local/distant source available for recharge (MCM)	Types of artificial recharge structures feasible* and their numbers	Unit cost (Rs. in crore)	Total costs (unit cost x number) (Rs. in crore)
1	Central	25	8	17.26	86.3	7.14	0.851	RSwith I -700 CD -1	0.05 0.05	35.05
2	East	64	7	51.28	205.12	23.44	1.71	RSwith I -1500	0.05	75
3	North	60	6	12.03	36.09	3.1	0.38	RSwith I -300	0.05	15
4	New Delhi	35	12	34.09	306.81	26.09	0.708	RSwith I -620 CD -1	0.05 0.05	31.05
5	North East	60	6	12.84	38.52	4.4	0.479	RSwith I -430	0.05	21.5
6	North West	440	10	155.46	1088.22	124.37	5.147	RS with I -4500	0.05	225
7	South	250	30	170.75	4610.25	240.95	5.6	RS with I -3000 CD -3	0.05 0.05	150.15
8	South West	420	20	165.69	2816.73	315.29	6.348	RS with I -4000 CD -3	0.05 0.05	200.15
9	West	129	15	80.46	965.52	109.05	3.17	RS with I-2800	0.05	140
State Total		**1483**		**699.86**	**10153.56**	**853.83**	**24.393**	**RS with I-17850 CD -8**		**892.90**

RS with I : Recharge Shaft with Injection well CD : Check dam

8.5 GOA

Goa state is situated in West Coast of India having geographical area of 3702 sq km. It is divided into two districts and 11 Taluks. Out of the total area, 218 sq km falls in command where as 1561 falls in non command area. 430 sq km falls in poor ground water quality area. The state receives more than 3000 mm of annual rainfall. Though the state is rich in water resources, hydrogeological and physiographical conditions in the state do not permit large scale surface and ground water storage. There is surface run off due to steep gradient. Ground water gets discharged quickly due to steep hydraulic gradient and porous nature of lateritic aquifers. Hence wells dry up fast during summer months resulting in water scarcity.

8.5.1 IDENTIFICATION OF FEASIBLE AREAS

Feasible areas for artificial recharge to groundwater have been identified on the basis of depth to water level areas showing declining trend in water level and having surplus water availability. The area identified for artificial recharge to ground water is 2027.30 sq.kms.

8.5.2 SOURCE WATER AVAILIBILITY

Base flow occurs during the non-monsoon period. The decline of water level can be reduced by arresting base flow by suitable water conservation and artificial recharge structures. This also helps to recharge the aquifer system during summer months thereby to sustain the ground water abstraction structures. Annual surface run off in the state is 8811 MCM. A part of this run off is being harnessed through major and medium irrigation projects and the rest goes to sea as non-committed run off. The non monsoon surplus runoff available in the state is 528.69 MCM/annum. Taluk-wise surplus water resource available, number of recharge structures feasible is given in Table 8.5.1.and area suitable for artificial recharge in Goa state is indicated in Fig.8.5.1.

Table -8.5.1 District wise details of Artificial Recharge Structures in Goa

Sl. No.	Name of the district	Area of District (sq.km.)	Average Post Monsoon Depth to Water Level (mbgl)	Area feasible for Artificial Recharge (sq.km.)	Volume of unsaturated zone available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of surplus water available for recharge (MCM)	Unit and Total Cost of Recharge Structures in crores	
								Vented Dam (Number)	Vented Dam @ Rs. 0.06 crore
1	North Goa	1755.9	7.0	1154.39	8080.73	622.03	259.24	764	45.84
2	South Goa	1946.08	7.0	872.91	6110.37	243.8	269.45	629	37.74
	Total	**3701.98**		**2027.30**	**14191.10**	**865.83**	**528.69**	**1393**	**83.58**

8.5.3 RECHARGE STRUCTURES AND COST ESTIMATES

Bhandaras and vented dams are suitable structures in the state. These structures will allow the run off to go away during heavy rainfall and arrest non monsoon run off. These structures can be taken up leaving the coastal plains of the state where water table is shallow.

Cost estimates for bhandaras/vented dams are as follows:

Water available for conservation	: 528.69 MCM
Water which can be conserved per structure	: 0.38 MCM
No. of feasible structures	: 1393
Unit cost per structure	: Rs.6 lakhs
Total cost	: Rs.83.58 crore

8.5.4 ROOF TOP RAIN WATER HARVESTING

It has been assessed that roof top rainwater harvesting can be adopted in 10,000 houses, govt buildings, institutes etc. in urban and municipal area of the state suitable for artificial recharge in the first phase. It will harness 5.76 MCM rain water to augment groundwater resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a buildings having roof and paved areas of ~ 200 sq.m has been assessed to be Rs. 12,000/- and for bigger building having more than 1000 sq.m will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 16.40 crore in the first phase considering 5% of the total buildings having larger roofs.

8.5.5 TOTAL COST

A total of Rs. 99.98 crores is estimated for ground water conservation and rain water harvesting in the state of Goa.

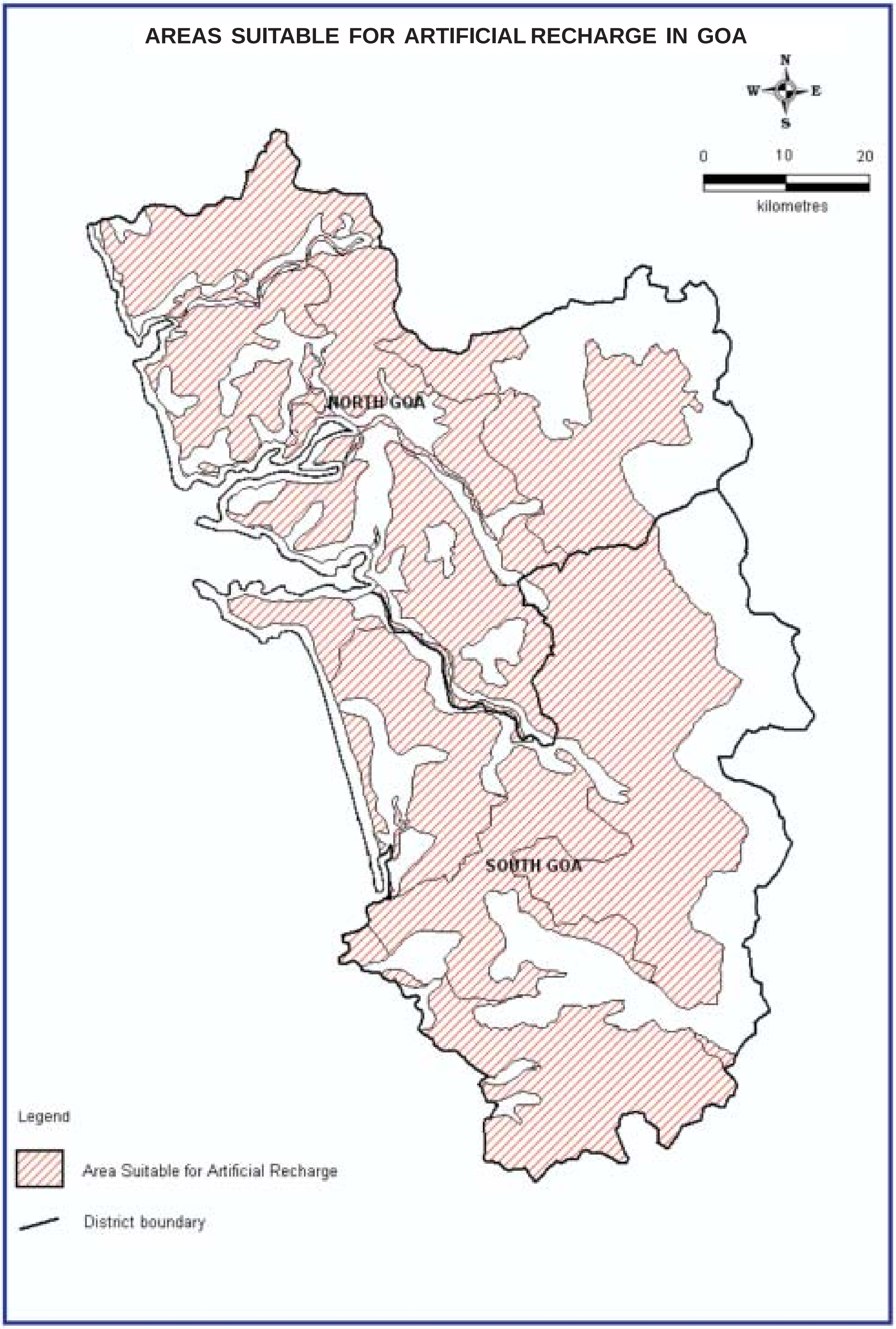


Fig. 8.5.1 Areas Suitable for Artificial Recharge in Goa

8.6 GUJARAT

The State of Gujarat has a geographical area of 1,96,024 Sq.Km. with the longest coastline of 1600 km. There are 18,066 villages and 242 towns with a population of 6.03 crore (2011 census). The droughts are frequent in major part of Gujarat. The annual rainfall shows steep reduction from 2000 mm in extreme south (Dangs and Valsad districts) to 300 mm in Kutch district. Gujarat has three distinct physiographic areas namely main land Gujarat, Saurashtra and Kutch regions. Gujarat is covered by number of large and small river basins having varied nature. These basins represent varied and complex hydrogeological, agro-climatic and hydrological features.

8.6.1 IDENTIFICATION OF AREA

Various water bearing geological formations occurring in the State have been categorized broadly in three hydrogeological units, namely, unconsolidated alluvial deposits, consolidated rock units of igneous and meta sediments and semi consolidated units of other sedimentary rocks. The thickness of available unsaturated zone (below 6 m bgl) is computed on basis of Post monsoon (2000-09) decadal average depth to water level map and decadal water level trend map of Gujarat State. Based on the decadal average depth to water level of post monsoon period (2000-09) data and long term trend of ground water level (2000-09) four categories were identified as follows.

(i) Area showing declining trend > 0.10 m / year and water level between 6-9 m bgl.

(ii) Area showing declining trend 0 to 0.10 m / year and water level between 6 -9 m bgl.

(iii) Area showing declining trend > 0.10 m / year and water level between > 9 m bgl.

(iv) Area showing declining trend 0 to 0.10 m / year and water level between > 9 m bgl.

Table – 8.6.1- Computation of area feasible for Artificial Recharge in Gujarat

S. No.	District	Area: (DTW >9m; Trend 0 to 10 cm /year) (sq. km.)	Area: (DTW > 9m ; Trend > 10 cm / year) (sq. km.)	Area: (DTW < 9m; Trend 0 to 10 cm / year) (sq. km.)	Area: (DTW < 9m; Trend > 10 cm / year) (sq. km.)	Area feasible for artificial recharge (sq. km.)
1	Kutch	4822	1258	133		6213
2	Patan		1241	221		1462
3	Sabarkantha	89	56			145
4	Banaskantha	2608	4126	95		6829
5	Mahesana	252	363		346	961
6	Gandhinagar	468	27	218		713
7	Ahmedabad	1142	42	29	438	1651
8	Surendranagar	581		398		979
9	Bhavnagar			267		267
10	Amreli	23		71		94
11	Rajkot	51		42		93
	Total					**19407**

A total of 19,407 sq. km area spread over eleven district having water level & trend as above is computed (Table 8.6.1) and same is depicted as suitable areas for artificial recharge (Fig 8.6.1).

8.6.2 SUB-SURFACE STORAGE SPACE AND WATER REQUIREMENT

Further, while calculating the total volume of unsaturated zone available for recharge, clay & massive non porous intervening zones have been deleted from the total thickness of potential zone for recharge. Average specific yield data of above formations, as per norm of GEC, 1997 were considered to compute volume of water required for recharge to saturate dry zones. Storage space volume available in aquifers is 109,668 MCM. On the basis of specific yield factor of major aquifer system considered in 'Ground Water Resources Estimate – 2009, the volume of water required for artificial recharge to fully saturate aquifer in each district areas is around 10,708 MCM (Table 8.6.2 &8.6.3)

Table: 8.6.2 - Computation of volume of unsaturated zone available for recharge, Gujarat

S. No.	District	Volume : (DTW > 9 m ; Trend 0 to 10 cm /year) (MCM)	Volume : (DTW > 9 m ; Trend > 10 cm / year) (MCM)	Volume : (DTW < 9 m ; Trend 0 to 10 cm / year) (MCM)	Volume : (DTW < 9 m ; Trend > 10 cm / year) (MCM)	Volume of unsaturated zone available for artificial recharge (MCM)
	Average depth unsaturated below 6 m bgl (Excluding clay & impervious hard zones)	6 m	6 m	3 m	3 m	
1	Kutch	28932	7548	399	0	36879
2	Patan	0	7446	663	0	8109
3	Sabarkantha	534	336	0	0	870
4	Banaskantha	15648	24756	285	0	40689
5	Mahesana	1512	2178	0	1038	4728
6	Gandhinagar	2808	162	654	0	3624
7	Ahmedabad	6852	252	87	1314	8505
8	Surendranagar	3486	0	1194	0	4680
9	Bhavnagar	0	0	801	0	801
10	Amreli	138	0	213	0	351
11	Rajkot	306	0	126	0	432
	Total					**109668**

Table 8.6.3: Computation of volume of water required for recharge in Gujarat

S. No.	District	Volume of unsaturated zone available for artificial recharge (MCM)	Specific yield factor	Volume of water required for recharge (MCM)
1	Kutch	36879	0.08	2950
2	Patan	8109	0.1	811
3	Sabarkantha	870	0.08	70
4	Banaskantha	40689	0.1	4069
5	Mahesana	4728	0.12	567
6	Gandhinagar	3624	0.15	544
7	Ahmedabad	8505	0.15	1276
8	Surendranagar	4680	0.08	374
9	Bhavnagar	801	0.03	24
10	Amreli	351	0.03	11
11	Rajkot	432	0.03	13
	Total	**109668**		**10708**

8.6.3 SOURCE WATER AVAILABILITY

The availability of source water, one of the prime requisites of artificial recharge has been worked out based on basin approach by the Ground Water Department of Gujarat State. Considering monsoon rainfall as main source of water, basin wise source water availability is computed. Broadly, the data of each basin takes in to account of committed runoff, provision for future planning and surplus water available. The quantity considered available for artificial recharge includes provisions for future planning with surplus water available. This availability so worked out is for entire basin has been further redistributed on prorata basis for different districts for planning of Artificial Recharge. The Gujarat Government is planning to take-up ambitious project of Kalpasar in the Gulf of Cambay by creating a fresh water reservoir by conserving fresh water of Sabarmati, Mahi, Dadhar, and Narmada rivers of mainland Gujarat and other minor rivers of Saurashtra Region flowing into Gulf of Cambay. The surplus water of all these rivers is accounted for Kalpasar Project and therefore, different district covered by these river basins are not considered in present proposal of artificial recharge. The total surplus water available for planning of artificial recharge in the state is 2058 MCM/yr. (Table 8.6.4.). Taking in to consideration of various types of artificial recharge structures constructed up to year 2008 & the quantity of surplus runoff accounted for artificial recharge through these structures, the balance volume of surplus available is 1483.54 MCM (table 8.6.4).

Table 8.6.4- District-wise Artificial Recharge Structures considered for Ground Water Estimation, 2009 in Gujarat

S. No.	District Name	Tanks as on 2008	Percola tion Tanks as on 2008	Check Dams as on 2008	Total Quantity of Recharge due to all AR structure 2009	Volume of surplus local / distant source available for recharge (MCM)	Balance Volume of surplus local / distant source available for recharge (MCM)
1	Ahmedabad	211	261	546	7.67	101.19	93.52
2	Amreli	549	488	7215	70.18	122.53	52.35
3	Anand	461	13	136	3.76	-	-
4	Banaskantha	697	292	1401	21.29	240.33	219.04
5	Bharuch	59	53	410	4.81	-	-
6	Bhavnagar	639	920	13389	131.74	133.07	1.33
7	Dahod	603	98	3745	36.47	-	-
8	Dangs	0	0	823	37.24	-	-
9	Gandhinagar	181	16	110	2.62	14.79	12.17
10	Jamnagar	595	864	6374	66.02	263.72	197.70
11	Junagadh	824	377	8867	85.00	143.91	58.91
12	Kutch	377	650	2488	29.30	292.35	263.05
13	Kheda	778	20	406	7.86	-	-
14	Mahesana	462	180	387	9.60	103.00	93.40
15	Narmada	26	0	357	3.00	-	-
16	Navsari	276	0	227	3.51	-	-
17	Panchamahals	1219	98	5173	51.73	-	-
18	Patan	78	92	310	5.28	162.00	156.72
19	Porbandar	100	199	307	4.89	37.02	32.13
20	Rajkot	860	1290	13037	129.87	247.74	117.87
21	Sabarkantha	1089	708	5514	38.42	-	-
22	Surat	314	1	254	4.00	-	-
23	Surendranagar	145	629	549	11.00	196.35	185.35
24	Tapi	122	7	251	2.57	-	-
25	Vadodara	612	551	1475	21.56	-	-
26	Valsad	304	20	1837	17.68	-	-
	Total	**11581**	**7827**	**75588**	**807.07**	**2058.00**	**1483.54**

8.6.4 RECHARGE STRUCTURES AND COST ESTIMATES

In hard rock areas with moderate relief, weirs/check dams are considered feasible, whereas, in plateau and plain areas occupied by hard rock, percolation tanks are considered appropriate. In semi-consolidated formation weirs/check dams are considered feasible. In the areas occupied by alluvium percolation tanks are considered appropriate. A percolation tank generally has a capacity of 0.09 MCM and receives three fillings in two years, hence, on an average 1.5 times capacity utilization (0.140 MCM) has been considered on an annual basis. A weir/check dam of 0.017 MCM capacities will actually store 300% of its capacity due to multiple filling. Thus gross storage capacity of weir/check dam has been considered as 0.05 MCM/ yr. Taking into consideration of existing artificial recharge structures suitable in the district area, it is worked out that additional 1800 percolation tanks and 16,975 check dams / weirs are feasible in the State (Table 8.6.5). Based on the experience gained from recharge studies in the past, it is observed that cost of structure depends upon local situation. For the present planning average cost of structure has been adopted from the guidelines laid down by Govt. of Gujarat. A percolation tank may cost around Rs.5 Lakh. Similarly a weir/check dam may cost around Rs. 4 lakh. Thus the total cost of project is estimated to be Rs.769 crores for constructing various structures as indicated in table 8.6.5.

8.6.5 ROOF TOP RAIN WATER HARVESTING

It has been assessed that roof top rainwater harvesting can be adopted in 5 lakh houses, govt buildings, institutes etc. in urban and municipal area of the state suitable for artificial recharge in the first phase. It will harness 110.4 MCM rain water to augment groundwater resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a buildings having roof and paved areas of ~ 200 sq.m has been assessed to be Rs. 10,000/- and for bigger building having more than 1000 sq.m will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 725 crore in the first phase considering 5% of the total buildings having larger roofs.

8.6.6 TOTAL COST

The total cost of artificial recharge structures and roof top rain water harvesting is estimated as Rs. 1494 crores for the state of Gujarat.

Table – 8.6.5 District wise details of Artificial Recharge Structures in Gujarat

S.No	District Name	Area of District (sq.km)	Average post monsoon depth to water (2000-09) (mbgl	Area feasible for artificial recharge (sq km)	Volume of unsaturated zone available for recharge (MCM)	Volume of water required for recharge (MCM)	Balance Volume of surplus local / distant source available for recharge (MCM)	Additional Percolation Tank Structures Proposed Recharge capacity@0.14 MCM	Additional Check Dam / Weir Structures Proposed Recharge capacity@ 0.05 MCM	Unit Cost (Rs in crores)		Total Cost
1	Amedabad	8100	8.74	1651	8505	1276	93.52	215	1200	0.05	0.04	58.75
2	Banaskantha	10800	22.00	6829	40689	4069	219.04	250	3500	0.05	0.04	152.50
3	Bhavnagar	10000	8.31	267	801	24.03	1.33	0	25	0.05	0.04	1.00
4	Gandhinagar	2200	10.86	713	3624	544	12.17	10	200	0.05	0.04	8.50
5	Kutch	45700	12.83	6213	3679	2950	263.05	300	4000	0.05	0.04	175.00
6	Mahcsana	4400	11.16	961	4728	567	93.4	200	1200	0.05	0.04	58.00
7	Patan	5700	10.60	1462	8109	811	156.72	250	2250	0.05	0.04	102.50
8	Rajkot	11200	7.01	94	351	13	117.87	75	2000	0.05	0.04	83.75
9	Surendranagar	10500	6.79	979	4680	374	185.35	480	1700	0.05	0.04	93.00
10	Amreli	7400	10.29	93	432	11	52.35	20	900	0.05	0.04	37.00
11	Jamnagar	14100	6.89				197.7	Additional Artificial Recharge Structures are not recommended ; Most of the areas post monsoon water level are above 6 m bgl and there is rising water level trend				
12	Junagadh	8800	9.67				58.91					
13	Porbandar	2300	6.77				32.13					
14	Sabarkantha	7400	11.63	145	870	70		No surplus runoff available for AR structures.				
15	Anand	2900	9.68					Additional Artificial Recharge Structures are not recommended ; Surplus runoff is accounted for Kalpasar Project				
16	Dohad	3600	6.25									
17	Kheda	4200	7.65									
18	Panchamahal	5200	5.76									
19	Bharuch	6500	5.35		Additional Artificial Recharge Structures are not recommended ; Most of the areas post monsoon water level are above 6 m bgl and there is rising water level trend : No surplus runoff							
20	Dangs	1800	2.36									
21	Narmada	2800	9.64									
22	Navsari	2200	5.58									
23	Surat	4400	5.20									
24	Tapi	3300										
25	Vadodara	7600	8.67									
26	Valsad	3000	4.61									
	Total			**19407**	**109668**	**10708**	**1483.54**	**1800**	**16975**	**-**	**-**	**769.0**

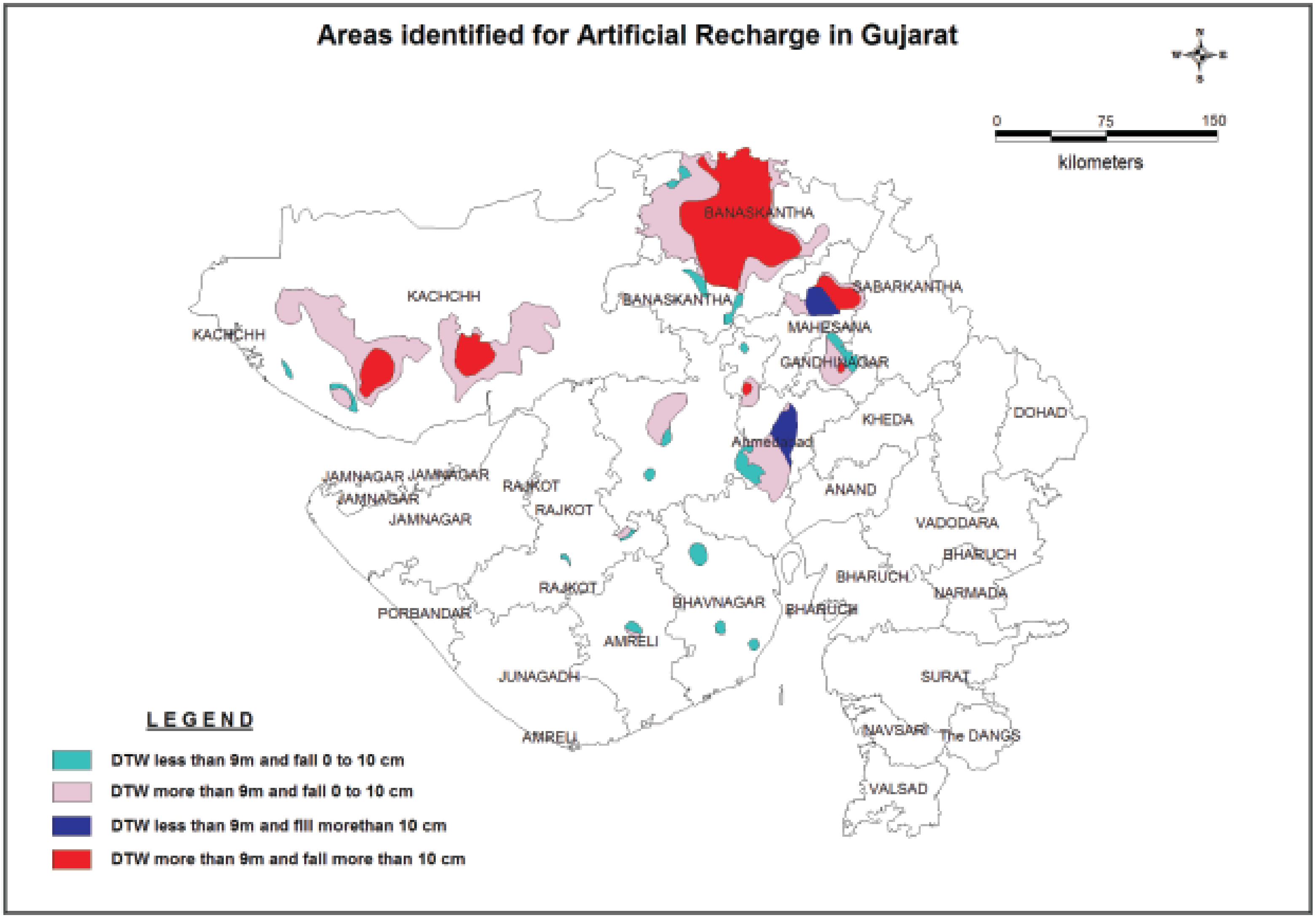


Fig. 8.6.1: Areas identified for Artifical Recharge in Gujarat

8.7 HARYANA

Haryana state is located in the north western part of India. It has an areal extent of 44,212 sq.km. and forms 1.35 % of the geographical area of the country. Around 97% of the state area is plain and known as Indo-Gangetic plain. The state forms the part of Ganga & Indus basin. The normal annual rainfall varies from more than 1000 mm in the north east to less than 300 mm in the south west. In the south western parts of the state, drought is a common feature.

In the north eastern and eastern parts of the state, fairly thick and regionally extensive confined/unconfined aquifers exist down to a depth of more than 300 m with yield prospects of about 150 m^3/hour. The alluvium down to 450 m below land surface has been explored in this part. In the south-western and the central parts of the state, moderately thick and regionally extensive confined/unconfined aquifers exist. The ground water here is generally saline at all levels except local patches. The yield prospects in this area are less than 50 m^3/hour. In the remaining areas moderately thick and regionally extensive aquifers exist and their yield prospects are 50-150 m^3/hour mainly due to limitation of depth as underlying ground water is saline. In the hard rock areas the ground water potentials are limited and there the yield prospects are 5 to 20 m^3/hour within weathered residum and fractured zones.

Ground water resources of state have been estimated as on 31.03.2009. The Net annual ground water availability of state has been assessed to be 9.80 BCM. Net annual draft of the state has been estimated to be 12.43 BCM. The average stage of ground water development in the state is 127%. Out of 117 blocks assessed, 68 fall under 'Over exploited' category, 21 in 'Critical', 9 as 'Semi Critical' and 18 as 'Safe' category. The reason for this stage of ground water development are excessive withdrawal of ground water mainly to meet growing demands of agriculture in addition to industrial and domestic needs. Thus stress is more and more on ground water. These over-exploited aquifers require augmentation for sustaining the ground water abstraction structures.

8.7.1 IDENTIFICATION OF AREA

Based on the post monsoon depth to water level and long term ground water level trends, it has been estimated that ~37,029 sq. kms area is feasible for artificial recharge. (Fig 8.7.1).

8.7.2 SUB-SURFACE STORAGE SPACE AND WATER REQUIREMENT

The total volume of unsaturated strata is calculated by considering unsaturated thickness of aquifers on block-wise basis. This volume of unsaturated aquifer is multiplied by average specific yield i.e. 12% to arrive at the quantity of water required which is to be recharged by artificial methods to saturate the aquifer up to 3 mbgl. Sub surface storage potential of the State is estimated as 54,175 MCM. District-wise break up is given in the table 8.7.1

8.7.3 SOURCE WATER AVAILABILITY

The quantity of non-committed surplus surface water in the Haryana state has been estimated to be only 679.26 MCM against the requirement of 54,175 MCM.

8.7.4 RECHARGE STRUCTURES AND COST ESTIMATES

The main recharge structures suitable in the state are recharge shaft, horizontal trench with or without injection wells and check dams. The average cost of a recharge shaft to recharge 0.015 MCM water annually will be around Rs. 2.50 lakh and of check dam to recharge 0.04 MCM annually will be around Rs. 50 lakhs in Aravali hills and Rs. 30 lakhs in Siwaliks. The total cost of 44,727 recharge structures required to recharge will be around Rs. 1255.30 crores. The district wise number of structures feasible and cost estimates is given in table 8.7.1.

8.7.5 AREA BENEFITED

It is estimated that influence of recharge schemes as proposed will be observed in about 16,000 sq km and it will not only check decline in ground water level but rise of water level up to 0.5 m per year is expected. In Haryana state almost entire cultivable area in northern and eastern parts is under irrigation by surface or ground water. The area falling in southern and south western parts have less irrigation facility. The additional recharge to ground water will bring about 1, 37,000 ha of additional area under assured irrigation.

8.7.6 ROOF TOP RAIN WATER HARVESTING

It has been assessed that roof top rainwater harvesting can be adopted in 15 lakh houses, govt buildings, institutes etc. in urban and municipal area of the state suitable for artificial recharge in the first phase. It will harness 187 MCM rain water to augment groundwater resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a buildings having roof and paved areas of ~ 200 sq.m in a cluster of 4-6 houses has been assessed to be Rs. 30,000/- and for bigger building having more than 1000 sq.m will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 1650 crore in the first phase considering 3 lakh structures for houses on cluster basis and 75,000 structures for government/institutional buildings.

8.7.7 ARTIFICIAL RECHARGE FROM SEWAGE WATER

Besides rainfall, ample scope exists to recharge treated sewage water, which is disposed away from the town without any purposeful gain. At present, in majority of the towns sewage water is subjected to primary treatment only. In certain towns, the sewage water is subjected to secondary treatment. This secondary treated water can also be used as source for artificial recharge after assessing the suitability of chemical quality. The towns where treated sewage water is available are Panipat, Karnal, Faridabad, Yamunanagar, Gurgaon, Sonepat etc. The total capacity of the plants installed for treatment in these towns is 0.325 MCM per day. Therefore, total treated water availability per year is 118.6 MCM. To recharge this water around 1000 recharge structures will be required. The total cost of these structures will be Rs 2500 lacs @ Rs 2.50 lakh per structure. Besides this, there are about 48 urban agglomerations which are located in the area suitable for artificial recharge. The total population of these towns is around 13 lakhs. The sewage generated from these towns is around 45.5 MCM annually. The sewage in these towns is subjected to primary treatment only, which is not suitable for artificial recharge. If sewage in these towns is given secondary/tertiary treatment, it may be utilized for artificial recharge in proximity of the towns.

8.7.8 TOTAL COST

The cost of taking up artificial recharge in rural and urban areas will be Rs.2930.30 crores.

Table 8.7.1 District Wise details of Artificial Recharge Structures in Haryana

S. No.	District	Area of district (sq.km)	Area feasible for artificial recharge (sq.km)	Volume of unsaturated zone available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of surplus local/ distant source available for recharge (MCM)	Types of artificial recharge structures feasible and their numbers: Type of structure	Recharge capacity	Number	Unit cost (Rs. in lakhs)	Total costs (unit cost x number) (Rs. in lakhs)
1	Ambala	1574	1199	783	1041	12.01	CD	0.04	25	30	750
							RS	0.015	734	2.5	1835
2	Bhiwani	4778	4186	9326	12404	62.46	CD	0.04	25	30	750
							RS	0.015	4097	2.5	10242.5
3	Faridabad	782	782	737	980	9.95	CD	0.04	25	50	1250
							RS	0.015	597	2.5	1492.5
4	Fatehabad	2538	2538	2975	3957	62.35	RS	0.015	4157	2.5	10392.5
5	Gurgaon	1215	1215	2572	3421	30.57	CD	0.04	50	50	2500
							RS	0.015	1905	2.5	4762.5
6	Hissar	3983	3035	1922	2556	26.32	RS	0.015	1755	2.5	4387.5
7	Jhajjar	1834	331	166	221	18.87	RS	0.015	1258	2.5	3145
8	Jind	2702	2352	1998	2657	37.82	RS	0.015	2521	2.5	6302.5
9	Kaithal	2317	2317	3550	4722	85.44	RS	0.015	5696	2.5	14240
10	Karnal	2520	2520	3140	4176	30.26	RS	0.015	2017	2.5	5042.5
11	Kuruk shetra	1530	1530	4586	6099	49.07	RS	0.015	3271	2.5	8177.5
12	Mahendra garh	1900	1900	8285	11019	68.31	CD	0.04	50	50	2500
							RS	0.015	4421	2.5	11052.5
13	Mewat	1499	820	893	1188	14	CD	0.04	25	50	1250
							RS	0.015	867	2.5	2167.5
14	Palwal	1367	1367	663	882	18.34	CD	0.04	25	50	1250
							RS	0.015	1156	2.5	2890
15	Panchkula	898	989	653	868	8.01	CD	0.04	50	30	1500
							RS	0.015	401	2.5	1002.5
16	Panipat	1268	1268	1402	1865	17.1	RS	0.015	1140	2.5	2850
17	Rewari	1595	1595	3152	4192	54.15	CD	0.04	50	50	2500
							RS	0.015	3477	2.5	8692.5
18	Rohtak	1745	0	0	0	0	0	0	0	0	0
19	Sirsa	4277	4277	4923	6548	55.11	RS	0.015	3674	2.5	9185
20	Sonipat	2122	1040	981	1305	17.22	RS	0.015	1148	2.5	2870
21	Yamuna nagar	1768	1768	1468	1952	1.9	CD	0.04	10	30	300
							RS	0.015	100	2.5	250
	Sub total	**44212**	**37029**	**54175**	**72053**	**679.26**			**44727**		**125530**

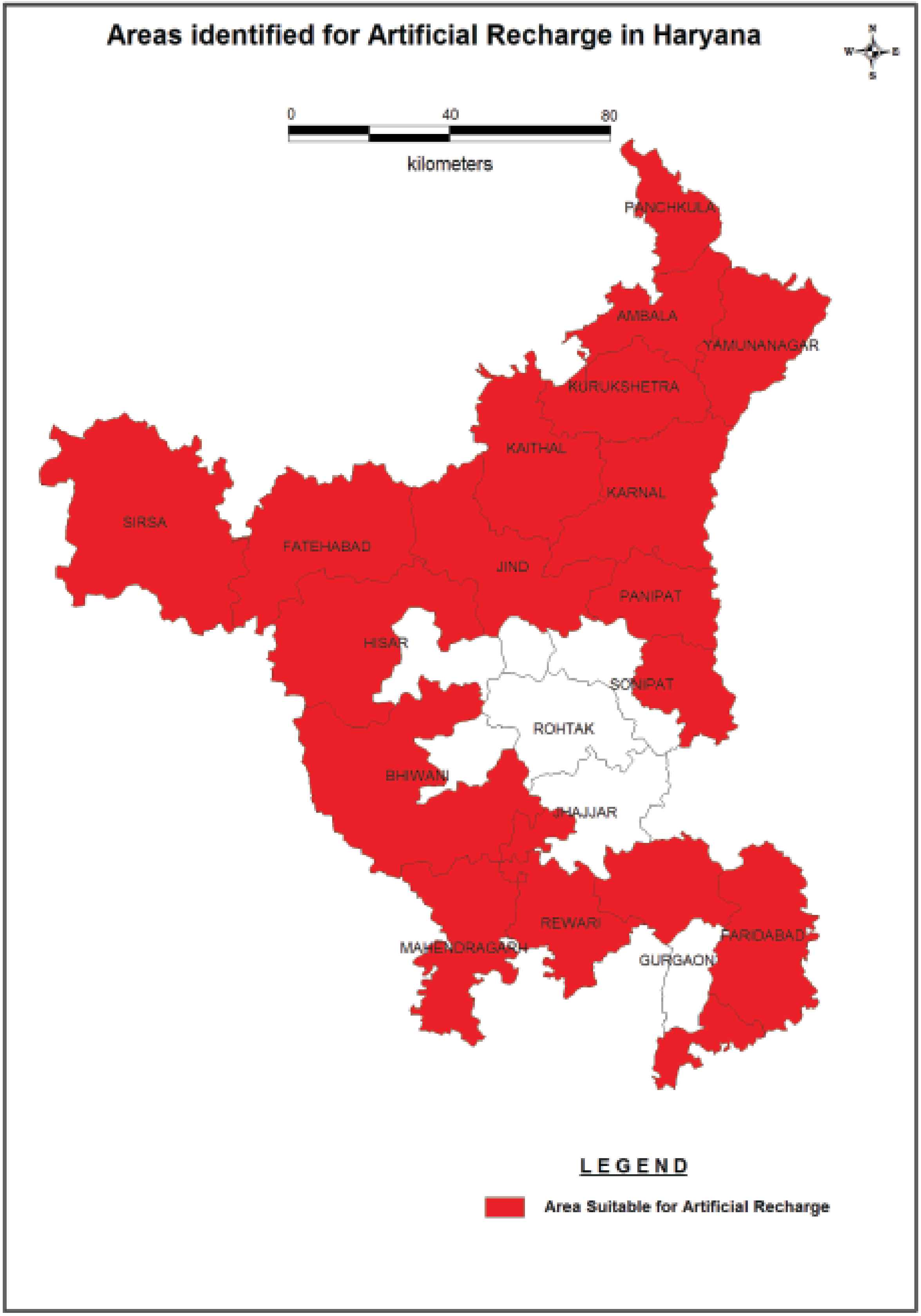


Fig.8.7.1 Areas suitable for Artificial Recharge in Haryana

8.8 HIMACHAL PRADESH

Himachal Pradesh is one of the northern most states with an area of 55,673 sq. km. The major river systems of the region are the Chandra Bhag (Chenab) the Ravi, the Beas, the Sutlej, and the Yamuna. The catchments of these rivers are fed by snow and rainfall and are protected by fairly extensive cover of natural vegetation. The rainfall in the state varies from 900 to 2000 mm. In the high altitude areas where rainfall is as low as 200 - 800 mm, snow is the major source of precipitation. Average rainy/snowfall days varies from 50 - 75 / year.

Rainfall though is abundant, often not available precisely as and when required for domestic or irrigation purpose. This situation has resulted from time immemorial to supplement and conserve the rainfall by construction of wells, storage reservoirs and by bunding the streams. All the traditional water harvesting practice developed as per the water resources and terrain conditions prevalent in the State. These practices differ depending upon the terrain

Roof top rain water is common in State. All new government buildings have adopted rooftop rainwater harvesting. Traditionally, roof top water after the first shower, was collected in small subsurface tanks for utilizing during the lean period. This practice was also adopted by the Britishers in all the hill stations like Kasauli, Dagshai, Shimla, Dalhousie etc.

All of this traditional water harvesting practice were maintained and used by the people themselves. These were eco-friendly and socially accepted. Most of these traditional practices has been abandoned or become defunct. Piped water supply has been made available to all the villages in the Himachal Pradesh from various sources like springs, infiltration galleries, streams etc. Water resources are depleting due to ever increasing population. Now there is an urgent need for the revival of traditional water harvesting practices by adding modern technology inputs. This will solve the water problems to a larger extent.

8.8.1 SOURCE WATER AVAILABILITY

The state is having abundance of surface water sources, major rivers like the Chandra-Bhaga, the Beas and the Ravi are originating in the central part of the State whereas Satluj and Yamuna rivers pass through the state. The flow in the rivers is received both by rainfall and snowfall received in the catchment area. Major dams, such as Bhakra dam with a storage capacity of 9,621 MCM (7.8 MAF) on Satluj river and Pong dam with a storage capacity of about 7,290 MCM (5.91 MAF) on Beas river are constructed. At Pandoh, another dam with a gross storage capacity of 1400 ham, has also been constructed to divert the water from the Beas River to Bhakra dam. On the Ravi River, a reservoir named as Chamera dam has been constructed for power generation. Thein dam is under construction. All the water of the Satluj, the Beas and the Ravi are being utilized for power generation and irrigation in Punjab, Haryana and Rajasthan States. Water of the Chandra-Bhaga River remains un-utilized in the State.

In most of the areas in the hilly region, there is a tradition to divert stream flow by making full use of slope for irrigating the fields by short approach channels locally called Kulhs. In high hill areas, spring water is being utilized for irrigation. In the lower areas of Siwaliks where perennial water sources are limited ponds/ tanks locally called Talabs are the major source of water supplies. These Talabs are generally constructed adjacent to the rivulets or in low topography areas for collection of rain waters. Almost all the villages in Hamirpur, Bilaspur, Sirmaur, Solan, Una and Kangra districts have such talabs used for domestic purposes.

8.8.2. DESIGN OF ARTIFICIAL RECHARGE STRUCUTRES

Wide spectrums of techniques are in vogue to recharge ground water reservoir. Similar to the variations in Hydrogeological frame work, the artificial recharge techniques too would vary accordingly. The artificial recharge structures which are feasible in varied Hydrogeological situation are gabion structures, check dams, cement plug/nala bund, sub-surface dykes, recharge shaft and injection wells. The area suitable for artificial recharge is shown in fig 8.8.1

8.8.3 ROOF TOP RAIN WATER HARVESTING

It has been assessed that roof top rainwater harvesting can be adopted in 50,000 houses, govt buildings, institutes etc. in urban and municipal area of the state suitable for artificial recharge in the first phase. It will harness 13.0 MCM rain water to augment groundwater resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a buildings having roof and paved areas of ~ 200 sq.m has been assessed to be Rs. 12,000/- and for bigger building having more than 1000 sq.m will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 82.0 crore in the first phase considering 5% of the total buildings having larger roofs.

8.8.4 TOTAL COST

The total cost of artificial recharge structures roof top rainwater harvesting structures and revival of tanks and ponds would be around Rs.655.47 crore as per table 8.8.1.

Table 8.8.1 Details of Artificial Recharge Structures proposed in Himachal Pradesh

S. No	RTRWH / Artificial Recharge Structures proposed	Formation									Total No. of Structures	Total Cost (Rs. in lakhs)
		Valley Fills (Area:3475 sq.km)			Siwaliks / Semi – Consolidated / Low Hill Ranges/ (Area:10104 sq.km)			Igneous / Crystalline / Consolidated / High Hill Ranges (Area: 42094 sq.km)				
		No. of Proposed structures	Unit cost (Rs. in lakhs)	Total Cost (Rs. in lakhs)	No. of Proposed structures	Unit cost (Rs. in lakhs)	Total Cost (Rs. in lakhs)	No. of Proposed Structures	Unit Cost (Rs. in lakhs)	Total Cost (Rs. in lakhs)		
1	Gabion Structures	0	0	0	20149	0.2	4029.8	78626	0.3	23587.8	98775	27617.60
2	Check dams / Nala Bunds / Cement Plug	0	0	0	1008	8	8064.0	841	8	6728	1849	14792.00
3	Sub-surface dykes	347	12	4164	0	0	0	0	0	0	347	4164.00
4	Check dam cum sub surface dykes	684	14	9576	0	0	0	0	0	0	684	9576.00
5	Recharge shaft	348	1	348	194	1	194.0	0	0	0	542	542.00
6	Injection well	131	5	655	0	0	0	0	0	0	131	655.00
	TOTAL	**1510**		**14743**	**21351**		**12287.8**	**79467**		**30315.8**	**102328**	**57346.60**

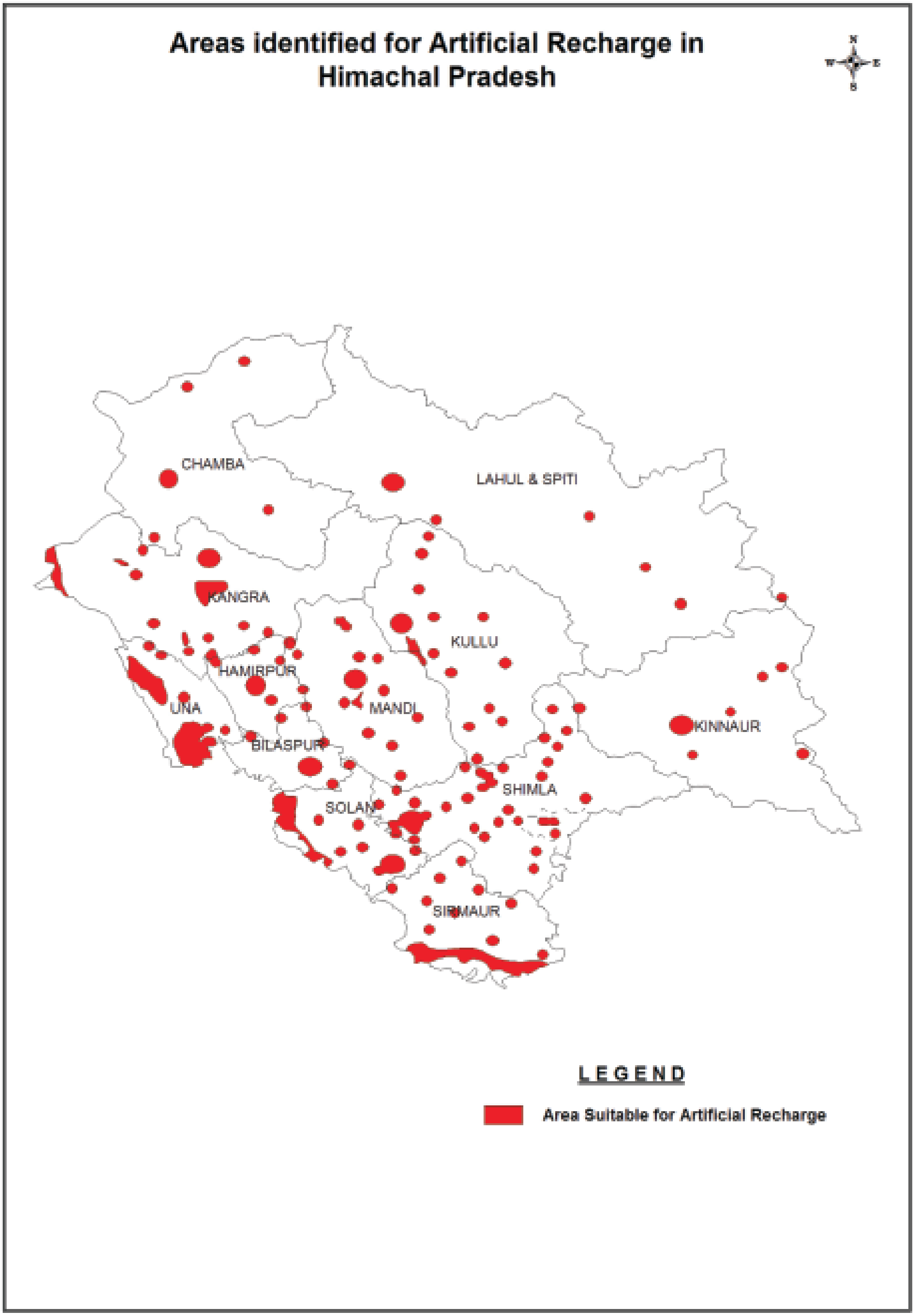


Fig: 8.8.1 Areas suitable for Artificial Recharge in Himachal Pradesh.

8.9 JAMMU & KASHMIR

Jammu & Kashmir has a total geographical area of 2, 22,236 sq.km which includes an area of 78,932 sq.km under illegal occupation of Pakistan and 37,555 km^2 area under illegal occupation of China. The Jammu and Kashmir State is divided into two administrative divisions viz. Kashmir Division comprising Kashmir and Ladakh regions, and Jammu division comprising Jammu region. The average annual precipitation is 660 mm. The state is drained by the rivers of Indus River System whereas a small area in the extreme north-east is drained by the rivulets of QaraQash River Basin. Kandi region of the state has an average annual rainfall of about 1100 mm. It faces acute water scarcity, especially during summer due to very high run-off resulting from high topographic gradient. The fragile eco-system of the Kandi region is prone to erosion and as result high rate of siltation takes place in the ponds which necessitates periodic de-silting. The problem of water scarcity is more acute in higher reaches of the Kandi area as the villages are located on high slopes of Siwalik hills and the rivers and streams flow through deep cut valleys.

8.9.1 SOURCE WATER AVAILABILITY

The mean annual surplus run-off in Chenab sub-basin is 27,220 MCM while in Tawi sub-basin it is 1953 MCM. Thus, the total surplus run-off available is 29,173 MCM. Volume of water required for recharge is estimated considering specific yield as 3%.

8.9.2 RECHARGE STRUCTURES AND COST ESTIMATES

The depth to water level during pre-monsoon season in Kandi region is generally very deep (15 to 74 m below ground level). Rainwater harvesting and groundwater conservation structures are required to provide sustainability to existing sources such as springs, ponds wells etc. The area identified for artificial recharge to groundwater in Jammu & Kashmir are given in fig 8.9.1. Considering the topography, precipitation and local aspects following structures are proposed:

8.9.2.1 Nala bund/Check dams

Nala bund/check dams are the most suitable structure in Kandi area to store and recharge the ground water. The average length of such structure will be about 15m with average height of 1.5m above the nala bed. The underlying formations are highly permeable down to water level. The average cost of such structure will be around Rs. 10 lakhs. Each nala bund/check dam will impound 0.0135 MCM of surface flow in single filling. Considering the average of three fillings per year, the structure is expected to harvest about 1.0 MCM annually. Taking into account the topography of the catchment it is proposed to construct 1000 such structures to conserve 1000 MCM of surface flow. The total cost of these structures at the rate of Rs. 10.0 lakh per structure works out to be Rs. 100 crores.

8.9.2.2 Revival of Ponds

There are 336 big ponds in Kandi region, covering on an average of 1, 50,000 m^2 area, which need to be revived for increasing their efficiency as rainwater harvesting structure. These major ponds in Kandi region should be desilted and deepened for storing the rainwater. The ponds can also be connected with nearby rivulets by constructing small check dams and diversion channels. The deepening of ponds may be done to the extent that the average depth of water in it is about 2 m. Considering an average depth of deepening as 2 m the volume of water that can be harnessed by one pond of the dimension of 300 x 500 m, the storage would be 0.30 MCM in one filling and approximately 1 MCM due to multiple filling. Thus, additional storage of 336 MCM water can be created in 336 Kandi ponds for recharge. Considering the cost as Rs.

10 lakh per pond the total cost of deepening 336 ponds and connecting them with the nearby rivulets works out to be Rs. 33.60 crores. There are ponds in other regions of the state which can also be used for recharge purpose. It is expected to recharge around 352 MCM through additional 352 ponds. The approximate cost would be Rs.35.20 crores. Thus total amount would be Rs. 68.80 crore.

8.9.2.3 ROOF TOP RAIN WATER HARVESTING

It has been assessed that roof top rainwater harvesting can be adopted in 1.0 lakh houses, govt buildings, institutes etc. in urban and municipal area of the state suitable for artificial recharge in the first phase. It will harness 12.0 MCM rain water to augment groundwater resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a buildings having roof and paved areas of ~ 200 sq.m has been assessed to be Rs. 10,000/- and for bigger building having more than 1000 sq.m will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 145.0 crore in the first phase considering 5% of the total buildings having larger roofs.

8.9.3 TOTAL COST

The total cost of artificial recharge to the groundwater in the State of Jammu & Kashmir would be around Rs. 331.80 crores, with break up as follows:

(i) Nala bund/Check dams	……	Rs.	100.00 crores
(ii) Construction/ Revival of Kandi Ponds	……	Rs.	68.80 crores
(iii) Rooftop Harvesting in Houses	…. ..	Rs.	95.00 crores
(iv) Rooftop Harvesting in			
Govt./Institutional buildings	……	Rs.	50.00 crores
TOTAL COST	……	Rs.	313.80 crores.

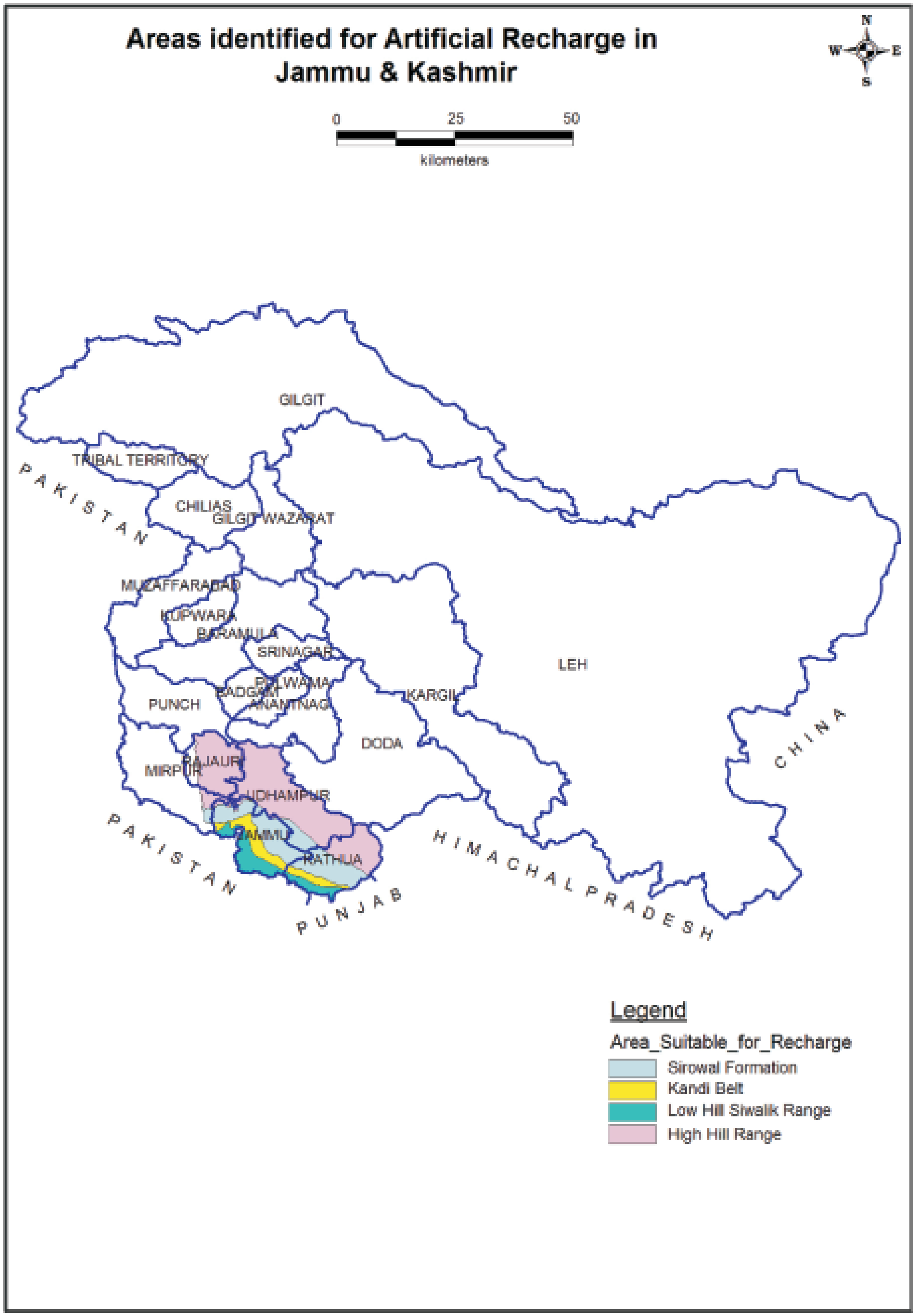


Fig 8.9.1 Areas identified for Artificial Recharge to Ground Water in Jammu & Kashmir

8.10 JHARKHAND

The state of Jharkhand covers an area of 79,714 sq.km. As per the 2011 census, the population of Jharkhand is 329.66 lakh. The average annual rainfall is 1238.6 mm. Administratively, the State is divided into 24 districts and 260 blocks. The state comprises of 3 major basins namely Ganga, Subarnarekha and Brahmani.

8.10.1 IDENTIFICATION OF AREA

The identification of the area suitable for artificial recharge has been done on the basis of depth of mean post-monsoon water level. The areas where the average water level of last 10 years is more than 5 bgl in post-monsoon period (November) has been considered suitable for artificial recharge. Suitable areas for artificial recharge were identified in 12 districts viz; East Singhbhum, West Singhbhum, Godda, Lohardaga, Ranchi, Bokaro, Chatra, Hazaribagh, Dumka, Giridih, Latehar and Gumla. Maximum area found feasible for recharge is in Bokaro district. An area of 7863.6 sq.km. is found suitable for artificial recharge in the state (Fig.8.10.1).

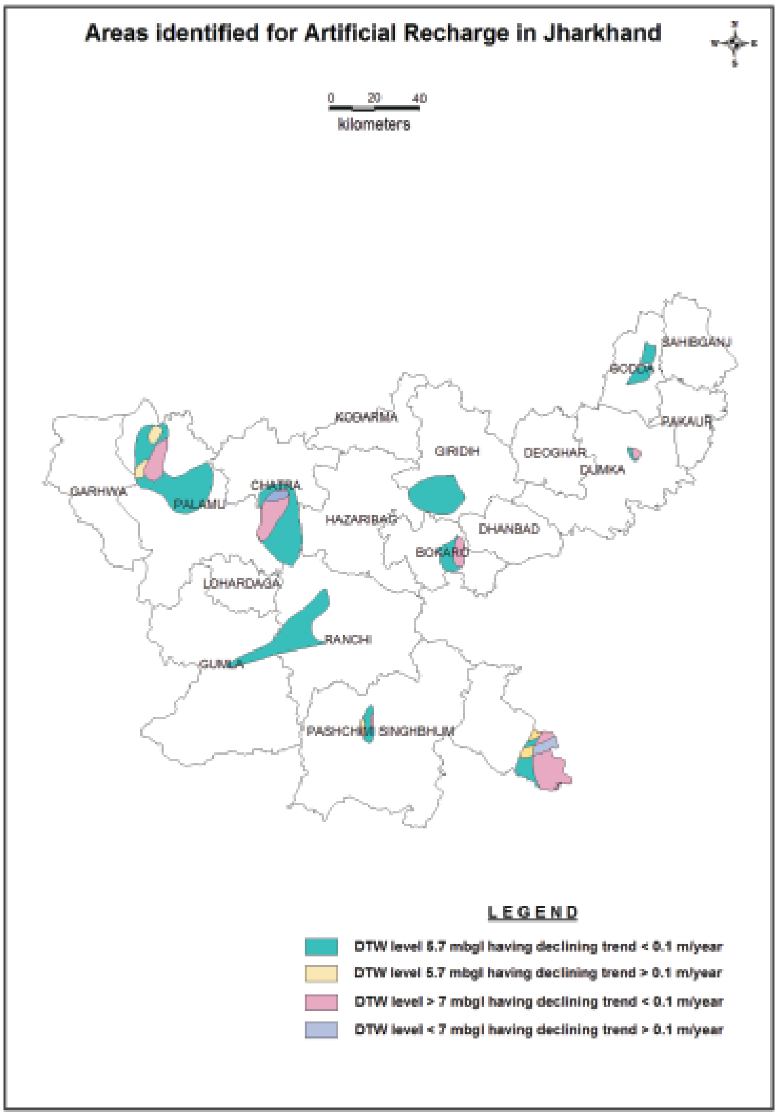


Fig.8.10.1 Areas feasible for Artificial Recharge in Jharkhand

8.10.2 SOURCE WATER AVAILABILITY

The basin wise surface water availability with 60% dependability has been taken from the existing field condition. The surface water required at 60% efficiency for artificial recharge is 1414.313 MCM. Total volume of water required for artificial recharge up to the depth of 3 mbgl is 847.89 MCM. Total surplus runoff available after the recharging of the required volume of water is 4042.956 MCM. The district wise distribution of surplus surface water resource generated within the twelve identified districts is given below.

Table 8.10.1- Requirement of Surface Water Resources for Artificial Recharge to Ground Water in Jharkhand.

S. No.	Name of District	Area identified for Artificial Recharge (sq.km.)	Volume of un saturated zone available for recharge (MCM)	Total Volume of water that can be recharged (MCM)	Surface Water required for recharge at 60% efficiency (MCM)	Total surface water available (MCM)	Total surplus runoff available (MCM)
1.	Bokaro	339	1006.83	37.29	62.2743	100.2	37.9257
2.	Chatra	1657	6280.03	77.46	129.3582	497.1	367.7418
3.	Dumka	79	168.27	10.93	16.59	16.59	00
4.	E.Singhbhum	1156	3999.74	295	492.65	520.2	27.55
5.	Giridih	821	2331.64	73.9	123.413	246.3	122.887
6.	Godda	313	685.47	22.54	37.6418	143.98	106.3382
7.	Gumla	156	333.84	14.04	23.4468	54.6	31.1532
8.	Hazaribagh	156	553.8	14.04	23.4468	46.8	23.3532
9.	Latehar	312	698.88	28.03	46.8101	81.72	34.9099
10.	Palamu	1875	6787.5	187.38	312.9246	3300	2987.075
11.	Ranchi	750	1552.5	75	125.25	337.46	212.21
12.	W.Singhbhum	249.6	536.64	12.28	20.5076	112.32	91.8124
	Total	**7863.6**	**24935.16**	**847.89**	**1414.313**	**5457.27**	**4042.956**

8.10.3 RECHARGE STRUCTURES

For consideration of suitability of artificial recharge structures, the states have been divided into two broad groups

(i) Hard rock area of Jharkhand

(ii) Tertiary formation of East Singhbhum district, Jharkhand.

In hard rock areas the suitable artificial recharge structures are:

a) Percolation Tank

b) Nala Bunding

The volume of surface water considered for planning the artificial recharge is based on the surplus runoff availability and the space available for recharge. Based on the field situation it has been considered that 50% storage will be through percolation tanks and 50% through nala bunding in hard rock areas. For the percolation tank single filling capacity is 94 TCM. Considering 100% of double filling, the gross storage is 188 TCM. For nala bunding single filling capacity of 12 TCM , the actual storage will be 30 TCM based on 250% of multiple filling. The nala bunds should be concrete structures in lower order streams. Numbers of structures have been worked out at district level based on gross storage capacity of individual structure. The district wise number of different type of artificial recharge structures is given in table 8.10.2

Table 8.10.2- District wise feasibility of Artificial Recharge Structures in Jharkhand

District	Volume of unsaturated zone available for recharge	Volume of water required at 60% efficiency (MCM)	Resource to be harnessed by Artificial Recharge Structures				Cost (Rs. in Lakhs)	
			Percolation tank		Nala Bund		Percolation tank @ Rs 27.75 lakhs	Nala Bund@ Rs 3.07 lakhs
			Vol. MCM	No	Vol. MCM	No		
Bokaro	1006.83	62.2743	31.14	165	31.14	992	4578.750	3045.440
Chatra	6280.03	129.3582	64.68	343	64.68	2060	9518.250	6324.200
Dumka	168.27	16.59	8.3	44	8.3	265	1221.000	813.550
E.Singhbhum	3999.74	492.65	246.33	1308	246.33	7847	36297.000	24090.290
Giridih	2331.64	123.413	61.71	328	61.71	1966	9102.000	6035.620
Godda	685.47	37.6418	18.82	100	18.82	600	2775.000	1842.000
Gumla	333.84	23.4468	11.72	62	11.72	373	1720.500	1145.110
Hazaribagh	553.8	23.4468	11.72	62	11.72	373	1720.500	1145.110
Latehar	698.88	46.8101	23.41	124	23.41	746	3441.000	2290.220
Palamu	6787.5	312.9246	156.46	831	156.46	4984	23060.250	15300.880
Ranchi	1552.5	125.25	62.63	333	62.63	1995	9240.750	6124.650
W.Singhbhum	536.64	20.5076	10.25	54	10.25	327	1498.500	1003.890
Total	**24935.16**	**1414.313**	**707.17**	**3754**	**707.17**	**22528**	**104173.500**	**69160.960**

8.10.4 COST ESTIMATES

Based on experiences gained by CGWB, the cost of structures has been work out and is given below-

S. N.	Structure	Unit cost (Rs. in lakhs)	No. of structures	Cost (Rs. in lakhs)
1.	Percolation Tank	27.75	3754	104173.50
2.	Nala Bunding	3.07	22528	69160.96

The district wise cost estimates for different types of structures are given in table 8.10.2. In 12 districts, the total cost of the percolation tanks is 1041.74 crores and nala bunds is 691.61 crores. Thus, the total cost required for artificial recharge structures (3754 percolation tanks + 22,528 Nala bund) is 1733.34 crores.

8.10.5 ROOFTOP RAINWATER HARVESTING IN URBAN AREAS

It has been assessed that roof top rain water harvesting can be adopted in 2 Lakh houses, govt. buildings, institutes etc. in urban and municipal areas of the state suitable for artificial recharge in the first phase. It will harness 47.56 MCM rain water to augment ground water resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a building having roof and paved area of ~ 200 sq.m. has been assessed to be Rs. 10,000/- and for bigger buildings having more than 1000 sq.m. will be Rs. 1.0 lakhs. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs.290.0 Crores in the first phase considering 5% of the total buildings having larger roofs.

8.10.6 TOTAL COST

Total cost of the artificial recharge schemes and roof top rain water harvesting is Rs. 2023.34 crores for the state of Jharkhand.

8.10.7 PRESENT STATUS OF ARTIFICIAL RECHARGE STRUCTURES

Out of total number of proposed nala bund (22528) only 4974 nala bund / check dam have been completed and out of 2,00,000 buildings which has to be rain water harvested through roof top only 1203 numbers have been constructed, through different Govt. Departments (as per the data available). With regard to percolation tank no data was available (Table-8.10.3).

Table 8.10.3 - District wise numbers of completed Check Dam and Roof Top Rain Water Harvesting structures of State Govt. Departments, Jharkhand

S. N.	District	Name of Department					
		Drinking Water & Sanitation		Ground Water Directorate		Directorate of Soil Conservation	
		RTRWH	Check Dam	RTRWH	Check Dam	RTRWH	Check Dam
1	2	3	4	5	6	7	8
1.	Ranchi	21	1	16	-	-	100
2.	Gumla	24	-	-	-	-	38
3.	Simdega	26	-	-	-	-	30
4.	East Singhbhum	-	-		-	-	47
5.	West Singhbhum	-	-	-	-	-	55
6.	Saraikela	33	-	-	-	-	32
7.	Dumka	95	-	2	-	-	36
8.	Sahebganj	44	-	-	-	-	32
9.	Pakur	50	-	-	-	-	26
10.	Palamu	6	-	12	-	-	101
11.	Hazaribagh	40	-	2	-	-	63
12.	Ramgarh	4	-	-	-	-	41
13.	Koderma	23	-	-	-	-	32
14.	Chatra	20	-	-	-	-	47
15.	Dhanbad	208	-	-	-	-	28
16.	Bokaro	167	-	-	-	-	26
17.	Giridih	208	1	-	-	-	44
18.	Deoghar	151	-	-	-	-	53
19.	Jamtara	31	-	-	-	-	50
20.	Godda	20	-	-	-	-	32
	Total	**1171**	**2**	**32**	**-**	**-**	**4972**

8.11 KARNATAKA

Karnataka state is located in south western part of India with a population as per the census (2011) is 61,130,704 and population density of 319 per sq km. It covers an area of 1,91,791 sq. km. and divided into 30 districts and 176 Taluks for administrative convenience.

The state is covered with black, red, lateritic, gravelly, alluvial and mixed soils. Infiltration rates of these soils vary from 0.5 to 114 cm/hour. Bulk of the annual rainfall is received during the south-west and north-east monsoons. Humid to semi arid climatic conditions prevail in the state. Normal annual rainfall varies from 573 to 4119mm.

Physiographically, Karnataka is divided into four regions

(i) The Coastal belt

(ii) The Malnad region

(iii) The Northern Maidan region

(iv) The Southern Maidan region

The Western Ghats which runs North-South forms the principal water divide in the state, giving rise to West and East flowing rivers of Karnataka. The Sharavati, the Kalinadi, the Netravati, the Varahi, the Bedti and Aghanashini are some of the important rivers which originate from the Western Ghats and flow westerly and join the Arabian Sea. The Krishna River system covers an area 1,13,271 sq. km and drains 59.06 percent of Karnataka State followed by the Cauvery river system which drains 34273 sq. km covering 17.87 percent. The west flowing rivers drain 26,214 sq. km area of the state covering 13.68 percent. Other river systems cover appreciably small areas.

Geologically, the important formations occurring in the state are gneisses, granites, schists, basalts and sedimentaries. Quality of ground water in general is good and potable in the state. However fluoride concentration of more than 1.5 ppm is found in areas falling in Bellary, Raichur, Kolar, Chitradurga, Dharwar and Tumkur district which are underlain by closepet granites and other younger granites and pegmatites etc. High nitrate concentrations are mostly seen in the districts of Raichur, Bijapur, Gulbarga, Hassan, Mandya, Bangalore and Tumkur having intensive surface irrigation agriculture practices using chemical and organic manures or having poor solid waste disposal.

8.11.1 IDENTIFICATION OF AREA

The area characterized by depth to water level of more than 3 m bgl during the post-monsoon period and area with declining decadal water level trend is considered as area requiring artificial recharge. The area characterized by both declining trend and depth to water levels has been taken into consideration for taking up artificial recharge schemes. The rain-fed catchment areas are most suitable to take up artificial recharge through watershed treatment structures such as check dams.

As far as ground water quality is concerned, poor ground water quality areas need special attention. The quality of ground water will improve due to dilution by way of adding fresh water through artificial recharge. Hence, such areas are also taken into consideration while preparing the present plan. The stage of ground water development is an important bench mark in finalizing the area to take up artificial recharge scheme.

The area where the stage of development is more than 100 percent is considered as the priority areas. Areas suitable for artificial recharge are given in Fig. 8.11.1

8.11.2 SUBSURFACE STORAGE SPACE

The thickness of unsaturated zone for each category of depth to water level is arrived and 3 m is subtracted to get the unsaturated thickness available for recharge in the regional level. The state is covered by crystalline formations, an average specific yield of 1 % has been assumed. The density of various artificial recharge structures and design are inferred by the integrated hydro geological set-up and the status of ground water development as well as the feasibility of structures with source water.

8.11.3 SOURCE WATER AVAILABILITY

Monsoon rainfall run off is the only source water for artificial recharge in the state. Non-committed monsoon runoff is taken based on "Theme paper on water Vision 2050 water resources day 99" of NWDA.

8.11.4 NUMBER OF RECHARGE STRUCTURES

The estimated cost of artificial recharge structures in Karnataka State works out to be 1998.65 crores and the proposed structures and other details are given in Table 8.11.2. Out of this the state govt has already spent about Rs 250 crores towards construction of such structures in various parts of the state.

8.11.5 ROOF TOP RAIN WATER HARVESTING

It has been assessed that roof top rain water harvesting can be adopted in 7 lakh houses, govt. buildings, institutes etc. in urban and municipal areas of the state suitable for artificial recharge in the first phase. It will harness 167.73 MCM rain water to augment ground water resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a building having roof and paved area of ~ 200 sq.m. has been assessed to be Rs12,000/- and for bigger buildings having more than 1000 sq.m. will be Rs. 1.0 lakhs. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs.1148.0 crores in the first phase considering 5% of the total buildings having larger roofs.

8.11.6 COST ESTIMATES

The total cost of the artificial recharge structures and roof top rain water harvesting structures is estimated to be Rs.3146.65 crores for implementation.

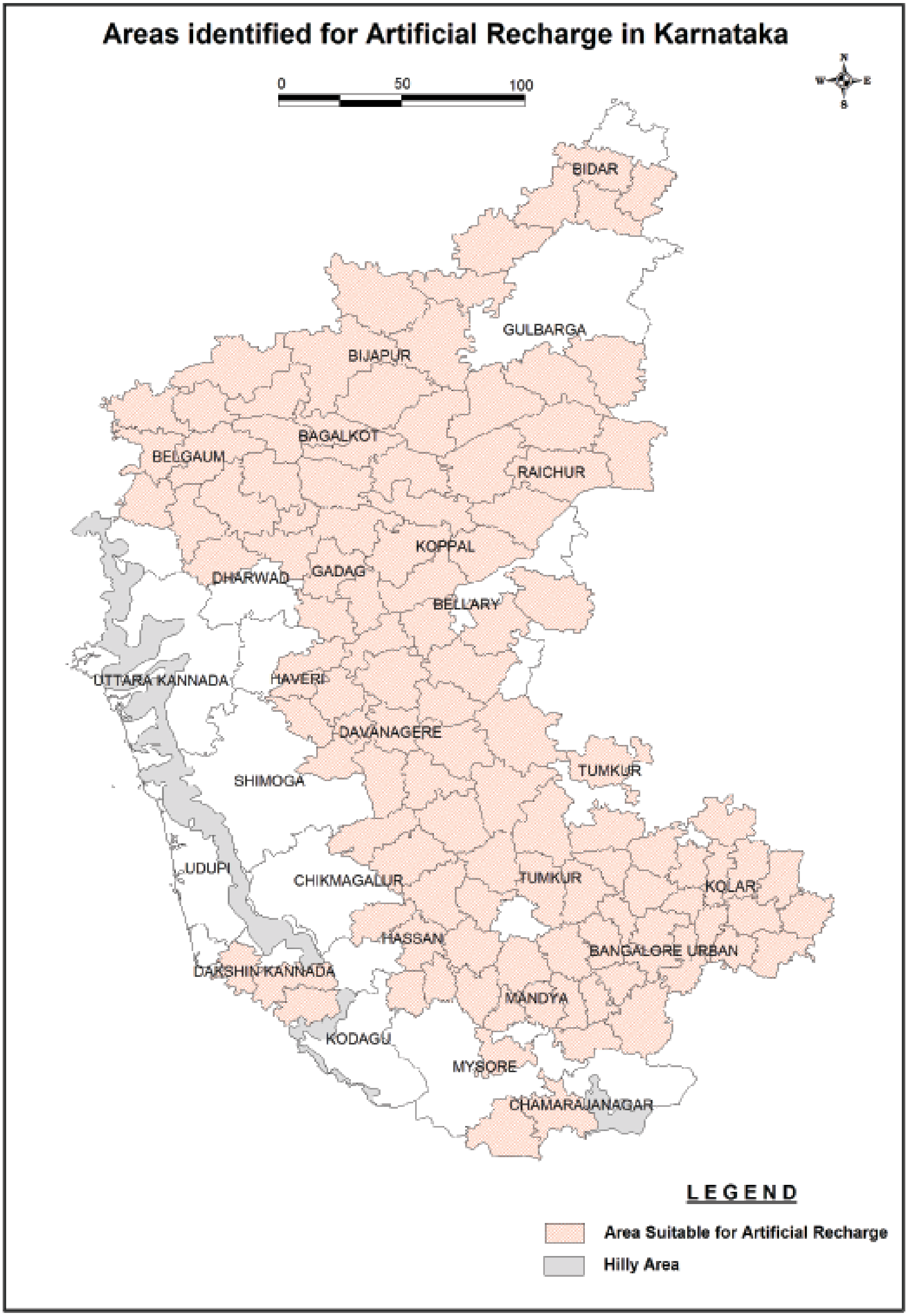


Fig. 8.11.1: Areas suitable for Artificial Recharge in Karnataka

Table – 8.11.1 District wise details of Artificial Recharge Structures in Karnataka

S. No.	District Name	Area of the District (sq. km.)	Average Post Monsoon Depth to Water Level (m bgl)	Area Feasible for Artificial Recharge (sq.km)	Volume of unsaturated zone Available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of surplus source available for recharge (MCM)	Type and Number of Proposed Recharge Structure				Unit and Total Cost of Recharge Structures (Rs. in crore)				
								Sub surface dyke	Percolation tank	Check dam	Point Recharge Structure	Sub surface dyke (@Rs0.045 crore)	Percolation tank @Rs0.075 crore)	Check dam(@Rs 0.02 crore)	Point Recharge Structure @Rs 0.01 crore)	Taluk Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	BAGALKOTE	6575	8	4084	19888	529	666	13	428	2536	114	0.585	32.1	50.72	1.14	84.545
2	BANGALORE(R)	2259	8	2060	10031	267	1079	7	308	1423	64	0.315	23.1	28.46	0.64	52.515
3	RAMANAGARAM	3556	7	2970	11444	304	1555	8	274	1624	73	0.36	20.55	32.48	0.73	54.12
4	BANGALORE(U)	2190	6	1809	6070	161	947	4	145	861	39	0.18	10.875	17.22	0.39	28.665
5	BELGAUM	13415	9	7628	77167	2053	1938	44	1476	8746	394	1.98	110.7	174.92	3.94	291.54
6	BELLARY	8450	8	1952	19517	519	399	11	359	2129	96	0.495	26.925	42.58	0.96	70.96
7	BIDAR	5448	9	212	1251	33	46	1	30	178	8	0.045	2.25	3.56	0.08	5.935
8	BIJAPUR	10494	8	5681	28182	750	927	20	675	3998	180	0.9	50.625	79.96	1.8	133.285
9	CHAMRAJANGAR	5101	9	334	1869	50	57	1	45	265	12	0.045	3.375	5.3	0.12	8.84
10	CHIKMAGALUR	7201	11	1587	14750	392	212	6	191	1131	51	0.27	14.325	22.62	0.51	37.725
11	CHITRADURGA	8440	9	3110	19840	528	602	12	417	2472	111	0.54	31.275	49.44	1.11	82.365
12	D. KANNADA	4560	6	2155	6464	172	297	4	123	729	33	0.18	9.225	14.58	0.33	24.315

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
13	DAVANGERE	5924	6	3350	10350	275	637	11	369	2189	98	0.495	27.675	43.78	0.98	72.93
14	DHARWAR	4260	9	201	11376	303	490	8	272	1614	73	0.36	20.4	32.28	0.73	53.77
15	GADAG	4656	10	4141	30640	815	1005	17	585	3467	156	0.765	43.875	69.34	1.56	115.54
16	GULBARGA	10990	7	1269	4811	128	194	3	1031	6113	275	0.135	77.325	122.26	2.75	202.47
17	HASSAN	6814	9	2613	16171	430	389	8	284	1685	76	0.36	21.3	33.7	0.76	56.12
18	HAVERI	4823	9	2371	15008	399	576	11	359	2129	96	0.495	26.925	42.58	0.96	70.96
19	CHIK BALLAPUR	4254	10	3214	22647	602	808	16	542	3213	145	0.72	40.65	64.26	1.45	107.08
20	KOLAR	3969	10	3401	23602	628	855	16	532	3150	142	0.72	39.9	63	1.42	105.04
21	KOPPAL	7189	9	2974	18536	493	470	12	405	2400	108	0.54	30.375	48	1.08	79.995
22	MANDYA	4961	8	3032	12940	344	1242	9	310	1836	83	0.405	23.25	36.72	0.83	61.205
23	MYSORE	6854	7	1708	6447	171	291	5	154	915	41	0.225	11.55	18.3	0.41	30.485
24	RAICHUR	6827	4	1721	2083	55	272	1	50	295	13	0.045	3.75	5.9	0.13	9.825
25	TUMKUR	10597	7	7385	30277	805	981	19	657	3895	175	0.855	49.275	77.9	1.75	129.78
26	YADGIR	5234	8	1227	6063	161	187	4	145	860	39	0.18	10.875	17.2	0.39	28.645
	STATE	**165041**		**74007**	**427424**	**11367**	**17122**	**271**	**10166**	**59853**	**2695**	**12.195**	**762.45**	**1197.06**	**26.95**	**1998.655**

Note: Taluk wise average water levels are used for estimations and values are totaled district wise. Average water level of the district is not used for estimation.

8.11.7 MODEL PLAN IN ONE IDENTIFIED OVER-EXPLOITED BLOCK

The Honnaghatta sub-watershed was identified in consultation with the State Government authorities with an objective to study the area and suggest the action plan for artificial recharge to ground water. Honnaghatta sub-watershed is over-exploited with the stage of ground water development of 173% and falls in Doddaballapura taluk (one of the 65 OE blocks of Karnataka), Bangalore Rural district, Karnataka. The phreatic aquifer in general is completely dried-up. Ground water is the lifeline of the farmers for the domestic and irrigation water requirements in this area. Annual recharge in the watershed is 1.017 MCM against total draft of 1.759 MCM. There is an over-draft of 0.742 MCM annually. This has led to declining trend in Ground Water levels at the rate of 1.17 m annually. The present action plan suggests an integrated water management strategy comprising of rainwater harvesting and artificial recharge to augment ground water resources on one hand and reducing the draft by changing the cropping and irrigation pattern on the other hand. These measures are likely to result in saving 0.951 MCM of Ground Water and hence it will be possible not only to arrest the declining trend but also raise the Water Levels in the study area gradually.

8.11.7.1 Ground Water Abstraction Structures

Ground water was extracted through dug wells till 1990's in the area. Bore well construction was started from 1990's and the usage of dug wells was reduced. At present the dug wells are dried up due to lowering of ground water levels. Very few wells are in use, which are seasonal in nature, during rainy and/or post rainy season. They are mostly located in topographically low-lying areas in the tank commands. Presently, bore wells are the main source of ground water abstraction. Totally 173 bore wells are in use out of the total 262 bore wells drilled, 89 bore wells are dried-up. The depth of bore wells ranges between 60 to 260 m. The yield is in the range of about 4 to 10 m^3/hr. The depth to water level in the deeper zone is generally represented by fractured aquifers ranging in depth range between 20 and 60 m bgl. Network Hydrograph Station of D.B.Pura which was a dug well has dried up and CGWB is monitoring water levels in Piezometers constructed under Hydrology Project, the Hydrograph of the same is presented in Fig-8.11.2, which shows a declining trend in water level.

Table-8.11.2: Hydrologic framework statistics in Honnaghatta sub-watershed, Karnataka

Hydrological frame work	Short term & Long term water level behavior	Number of ground water abstraction structures	Ground water resource availability	Ground Water problems	Quantity	Existing recharge structures in the proposed project area
Granitic gneiss	Decline of 0.17 meter / annum All dug wells dried-up	173 bore wells in the proposed area	173 % Over-exploited Phreatic aquifer has dried up	Declining trend & dwindling of yield	Insufficient	Tanks – 6 Check Dams–1 Nala bund -2

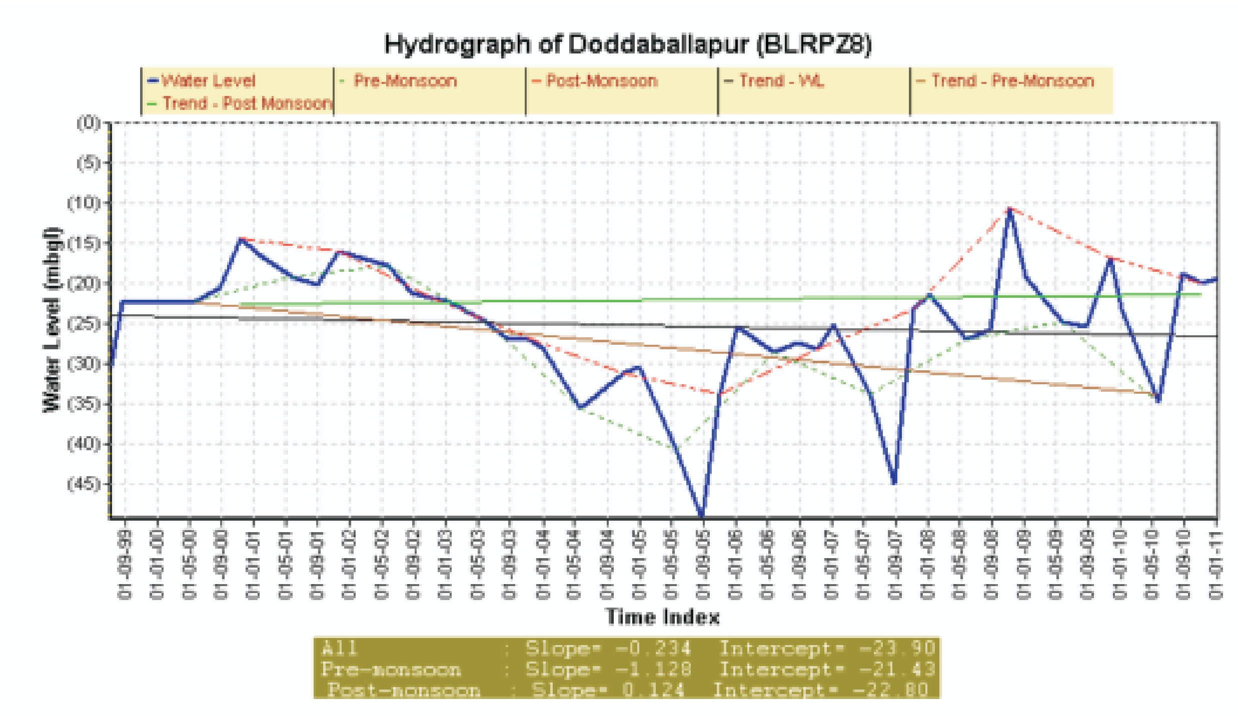


Fig-8.11.2 Hydrograph of Doddaballapur observation well.

8.11.7.2 Availability of Source Water:

The area receives on an average about 662 mm of rainfall during monsoon period, which generates about 8.56 MCM run-off (table-8.11.3). Of this 1.98 MCM is committed to be harnessed for the existing 6 Tanks (table-8.11.4) in the area. It leaves on an average 6.58 MCM non-committed surplus monsoon runoff for harnessing annually.

Table-8.11.3: Status of availability of source water for augmentation of Aquifer system, Honnaghatta Sub-water shed, Karnataka

Source	Location	MONSOON RUN-OFF						
		Mons oon rain fall (mm)	Area of watershed (sq. km)	Run-off Coeffi cient	Rainfall Run-off (MCM)	Committed Run-off (MCM)	Non Committed / Surplus Run-off (MCM)	Period of Availability
Rain fall	Honnaghatta Sub-watershed	662	21.559	60	8.56	1.98	6.58	4 months

Table-8.11.4 Details of existing surface water bodies in Honnaghatta Sub-watershed, Karnataka

Name of the of the surface water body	Water spread Area (acres)	Storage capacity (MCM)	Water remains in Tank (Month)	Runoff Characteristics
Kamlur Tank	37.50	0.300	Aug - Nov	Average
Antharahalli	38.00	0.280	Aug - Nov	Average
Tapasihalli	25.20	0.240	Aug - Nov	Average
Kolur Tank	62.00	0.650	Aug - Nov	Average
Kolur Hosakere	9.00	0.100	Aug - Nov	Average
Honnaghatta	42.00	0.400	Aug - Nov	Average
Total	**213.70**	**1.970**		

8.11.7.3 Proposal for Ground Water Recharge:

The action plan recommended to improve the ground water condition is given in table-8.11.5.

Table-8.11.5: Conservation and augmentation components of the proposed Action Plan in Honnaghatta Sub-watershed, Karnataka

S. No.	Proposed Action	Benefit
1.	Construction of Artificial Recharge structures	0.4159 MCM
2.	Roof Top Rainwater harvesting for domestic use	0.0380 MCM
3.	De-silting of existing Irrigation Tanks	0.0238 MCM
4.	Change in Cropping Pattern and Irrigation Practices	0.3170 MCM
	Total	**0.7947 MCM**

Detailed calculations about various components of Table-8.11.3 are given below:

Total Non Committed Monsoon Run-off available = **6.58 MCM**

Total Storage Capacity of De-saturated weathered Zone

Area Suitable for Recharge * Specific Yield* Thickness of Weathered Zone

20 sq km * 0.01* 17m = **3.4 MCM**

1. Conservation by de-silting of Irrigation Tanks

Water Spread Area of Existing Tanks = 87.58 hectares

Average Water Spread Area (60%) = 52.54 hectares

No of days water remains in Tanks = 90 days

Seepage Factor = 0.00144m /ha/day

Recharge from Tank = 52.54*90*0.00144 = 6.8 ham = 0.068 MCM

Percentage of recharge to be increased due to de-silting = 35%

Hence increase in recharge after de-silting = 0.0238 MCM

2. Conservation by Artificial Recharge

a. Check Dam

Average annual storage capacity of check dam in the area is 0.00404 MCM which will cause 0.00364 MCM. recharge to ground water annually. 35 check dams are feasible in the area. So the total annual recharge by these 35 check dams will be 0.1274 MCM.

b. Nala Bund

Average annual storage capacity of Nala bund in the area is 0.01125 MCM. 6 nala bunds are feasible in the area. It will cause annual storage of 0.0675 MCM and annual recharge of approximately 0.060 MCM.

c. Point Recharge Structures

Total no of 173 bore wells are working in the area where as 89 have dried up. 50% percent of these bore i.e., 131 bore wells may be used as point recharge structures. As average yield of these bore wells is/was in the range 4-10 cub m / hour. Thus average yield works out to be $7m^3$/hour. It has been observed that intake capacity of bore well is equal to its yield. Hence intake can be taken as $7m^3$/well/hour. Number of run-off generating rainy days in the area is, 30. Considering 8 hours intake period on each rainy day at the rate of $7m^3$/hour, recharge by one point recharge structure will be 1680 m^3/annum. Hence, total expected recharge from 136 point recharge structures will be 0.2285 MCM.

3. Conservation by Change in Irrigation Pattern

Existing draft for Irrigation (Unit Draft)		= 1.557 MCM
Total Area Irrigated from Ground water		= 380.87 hectares
Average crop water requirement		= 0.325 m
Water required to grow crop	= 380.87* 0.325	= 1.24 MCM

Hence Water Saved by Adopting Crop water Requirement

Existing draft – Crop Water Requirement	= 1.557-1.24
	=0.317MCM (20% saving)

8.12 KERALA

Kerala State is a narrow stretch of land covering an area of 38,863 sq km in the southernmost part of India has been subdivided into 14 districts, 61 Taluks, 152 community development blocks and 978 panchayat for administrative convenience. The total population of the state as per 2011 census is 3,33,87,677, with a density of about 859 persons per sq.km. Thiruvananthapuram, with a population density of 1509 persons per sq.km is the most densely populated district in Kerala followed by Alappuzha with 1501 people per sq.km and Kozhikode with 1318 persons per sq.km. Idukki with a density of just 254 persons per sq.km is the least densely populated district followed by Wayanad with a density of 383 persons. Kerala receives rainfall from both south west and north east monsoons. The precipitation is highest in the Western Ghats and the lowest in the vicinity of Palghat gap. Kuttiyadi basin in northern Kerala experiences the highest rainfall of 3934 mm, while Pambar (Amaravathi) basin, which is a rain shadow area, records the lowest annual rainfall of 1367 mm. Kerala State is drained by 41 west flowing rivers and 3 east flowing rivers. The Bharathapuzha, Periyar and Pamba are the most important rivers draining the State. The run-off estimated in the state is about 70165 MCM, out of which 42672 MCM is considered to be utilizable.

8.12.1 IDENTIFICATION OF AREA

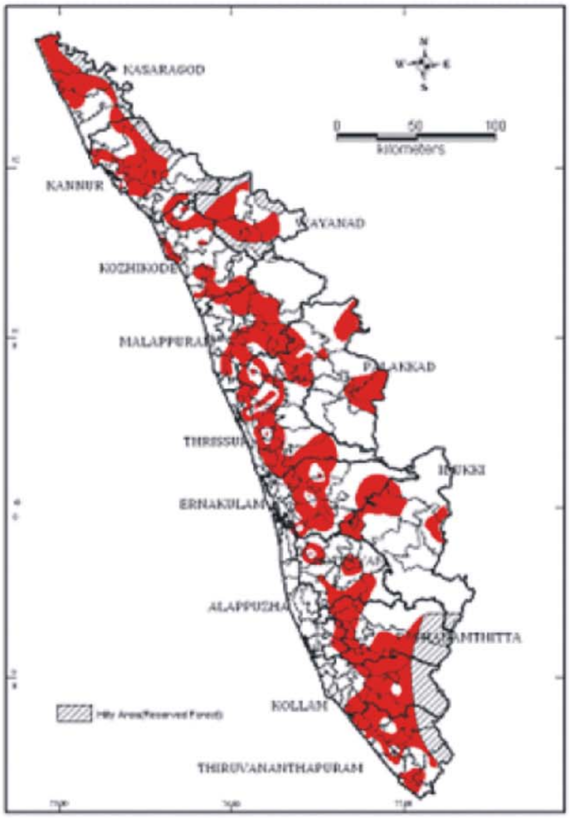
Area suitable for ground water augmentation through artificial recharge has been demarcated based on the analysis of available data on depth to water level and long-term water level trends. Post-monsoon depth to water level data in the observation wells for the period 2006-10 and water level trends for the period 2001-2010 have been used for the analysis, based on which an area of about 10849 sq.km, excluding reserved forests has been identified as suitable for implementation of artificial recharge. The area identified for artificial recharge based on depth and long-term trend of water levels and areas identified for recharge through specific recharge techniques are shown in Fig. 8.12.1& 8.12.2

8.12.2 SUB SURFACE STORAGE SPACE AND WATER REQUIREMENT

In order to estimate the Sub-surface storage space available for recharge, area suitable for artificial recharge based on deep (>6m) and declining ground water level trends and average post-monsoon water levels were demarcated in each district. The availability of sub-surface storage space available in each district was computed as the product of area feasible and thickness of aquifer zone between 3 mbgl and the average post-monsoon water level. The net quantum of source water required to saturate the aquifer up to 3 mbgl was then computed as the product of the storage space available and the average specific yield of the aquifer material

8.12.3 SOURCE WATER AVAILABILITY

The data on surface water resources available in various basins in the state were provided by the state government. The data available for each basin includes committed runoff and surplus water available for future planning. The availability of source water was worked out by adding the amount of surface water provided for future planning and surplus available. The availability so worked out is for the entire basins were then apportioned for the districts in the basin and then again for the area identified suitable for recharge augmentation. The availability of surplus surface water available for recharge augmentation in identified areas for the state as a whole is of the order of 17678 MCM.



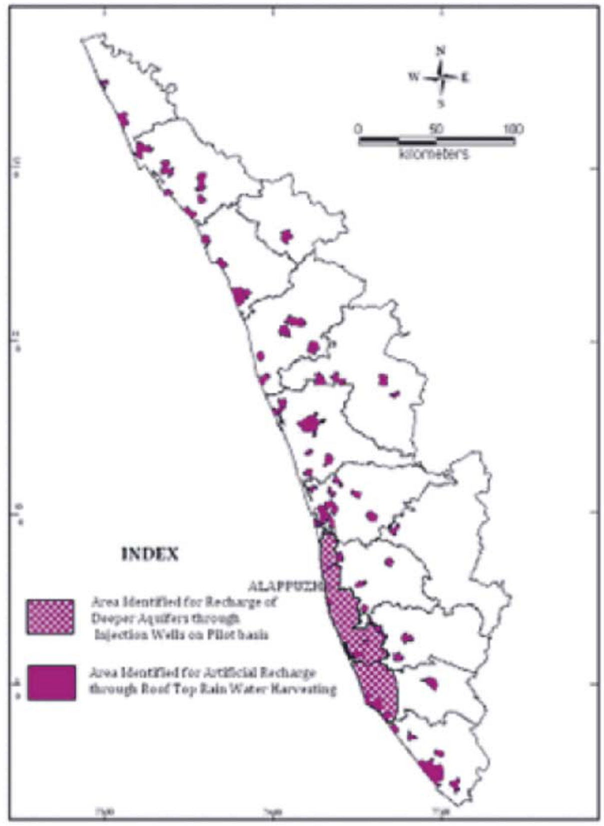


Fig. 8.12.1: Area suitable for Artificial Recharge in Kerala

Fig. 8.12.2: Specific area suitable for Artificial Recharge in Kerala

8.12.4 STRUCTURES AND COST ESTIMATES

Hydrogeologically, the areas have been grouped into hard rock and alluvial areas. Areas having water levels deeper than 6.0 mbgl have been considered for artificial recharge. Surface spreading techniques such as check dams, percolation ponds, gully plugs and nala bunds; ground water conservation structures such as sub-surface dykes and soil & water conservation techniques such as contour bunds have been considered as appropriate structures for ground water augmentation in the State. Ground water conservation structures like sub-surface dykes are also appropriate in parts of the districts depending on the topography. Soil & water conservation structures such as contour bunds are also feasible in the hilly areas of all the districts.

The volume of surface water required for recharge augmentation in identified areas of the state is 1520 MCM. Based on the geomorphological and hydrogeological settings, the feasibility of artificial recharge through different structures has been assessed. The number of structures of each category required to facilitate the recharge in each district has been computed accordingly. Based on local enquires, it has been gathered that about 34300 artificial recharge structures of different types have already been constructed by various agencies under various schemes. The net number of recharge structures in each district has been arrived at by deducting the number of structures constructed from the number of structures feasible.

The details of unit capacity and unit cost of each type of artificial recharge structure proposed are furnished below.

Table 8.12.1- Details of unit capacity and unit cost of each type of artificial recharge structure, Kerala

Sl No	Type of AR Structure	Unit Capacity (MCM)	Unit Cost (Rs. in lakhs)
1	Check Dam	0.033	20.0
2	Percolation Pond	0.033	20.0
3	Sub-surface dyke	0.003	15.0
4	Gully Plugs	0.0001	0.15
5	Nala Bunds/Gabions	0.00225	2.0
6	Contour Bund	0.00075	2.0

In view of the pattern of historical rainfall in Kerala, the structures proposed are expected to have 3 fillings a year and the total quantum of water recharged through each type of structure has been computed accordingly.

8.12.5 AREA BENEFITED

The impact of artificial recharge to ground water shall be felt mainly in the downstream side of the recharge structures, except in the case of sub-surface dykes. This area will normally be highest during the end of monsoon and distinct rise in ground water level will be observed as compared to other areas not receiving the artificial recharge. Rise in water levels in the range of 0.5 to 2 m is expected depending on the quantity of recharge and variation in specific yield. This will also result in saving of energy due to reduction in suction heads of pump sets. The augmentation of ground water resources available in shallow aquifers will also facilitate development of additional irrigation potential in the area, the extent of which will depend on the local geomorphology and the cropping pattern.

8.12.6 ARTIFICIAL RECHARGE OF DEEPER AQUIFERS

Deep confined aquifers in zones below 100 m.bgl constitute important sources of water supply in Alappuzha and Kollam districts of Kerala. Continued extraction of groundwater for various uses from these aquifers over the last several years has resulted in the decline of piezometric heads and de-saturation of productive zones in these aquifers. Augmentation of recharge into these aquifers through suitable techniques will help bring up the piezometric heads in these aquifers and in sustainable development of these aquifers.

Based on the studies carried out by CGWB elsewhere in the country, injection wells for recharging surface runoff has been considered as the most suitable structures for artificial recharge of these aquifers. However, quantification of surface runoff required for recharge has not been computed for want of detailed information pertaining to the intake capacities of these aquifers and long-term decline of piezometric heads in the aquifers. In view of this, it is proposed to implement schemes for recharge augmentation of the deeper sedimentary aquifers in Alappuzha and Kollam districts on pilot basis. More recharge structures could be constructed after studying the impact of the pilot scheme. The details of injection wells proposed to be constructed are furnished below:

Table -8.12.2 Injection wells proposed in Kerala

S. No.	District	Area (sq.km)	Area identified for recharge (sq.km)	No. of Injection wells proposed		
				Depth (m)	Number	Cost (Rs.in lakhs)
1	Alappuzha	1398	1000	100	20	100.00
				200	10	80.00
2	Kollam	2497	500	100	10	50.00
				200	5	40.00
TOTAL					**45**	**270.00**

8.12.7 ROOF TOP RAIN WATER AND RUNOFF HARVESTING IN URBAN ARES

It has been assessed that roof top rain water harvesting can be adopted in 3.15 Lakhs houses, govt. buildings, institutes etc. in urban and municipal areas of the state suitable for artificial recharge in the first phase. It will harness 181.44 MCM rain water to augment ground water resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a building having roof and paved area of ~ 200 sq.m. has been assessed to be Rs. 10,000/- and for bigger buildings having more than 1000 sq.m. will be Rs. 1.0 lakhs. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 456.75 Crores in the first phase considering 5% of the total buildings having larger roofs.

8.12.8 IMPLEMENTATION OF ARTIFICIAL RECHARGE SCHEMES

The surface water availability and the number of recharge structures feasible as mentioned in the foregoing sections have been computed for the district as a whole. Implementation of recharge schemes in an area will require detailed studies for assessing the source water availability, requirement and design criteria of recharge structures depending on local conditions and requirements. It may also be necessary to modify standard designs of common recharge augmentation structures to suit local conditions. For example, in the mid land areas with thick laterite capping, the hard upper crust needs to be removed to facilitate recharge into the underlying aquifers. Similarly, areas vulnerable to landslides, especially in Idukki and Wayanad districts are to be excluded while selecting locations suitable for contour bunding / check dams. The cost of structures constructed will also vary depending upon the local availability of construction material and topographic settings.

8.12.9 TOTAL COST

The total cost of implementation of the artificial recharge schemes including roof top rain water harvesting systems in the state of Kerala will be about Rs. 5914.47 crores.

Table 8.12.3. District-wise details of Artificial Recharge Structures in Kerala

S. No.	District name	Area of district (sq.km)	Average post monsoon depth to water (bgl)	Area feasible for artificial recharge (sq.km)	Volume of unsaturated zone available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of surplus local/distant source available for recharge (MCM)	Types of artificial recharge structures feasible and their numbers (Excluding structures constructed by various agencies)		Unit cost (Rs. in lakh)	Total costs (unit cost x number) (Rs. in lakh)
1	Alappuzha	1398	0.0	0	0	0	0	CD	0	20	0
								P	0	20	0
								SSD	0	15	0
								GP	0	0.15	0
								NB	0	2	0
								CB	0	2	0
2	Ernakulam	2966	6.2	711	2261	90	621	CD	208	20	4160
								P	158	20	3160
								SSD	49	15	735
								GP	30154	0.15	4523
								NB	3586	2	7172
								CB	5829	2	11658
3	Idukki	4380	6.0	541	1623	43	1066	CD	61	20	1220
								P	56	20	1120
								SSD	24	15	360
								GP	28075	0.15	4211
								NB	1739	2	3478
								CB	3647	2	7294
4	Kannur	2958	7.9	1137	5515	221	2118	CD	522	20	10440
								P	507	20	10140
								SSD	123	15	1845
								GP	74205	0.15	11131
								NB	7343	2	14686
								CB	14206	2	28412
5	Kasargod	1972	10.0	851	5924	237	1710	CD	429	20	8580
								P	533	20	10660
								SSD	132	15	1980
								GP	79941	0.15	11991
								NB	7926	2	15852
								CB	20464	2	40928
6	Kollam	2497	6.2	574	1859	74	974	CD	168	20	3360
								P	158	20	3160
								SSD	39	15	585
								GP	25028	0.15	3754
								NB	2995	2	5990
								CB	3205	2	6410
7	Kottayam	2211	5.8	500	1395	47	449	CD	84	20	1680
								P	93	20	1860
								SSD	26	15	390
								GP	15275	0.15	2291
								NB	1622	2	3244
								CB	3933	2	7866
8	Kozhikode	2342	6.2	662	2112	70	597	CD	127	20	2540
								P	122	20	2440
								SSD	39	15	585
								GP	34870	0.15	5231
								NB	2457	2	4914
								CB	6057	2	12114

S. No.	District name	Area of district (sq.km)	Average post monsoon depth to water (bgl)	Area feasible for artificial recharge (sq.km)	Volume of unsaturated zone available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of surplus local/distant source available for recharge (MCM)	Types of artificial recharge structures feasible and their numbers (Excluding structures constructed by various agencies)		Unit cost (Rs. in lakh)	Total costs (unit cost x number) (Rs. in lakh)
9	Malappuram	3572	6.4	1258	4291	143	756	CD	259	20	5180
								P	317	20	6340
								SSD	79	15	1185
								GP	48557	0.15	7284
								NB	4997	2	9994
								CB	12213	2	24426
10	Palakkad	4513	6.1	1408	4379	146	1424	CD	260	20	5200
								P	319	20	6380
								SSD	76	15	1140
								GP	72414	0.15	10862
								NB	4840	2	9680
								CB	9231	2	18462
11	Pathanamthitta	2664	7.1	392	1623	54	1318	CD	127	20	2540
								P	89	20	1780
								SSD	30	15	450
								GP	17434	0.15	2615
								NB	1773	2	3546
								CB	4659	2	9318
12	Thrissur	3041	6.6	1171	4251	142	2788	CD	266	20	5320
								P	261	20	5220
								SSD	79	15	1185
								GP	70207	0.15	10531
								NB	4688	2	9376
								CB	12095	2	24190
13	Trivandrum	2186	7.4	961	4217	169	1027	CD	376	20	7520
								P	356	20	7120
								SSD	89	15	1335
								GP	51417	0.15	7713
								NB	8247	2	16494
								CB	3649	2	7298
14	Wayanad	2135	7.6	684	3158	84	2829	CD	145	20	2900
								P	140	20	2800
								SSD	47	15	705
								GP	38702	0.15	5805
								NB	2744	2	5488
								CB	6985	2	13970
State Total		**38835**		**10849**	**42607**	**1520**	**17678**	CD	**3032**	**20**	**60640**
								P	**3109**	**20**	**62180**
								SSD	**832**	**15**	**12480**
								GP	**586279**	**0.15**	**87942**
								NB	**54957**	**2**	**109914**
								CB	**106173**	**2**	**212346**

8.13 MADHYA PRADESH

Madhya Pradesh is a land locked State located in the central part of India. It has a geographical area of 3,08,144 Sq. km. There are 50 districts and 313 Community Development blocks in Madhya Pradesh. The population of state as per census 2011 is 7, 25, 97,565 with a population density of 236 persons per sq.km area. Out of total population, 74.7% is rural. The important urban areas in the State are Bhopal, Indore, Jabalpur, Ujjain and Gwalior. Dhupgarh in Pachmarhi is the highest point in the state.

Madhya Pradesh is drained by five major river basins namely Ganga, Narmada, Godavari, Tapi and Mahi. These basins are divided into 11 sub basins and further sub divided into 155 major watersheds out of which 6 watersheds in Son and Narmada sub-basin falls partly in adjoining Chhattisgarh State.

8.13.1 IDENTIFICATION OF FEASIBLE AREAS

Based on National Hydrograph Monitoring Wells data, two maps were prepared. A district wise base map showing administrative boundary and post monsoon depth to water level (2010) zones varying from 0-3, 3-6, 6-9 and more than 9 meters below ground level is prepared and given as Fig 4 and the other district wise base map showing administrative boundary and post monsoon depth to water level (2010) zones varying from 0-3, 3-6, 6-9 and more than 9 meters below ground level with post monsoon declining trend of >0.10 meters/year for 10 years from 2001 to 2010 were prepared to visualize and identify the feasible areas. Areas showing depth to water level between 0 and 3 m bgl have not been considered for computing the potential zones available for recharge.

Based on the information mentioned above the area suitable for artificial recharge has been segregated into two categories as follows:

- Depth to water level < 3 m bgl and declining trend of 0.10 m /year.
- Depth to water level more than > 3 m bgl and declining trend of 0.10 m /year.

The areas of above two categories are demarcated on base map. The areas with water level more than 3 mbgl and declining trend of more than 0.1 m/yr are identified for artificial recharge to ground water and are shown in fig. 8.13.1.

8.13.2 ESTIMATION OF AVAILABLE SUB SURFACE STORAGE POTENTIAL

The thickness of available unsaturated zone (below 3 m bgl) of above categories is estimated by considering the different ranges of water level. The total volume of unsaturated zone is calculated by considering the above categories and unsaturated thickness of different range. This volume was then multiplied by average specific yield i.e. 1.5% for hard rock and 10% for alluvium on area specific basis to arrive at the net amount of water required which is to be recharged by artificial recharge to saturate the aquifer up to 3 m bgl.

8.13.3 SURFACE WATER REQUIREMENT

After assessing the volume of water required for saturating the unsaturated zone, the actual requirement of source water is to be estimated. Based on the experience gained in the field experiments, an average recharge efficiency of 75% of the individual structure is only possible. Therefore, to arrive at the total volume of actual source water required at the surface, the volume of water required for artificial recharge calculated is multiplied by 1.33 (i.e. reciprocal of 0.75).

8.13.4 SOURCE WATER AVAILABILITY FOR ARTIFICIAL RECHARGE

The availability of non-committed source water is one of the main requirements for any artificial recharge scheme. The surplus non-committed monsoon runoff can be utilized as source water for artificial recharge schemes. The rainfall received during southwest monsoon between June and September is the principal source of water in the state of Madhya Pradesh.

The surface water resources have been calculated district wise by considering Strange's Table showing depth of runoff as percentage of total monsoon rainfall and yield of runoff per square kilometer in mcm for average catchment. Out of 99785.90 MCM available surface water, 16869.49 MCM is committed to large dams; basin wise details are given in table 8.13.1.

Table 8.13.1: *Basin wise committed surface water in Madhya Pradesh (Large Dams)

S. No.	Basin	Effective Capacity of Reservoirs (MCM)
1	Chambal-Betwa	748.88
2	Yamuna	841.91
3	Dhasan-Ken	506.65
4	Ganga	413.89
5	Wainganga	1120.69
6	Narmada-Tapti	7820.42
7	Tawa	139.50
8	Narmada	2070.94
9	Rajghat	845.08
10	Bansagar	637.00
11	Others	1724.55
	Total	**16869.49**

*Data Source: Resource Atlas Madhya Pradesh: MPCST

Considering the above data the source water availability does not appear to be a constraint to plan the artificial recharge schemes in the state. Many recharge structures would normally be using the surface flow generated in the Ist to IIIrd order drainage. Some of the recharge schemes i.e. recharge shaft etc. would be generating the additional recharge to ground water through direct recharge to aquifer thereby reducing the soil moisture losses.

8.13.5 PLANNING OF SUITABLE RECHARGE STRUCTURES

Hydrogeologically, the areas have been broadly grouped into hard rock and alluvial areas. In hard rock areas the surface spreading techniques consisting of percolation tanks and check dams/cement plugs/nala bunds along with recharge shafts are most appropriate. In alluvial areas the percolation tanks in mountain fronts are most suitable. Recharge shaft in check dam will facilitate direct recharge to the ground water regime. Accordingly these structures have been recommended for artificial recharge.

Other structures like contour trenches and gabion structure etc. may also be taken up side-by-side, which would be more appropriate for soil and moisture conservation. The underground bhandaras or sub surface dykes are ground water conservation structures and hence may be taken up at site specific location to conserve the ground water at technically suitable locations.

8.13.6 STORAGE CAPACITY OF RECHARGE STRUCTURES

The storage capacity of recharge structure was worked out based on the findings of various artificial recharge studies under taken in Madhya Pradesh. Depending upon the rainfall pattern during the monsoon season, 3 to 4 fillings of the structures are considered to arrive at the storage capacity of the structure.

1. A percolation tank of 0.1million cubic meter capacity (single filling) will actually store more than 300% due to multiple fillings during monsoon. This will have gross storage capacity of 0.35 MCM.

2. A check dam with recharge shaft, of 0.01 MCM capacity (single filling) will actually store more than 300% due to multiple filling in monsoon. This will provide gross storage of 0.030 MCM. The recharge shaft will facilitate additional recharge to the ground water regime.

3. A cement plug will store more than 300% due to multiple filling in monsoon and it will provide gross storage of 0.02 MCM.

4. A nala bund will store more than 300% due to multiple filling in monsoon. This will provide gross storage of 0.01MCM in multiple fillings.

8.13.7 NUMBER OF RECHARGE STRUCTURES:

The number of recharge structures required to store and recharge the ground water reservoir has been worked out as follows:

$$\text{No. of structures} = \frac{\text{Total surface water considered}}{\text{Average gross capacity of P/CP/CD/NB (Considering multiple fillings)}}$$

The amount of surface water considered for planning the artificial recharge is 15280.15 MCM. Based on the field situation it has been considered that 35% storage would be through percolation tank, 45% by check dams, 15% by nala bunds and remaining 5% by cement plug. Accordingly 35% of it i.e. 5348 MCM will be stored in percolation tanks, 45% of it i.e., 6876.07 MCM to be stored in check dams, 15% of it i.e., 2292.02 mcm to be stored in nala bunds and remaining 5% i.e., 764.01 mcm to be stored in Cement plugs. Therefore, 15284 percolation tanks, 125019 check dams, 38200 cement plugs and 229202 nala bunds are proposed in the identified areas of Madhya Pradesh.

One recharge shaft in each check dam has been proposed for effective recharge through these structures. Therefore, 125019 recharge shafts are proposed. The percolation tanks should be constructed on second and third order drainage, on favorable hydrogeological and physiographical locations. The nala bunds/ cement plugs can be constructed on II^{nd} or III^{rd} order of drainage in hard rock areas.

8.13.8 COST ESTIMATES

Based on the experiences gained from central sector scheme, “Study of artificial recharge to Ground Water”, it is observed that the cost of recharge schemes depends upon the site-specific conditions. The average cost of construction of a percolation tank is considered around Rs. 18 lakhs. The cost of masonry check dam considered is Rs. 4 lakhs. The cost of cement plug considered is Rs. 1 lakh. The average cost of one recharge shaft considered is Rs. 60 thousand. The average cost of nala bund considered is Rs 80 thousand lakhs. However, the costs may vary from area to area depending upon site-specific conditions. Therefore, an expenditure of Rs. 10,717.60 Corers is estimated to undertake the constructions of proposed recharge structures (Table 8.13.2).

However, it is pertinent to note that expenditure of Rs. 3148.27 crores have been incurred under Jal Abhishek Abhiyan, Rajiv Gandhi Watershed Mission, Government of Madhya Pradesh, during the period from 2006 to 2010 for water conservation and ground water recharge.

8.13.9 ROOF TOP RAIN WATER HARVESTING:

It has been assessed that roof top rain water harvesting can be adopted in ~ 6.0 lakh houses, govt. buildings, institutes etc. in urban and municipal areas of the state suitable for artificial recharge in the first phase. It will harness 103.39 MCM rain water to augment ground water resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a building having roof and paved area of ~ 200 sq.m. has been assessed to be Rs. 12,000 and for bigger buildings having more than 1000 sq.m. will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs.984 crores in the first phase considering 5% of the total buildings having larger roofs.

8.13.10 TOTAL COST:

Total cost of the recharge structures and rain water harvesting in Madhya Pradesh is estimated as Rs. 11701.60 crores.

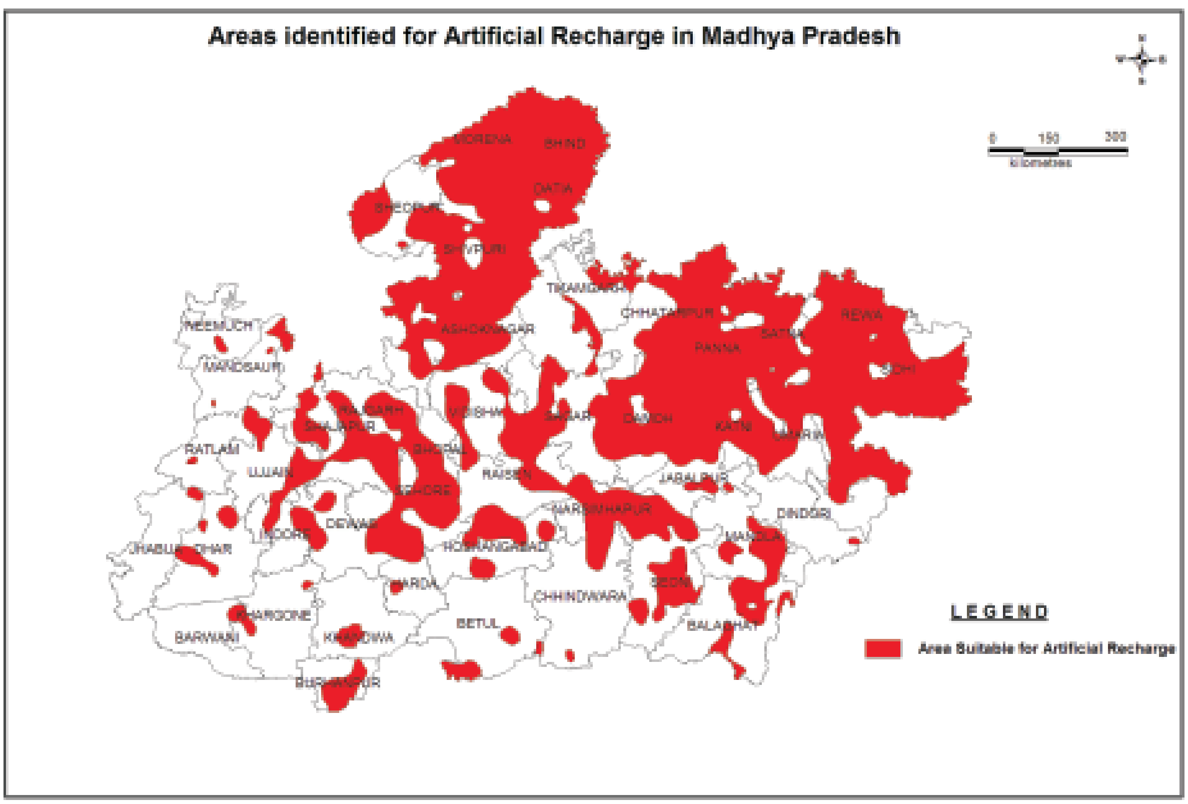


Fig.8.13.1 Areas suitable for Artificial Recharge in Madhya Pradesh

8.13.2: Cost estimates for proposed district wise ground water recharge plan, Madhya Pradesh

S. No.	District	Area of district (sq.km)	Average post monsoon depth to water level (m)	Area Suitable for AR (sq. km)	Volume of unsaturated zone available for recharge (MCM)	Volume of Surface Water available for AR (MCM)	Volume of Water required for recharge (MCM)	Proportionate Surface water for planning AR (MCM)	Types of Artificial recharge structures feasible and their numbers	Unit Cost (Rs. in Crores)	Total Costs (Unit cost x number) (Rs. in Crores)
1	2	3	4	5	6	7	8	9	10	11	12
1	Alirajpur	3349.4	5.79	21	1.89	608.93	2.51	2.51	PT 03 CD 21 RS 21 NB 38 CP 06	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 0.54 CD 0.84 RS 0.13 NB 0.30 CP 0.06
2	Anooppur	3724.0	6.23	994.8	83.33	1195.24	110.83	110.83	PT 111 CD 907 RS 907 NB 1662 CP 277	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 19.98 CD 36.28 RS 05.44 NB 13.30 CP 0 2.77
3	Ashoknagar	4673.9	8.16	3454.21	340.40	855.73	452.73	452.73	PT 453 CD 3704 RS 3704 NB 6791 CP 1132	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 81.54 CD 148.16 RS 22.22 NB 54.33 CP 11.32
4	Balaghat	9266.0	5.29	2347	166.11	4503.25	220.93	220.93	PT 221 CD 1808 RS 1808 NB 3314 CP 552	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 39.78 CD 72.32 RS 10.85 NB 26.51 CP 05.52
5	Badwani	4584.0	7.04	237.76	28.53	488.11	37.95	37.95	PT 38 CD 310 RS 310 NB 569 CP 95	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 06.84 CD 12.40 RS 01.86 NB 04.55 CP 00.95
6	Betul	10043.0	6.3	821	53.98	2314.97	71.79	71.79	PT 72 CD 587 RS 587 NB 1077 CP 179	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 00.01	PT 12.96 CD 23.48 RS 03.52 NB 08.61 CP 01.79

1	2	3	4	5	6	7	8	9	10	11	12
7	Bhind	4459.0	17.24	4598.12	2695.58	524.90	3585.12	524.90	PT 525 CD 4295 RS 4295 NB 7873 CP 1312	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 94.50 CD 171.80 RS 25.77 NB 62.99 CP 13.12
8	Bhopal	2772.4	8.49	1338.35	94.05	797.95	125.08	125.08	PT 125 CD 1023 RS 1023 NB 1876 CP 313	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 22.50 CD 40.92 RS 06.14 NB 15.01 CP 03.13
9	Burhanpur	2722.0	11.34	1297.74	116.69	415.53	155.19	155.19	PT 155 CD 1270 RS 1270 NB 2328 CP 388	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 27.90 CD 50.80 RS 07.62 NB 18.62 CP 03.88
10	Chhatarpur	8630.0	7.24	4325.83	289.20	2035.35	384.64	384.64	PT 385 CD 3147 RS 3147 NB 5770 CP 962	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 69.30 CD 125.88 RS 18.88 NB 46.16 CP 09.62
11	Chhindwara	11815.0	7.01	931.23	74.62	2526.93	99.24	99.24	PT 99 CD 812 RS 812 NB 1489 CP 248	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 17.82 CD 32.48 RS 04.87 NB 11.91 CP 02.48
12	Damoh	7306.0	5.35	3807.36	151.95	1710.51	202.10	202.10	PT 202 CD 1654 RS 1654 NB 3031 CP 505	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 36.36 CD 66.16 RS 09.92 NB 24.25 CP 05.05
13	Datia	2690.0	12.02	2491.01	959.80	399.77	1276.53	399.77	PT 400 CD 3271 RS 3271 NB 5997 CP 999	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 72.00 CD 130.84 RS 19.63 NB 47.97 CP 09.99
14	Dewas	6980.0	7.77	1796.65	152.45	1504.20	202.75	202.75	PT 203 CD 1659 RS 1659 NB 3041 CP 507	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 36.54 CD 66.36 RS 09.95 NB 24.33 CP 05.07
15	Dhar	8153.0	8.02	1005.28	102.72	1313.67	136.62	136.62	PT 137 CD 1118 RS 1118 NB 2049 CP 342	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 24.66 CD 44.72 RS 06.71 NB 16.39 CP 03.42

1	2	3	4	5	6	7	8	9		11	12
16	Dindori	5725.0	3.59	48	5.76	1938.31	7.66	7.66	PT 08 CD 63 RS 63 NB 115 CP 19	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 01.44 CD 02.52 RS 00.38 NB 00.92 CP 00.19
17	Guna	6378.0	8.15	2384.22	190.46	1669.13	253.31	253.31	PT 253 CD 2073 RS 2073 NB 3800 CP 633	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 45.54 CD 82.92 RS 12.44 NB 30.40 CP 06.33
18	Gwalior	5214.0	11.34	1967.22	319.18	695.44	424.51	424.51	PT 425 CD 3473 RS 3473 NB 6368 CP 1061	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 76.50 CD 138.92 RS 20.84 NB 50.94 CP 10.61
19	Harda	3650.0	8.01	266.06	81.60	1411.12	108.52	108.52	PT 109 CD 888 RS 8 88 NB 1628 CP 271	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 19.62 CD 35.52 RS 05.33 NB 13.02 CP 02.71
20	Hoshangabad	6654.0	6.75	1611.65	778.02	2373.37	1034.77	1034.77	PT 1035 CD 8466 RS 8466 NB 15521 CP 2587	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 186. 30 CD 338.64 RS 50.80 NB 124.17 CP 25.87
21	Indore	3898.0	8.38	210.5	24.50	815.63	32.58	32.58	PT 33 CD 267 RS 267 NB 489 CP 81	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 05.94 CD 10.68 RS 01.60 NB 03.91 CP 00.81
22	Jabalpur	5266.9	5.44	2031.3	598.04	1722.27	795.39	795.39	PT 795 CD 6508 RS 6508 NB 11931 CP 1988	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 143.10 CD 260.32 RS 39.05 NB 95.45 CP 19.88
23	Jhabua	3464.0	4.58	186.72	17.99	500.53	23.92	23.92	PT 24 CD 196 RS 196 NB 359 CP 60	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 04.32 CD 07.84 RS 01.18 NB 02.87 CP 00.60
24	Katni	4894.0	6.98	2229.35	120.48	1485.25	160.23	160.23	PT 160 CD 1311 RS 1311 NB 2404 CP 401	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 28.80 CD 52.44 RS 07.87 NB 19.23 CP 04.01

1	2	3	4	5	6	7	8	9	10	11	12
25	Khandwa	7524.0	6.29	502.6	30.16	1158.44	40.11	40.11	PT 40 CD 328 RS 328 NB 602 CP 100	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 07.20 CD 13.12 RS 01.97 NB 04.81 CP 01.00
26	Khargone	8866.0	6.53	301.65	24.72	1045.71	32.88	32.88	PT 33 CD 269 RS 269 NB 493 CP 82	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 05.94 CD 10.76 RS 01.61 NB 03.95 CP 00.82
27	Mandla	7544.0	4.47	2297.02	181.05	2666.95	240.80	240.80	PT 241 CD 1970 RS 1970 NB 3612 CP 602	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 43.38 CD 78.80 RS 11.82 NB 28.90 CP 06.02
28	Mandsaur	5523.2	9.1	510.52	45.38	866.73	60.35	60.35	PT 60 CD 494 RS 494 NB 905 CP 151	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 10.80 CD 19.76 RS 02.96 NB 07.24 CP 01.51
29	Morena	4928.9	15.24	4530.61	1964.14	524.77	2612.31	524.77	PT 525 CD 4294 RS 4294 NB 7871 CP 1312	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 94.50 CD 171.76 RS 25.76 NB 62.97 CP 13.12
30	Narsinghpur	5133.0	9.57	3510.75	211.57	1681.93	281.39	281.39	PT 281 CD 2302 RS 2302 NB 4221 CP 703	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 50.58 CD 92.08 RS 13.81 NB 33.77 CP 07.03
31	Neemuch	4000.4	8.22	175.84	21.10	607.41	28.06	28.06	PT 28 CD 230 RS 230 NB 421 CP 70	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 05.04 CD 09.20 RS 01.38 NB 03.37 CP 00.70
32	Panna	7135.0	6.19	4087.77	248.07	2110.53	329.94	329.94	PT 330 CD 2699 RS 2699 NB 4949 CP 825	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 59.40 CD 107.96 RS 16.19 NB 39.59 CP 08.25
33	Raisen	8467.4	6.4	2381.6	218.18	985.66	290.19	290.19	PT 290 CD 2374 RS 2374 NB 4353 CP 725	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 52.20 CD 94.96 RS 14.24 NB 34.82 CP 07.25

1	2	3	4	5	6	7	8	9	10	11	12
34	Rajgarh	6155.0	8.26	3670.8	403.79	1392.57	537.04	537.04	PT 537 CD 4394 RS 4394 NB 8056 CP 1343	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 96.66 CD 175.76 Rs 26.36 NB 64.44 CP 13.43
35	Ratlam	4861.0	8.8	557.84	66.94	1044.37	89.03	89.03	PT 89 CD 728 RS 728 NB 1335 CP 223	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 16.02 CD 29.12 RS 04.37 NB 10.68 CP 02.23
36	Rewa	6313.6	8.41	6126.6	457.79	1670.25	608.86	608.86	PT 609 CD 4982 RS 4982 NB 9133 CP 1522	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 109.62 CD 199.28 RS 29.89 NB 73.06 CP 15.22
37	Sagar	10252.0	6.92	4487.11	444.84	3264.21	591.64	591.64	PT 592 CD 4841 RS 4841 NB 8875 CP 1479	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 106.56 CD 193.64 RS 29.05 NB 71.00 CP 14.79
38	Satna	7520.3	6.78	5718.95	503.38	1716.79	669.49	669.49	PT 669 CD 5478 RS 5478 NB 10042 CP 1674	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 120.42 CD 219.12 RS 32.87 NB 80.34 CP 16.74
39	Sehore	6578.0	7.03	2444.82	154.63	29402.28	205.66	205.66	PT 206 CD 1683 RS 1683 NB 3085 CP 514	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 37.08 CD 67.32 RS 10.10 NB 24.68 CP 05.14
40	Seoni	8758.0	5.14	3055.25	217.20	2973.14	288.88	288.88	PT 289 CD 2364 RS 2364 NB 4333 CP 722	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 52.02 CD 94.56 RS 14.18 NB 34.67 CP 07.22
41	Shahdol	5765.0	6.2	3885.47	411.76	1345.55	547.63	547.63	PT 548 CD 4481 RS 4481 NB 8215 CP 1369	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 98.64 CD 179.24 RS 26.89 NB 65.72 CP 13.69
42	Shajapur	6145.2	9.17	2450.4	239.58	1420.94	318.64	318.64	PT 319 CD 2607 Rs 2607 NB 4780 CP 797	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 57.42 CD 104.28 RS 15.64 NB 38.24 CP 07.97

1	2	3	4	5	6	7	8	9	10	11	12
43	Sheopur	6666.0	10.19	2137.9	328.27	862.40	436.60	436.60	PT 437 CD 3572 RS 3572 NB 6549 CP 1092	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 78.66 CD 142.88 RS 21.43 NB 52.39 CP 10.92
44	Shivpuri	10278.0	8.79	9533	808.47	1947.88	1075.26	1075.26	PT 1075 CD 8798 RS 8798 NB 16129 CP 2688	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 193.50 CD 351.92 RS 52.79 NB 129.03 CP 26.88
45	Sidhi	4854.0	9.19	4281.08	417.48	751.12	555.25	555.25	PT 555 CD 4543 RS 4543 NB 8329 CP 1388	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 99.90 CD 181.72 RS 27.26 NB 66.63 CP 13.88
46	Singrauli	5672.0	8.83	5005.96	556.91	677.69	740.69	677.69	PT 678 CD 5545 RS 5545 NB 1016 CP 1694	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 122.04 CD 221.80 RS 33.27 NB 81.32 CP 16.94
47	Tikamgarh	5048.0	7.01	1397	97.88	1246.77	130.17	130.17	PT 130 CD 1065 RS 1065 NB 1953 CP 325	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 23.40 CD 42.60 RS 06.39 NB 15.62 CP 03.25
48	Ujjain	6130.2	8.47	1305.31	136.14	1181.49	181.06	181.06	PT 181 CD 1481 RS 1481 NB 2716 CP 453	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 32.58 CD 59.24 RS 08.89 NB 21.73 CP 04.53
49	Umaria	4539.0	6.24	2109	211.82	1412.92	281.73	281.73	PT 282 CD 2305 RS 2305 NB 4226 CP 704	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 50.76 CD 92.20 RS 13.83 NB 33.81 CP 07.04
50	Vidisha	7371.0	6.9	2541.33	217.37	2021.30	289.10	289.10	PT 89 CD 2365 RS 2365 NB 4336 CP 723	PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01	PT 52.02 CD 94.60 RS 14.19 NB 34.69 CP 07.23
	Total	**308339.8**	**7.82**	**119409**	**16065.9**	**99785.9**	**21367.7**	**15280**	**PT 15284 CD 125019 RS 125019 NB 229202 CP 38200**	**PT 0.18 CD 0.04 RS 0.006 NB 0.008 CP 0.01**	**PT 2751.12 CD 5000.80 RS 750.14 NB 1833.62 CP 382.00**

8.14 MAHARASHTRA

Maharashtra State covers an area of 3,07,713 sq.km.and comprises of 35 districts and 357 taluks. There are 322394 inhabited villages. The population of state is 112.3 million as per 2011 census. The State experiences south west monsoon with rainfall ranging from 6000 mm in Western Ghats to less than 500 mm in Madhya Maharashtra. The eastern part of Maharashtra, known as Vidharba Region, receives rainfall up to 1500 mm. Geographical area of Maharashtra falls in four major basins namely Godavari (49%), Krishna (22.6%), Tapi-Purna (16.7%) and west flowing small rivers known as Coastal river basin.

8.14.1 IDENTIFICATION OF AREA

Identification and prioritization of need based areas for artificial recharge to ground water is based on long term (decadal) monsoon (August) depth to water level. The areas with depth to water level between 5 and 7 m bgl and areas with water level more than 7 m bgl were identified as feasible areas for artificial recharge. Estimation of sub surface storage space available for artificial recharge below 5 m bgl was done by considering the different ranges of water level as above.

Quantification of surface water requirement and surplus annual run off availability as source water for artificial recharge in each district based on proportionate basin area was calculated. Basin wise available surface run off has been considered for working out the number of feasible structures for artificial recharge to have maximum benefit 70% of the available surface water is allocated for construction of percolation tanks and remaining 30% for construction of check dams/cement nala bunds in hard rock areas and recharge shafts in soft rock areas. The estimated storage space and available source water for recharge were considered for working out type of suitable recharge structures, their numbers, storage capacity and efficiency.

The capacity of recharge structures is worked out based on the findings of various artificial recharge studies undertaken in different districts and the same was used for planning the recharge structures. The storage capacity for different structures considering multiple fillings is worked out as 200 TCM (100 TCM for single filling) for percolation tanks, 30 TCM (10 TCM for single filling) for check dams and 60 TCM (1 TCM/day*60 days) for recharge shafts.

An area of 13,00,11 sq.km. had been identified for artificial recharge in 35 districts of Maharashtra State. The district wise area identified for artificial recharge measures is given in Table-8.14.1 and Fig.8.14.1 to 8.14.5.

The plan for artificial recharge has been prepared considering the hydrogeological parameters and hydrological data base.

8.14.2 SUB-SURFACE STORAGE AND WATER REQUIREMENT

The thickness of available unsaturated zone (below 5 m bgl) is estimated by considering the different ranges of water level i.e., 5 to 7 m bgl and more than 7 m bgl. The different range of depth to water level is averaged to arrive at thickness of unsaturated zone effectively. The total volume of unsaturated strata is calculated as 2,60,022 MCM. This volume was then multiplied by average specific yield i.e. 2% (0.020) in hard rock areas and 7.0% (0.07) in soft rock areas to arrive at 6,355 MCM of water required for artificial recharge. However, based on the experiences gained in the field experiments, an average recharge efficiency of 75% of the individual structure is only possible. Therefore, to arrive at the total volume of actual source water required at the surface, the volume of water required for artificial recharge has been multiplied by 1.33 (i.e. reciprocal of 0.75). About 8474 MCM is required as source water to bring water level up to 5 mbgl.

8.14.3 SOURCE WATER AVAILABILITY

The surface water resources available in various basins & sub basins were based on information provided by the state government. The data available for each sub basin included committed runoff, reserved for future planning and surplus water available. Considering the water as single entity for surface and ground water resource planning the availability of source water is worked out by adding the amount of surface water provided for future planning and surplus available. This availability so worked out is for the entire sub basin and not for the requirement of the areas identified for artificial recharge. Hence, to account for the requirement of identified area, district wise apportioning of surface water availability was done. For planning the artificial recharge structures in each district of Maharashtra, the amount of proportionate surplus runoff/surface water availability in the targeted area and storage volume was matched to arrive at the feasibility of the scheme.

A total of 12308 MCM run off/surface water is available in the State and can be utilized for artificial recharge, however after proportioning it for the target area of 1,30,011 sq. km, the surface water availability comes out to be 3,167 MCM. Invariably the proportionate surface water availability is less (3,167 MCM) and the storage volume or requirement of surface water for artificial recharge is more (8,473 MCM). However, in coastal districts of Maharashtra the availability of source water is more and the requirement for artificial recharge is less due to shallow ground water level conditions. Thus the proportionate surface water availability for artificial recharge is 2846 MCM for the state.

8.14.4 RECHARGE STRUCTURES AND COST ESTIMATES

Hydrogeologically, the areas have been broadly grouped into hard rock and alluvial areas. In hard rock areas i.e. Godavari, Krishna, Coastal basins and part of Tapi-Purna, the surface spreading techniques consisting of percolation tanks and cement plugs/bunds are most appropriate. In alluvial areas i.e. part of Tapi and Purna basins, the percolation tanks in mountain fronts and recharge shaft in alluvial/bazada zone are the most feasible structures. Accordingly these structures have been recommended for artificial recharge.

Other structures like contour trenches, gabion structure, nala bunds, village ponds etc. may also be taken up side by side which would be more appropriate for soil and moisture conservation. The underground bandharas or sub surface dykes are ground water conservation structures and hence can be taken up at site specific location to conserve the ground water.

The amount of surface water considered for planning the artificial recharge is 2846 MCM. Based on the field situation it has been considered that 70% storage would be through percolation tanks and remaining by check dams (hard rock areas) or recharge shafts (alluvial areas). Accordingly 1,992 MCM (70%) will be stored in percolation tanks, 808 MCM will be stored in cement plugs/check dams and 46 MCM through recharge shafts. Therefore, 9961 percolation tanks, 26924 check dams/cement plugs and 772 recharge shafts are proposed in the identified areas of Maharashtra.

The cost estimate for artificial recharge structures viz. percolation tank, cement plug and recharge shaft are worked out based on the experiences gained from artificial recharge studies under central sector scheme, it is observed that the cost of recharge schemes depends upon the specific situation. At present the average cost of construction of a percolation tank (100 TCM single filling storage capacity) is around Rs. 60 lakhs. The cost of cement plugs or masonry check dam of 10 TCM single filling capacity is Rs. 6.0 lakh. These costs were estimated as per the Irrigation Dept. Schedule of Rates (SOR). The average cost of one recharge shaft is Rs. 2.5 lakhs. Therefore, an expenditure of Rs. 7611.34 crores is estimated to undertake the construction of proposed recharge structures. The district wise plan of artificial recharge is given in Table 8.14.1.

8.14.5 AREA BENEFITED

The impact of artificial recharge to ground water shall be created mainly at the downstream side of recharge structures. It is estimated that the maximum influence of recharge schemes proposed in Master Plan would be distinctly observed in around 51,305 Sq.Km. area at the monsoon period. A rise of 1 to 3 m in water level shall be observed depending upon the quantity of recharge and variation in specific yield provided the present rate of ground water development remains the same. This will also result in saving of energy as the average suction lift of pump sets would be reduced by 1 to 3 m.

Though the impact of artificial recharge will be witnessed in around 51305 sq km., the entire area will not be brought under assured irrigation. Therefore the calculation of additional area to be brought under assured irrigation from the proposed recharge schemes has been done. Considering the prevailing cropping pattern the Delta factor of 0.5 m/year is adopted for further calculation.

It is estimated that a total of about 5691 sq. km. additional land can be brought under assured irrigation during rabi & kharif seasons. The scheme wise additional irrigation from percolation tanks, cement plugs and recharge shafts would be 3983.70 sq. km. 1615.55 sq. km. and 91.75 sq. km. respectively. This will also provide sustainability to the ground water round the year and remove the dependability on tanker water supply in proposed areas.

8.14.6 ROOF TOP RAIN WATER AND RUNOFF HARVESTING IN URBAN AREAS

Considering the overall demographic, climatic, hydrogeological, physiographic and socio-economic set up and quality of the source water available in the urban areas, following recharge techniques are proposed:

- Roof Top Rainwater Harvesting (RTRWH),
- Runoff Harvesting

8.14.6.1 Roof Top Rainwater Harvesting

It has been assessed that roof top rain water harvesting can be adopted in ~ 16 lakh houses, govt. buildings, institutes etc. in urban and municipal areas of the state suitable for artificial recharge in the first phase. It will harness 257.43 MCM rain water to augment ground water resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a building having roof and paved area of ~ 200 sq.m. has been assessed to be Rs. 12,000 and for bigger buildings having more than 1000 sq.m. will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs.2624 crores in the first phase considering 5% of the total buildings having larger roofs.

8.14.6.2 Runoff Water Harvesting

The rainfall runoff flowing from the roads and open grounds is substantial during rains. This water often creates the water logging and the drainage system is put under stress in the urban agglomerates. A scheme suitable for artificial recharge in urban area is prepared by C.G.W.B and is successfully implemented and operated at Nagpur Municipal Corporation. In this scheme about 15000 sq.m of residential catchment was intercepted and runoff generated was diverted into the specially constructed recharge well in the public garden. The runoff water was filtered silt free by providing a filter pit. Number of such locations can be identified within city areas where such structure may be constructed to provide a sustainable ground water based water supply in the city.

It is estimated that in 378 urban areas of Maharashtra around 5,670 structures (recharge shafts) would be needed with an average of 15 schemes per town/city. The cost of each scheme will be around Rs. 2.5 lakh. Therefore an expenditure of Rs. 142 crores is estimated for taking up the scheme. It is estimated that more than 15 lakh additional urban population would get adequate water supply round the year by implementing the scheme in the urban areas.

8.14.7 RECHARGE IN HILLY AREAS

Maharashtra State covers an area of 3,07,713 sq.km., and about 15% of the state area is hilly. Thus, about 46,157 sq. km. can be categorized as hilly area. The Continuous Contour Trenches (CCT), loose boulder structures (gully plugs) are the most suitable structures for hilly area as these structures have proved their effectiveness in the schemes implemented by state govt. on pilot basis. Such structures will function initially as soil conservation structure and subsequently improve the soil moisture retention and also enhance the recharge to ground water, which in turn will support development of fauna and flora in the area. These structures will also improve sustainability of springs thereby improving water supply scenario in the small hamlets situated in hilly areas. The areas identified for recharge in hilly areas are shown in Fig.8.14.1. The estimated cost for 1500 structures @ Rs 1.0 lakh is Rs.15 crores.

8.14.8 RECHARGE IN COASTAL AREAS

Maharashtra State has a coast line of about 700 kms. along the west coast adjoining Arabian Sea. In the coastal areas, the salinity affected area is restricted to coastal alluvial aquifer comprising of silt, sand, gravel and clay and occupy vary limited area in parts of Thane and Raigarh districts of the states, whereas in hard rock aquifers such problem is not observed along the coast line of the state. In the coastal areas nala bunds, cement plugs and earthen bandharas are the most suitable structures for artificial recharge. The areas identified for recharge in coastal areas are shown in Fig-8.14.2.The estimated cost for 8000 sturctures @ Rs 2.5 lakh is Rs.200 crores.

8.14.9 RECHARGE IN AREAS HAVING INLAND SALINITY

The Purna alluvial basin possesses unique features of inland salinity, spared over an area of 7500 km^2 in parts of Amravati, Akola and Buldhana districts of the state. About 2700 km^2 area of the basin is badly is affected by ground water salinity at both shallow and deeper depth. In the saline tract of the basin, few river terraces and buried channels (old river courses) are found, and one of it, is very well seen as old Shahnur River channel. These buried channels and river terraces are mainly consisting of sand, gravel & pebbles and holds fresh water in saline tract of basin. A series of nala bunds, cement plugs and earthen bandharas in these buried channels and dug well recharge in river terraces will help in building fresh water repositories in the area affected by inland salinity. Similarly the construction of nala bunds and percolation tanks in surrounding area of saline tract would also help in straightening the pipe water based water supply situation in area. The areas identified for recharge in inland salinity affected areas are shown in fig.8.14.3. The estimated cost for 4000 structures @ Rs 2.5 lakh is Rs.100 crores.

8.14.10 RECHARGE IN OVER-EXPLOITED AREAS BY RECHARGE CANALS

In Jalgaon district, Yaval and Raver are the 2 over-exploited talukas. In these talukas the recharge through canals from surplus surface water source can be taken up. The most feasible recharge structures in this area are recharge shafts and injection wells. The areas identified for recharge in over-exploited areas are shown in fig.8.14.4.

8.14.11 TOTAL COST

The total cost of the recharge structures proposed in rural and urban areas of the Maharashtra in the Plan is Rs. 10377.09 Crores. The additional expenditure for hilly areas, inland salinity and coastal areas is estimated to be Rs.315 crores. Thus the total expenditure comes to Rs.10692.09 crores.

Table-8.14.1 District wise Artificial Recharge to Ground Water by Suitable Artificial Recharge using Surface Water Resources, Maharashtra.

S.No.	District	Area identified for AR (WL>5)	Volume of surface water required for AR	Volume of surface water available for AR	Proportionate Surface water proposed for AR	Percolation Tanks (@ Rs.60 lakh, Av. Gross Capacity-200 TCM)		Check Dams (@ Rs.6 lakh, Av. Gross Capacity-30 TCM)		Recharge Shafts (@ Rs.2.5 lakh, Av. Gross Capacity-60 TCM)	
		(sq.km.)	(MCM)	(MCM)	(MCM)	No.	Cost (Rs. in crore)	No.	Cost (Rs. in crore)	No.	Cost (Rs. in crore)
1	AHMEDNAGAR	13003.70	693.53	300.52	300.52	1052	631.20	3005	180.30		
2	AKOLA	4583.68	521.40	47.79	47.79	167	100.20	261	15.66	109	2.73
3	AMRAVATI	6488.50	739.25	92.68	92.68	324	194.40	506	30.36	212	5.30
4	AURANGABAD	7479.57	398.91	156.85	156.85	549	329.40	1569	94.14		
5	BEED	4006.61	213.69	90.74	90.74	318	190.80	907	54.42		
6	BHANDARA	332.94	17.76	7.44	7.44	26	15.60	74	4.44		
7	BULDANA	5271.98	482.24	79.52	79.51	279	167.40	568	34.08	115	2.88
8	CHANDRAPUR	2236.82	119.30	50.01	50.01	175	105.00	500	30.00		
9	DHULE	4192.87	340.95	43.71	43.71	153	91.80	345	20.70	47	1.18
10	GADCHIROLI	1182.40	63.06	26.44	26.44	93	55.80	264	15.84		
11	GONDIA	10.80	0.57	0.24	0.24	1	0.60	2	0.12		
12	HINGOLI	978.83	52.20	21.88	21.88	77	46.20	219	13.14		
13	JALGAON	8317.96	793.49	86.72	86.72	304	182.40	594	35.64	138	3.45
14	JALNA	4731.06	252.32	105.78	105.78	370	222.00	1058	63.48		
15	KOLHAPUR	772.24	41.19	18.92	18.92	66	39.60	189	11.34		
16	LATUR	4959.58	264.51	110.89	110.89	388	232.80	1109	66.54		
17	MUMBAICITY	0.00	0.00	0.00	0.00	0	0.00	0	0.00		
18	MUMBAI SUBURBAN	0.00	0.00	0.00	0.00	0	0.00	0	0.00		
19	NAGPUR	3067.33	163.59	68.58	68.58	240	144.00	686	41.16		

S.No.	District	Area identified for AR (WL>5)	Volume of surface water required for AR	Volume of surface water available for AR	Proportionate Surface water proposed for AR	Percolation Tanks (@ Rs.60 lakh, Av. Gross Capacity-200 TCM)		Check Dams (@ Rs.6 lakh, Av. Gross Capacity-30 TCM)		Recharge Shafts (@ Rs.2.5 lakh, Av. Gross Capacity-60 TCM)	
		(sq.km.)	(MCM)	(MCM)	(MCM)	No.	Cost (Rs. in crore)	No.	Cost (Rs. in crore)	No.	Cost (Rs. in crore)
20	NANDED	5220.03	278.40	116.71	116.71	408	244.80	1167	70.02		
21	NANDURBAR	2896.94	315.30	41.03	41.03	144	86.40	240	14.40	86	2.15
22	NASHIK	6911.18	409.26	289.80	289.80	1015	609.00	2770	166.20	65	1.63
23	OSMANABAD	5071.73	270.49	119.42	119.42	418	250.80	1194	71.64		
24	PARBHANI	4132.68	220.41	92.40	92.40	323	193.80	924	55.44		
25	PUNE	5753.19	306.84	140.94	140.94	493	295.80	1409	84.54		
26	RAIGAD	75.34	4.02	15.77	4.02	14	8.40	40	2.40		
27	RATNAGIRI	1252.49	66.80	262.20	66.80	234	140.40	668	40.08		
28	SANGLI	4029.10	214.89	98.71	98.71	345	207.00	987	59.22		
29	SATARA	3479.68	185.58	85.25	85.25	298	178.80	852	51.12		
30	SINDUDURG	731.90	39.03	153.22	39.03	137	82.20	390	23.40		
31	SOLAPUR	11795.67	629.10	288.97	288.97	1011	606.60	2890	173.40		
32	THANE	0.00	0.00	0.00	0.00	0	0.00	0	0.00		
33	WARDHA	1477.46	78.80	33.03	33.03	116	69.60	330	19.80		
34	WASHIM	1146.64	61.15	21.86	21.86	77	46.20	219	13.14		
35	YAVATMAL	4420.34	235.75	98.83	98.83	346	207.60	988	59.28		
	STATE TOTAL	**130011.24**	**8473.78**	**3166.85**	**2845.49**	**9961**	**5976.60**	**26924**	**1615.44**	**772**	**19.30**

Water level in Mumbai city, Mumbai Suburban and Thane district are within 5m bgl.
Hence, in these districts artificial recharge structures are not proposed.

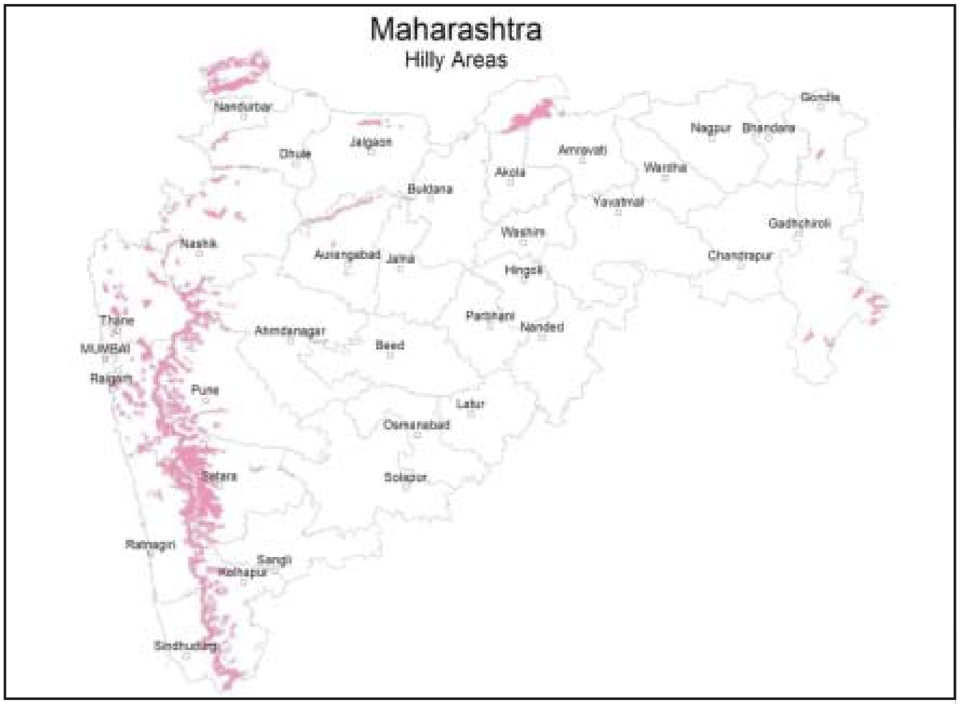


Fig. - 8.14.1: Hilly Areas Identified for Artificial Recharge in Maharashtra

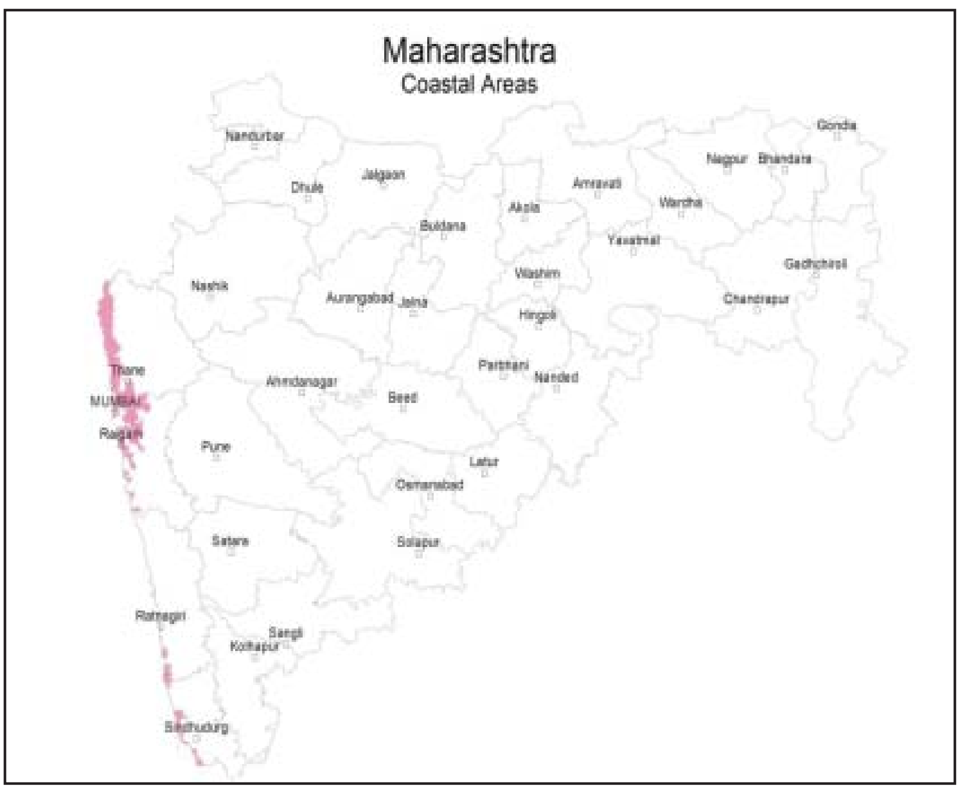


Fig. - 8.14.2: Coastal Areas Identified for Artificial Recharge in Maharashtra

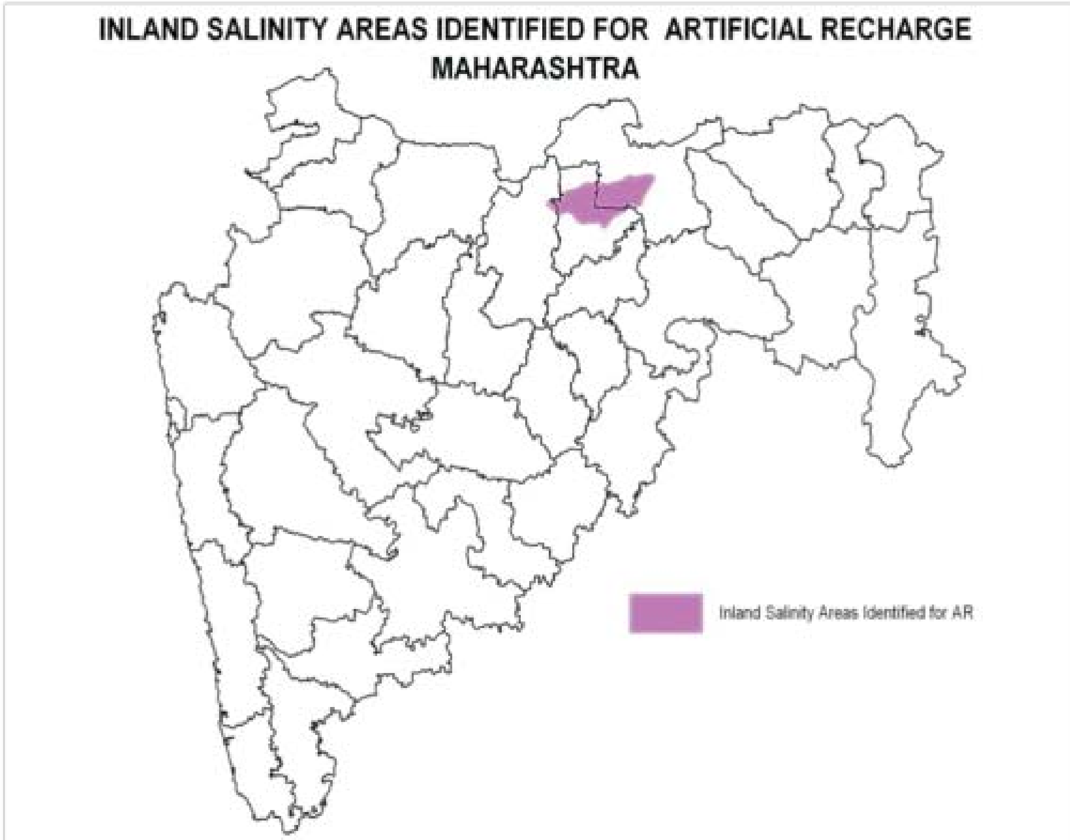


Fig .- 8.14.3: Inland Salinity Areas Identified for Artificial Recharge in Maharashtra

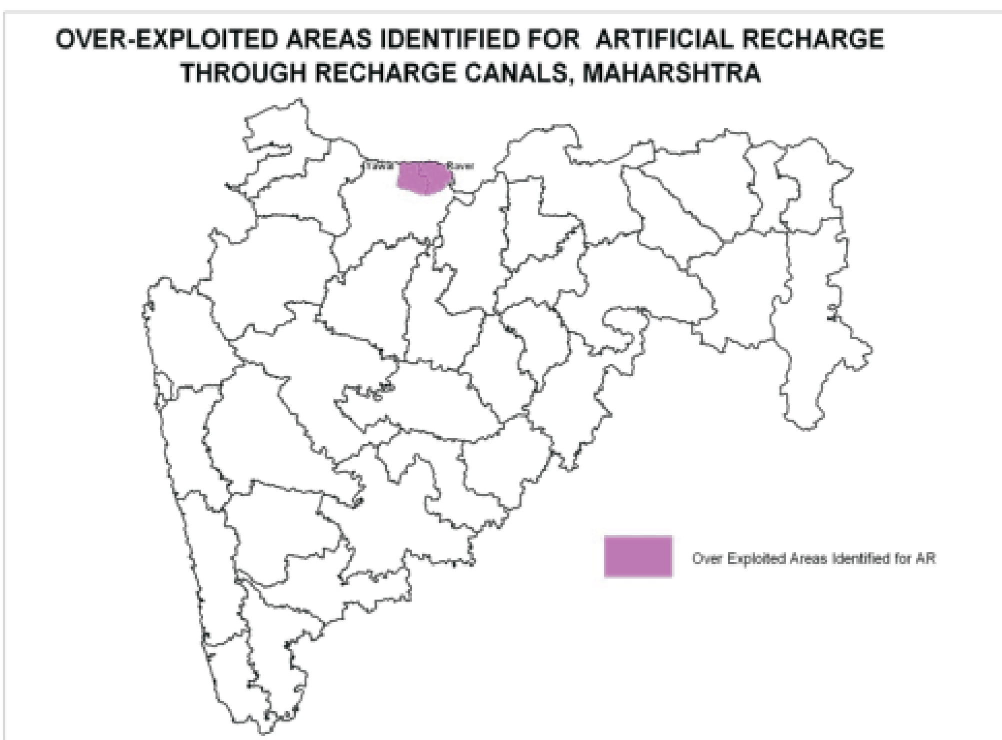


Fig. - 8.14.4: Over-Exploited Areas Identified for Artificial Recharge through Recharge Canals, Maharashtra

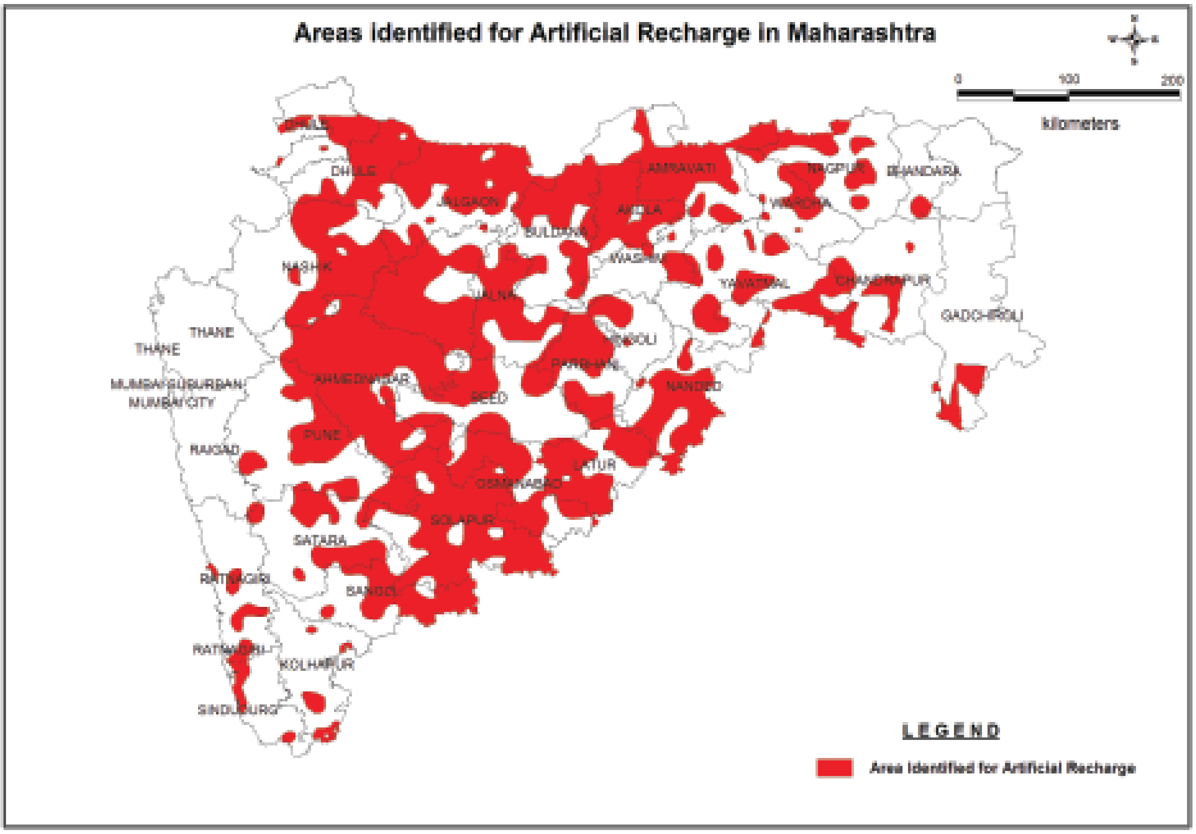


Fig. - 8.14.5 Areas identified for Artificial Recharge in Maharashtra

8.15 NORTH EASTERN STATES

The North Eastern States of India comprises Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura. The region is mainly a hilly terrain except vast alluvial plains of Brahmaputra and Barak rivers in Assam and small intermundane valleys scattered in other states of the region. In spite of the world's record of heavy rainfall at Mawsynram near Cherrapunji of Meghalaya, many parts of the region face acute scarcity of drinking water especially during lean period. Table-8.15.1 shows the details of the state-wise geographical area, districts, population, nos. of blocks and inhabited villages of the seven states.

Table 8.15.1: State-wise Area, Population, Districts, Blocks and Villages in North Eastern States

State	Area (km^2)	Population	No. of districts	No. of blocks	Inhabited villages
Arunachal Pradesh	83,743	1,09,768	16	92	3,863
Assam	78,438	2,66,55,528	27	219	26,312
Manipur	22,327	22,93,896	9	18	2,082
Meghalaya	22,429	29,64,007	7	30	4,902
Mizoram	21,081	6,89,756	8	22	782
Nagaland	16,579	19,886,36	11	28	1,112
Tripura	10,486	36,71,032	4	40	1,040
TOTAL	**2,55,083**	**3,83,72,623**	**82**	**449**	**40,093**

Ground water occurs in alluvial terrain under unconfined to semi-confined conditions and the depth to water level rests within 5 meters below ground level. Groundwater occurs in the Bhabar zone of Arunachal Pradesh and Assam under unconfined to semi-confined conditions and depth to water level rests within 15m.

In the southern part of Arunachal Pradesh and in parts of Manipur, Mizoram, Nagaland, Tripura, West Garo Hills, semi-consolidated Tipam sandstone of Tertiary age forms potential aquifer. Ground water occurs in this formation under semi-confined to confined conditions and depth to water level ranges from 5 to 10m. The hard rock terrain includes high hill ranges of Arunachal Pradesh, high land plateau of Meghalaya, Karbi-Anglong, N.C. Hills and the inselberg areas of Assam. Quartzite, phyllite, granite gneiss and schists are the rock types. Ground water occurs in the secondary porosity developed by fractures, joints, gneissosity and schistosity under unconfined to semi-confined conditions.

The area identified for artificial recharge is about 25508 sq.km and volume of unsaturated zone available for recharge is 114186 MCM

8.15.1 SOURCE WATER AVAILABILITY

Physiographically the major parts of North Eastern States are hilly with localized small valleys through which the entire run off passes. As the area is hilly with high slope the major part of the rainfall is lost in surface runoff. Apart from this the small rivers, nallas also act as carriers for base flow, spring water. In spite of good rainfall of more than 2000mm in hilly areas there is acute shortage of water especially during the summer. Further availability of water is restricted in these streams only. Thus the water in the streams should be harvested for irrigation and domestic needs through the structures given below.

8.15.2 RECHARGE STRUCUTRES AND COST ESTIMATES

Considering the physiography, rainfall and hydrogeology, areas were identified for artificial recharge structures (fig 8.15.1). 2650 check dams, 5100 weirs, and 6100 gabion structures are recommended as per following state wise breakup (table.8.15.2). The unit cost of check dams, weirs and gabion structure has been considered as Rs.15 lakh, Rs.4 lakh and Rs.0.4 lakh respectively.

Table – 8.15.2 Artificial Recharge Structures and Cost Estimates in North Eastern States

State	Check Dams		Weirs		Gabion Structures		Total Cost (Rs.in lakh)
	Total No.	Total Cost (Rs.in lakh)	Total No.	Total Cost (Rs.in lakh)	Total No.	Total Cost (Rs.in lakh)	
Arunachal Pradesh	500	7,500	1,000	4,000	1,000	400	11,900
Assam	250	3,750	500	2,000	1,000	400	6,150
Manipur	300	4,500	500	2,000	500	200	6,700
Meghalaya	300	4,500	600	2,400	600	240	7,140
Mizoram	500	7,500	1,000	4,000	1,000	400	11,900
Tripura	300	4,500	500	2,000	1,000	400	6,900
Nagaland	500	7,500	1,000	4,000	1,000	400	11,900
TOTAL	**2,650**	**39,750**	**5,100**	**20,400**	**6,100**	**2,440**	**62,590**

8.15.3 ROOF TOP RAIN WATER HARVESTING IN URBAN AREAS

It has been assessed that roof top rain water harvesting can be adopted in ~ 4 lakh houses, govt. buildings, institutes etc. in urban and municipal areas of the state suitable for artificial recharge in the first phase. It will harness 115.2 MCM rain water considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a building having roof and paved area of ~ 200 sq.m. has been assessed to be Rs. 12,000 and for bigger buildings having more than 1000 sq.m. will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 656 crores in the first phase considering 5% of the total buildings having larger roofs.

8.15.4 DEVELOPMENT OF SPRINGS

The seven North Eastern States experience heavy to very heavy rainfall ranging from annual 2000 mm to 3000 mm. Emergence of spring is very common but they are far from the settlement. These springs can be developed scientifically for providing safe drinking water to the rural people. Presently rural people are to walk long distance in rugged terrain to fetch drinking water.

It is estimated that in North Eastern States there are about 1400 numbers of springs. Considering an average discharge of 2 lps per spring, the springs can be developed safely at an estimated cost of Rs. 140 crores. By doing so it is estimated that 88.3 MCM will be made available for drinking and other purposes annually. Generally the life of such structure is 20 years. Table-8.15.3 gives the details of calculation of total cost for development of 1400 springs of North Eastern States.

Table – 8.15.3 Estimate for Development of springs in North Eastern States

State	Area sq. km.	No. of springs	Average Discharge (lps)	Annual discharge (MCM)	Unit cost (Rs.in lakh)	Total cost (Rs.in lakh)
Arunachal Pradesh	83,743	300	2	18.92	10	3,000
Assam	78,438	250	2	15.77	10	2,500
Manipur	22,327	150	2	9.46	10	1,500
Meghalaya	22,429	200	2	12.61	10	2,000
Mizoram	21,081	200	2	12.61	10	2,000
Nagaland	16,579	200	2	12.61	10	2,000
Tripura	10,486	100	2	6.31	10	1,000
TOTAL		**1400**		**88.30**		**14,000**

Table - 8.15.4 gives the summarized cost estimate for various types of structures feasible in North Eastern states which works out to Rs. 1421.90 crores.

Table - 8.15.4 Cost Estimate for various structures in North Eastern States

S. No.	Type of structure	Total No.	Unit cost (Rs. in lakh)	Total cost (Rs. in lakh)
1	Check Dams	2,650	15.0	39,750
2	Nala Bund/Weir	5,100	4.0	20,400
3	Gabion Structure	6,100	0.4	2,440
4	Roof Top Rainwater Harvesting	4,00,000	0.12 -1.0	65,600
5	Spring Development	1,400	10.0	14,000
	Total	4,15,250		**142190**

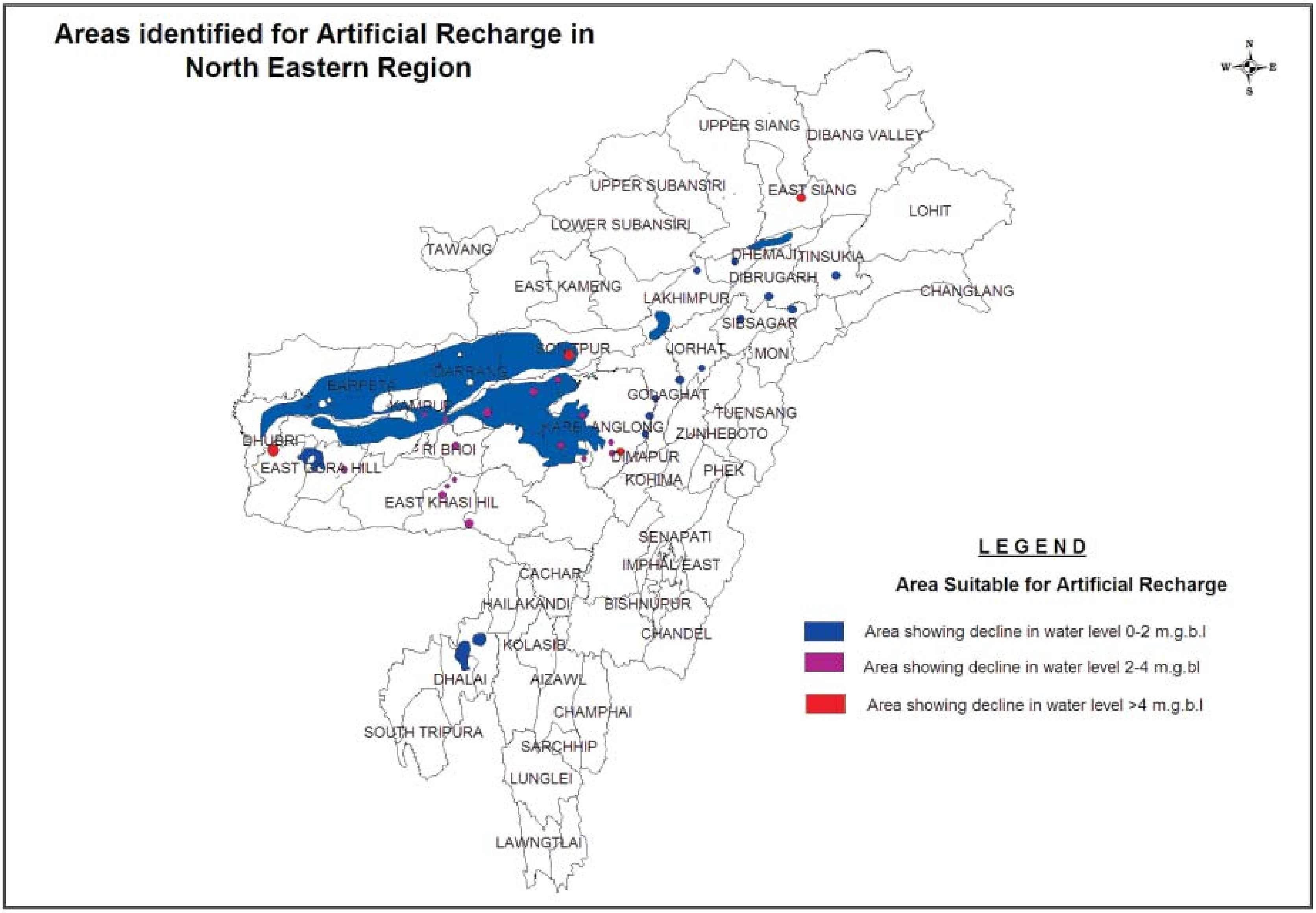


Fig. 8.15.1 Areas suitable for Artificial Recharge in North Eastern States

8.16 ODISHA

The state of Odisha with an aerial extent of 1,55,707 sq. km is drained by 11 principal rivers, among which Mahanadi is the largest. These are grouped under eight major river basins within the state. Physiographically the state is divided into five distinct units namely coastal plains, northern uplands, the erosional plains of Mahanadi valley, south western hilly regions and subdued plateaus. Administratively, the State is divided into 30 districts and 314 blocks.

8.16.1 IDENTIFICATION OF AREA

The areas sowing DTW more than 6 m below ground level are taken as first criteria for demarcation of feasible areas for artificial recharge purpose. Areas having depth to water level between 4-6 m bgl with appreciable decline (> 0.1 m/year) are also considered. Total 5338.98 sq. km area in 14 districts of the state has been identified for artificial recharge (Fig– 8.16.1)

8.16.2 SUBSURFACE STORAGE SPACE AND WATER REQUIREMENT

The volume of water to be added for the optimal recharge of the aquifer in these pockets is calculated by multiplying the volume of aquifer with the specific yield value of that particulars aquifer. The specific yield values of the major types of aquifers are taken from 0.02 to 0.26. Total sub surface storage potential in the vadose zone is estimated as 1076.31 MCM in the state.

Based on the experiences gained in the field experiments and ground conditions, 100% water stored at surface do not reach to the aquifer due to various losses. Therefore, surface water requirement shall be higher than the subsurface storage available. This has been estimated depending upon local situation and type of artificial recharge techniques. Total volume of surface water required is 1192.05 MCM for the state (table – 8.16.1).

Table – 8.16.1: Surface Water Availability and Requirement in Odisha

S. N.	District	Geographical Area	Area Identified for Recharge	Volume of Aquifer to be Recharged	Specific Yield	Volume of Water Required for Recharge	Surface Water Available
		sq. km.	sq. km.	MCM	%	MCM	MCM
1	Angul	1167.38	28.06	4.51	0.03	4.90	25.87
2	Balasore	381.54	0.50	0.22	0.11	0.26	0.82
3	Bargarh	873.53	313.36	64.58	0.03	73.38	266.71
4	Bolangir	831.82	55.93	8.69	0.03	9.64	49.98
5	Dhenkanal	1902.54	58.94	11.73	0.04	13.00	68.91
6	Gajapati	1461.79	30.00	4.46	0.03	4.95	34.67
7	Kalahandi	1077.81	23.85	2.06	0.02	2.24	17.47
8	Keonjhar	4233.12	848.63	112.66	0.03	123.06	1119.67
9	Khurda	1232.68	190.78	36.10	0.04	39.43	285.68
10	Koraput	4195.99	1787.81	358.85	0.03	395.88	1613.37
11	Mayurbhanj	3036.20	238.18	58.44	0.04	66.12	298.02
12	Nayagarh	612.56	88.57	14.96	0.03	16.26	89.71
13	Rayagada	3345.54	1657.08	396.37	0.03	440.00	1649.27
14	Sonepur	723.74	17.29	2.69	0.03	2.93	18.34
	TOTAL	**25076.24**	**5338.98**	**1076.32**		**1192.05**	**5538.49**

8.16.3 SOURCE WATER AVAILABILITY

A total of 5538.49 MCM surface water is available in the state for artificial recharge against the requirement of 1192.05 MCM. This forms around 21.52% of the available surface water. Therefore source water availability would not be problem.

8.16.4 RECHARGE STRUCTURES AND COST ESTIMATES

Physiography, hydrogeology and hydrology control the feasibility of structures in a particular area. The recharge structures recommended and their weightage is given in table 8.16.2 depending upon the physiography and hydrogeology (table 8.16.3)

Table-8.16.2: Artificial Recharge Structures and their weightage in Odisha

S. N.	Description of the location	Percolation tank	Sub Surface dyke	Nala Bund/ Contour bunding	Check dams weirs	Water spreading and fooding	Induced recharge	Recharge shaft
1.	Hilly areas> 600 m elevation Mod-high slope.	15%	15%	70%				
2.	High land areas 9300-600 m elevation plateaus & hills	50% (50%)	25%	25% (25%)		(25%)		
3.	Midland areas with rolling topography 50-300 m elevation	40% (55%)	15%	15% (15%)	15% (15%)	15% (15%)		
4.	In un-consolidated to semi consolidated formations.	25% (40%)			30% (30%)	15% (20%)	15% (10%)	15%

Note:- 50% of recharge allocated for percolation tank is planned to be met by modifying storage tank into percolation tank.

Induced recharge and water spreading structures are complementary to check dams and weirs, as they do not have surface water impounding facilities. The weightage given in brackets are applicable for artificial recharge to improve ground water quality.

Table 8.16.3: Elevation Breakup of the Prioritized Areas in Odisha

S. No	District	Problem Area (sq. km)	Elevation above msl (Area in sq. km)			
			> 600m	300 - 600m	50 - 300m	< 50m
1	Angul	28.06	0.62	27.44	0.00	0.00
2	Balasore	0.50	0.00	0.00	0.00	0.50
3	Bargarh	313.36	0.00	0.00	313.36	0.00
4	Bolangir	55.93	0.00	0.00	55.93	0.00
5	Dhenkanal	58.94	0.00	0.00	31.86	27.00
6	Gajapati	30.00	0.00	30.00	0.00	0.00
7	Kalahandi	23.85	7.41	14.16	2.28	0.00
8	Keonjhar	848.63	222.76	427.12	198.75	0.00
9	Khurda	190.78	0.00	0.00	24.97	165.81
10	Koraput	1787.81	1170.91	598.43	18.47	0.00
11	Mayurbhanj	238.18	0.00	0.00	130.27	107.91
12	Nayagarh	88.57	0.00	0.00	34.56	54.01
13	Rayagada	1657.08	600.60	626.28	430.20	0.00
14	Sonepur	17.29	0.00	0.00	17.29	0.00
	STATE TOTAL	**5338.98**	**2002.30**	**1723.43**	**1257.94**	**355.23**

Based on tables, the No. of structures to be constructed district wise is worked out taking average gross capacity of one percolation tank as 200 TCM, nala/contour bunding/check dam as 150 TCM, check weir is 150 TCM, recharge trench as 60 TCM and subsurface dyke as 60 TCM in multiple fillings.

The cost budgeted for each structure is calculated and is given in Table 8.16.4 along with unit cost of each scheme. The total amount required for the artificial recharge purpose for augmentation of ground water recharge is calculated to be Rs. 532.50 crores.

Table-8.16.4 Cost estimates of Artificial Recharge Structures in Odisha

S. No.	Structure	Total Number	Average unit cost (Rs. in crores)	Total Cost (Rs. in crores)
1	Percolation Tank	1107	0.20	221.40
2	Storage Tank Conversion to Percolation Tank	905	0.10	90.50
3	Dyke	871	0.10	87.10
4	Contour Bunding	2265	0.05	113.25
5	Check Weirs	181	0.05	9.05
6	Flooding	121	0.02	2.42
7	Induced Recharge	22	0.05	1.10
8	Recharge Shaft	384	0.02	7.68
	TOTAL	**5856**		**Rs. 532.50**

8.16.5. ROOF TOP RAIN WATER HARVESTING IN URBAN AREAS

It has been assessed that roof top rain water harvesting can be adopted in ~ 3 lakh houses, govt. buildings, institutes etc. in urban and municipal areas of the state suitable for artificial recharge in the first phase. It will harness 76.66 MCM rain water to augment ground water resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a building having roof and paved area of ~ 200 sq.m. has been assessed to be Rs. 12,000 and for bigger buildings having more than 1000 sq.m. will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs.492.00 crores in the first phase considering 5% of the total buildings having larger roofs.

8.16.6. TOTAL COST

Total cost of artificial recharge schemes and roof top rain water schemes in the state is estimated as Rs. 1,024.50 crores.

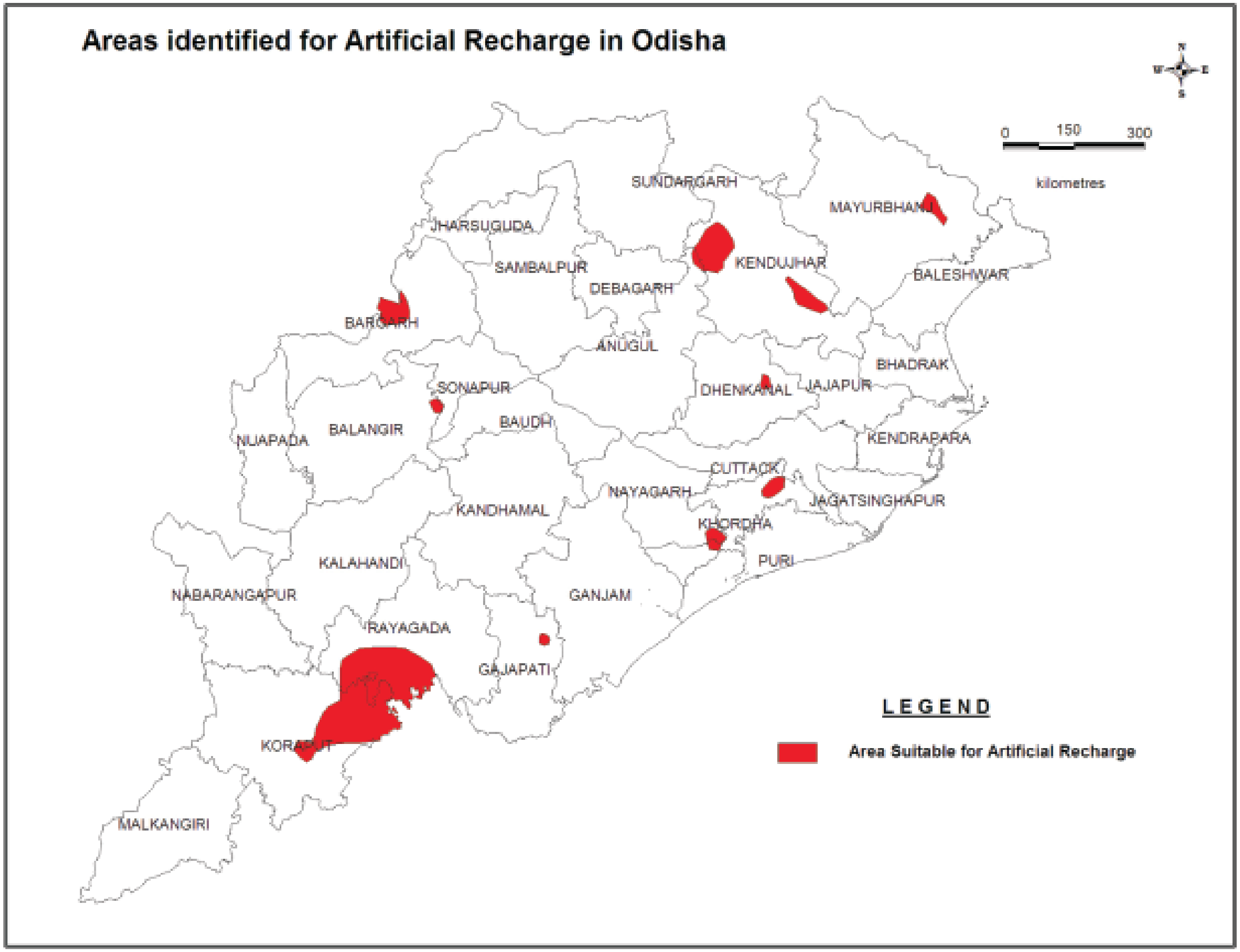


Fig. 8.16.1 Areas suitable for Artificial Recharge in Odisha

8.17 PUNJAB

The state of Punjab having total area of 50,362 sq.km. is occupied by Indus river basin and is drained by three major rivers, the Ravi, the Beas and the Satluj apart from other drainage channels. About 90% of the area is occupied by Quaternary alluvium and Tertiary formations outcrop as Siwalik hills ranges in northeastern part of the State.

Ground water exploration carried out by CGWB down to a depth of 450 m, reveals existence of thick fresh water aquifers throughout the State. These aquifers are laterally and vertically extensive and persistent in nature. However, in southwestern parts, the thickness of fresh water aquifer is much less as compared to the other parts because area is underlain by brackish / saline water. At places, the thickness of fresh water bearing aquifer is even less than 10 m.

Local and discontinuous, fairly thick aquifers having fresh water down to 150 meters with average yield of wells below 50 cu.m/hour exists in an area of about 12,350 sq.km. covering Muktsar, Faridkot, Moga, Bhatinda, Mansa, southern parts of Sangrur and Ferozepur districts. In a narrow strip extending from south of Fazilka to north of Moga and also in the north eastern parts of Gurdaspur, Hoshiarpur, Nawanshahar, Patiala, Ropar districts and Anandpur Sahib valley of Ropar district, comprising an area of about 6900 sq.kms., aquifers are regionally extensive and fairly thick down to 300 meters with an average yield of wells between 50 – 150 m^3/hours. In an area of about 29,280 sq.km. covering whole of Amritsar, Kapurthala, Fatehgarh Sahib, Ludhiana, Patiala districts and parts of Sangrur, Gurdaspur, Ferozepur, Patiala, Nawanshahar, Jalandhar and Ropar districts, regionally extensive and fairly thick aquifers down to 300 meters with an average yield of wells above 150 m^3/hour are occurring. Hilly terrain of about 11050 sq.km. in parts of Ropar, Gurdaspur, Hoshiarpur and Nawanshahar districts is underlain by semi-consolidated formations having limited yield potentials below 50 m^3/hour except plateau area (beet area) in Garhshankar block of Hoshiarpur district which has yield potential of 100 m^3 to 200 m^3/hr.

Ground water resources of state have been estimated as on 31.03.2009. The net annual ground water availability of state has been assessed to be 20.34 BCM. Net annual draft of the state has been estimated to be 34.66 BCM. The average stage of ground water development in the state is 170%. Out of 142 blocks assessed, 110 falls under 'Over- exploited' category, 3 in 'Critical', 2 as 'Semi Critical' and 23 as 'Safe' category. The reason for this stage of ground water development are excessive withdrawal of ground water mainly to meet growing demands of agriculture in addition to industrial and domestic. Surface water resources in the state are limited and are decreasing due to climate change. Thus stress is more and more on ground water. These over-exploited aquifers require augmentation for sustaining the ground water abstraction structures.

8.17.1 IDENTIFICATION OF AREA

Based on the post monsoon depth to water level and long term ground water level trends, it has been estimated that 43,340 sq. kms. area is feasible for artificial recharge (Fig. 8.17.1).

8.17.2 SUBSURFACE STORAGE SPACE AND WATER REQUIREMENT

The thickness of available unsaturated zone (below 3 m bgl) is estimated by considering the different ranges of water levels on block-wise basis. The different range of depth to water at 3 m interval is averaged to arrive at thickness of effective unsaturated zone. The total volume of unsaturated strata is calculated by considering the depth to water level and area of unsaturated thickness of different range. This volume then multiplied by average specific yield of 12% to arrive at the net amount of water required to be recharged by artificial methods to saturate the aquifer up to 3 m bgl . This is estimated as 52,684 MCM. Based on the experience gained in the field experiments, an average recharge efficiency of 75% of the individual structure is only possible. Therefore, to arrive at the total volume of actual source water required at the surface, the volume of water required for artificial recharge is calculated and multiplied by 1.33 (i.e. reciprocal of 0.75). A total of 70,071 MCM of surface water is required in the state for artificial recharge.

8.17.3 SOURCE WATER AVAILABILITY

The quantity of non-committed surplus surface water in the Punjab state has been estimated to be only 1200.99 MCM against the requirement of 70,071 MCM.

8.17.4 RECHARGE STRUCTURES AND COST ESTIMATES

The main recharge structures feasible in the state are recharge shaft, horizontal trench with or without injection wells and check dams. The average cost of a recharge shaft to recharge 0.015 MCM water will be around Rs. 2.50 lakh and of check dam to recharge 0.04 MCM will be around Rs. 40 lacs. It has been estimated that 79,924 artificial structures are required to recharge the available surplus water in the state. The total cost of 79,924 recharge structures will be around Rs. 2021.47 crores. The district wise number of structures feasible and cost estimates is given in table 8.17.1.

8.17.5 AREA BENEFITED

The impact of artificial recharge to ground water will be mainly all around the structures due to gradient of water table. The impact will be maximum during post monsoon period and a distinct rise in ground water level will be observed in the recharge area as compared to area not receiving the additional recharge. It is estimated that influence of recharge scheme as proposed in Master Plan will be observed in about 26650 sq. km. area and it will help to check in decline in water level. There will be rise in water level locally and mound will be formed around the recharge structures temporarily and ground water will flow in all the directions, which will dissipate after wards. This will result in saving of energy, due to reduction in pumping lift.

8.17.6 RAIN WATER HARVESTING IN URBAN AREAS

It has been assessed that roof top rainwater harvesting can be adopted in 15 lakh houses, govt buildings, institutes etc. in urban and municipal area of the state suitable for artificial recharge in the first phase. It will harness 187 MCM rain water to augment groundwater resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a buildings having roof and paved areas of ~ 200 sq.m in a cluster of 4-6 houses has been assessed to be Rs. 30,000/- and for bigger building having more than 1000 sq.m will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 1650 crore in the first phase considering 3 lakh structures for houses on cluster basis and 75,000 structures for government/institutional buildings.

8.17.7 ARTIFICIAL RECHARGE FROM TREATED SEWAGE WATER

Besides rainfall, ample scope also exists to recharge treated sewage water, which is disposed away from the towns without any purposeful gain. The treated sewage water can also be used as source for artificial recharge after ascertaining the suitability of chemical quality. In Ludhiana, Jalandhar and Amritsar towns, the sewage treatment plants are under construction and the water of these plants can be used for artificial recharge on their completion.

8.17.8 TOTAL COST

The cost of artificial recharge for surplus monsoon runoff of 1201 MCM will be Rs.2021.47 crores. The cost to harvest rainwater from roof top of urban areas will be Rs.1650 crores. Thus the total cost for implementing artificial recharge schemes in the state will be of the order of Rs. 3671.47 crores.

Table 8.17.1 - District-wise details of Artificial Recharge Structures in Punjab

S. No.	District	Area of district (sq.km)	Area feasible for artificial recharge (sq.km)	Volume of unsaturated zone available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of surplus water available for recharge (MCM)	Types of artificial recharge structures feasible and their numbers: Type of structure	Recharge capacity (MCM)	Number	Unit cost) (Rs.in lakh)	Total costs (unit cost x number) (Rs. in lakhs)
1	Amritsar	2403	2403	2447	3255	117.88	RS	0.015	7859	2.5	19648
2	Barnala	1352	1352	2607	3467	18.49	RS	0.015	1233	2.5	3083
3	Bathinda	3547	3547	2959	3935	32.08	RS	0.015	2139	2.5	5348
4	Faridkot	1419	1419	545	725	18.88	RS	0.015	1259	2.5	3148
5	Fateh Garh Sahib	1117	1117	1697	2257	21.68	RS	0.015	1445	2.5	3613
6	Ferozepur	5442	3924	1961	2608	65.18	RS	0.015	4345	2.5	10863
7	Gurdaspur	3513	2016	1213	1613	202.56	CD	0.04	15	30	450
							RS	0.015	13464	2.5	33660
8	Hoshiarpur	3331	3075	2924	3889	125.05	CD	0.04	25	30	750
							RS	0.015	8270	2.5	20675
9	Jalandhar	2634	2634	3975	5287	60.77	RS	0.015	4051	2.5	10128
10	Kapurthala	1618	1618	1871	2488	64.72	RS	0.015	4315	2.5	10788
11	Ludhiana	3587	3221	4564	6070	40.47	RS	0.015	2698	2.5	6745
12	Mansa	2071	2071	1350	1796	46.56	RS	0.015	3104	2.5	7760
13	Moga	2172	2172	4152	5522	20.76	RS	0.015	1384	2.5	3460
14	Muktsar	2656	0	0	0	0	RS	0.015	0	2.5	0
15	Nawan Shahr	1325	1325	2010	2673	10.92	CD	0.04	25	30	750
							RS	0.015	661	2.5	1653
16	Patiala	3303	3303	5935	7894	129.54	RS	0.015	8636	2.5	21590
17	Ropar	1370	641	341	454	18.98	CD	0.04	15	30	450
							RS	0.015	1225	2.5	3063
18	Mohali	1182	1182	914	1216	28.64	CD	0.04	5	30	150
							RS	0.015	1896	2.5	4740
19	Sangrur	3737	3737	8302	11042	51.12	RS	0.015	3408	2.5	8520
20	Taran Tarn	2583	2583	2917	3880	126.71	RS	0.015	8447	2.5	21118
	TOTAL	**50362**	**43340**	**52684**	**70071**	**1200.99**			**79924**		**202147**

Average post monsoon depth to water levels has been taken blockwise.

CD- Check dam

RS- Recharge Shaft

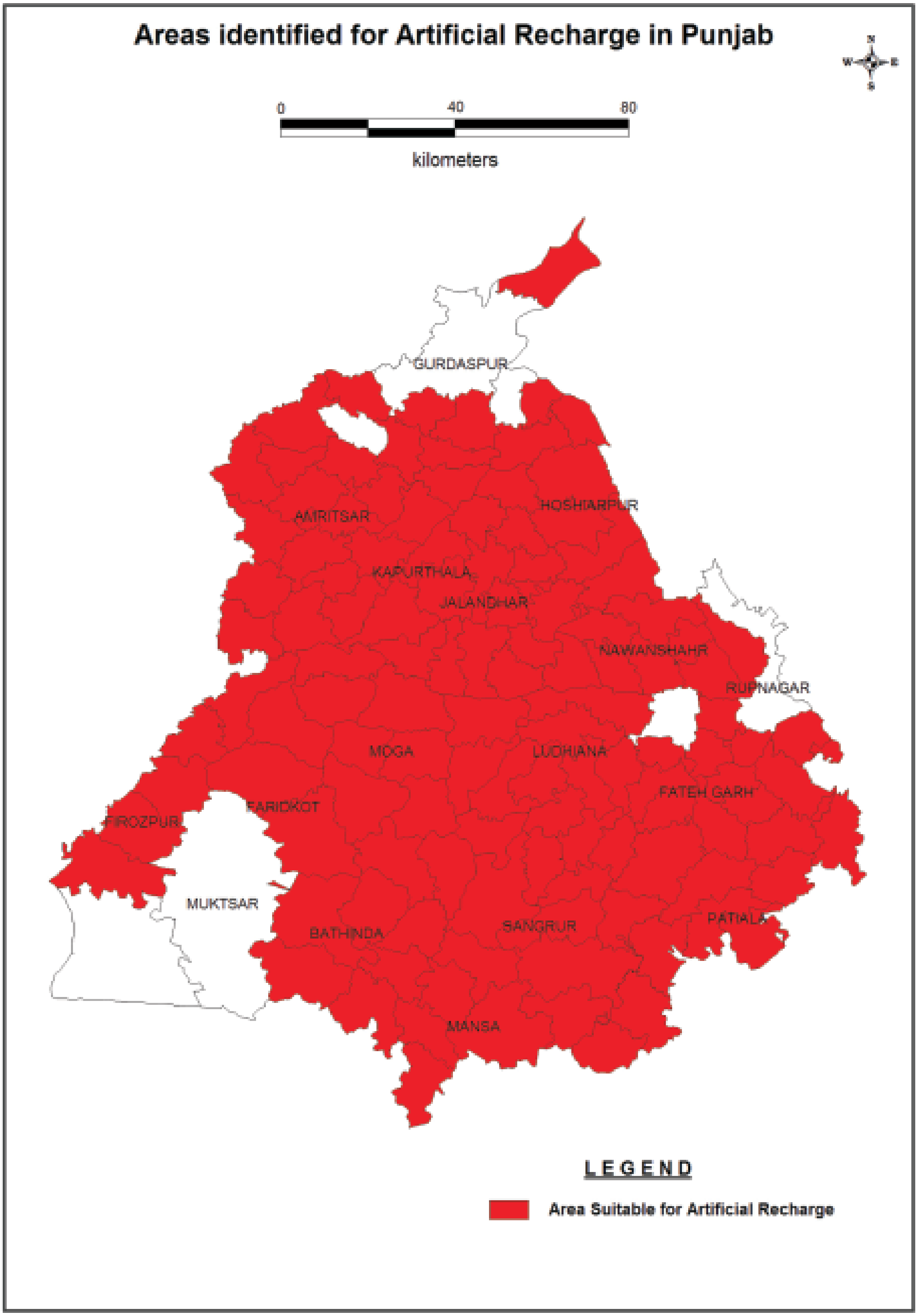


Fig.8.17.1 Areas Suitable for Artificial Recharge in Punjab

8.18 RAJASTHAN

Rajasthan is the driest and most water deficient state of India. The state is divided into 14 river basins, which cover eastern, northern and southern river catchments. Luni is the only river west of Aravalli and in remaining Western Rajasthan the drainage is internal in the desert sand.

The numbers of Critical and Over-exploited blocks have increased from 140 to 166 between 2004 and 2009. Out of a total of 239 assessment units (Blocks / Mandals/ Talukas) in the state, 166 have been categorized as 'Over-exploited' as on 31st March 2009,.There are 25 'Critical' assessment units and one block (Taranagar) having saline ground water (CGWB, 2009).

8.18.1 IDENTIFICATION OF AREA

The areas feasible for artificial recharge have been demarcated into following three categories:

- Areas showing declining trend (more than 0.2m/yr) and water level between 3 and 9 m bgl.
- Areas showing declining trend (more than 0.1m/yr) and water level between 9 and 20 m bgl.
- Water level more than 20 m bgl (Fig. 8.18.1)

8.18.2 SUBSURFACE STORAGE SPACE AND WATER REQUIREMENT

The thickness of available unsaturated zone (below 8 mbgl) of above 3 categories is estimated by considering the different ranges of water level. The total volume of unsaturated strata is calculated by considering and unsaturated thickness of different ranges. This volume is then multiplied by average specific yield of different aquifers to arrive at the net amount of water required which is to be recharged by artificial recharge to saturate the aquifer up to 8 m bgl. The storage space available in the feasible areas of the state is 2724364 MCM. (table-8.18.1)

8.18.3 SOURCE WATER AVAILABILITY

The amount of surface water considered for planning the artificial recharge is 860 MCM. Plan proposes that 70% of it i.e. 602 MCM can be stored in percolation tanks, 10 % i.e.86 MCM can be stored in anicuts and the rest 20% i.e. 172 MCM through recharge shafts. Therefore, a total of 3010 percolation tanks, 860 Anicuts and 5733 Recharge Shafts are proposed in the identified areas of Rajasthan for artificial recharge. District wise list is given in table-8.18.1. Basin wise details are given in table-8.18.2.

8.18.4 RECHARGE STRUCTURE AND COST ESTIMATES

Most of the artificial ground water recharge structures will be located in such areas where the stage of groundwater development is either overexploited or critical caused by excessive development of groundwater resulting in sharp decline in water level. A total number of 3010 percolation tanks, 860 Anicut and 5733 recharge shafts are proposed (table-8.18.1). Average cost of construction of a percolation tank of 200 TCM single filling storage capacity, Anicut average capacity of 100 TCM and recharge shaft of average capacity of 30 TCM has been considered in the computation. A total of Rs. 1566 crores are estimated to undertake the construction of proposed recharge structures. (table -8.18.1).

8.18.5 AREA BENEFITTED

Assured irrigation to be brought by percolation tank shall be around 90300 ha, by anicuts 2907 ha and by recharge shafts 30958 ha. Therefore total 124165 ha of additional land could be brought under assured irrigation in the feasible areas by considering delta factor as 0.5.

8.18.6 ROOF TOP RAIN WATER HARVESTING IN URBAN AREAS

It has been assessed that roof top rain water harvesting can be adopted in ~ 5 lakh houses, govt. buildings, institutes etc. in urban and municipal areas of the state suitable for artificial recharge in the first phase. It will harness 44.42 MCM rain water to augment ground water resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a building having roof and paved area of ~ 200 sq.m. has been assessed to be Rs. 12,000 and for bigger buildings having more than 1000 sq.m. will be Rs. 1.0 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs. 820 crores in the first phase considering 5% of the total buildings having larger roofs.

8.18.7 TOTAL COST

Total cost of artificial recharge schemes in the state including roof top rainwater harvesting is Rs. 2386 crores.

Table 8.18.1:District wise details of Artificial Recharge Structures in Rajasthan

S.No.	District	Area of dist. (sq. km)	Area feasible for artificial recharge (sq. km)	Volume of aquifer available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of water available for recharge (MCM)	Resource to be harnessed by						Estimated cost of structure (Rs.in crores)			Total cost (Rs.in crores)
							Percolation tanks		Anicut		Recharge shaft		Percolation Tank	Anicut	Recharge Shaft	
							MCM	No.	MCM	No.	MCM	No.				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Ajmer	8481	8481	144177	1192	38.9	0.2	143	0.1	40	0.03	244	58.63	1.23	13.005	72.865
2	Alwar	8720	5539	94180	12049	21.974	0.2	70	0.1	22	0.03	143	28.7	0.677	7.622	36.998
3	Banswara	5037	4925	39400	1970	18.87	0.2	65	0.1	17	0.03	87	26.65	0.523	4.637	31.81
4	Baran	6955	6884	20652	2828	70.87	0.2	255	0.1	66	0.03	386	104.55	2.03	20.574	127.153
5	Barmer	28387	6557	380306	53242	9.87	0.2	17	0.1	10	0.03	135	6.97	0.308	7.196	14.473
6	Bharatpur	5044	2714	13570	2035	8.742	0.2	22	0.1	9	0.03	53	9.02	0.277	2.825	12.122
7	Bhilwara	10455	10321	41284	2064	19.03	0.2	269	0.1	68	0.03	417	110.29	2.091	22.226	134.607
8	Bundi	5500	5500	220000	16940	64.03	0.2	228	0.1	59	0.03	347	93.48	1.814	18.495	113.789
9	Chittorgarh	10856	10796	194328	9716	75.83	0.2	275	0.1	70	0.03	415	112.75	2.153	22.12	137.022
10	Dausa	3420	3266	55522	7161	14.662	0.2	44	0.1	14	0.03	84	18.04	0.431	4.477	22.948
11	Dholpur	3009	869	2607	391	10.87	0.2	32	0.1	8	0.03	49	13.12	0.246	2.612	15.978
12	Dungerpur	3770	3285	5190	260	13.87	0.2	43	0.1	11	0.03	58	17.63	0.338	3.091	21.06

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
13	Jaipur	11061	11028	264672	30436	57.24	0.2	198	0.1	56	0.03	370	81.18	1.722	19.721	102.623
14	Jalore	10640	10624	339968	46900	20.47	0.2	48	0.1	22	0.03	241	19.68	0.677	12.845	33.202
15	Jhalawar	6219	6219	18675	887	63.87	0.2	230	0.1	60	0.03	349	94.3	1.845	18.602	114.747
16	Jhunjhunu	5928	2359	70770	8460	6.15	0.2	8	0.1	5	0.03	66	3.28	0.154	3.518	6.952
17	Jodhpur	22250	3032	84896	6367	5.87	0.2	8	0.1	4	0.03	62	3.28	0.123	3.305	6.708
18	Kota	5204	5204	15612	1186	55.87	0.2	197	0.1	43	0.03	298	80.77	1.322	15.883	98.266
19	Nagaur	17718	4514	117312	9739	8.55	0.2	14	0.1	8	0.03	111	5.74	0.246	5.916	11.902
20	Pali	12357	12357	247140	18668	17.87	0.2	33	0.1	18	0.03	254	13.53	0.554	13.538	27.622
21	Rajsamand	4635	4635	62662	3133	32.13	0.2	104	0.1	29	0.03	176	42.64	0.892	9.381	52.913
22	Sikar	7880	3373	121428	16271	38.07	0.2	18	0.1	9	0.03	95	7.38	0.277	5.064	12.72
23	Sirohi	5136	4986	55440	3619	55.62	0.2	172	0.1	65	0.03	448	70.52	1.999	23.878	96.397
24	Sawai Madhopur	10057	7008	84096	6622	53.902	0.2	189	0.1	48	0.03	288	77.49	1.476	15.35	94.316
25	Tonk	7200	7181	21543	1431	50.99	0.2	180	0.1	57	0.03	285	73.8	1.753	15.191	90.743
26	Udaipur	12643	8932	8934	542	25.87	0.2	148	0.1	42	0.03	272	60.68	1.292	14.498	76.469
Total		**238562**	**160589**	**2724364**	**264109**	**859.99**	**5.20**	**3010**		**860**		**5733**	**1234.1**	**26.450**	**305.570**	**1566.07**

Table 8.18.2 : Basin wise details of Artificial Recharge Structures in Rajasthan

Name of Basin	Volume of Surface water considered for planning of Artificial Recharge to ground water (MCM)	Districts	Area in Basin (sq.km)	Volume of aquifer available for recharge (MCM)	Resource to be harnessed by			Estimated cost of structure (Rs. in crores)		
					No.of Percolation tanks (Average capacity 0.2 MCM)	No. of Anicut (Average capacity 0.1 MCM)	No.of Recharge shaft (Average capacity 0.03 MCM)	Percolation Tank	Anicut	Recharge Shaft
1	2	3	4	5	6	7	8	9	10	11
Shekhawati	20.2	Jaipur	2089	5765.4	7	4	58	2.87	0.123	3.091
		Ajmer	968	135.64	3	2	27	1.23	0.062	1.439
		Alwar	545	1185.54	2	1	15	0.82	0.031	0.8
		Jhunjhunu	2359	8460	8	5	66	3.28	0.154	3.518
		Nagaur	2669	5760.95	9	6	74	3.69	0.185	3.944
		Sikar	2877	13878.35	12	6	80	4.92	0.185	4.264
Banganga	22.46	Alwar	2247	4887.9	18	7	43	7.38	0.215	2.292
		Bharatpur	2714	2035	22	9	53	9.02	0.277	2.825
		Dausa	2146	4705.3	17	7	42	6.97	0.215	2.239
		Jaipur	1495	4126.03	12	5	29	4.92	0.154	1.546
		Sawai Madhopur	273	257.96	3	1	5	1.23	0.031	0.267
Sabi	22.92	Alwar	2747	5975.56	50	14	85	20.5	0.431	4.531
		Jaipur	1198	3306.34	25	7	44	10.25	0.215	2.345
		Sikar	496	2392.65	6	3	15	2.46	0.092	0.8
Banas	308.8	Ajmer	5494	773.46	135	35	176	55.35	1.076	9.381
		Bhilwara	9157	1831.22	226	57	352	92.66	1.753	18.762
		Bundi	99	296.41	22	6	35	9.02	0.185	1.866
		Chittorgarh	5600	5039.79	135	35	211			
		Dausa	1120	2455.7	27	7	42	11.07	0.215	2.239
		Jaipur	6246	17238.24	154	40	239	63.14	1.23	12.739
		Rajsamand	4189	2841.16	102	28	167	41.82	0.861	8.901
		Sawai Madhopur	4828	4562.07	116	29	176	47.56	0.892	9.381
		Tonk	6636	1322.39	160	42	255	65.6	1.292	13.592
		Udaipur	2281	138.38	56	15	107	22.96	0.461	5.703

1	2	3	4	5	6	7	8	9	10	11
Chambal	315.63	Dholpur	869	391	32	8	49	13.12	0.246	2.612
		Sawai Madhopur	1907	1801.96	70	18	107	28.7	0.554	5.703
		Tonk	545	108.61	20	15	30	8.2	0.461	1.599
		Bhilwara	1164	232.78	43	11	65	17.63	0.338	3.465
		Chittorgarh	2961	2664.79	110	28	165	45.1	0.861	8.795
		Bundi	5401	16643.59	206	53	312	84.46	1.63	16.63
		Baran	6884	2828	255	66	386	104.55	2.03	20.574
		Jhalawar	6219	887	230	60	349	94.3	1.845	18.602
		Kota	5204	1186	197	43	298	80.77	1.322	15.883
Luni	49	Ajmer	2019	282.9	5	3	41	2.05	0.092	2.185
		Barmer	6557	53242	17	10	135	6.97	0.308	7.196
		Jalore	8820	38932	24	13	181	9.84	0.4	9.647
		Jodhpur	3032	6367	8	4	62	3.28	0.123	3.305
		Nagaur	1845	3982.37	5	2	37	2.05	0.062	1.972
		Pali	12357	18668	33	18	254	13.53	0.554	13.538
		Rajsamand	446	291.84	2	1	9	0.82	0.031	0.48
		Sirohi	2082	1511.18	5	3	4	2.05	0.092	0.213
		Udaipur	112	6.79	2	3	47	0.82	0.092	2.505
West Banas	39.06	Sirohi	1795	1302.87	125	45	300	51.25	1.384	15.99
		Udaipur	2	0.13	2	1	2	0.82	0.031	0.107
Sukli	13.54	Sirohi	946	686.64	39	16	138	15.99	0.492	7.355
Other Nala	8.38	Jalore	1804	7963.82	24	9	60	9.84	0.277	3.198
		Sirohi	163	118.31	3	1	6	1.23	0.031	0.32
Mahi	60	Banswara	4925	1970	65	17	87	26.65	0.523	4.637
		Chittorgarh	2235	2011.42	30	7	39	12.3	0.215	2.079
		Dungerpur	3285	260	43	11	58	17.63	0.338	3.091
		Udaipur	6537	396.58	88	23	116	36.08	0.707	6.183
Total	**859.99**		**160589**	**264109**	**3010**	**860**	**5733**	**1234.10**	**26.45**	**305.57**
								Grand Total Rs. 1566.07 crores		

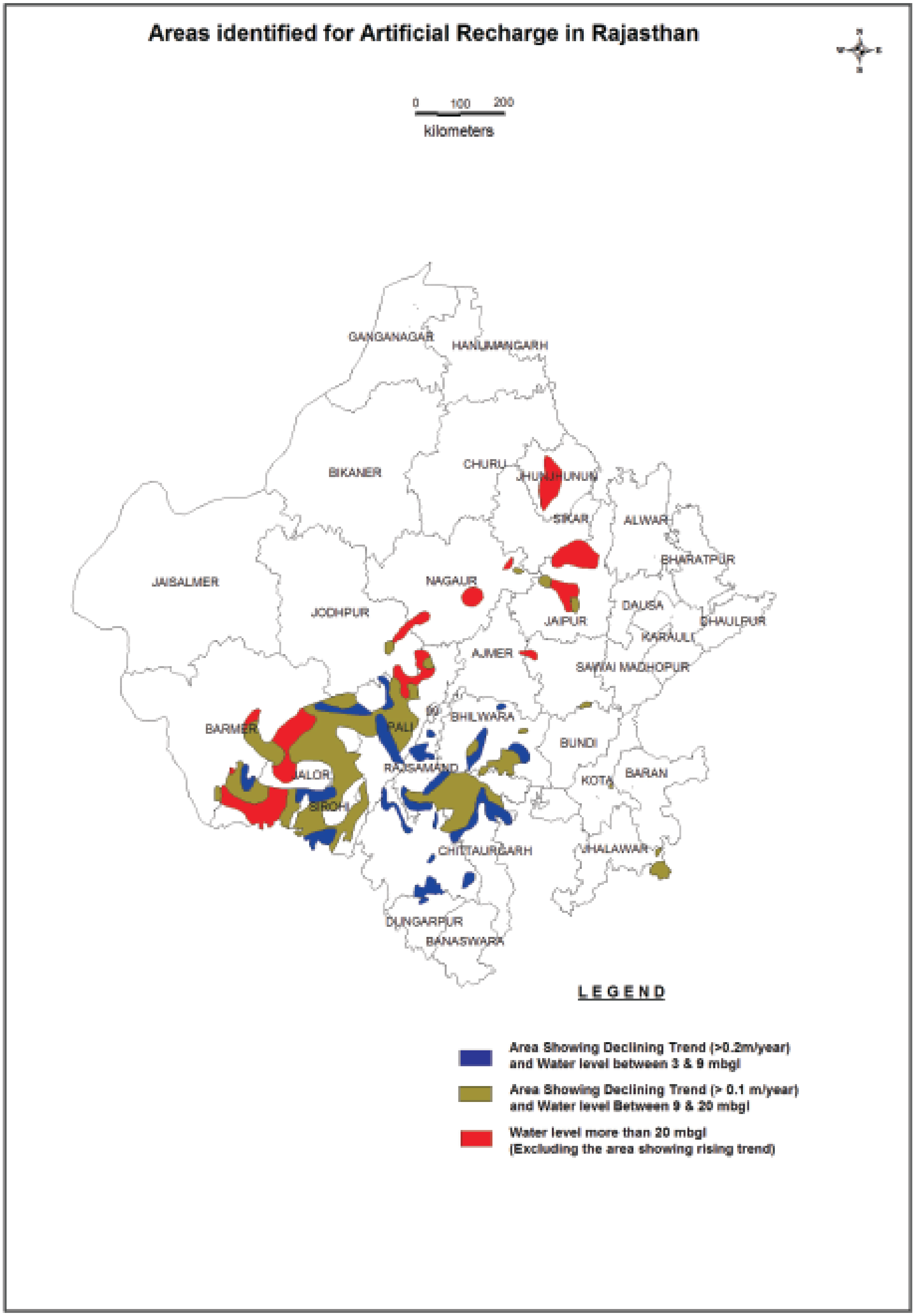


Fig.8.18.1 Areas identified for Artificial Recharge in Rajasthan

8.19 SIKKIM

Sikkim State, having an area of 7096 sq km. is constituted by four districts i.e.

1. South district

2. West district

3. East district

4. North district.

The state is drained by perennial Tista and Rangit rivers and their tributaries. The major river Tista, originates from Tista-Khangse glacier drains the major part of the state. In spite of copious rainfall received to the tune of 2500 mm per annum extreme water scarcity is felt in the lean periods (January to April) especially in the rain shadow areas in parts of South,West and East districts. Although there is negligible ground water development in the State of Sikkim, still there is scope for artificial recharge to ground water through construction of contour trenches, slope terracing, nala bunds, gabions, check dams etc. may augment the discharge from the springs, which are considered the lifeline in high altitude of Himalayas. Further to augment the water availability in such sloping and high rainfall region, there is vast scope for roof top rainwater harvesting and rainwater harvesting in slopes through impermeable membrane.

8.19.1 IDENTIFICATION OF AREA

The proposed structures through rain water harvesting may act both for ground water replenishment and conservation and are generally adopted in this hilly State to provide – assured water supply during non-rainy seasons, and to provide sustainability to springs whose discharge reduces considerably during non rainy season.

The State is dotted with number of springs which are mainly structurally controlled. These springs can be developed for providing water. The spring water is transported under gravity for drinking water supply and irrigation. In order to provide sustainability of water supply and availability various recharge and conservation structures in the feasible areas at higher elevation (Fig-8.19.1). The area identified for artificial recharge is about 500 sq.km and volume of unsaturated zone available for recharge is 1000 MCM.

8.19.2 SOURCE WATER AVAILABILITY

Volume of unsaturated zone available for recharge is estimated to be 1000 MCM assuming post monsoon water level as 5 m while volume of water required for recharge is estimated as 50 MCM. It is estimated that 277 MCM of water is available for ground water recharge.

8.19.3 RECHARGE AND CONSERVATION STRUCTURES AND COST ESTIMATE

Gabion structure, Check dam and Nala bund

In 1st or 2nd order streams to control siltation and also to harness surface water and augmentation of recharge in stream beds.

Subsurface dam/cement plug

In 1st or 2nd order streams to arrest base flow along the stream beds to enhance the water availability in the watersheds.

8.19.3.1 Spring area development

To enhance the discharge of the springs, catchment area treatment or spring shed development with construction of contour trench, staggered contour trench, contour bund, slope terracing structures are highly beneficial in such hilly and sloping terrain.

8.19.3.2 Roof top rain water harvesting and rain water harvesting along landscape

Rain water may be harvested directly through roofs and the accumulated water may be conserved for day to day use. Since the state receives considerable amount of rainfall, such structures may be highly useful especially during the non-rainy months. Similarly ample quantity of rainwater can be harvested along landscape utilizing impermeable membrane (Polythene sheet etc.).

A plan for development and augmentation of ground water resources in the state is envisaged and it is contemplated that 1400 springs development, 5000 roof top rain water harvesting structures, 325 nos. cement plugs and subsurface dykes, and 180 check dams/ gabion structures/nala bunds may be constructed in the state which would harness 277 MCM of water and would require a fund of Rs. 67.33 crores for construction purposes (table-8.19.1).

Table – 8.19.1 Rainwater Harvesting Structures and Cost Estimate in Sikkim

Type of structure	No. of structure	Unit Cost (Rs. in lakhs)	Total cost (Rs. in lakhs)	Total volume of water harvested (MCM)	Life of structure (in years)
Spring Development with catchment area treatment	1400	3.0	4200.00	7.71	20
Gabions(G), Check dam (CD), Nala bund(NB)	180	4.0	720.00	10.00	G-5 CD-10 NB-10
Cement plug, Subsurface Dam / Dyke	325	1.5	487.50	65.00	20
Roof top rain water harvesting (Houses)	4750	0.020	950.00	176.70	20
Roof top rain water harvesting (Govt. & Institutional)	250	1.5	375.00	9.30	5
Total	**6905**		**6732.50**	**276.71**	

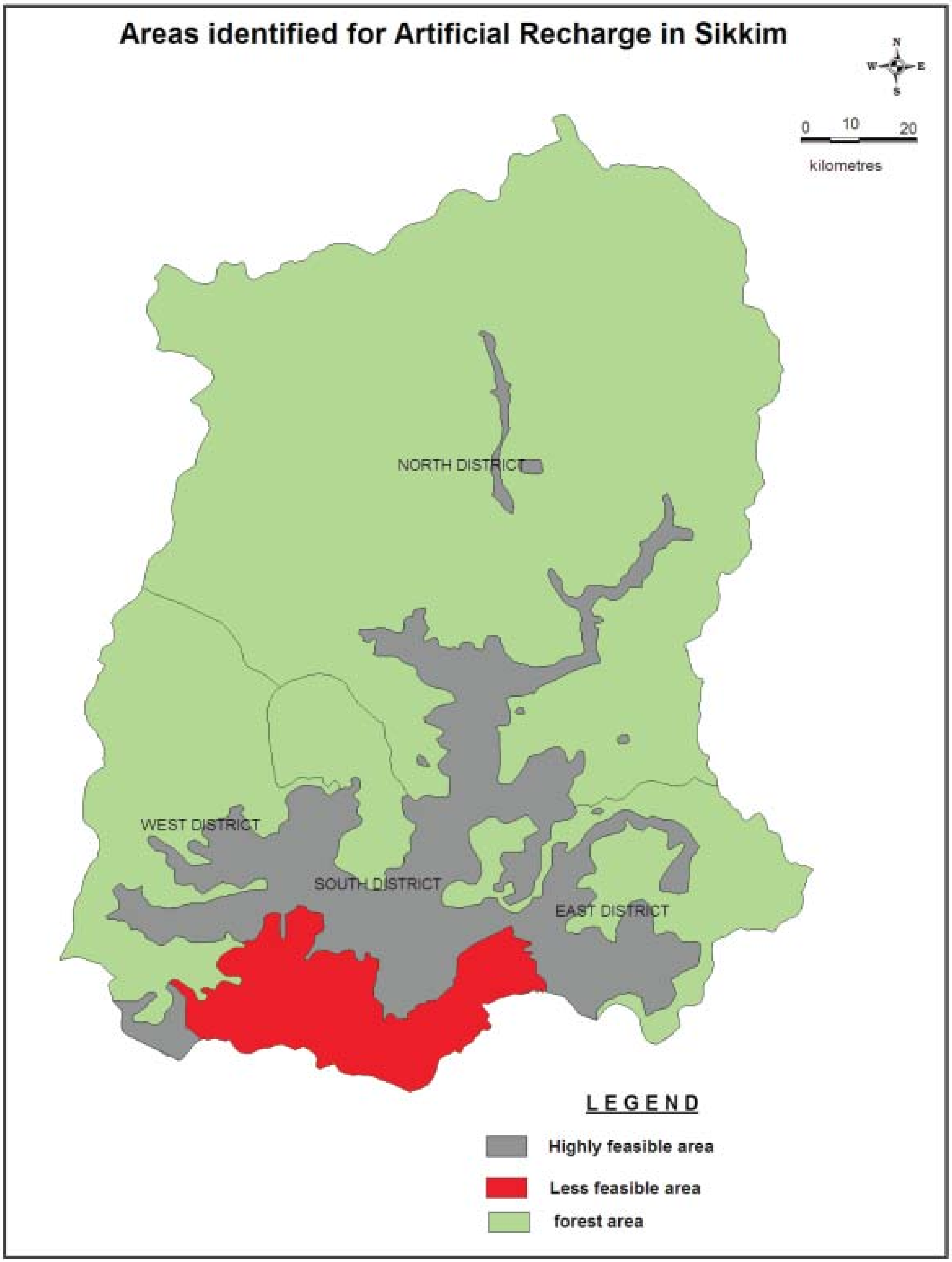


Fig. - 8.19.1 Areas suitable for Artificial Recharge in Sikkim

8.20 TAMIL NADU

Tamil Nadu spreads over an area of 130058 sq.km and has been divided into 30 districts excluding Chennai urban district, which are further sub-divided into 384 blocks. The State of Tamil Nadu, along with the enclaves constituting the Union Territory of Puducherry is characterized by diverse climatic, physiographic and hydrogeological conditions. The normal annual rainfall is of the order of 1008.1 mm (1901 – 1950). The contribution from south west monsoon is of the order of 525.1 mm (52%), while the contribution from north east monsoon is of the order of 28% and non monsoon rainfall (January – May) is of the order of 200.5 mm (20%). Development of ground water has already reached a critical stage in 175 blocks of the state. Over exploitation of ground water in these areas has resulted in declining ground water levels, shortage in water supply, increased pumping lifts and consequent increase in power consumption.

The increased ground water development in pockets for the industrial use has resulted in ground water mining in such pockets warranting a long term remediation. The regional ground water development in the sedimentary aquifers of larger aerial extent for industrial and agricultural activity is on the rise in recent years and the vulnerability of coastal aquifers for sea water ingress is noticed. The presence of pressure head below 45 m in parts of Neyveli basin is the concern for the long-term ground water management options.

The State and Central Agencies have already constructed artificial recharge structures under various schemes. Forest Department, Government of Tamil Nadu has constructed check dams in the high reaches of reserved forest area presently. The State Government has also proposal to construct check dams to supplement rain fed irrigation and water scarcity areas and subsurface dykes across Palar river. All these information has been taken into consideration while arriving at the number of additional structures.

8.20.1 IDENTIFICATION OF THE AREA

The area characterized by depth to water level more than 3 m during the post monsoon period coupled with declining long term trend (Decade) is considered as area requiring artificial recharge. The scope for artificial recharge denotes the surface water availability & the ability of the aquifer to take in the water.

The area characterizing, both declining trend and depth to water level in different categories have been identified for artificial recharge to ground water in Tamil Nadu. In addition, the localized pockets of intensive agriculture and industrial activity are identified by state agencies. Few sedimentary aquifers of multi layered and multi quality system also needs special intervention to augment the shallow and deeper aquifers.

The rain fed areas in major part of hard rocks are also having the potential for the localized ground water augmentation by water conservation structures to supplement the rain water with even limited ground water resources for a shorter duration.

The drinking water sources from the riverbed, springs and ground water system also requires localized stabilization of the water availability. Hence, a holistic approach in all the districts covered by sedimentary and crystalline rocks require site-specific recharge programme.

The present master plan envisages augmentation of ground water resources from the surplus monsoon run off as well as periodic floodwater and also local transporting of surplus water from the water logged and other specific pockets to needy places. Information on ongoing schemes under various state and central sector programs is collected and the balance requirement of the number of structures as well as budget requirement for artificial recharge is estimated. The unit cost of the recharge structures from the state experience is taken in to consideration for the report. The design of structures are also made more flexible based on the feedback from the various implementing agencies in the state and the performance evaluation by CGWB in select project sites, viz., Gangavalli block, Salem District.

8.20.2 SUBSURFACE STORE SPACE AND WATER REQUIREMENT

The thickness of unsaturated zone for each category of depth to water level is arrived and 3 m is subtracted to get the unsaturated thickness available for recharge in the regional level. Average specific yield of 1.5% & 10% has been assumed for crystalline & sedimentary formations respectively. The status of pressure head in hard rocks and select sedimentary rocks as well as the moisture requirement of the rain fed area in shallow water table pockets also considered for each distinct on the basis of micro level studies and block level hydro-morphological map prepared by Institute of Remote Sensing, Anna university for Govt. of Tamil Nadu. The ground water resources map of each district prepared in the Year 2003 as part of Fresh Water Year and the recommended artificial recharge structures for area specific formations are also considered. The density of various structures and design are inferred by the integrated hydrogeological set up and the status of ground water development as well as the feasibility of structures with source water.

The field experiments have shown that an average recharge efficiency of 75% of each structure is only possible; accordingly, the surface water required for artificial recharge is computed by multiplying the volume of water required for saturating the aquifer up to 3 m bgl by 1.33. Volume of available sub surface storage is of the order of 215937.187 MCM and surface water requirement is of 5982.64 MCM. The source water availability is of the order of 712.295 MCM and it is noticed that source water availability is adequate to saturate the aquifer up to 3 m bgl in all the districts.

8.20.3 SOURCE WATER AVAILABILITY

The surface water availability has been computed using improved ‘Strange curve’ for each watershed in a project entitled “Identification of Recharge areas Using Remote Sensing and GIS in Tamil Nadu, taken up by the Institute of Remote Sensing, Anna University, Chennai and sponsored by the Dept. of Rural Development, Govt. of Tamil Nadu and Tamil Nadu Water Supply and Drainage Board. The same has been utilized in this report for determining the surface water availability for each district. The map of area identified for artificial recharge has been superimposed over the block map and the blocks covering the critical area either full or in part has been identified and the harnessable surface water for each of the blocks have been summed up to get the surface water availability for each district. Based on the estimates, district wise recharge plan is given in table-8.20.1 and the areas identified are shown in Fig. 8.20.1

Table-8.20.1 : District-wise feasibility of Artificial Recharge Structures and estimated cost in Tamil Nadu

Sl.No.	Name of the district	Area of District (sq.km)	Average Post - monsoon water level (m bgl)	Area feasible for artificial recharge (sq.km)	Volume of unsaturated zone available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of Surplus water available for recharge (MCM)	Type of Artificial Recharge Structures feasible (Number): P	CD/ NB	RS/ BW	RTW	RT (km)	FP/ RP	Total number of structures	Estimated cost of P (Rs. In lakhs)	Estimated cost of CD/NB	Estimated cost of RS/ BW	Estimated cost of RTW	Estimated cost of RT (km)	Estimated cost of FP/ RP	Total estimated cost of all structures
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	Ariyalur	1934	5.43	977	4419.118	220.956	245.206	469	1408	7511	313	47	1408	11157	9389	14083	30045	2191	282	2817	58806
2	Coimba tore	4723	8.06	2198	14028.415	210.426	2.101	151	454	4844		15	454	5918	3027	4541	19375	0	91	908	27942
3	Cuddalore	3678	4.28	1600	5103.491	390.382	0.000	371	1114	11884		37	1114	14520	7427	11141	47534	0	223	2228	68553
4	Dharma puri	4498	6.05	3836	9641.207	144.618	27.553	266	798	8514		27	798	10403	5321	7982	34055	0	160	1596	49114
5	Dindigul	6267	7.92	4913	19400.344	291.005	17.806	388	1164	12414		39	1164	15168	7759	11638	49655	0	233	2328	71612
6	Erode	5722	5.84	2410	7231.662	108.475	13.760	143	430	4584		14	430	5601	2865	4297	18335	0	86	859	26442
7	Kanchee puram	4432	2.49	352	303.379	4.551	10.776	11	34	364		1	34	445	228	341	1456	0	7	68	2100
8	Kanya kumari	1672	7.62	864	4010.545	95.540	8.884	121	363	3526	14	12	363	4399	2417	3625	14106	99	73	725	21045
9	Karur	2896	5.39	2576	4054.170	158.974	16.576	129	388	4142		13	388	5061	2589	3883	16568	0	78	777	23894
10	Krishnagiri	5143	8.25	4281	17592.432	263.886	5.426	352	1055	11258		35	1055	13755	7036	10554	45030	0	211	2111	64942
11	Madurai	3742	5.02	2043	4380.626	65.709	33.599	99	296	3158		10	296	3859	1974	2961	12633	0	59	592	18220
12	Naga pattinam	2716	3.98	732	561.336	33.680	3.548	50	151	807	34	5	151	1199	1009	1513	3229	235	30	303	6319
13	Namakkal	3367	8.13	2178	11595.041	173.926	7.984	154	461	4913		15	461	6003	3071	4606	19652	0	92	921	28341
14	Perambalur	1757	4.16	1307	401.340	9.001	33.313	23	68	720		2	68	880	450	675	2880	0	14	135	4154
15	Puduk kottai	4663	4.37	2197	3640.058	57.998	53.402	127	381	2224	77	13	381	3204	2543	3814	8896	538	76	763	16630
16	Ramanatha puram	4090	6.19	1713	8576.542	1119.274	0.000	215	644	3436	143	21	644	5104	4295	6443	13745	1002	129	1289	26903

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
17	Salem	5205	6.82	3604	10901.251	163.519	17.632	279	836	8918		28	836	10897	5574	8361	35672	0	167	1672	51445
18	Sivaganga	4189	4.63	1841	3346.315	121.056	28.445	140	421	3716	32	14	421	4745	2807	4211	14866	226	84	842	23036
19	Thanjavur	3397	3.26	1093	3484.395	394.598	10.650	104	312	1665	69	10	312	2473	2081	3121	6658	486	62	624	13032
20	Theni	3242	8.75	2346	10645.424	159.681	0.000	222	666	7108		22	666	8685	4442	6664	28431	0	133	1333	41003
21	Thiruvarur	5196	4.87	203	1339.098	80.346	0.000	14	41	217	9	1	41	323	272	408	870	63	8	82	1703
22	Thoothukudi	3422	4.78	2951	5236.145	305.094	10.826	214	641	5950	37	21	641	7504	4275	6412	23798	260	128	1282	36155
23	Tirunelveli	6312	4.53	3404	8207.663	156.580	40.731	194	581	6193		19	581	7567	3871	5806	24773	0	116	1161	35728
24	Tiruppur	2097	9.47	4262	23342.226	350.133	0.000	264	793	8457		26	793	10334	5286	7929	33828	0	159	1586	48787
25	Tiruvallur	4707	3.61	689	1285.270	35.619	5.233	77	230	2450		8	230	2993	1531	2297	9799	0	46	459	14132
26	Tiruvannamalai	4404	3.97	2874	1377.734	20.666	3.343	21	64	679		2	64	830	424	637	2716	0	13	127	3917
27	Trichy	6759	3.97	3272	5342.767	187.561	54.005	192	575	6134		19	575	7495	3834	5750	24535	0	115	1150	35384
28	Vellore	5920	8.40	4117	20060.100	472.950	4.587	375	1125	12001		38	1125	14663	7500	11251	48003	0	225	2250	69229
29	Villupuram	7222	3.38	692	2002.524	30.038	14.617	73	218	1976	14	7	218	2506	1451	2177	7904	101	44	435	12111
30	Virudhu Nagar	4243	4.97	3314	4426.571	66.399	42.291	151	452	4816		15	452	5885	3010	4515	19266	0	90	903	27785
	Grand Total	**130058**	**5.56**	**68839**	**215937·189**	**5892·642**	**712·295**	**5388**	**16163**	**154578**	**743**	**539**	**16163**	**193574**	**107756**	**161634**	**618312**	**5201**	**3233**	**32327**	**928463**

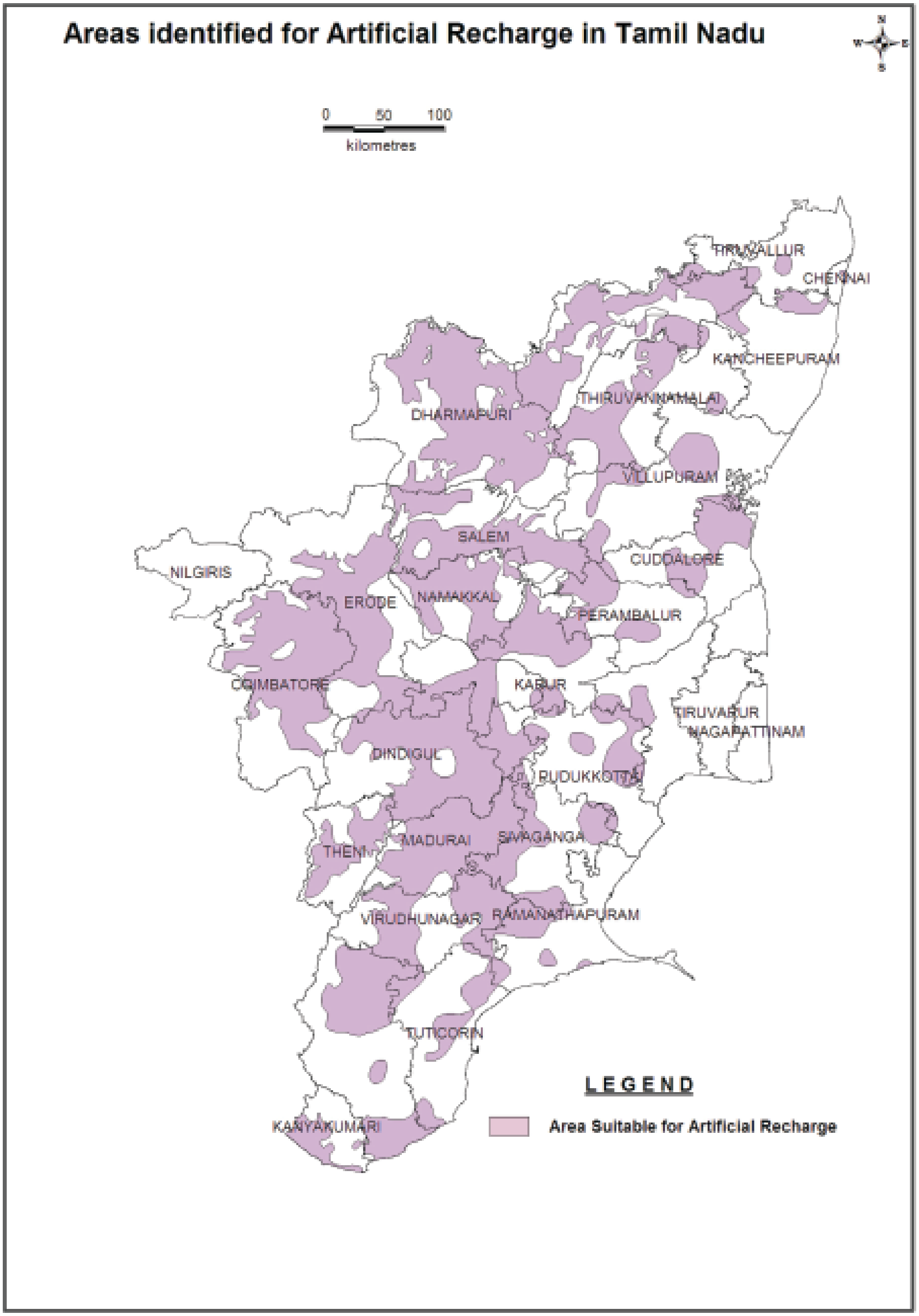


Fig. - 8.20.1 Areas identified for Artificial Recharge in Tamil Nadu

8.20.4. SPECIAL PROBLEMS

In coastal areas of Tamil Nadu, ground water development by tube wells is common and the heavy pumping in Neyveli Lignite mine has also affected the ground water levels. The pressure heads of Cuddalore aquifer in Neyveli-Sethiotope area Thiruvadanai aquifer in Sivaganga district, Kuttam aquifer in Tuticorin district are having very high decline in pressure head with time having very high decline in pressure head with time. There is a need for recharge to such aquifers. To formulate the guide lines for implementation of artificial recharge schemes for augmentation of ground water resource in the region, a trial well injection test was conducted on OW-2. The injection test area is underlain by Cuddalore formations consisting of multilayer aquifer system as mentioned below

1. Water table aquifer
2. Semi confined aquifer
3. Upper confined aquifer
4. Lower confined aquifer

It is observed that a lot of scope for recharge of ground water in the region. The observations made during the test are as under:

Duration of injection	—72 hours
Rate of injection	– 6 lps
Total volume of water injected	– 1555 cubic meter
Initial water level in the well	– 63.2 m bgl
Total rise of head in the well	– 59.9 m
Water in the well after 1100 minutes of stopping injection	– 63.10 m bgl

The recharge studies in Neyveli Hydrogeological Basin give very good scope for large scale diversion of flood water/tank water from the surplus of Cauvery flow system for deeper aquifer recharge.

The piezometric heads/ground water levels in the region are declining progressively as the ground water draft is very high in agricultural and industrial sectors. The piezometric head/water levels are recorded as deep as 74 m bgl in the lower confined aquifers and 63 m bgl in the upper confined aquifers. This clearly indicates that the de-saturation of shallow aquifer in the region.

The analysis of long term ground water levels/hydrographs mentioned in the table-8.20.2 indicates that the declining trend is at @ 0.251 to 8.407 m per year.

Table-8.20.2. Long term Trend of Ground Water levels around Neyveli area, Tamil Nadu

S. No.	Type of wells	Location	Water Level (m bgl)		Trend of water level decline/ year (m)
			1997	2010	
1	Tube wells	Irrupt-II	16.0	65.00	-8.407
2		Ranjangudi	1.11	23.48	-0.091
3		Panruti	13.20	23.50	-1.836
4		Nellikuppam	13.8	18.00	-0.251
5		Sethiathope	25.0(2001)	38.0	-1.87
6		Melur		52.9	
7		Kavarapalayam		73.79	
8	Dug well	Manjakuppam	3.50	7.00	-0.035

8.20.5 NEED FOR ARTIFICIAL RECHARGE TO GROUND WATER

- The ground water exploration reveals that the shallow aquifers up to 70 mbgl become desaturated due to high ground water development in the region by number of tube wells for both agricultural as well as Industrial uses.

- The decline of piezometric head with space and time in the region is monitored and deeper aquifer is necessitating the need of artificial recharge of ground water.

- In view of the future ground water situation along the coast, creation of an artificial fresh ground water barrier is essential to arrest the sea water intrusion which can be created with the surplus run off/flood water from Gadilam River or Veeranam and Perumal Eri tanks in monsoon periods.

- The shallow desaturated aquifer and the deep confined aquifers require artificial recharge with expertise from national and international institutions like PWD, Govt. of Tamil Nadu, CGWB, Govt. of India and BRGM, France etc.

As a part of study, well field consisting of three tube wells have been constructed at Kil Kavarapalayam, Ariyalur district. The details of wells are furnished in the table- 8.20.3.

Table-8.20.3 Details of Exploratory wells constructed in Neyveli area, Tamil Nadu

Well	Depth of well construction	Zones tapped	Water level	Discharge	Drawdown
	(m bgl)	(m bgl)	(m bgl)	(lps)	(m bgl)
Exploratory well	415	Between 132-412	73.79	10.16	1.4
OW-1	365	Between 315-360	64.3	5.0	.
OW-2	100	Between 60-97	63.2	1.0	-

Aquifer performance test on EW for 72 hours has been conducted and the details are as under :

Duration of test – 72 hours

Initial water level - 74.5mbgl

Discharge – 10.16 lps

Drawdown – 1.4 m

Specific capacity – 435.42 lpm/m of draw down

8.20.6 SCOPE OF ARTIFICIAL RECHARGE

The outcome of the Infiltration/Well injection studies conducted recently by NLC at Perumal Eri area and at Kilkavarapalayam by CGWB shows that the aquifer can accept the augmentation of ground water recharge. Thus there is a scope of artificial recharge in terms of ability of ground water system to accept recharge and availability of source water to implement artificial recharge schemes.

Surplus run off during flood period from Gadilam and Vellar River can be utilized as source water recharging ground water. Considering the sea water ingress and decline in water level pressure head, the recharge schemes in vulnerable areas of sea water ingress and over exploited sedimentary aquifers are recommended and shown in Fig. 8.20.2.

The cost estimates are furnished in table 8.20.4. The area identified for artificial recharge is shown in Fig. 8.20.1 and 8.20.2.

Table: 8.20.4: Structures feasible and Cost estimates in Tamil Nadu

Structure	Numbers	Cost (Rs. in crores)
Percolation Pond/Oorani	5388	1077.56
Check Dam/Nala Bond	16163	1616.34
Recharge Table Well	743	52.01
Recharge shaft/Recharge bore well	154578	6183.12
Recharge Trench (Km)	539	32.33
Farm Pond/Recharge Pit	16163	323.27
Total	**193574**	**9284.63**

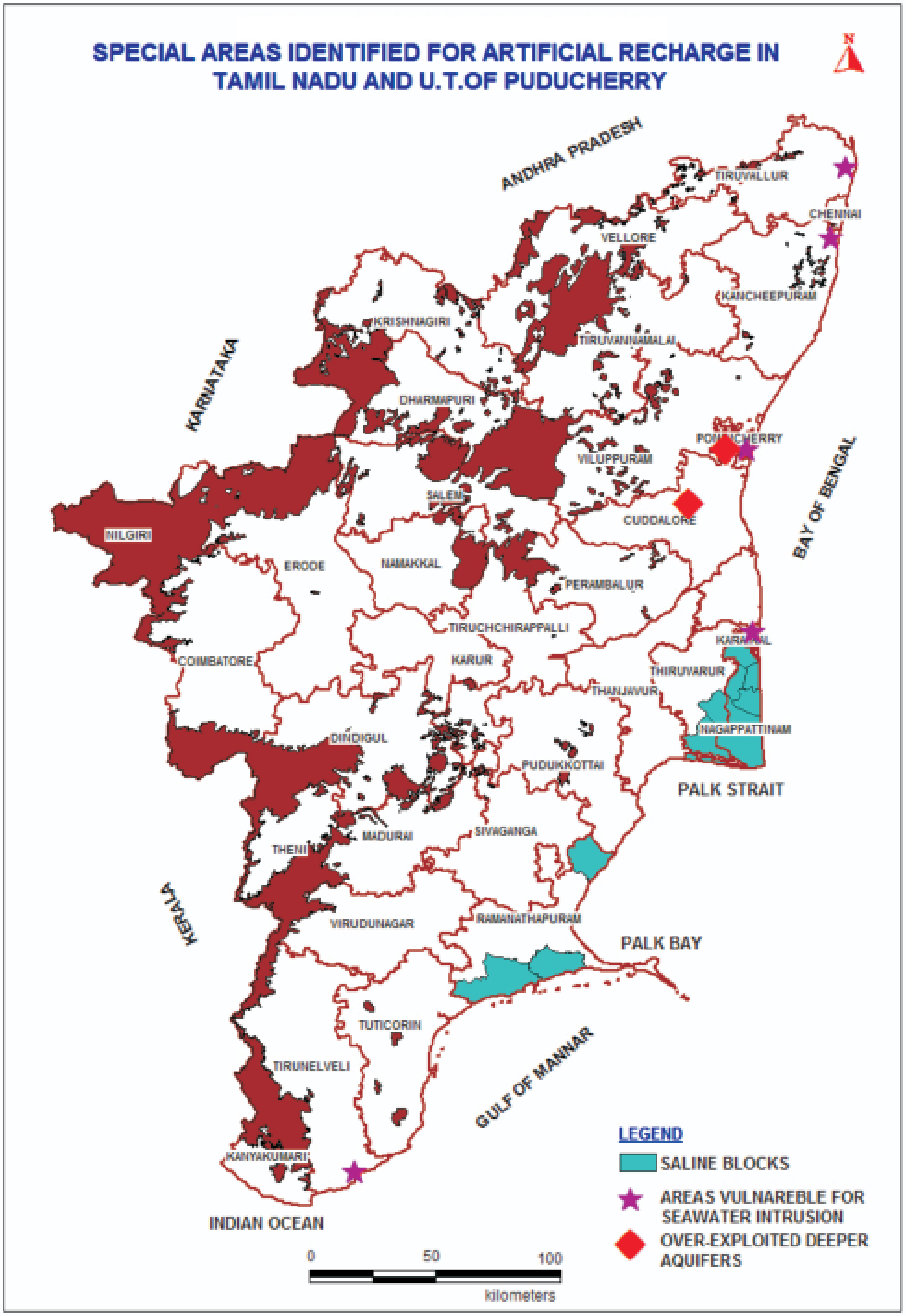


Fig.8.20.2. Special areas identified for Artificial Recharge in Tamil Nadu

8.21 UTTAR PRADESH

The State of Uttar Pradesh forms a part of vast Gangetic Alluvial Plain covering an area of 2,40,928 sq. km. The state is a part Ganga basin comprising of Yamuna, Ram Ganga, Gomti, Ghaghra and son sub basins. The alluvial plains and southern rocky terrain are main water bearing formations from point of view of ground water availability. In view of relative importance of this valuable resource it becomes imperative to adopt sound and scientific management of groundwater resources through formulation of district wise Recharge Plan for the state of Uttar Pradesh which should address the broad array of problems like over draft, pollution, poor quality and decline in ground water levels that have adverse impact on environment and natural conditions and should be a guiding tool for administrators and policy makers. Thus the most important issue is to identify the critical areas and thereafter provide appropriate designs for effecting artificial recharge to groundwater. The Master Plan for artificial recharge is prepared considering the hydrogeological and hydrological data base.

8.21.1 IDENTIFICATION OF AREA

The area identified for artificial recharge in the state has been taken as basin wise and district wise for technical and administrative convenience. Uttar Pradesh being a large state, the depth to water level map prepared incorporates lot of extrapolation to the areas which are not properly represented by monitoring stations, resulting in inclusion of some of the unworthy area as suitable for recharge and rejection of worthy areas at places. In addition to above mentioned problem, due to the fact that administrative block wise ground water resource information is available and for administrative convenience the areas suitable for recharge have been considered block wise. The block wise average depth to water levels and water level trends for last 10 years has been calculated for all the blocks of UP based on the data obtained from existing monitoring stations of State Ground Water Department, UP. In the Ground Water Resource Estimation report other relevant information such as block wise area, normal annual rainfall, specific yield values, annual recharge, ground water draft, stage of development etc. are also included. The district wise annual normal rainfall has been taken from Statistical Hand Book of 2008. For identifying areas suitable for artificial recharge, the feasibility of different ground water assessment units (administrative blocks) for artificial recharge has been considered. A total of 335 blocks falling in 52 districts covering 110783.14 sq.km. area, (103621.93 sq. km for alluvial area and 7161.21 sq.km for hard rock area), have been identified as feasible for artificial recharge. Areas suitable for artificial recharge are shown in Fig.8.21.1

8.21.2 SUB-SURFACE STORAGE SPACE AND WATER REQUIREMENT

The thickness of available unsaturated zone (below 3 m bgl) of above four categories was estimated by considering the different ranges of water levels. The difference between average depth to water level in the block and 3 m was calculated to arrive at thickness of effective unsaturated zone. The total volume of unsaturated strata was calculated by multiplying unsaturated thickness of different range by area of the unit. This volume was then multiplied by average specific yield of 10% (0.1as fraction) for alluvium and 2% (0.02) for hard rock area to arrive at the net amount of water required which is to be recharged by artificial methods to saturate the aquifer up to 3 m bgl. Thus net amount of water required to be recharged by artificial methods for the feasible areas of the state was calculated as 57831 MCM.

8.21.2.1 Surface Water Requirement

After assessing the actual volume of water was required for saturating the vadose zone, the actual requirement of source water. Based on the experience gained in the field experiments, an average recharge efficiency of 75% of the individual structure is only possible. Therefore, to arrive at the total volume of actual source water required at the surface, the volume of water required for artificial recharge was calculated and multiplied by 1.33 (i.e. reciprocal of 0.75) . The district wise requirement of water has been given in table-8.21.1. The total requirement of actual surface water is thus estimated as 76915 MCM.

Table-8.21.1. Total requirement of actual surface water in Uttar Pradesh

Regions of Uttar Pradesh	Area Suitable For Recharge/ Conservation (ha)		Volume of rechargeable unsaturated zone (MCM)	Surface water required (1.33 * Volume (MCM)
Ganga Basin	Alluvium	Hard Rock		
Basin Total	10362193	716121	57831	76915

8.21.2.2 Source Water Availability

For the state of UP the precise data on surface water utilization was not available. Hence to calculate surface water availability, 30% of monsoon rainfall has been considered as average monsoon run off and 50% of which is considered as non-committed water availability. The 30% of monsoon rainfall has been taken considering the erratic and localized rainfall pattern. Ensuring sufficient allocation for existing and ongoing surface water conservation projects 40% of the non-committed surface water has been considered for preparing the present district recharge plan. Non committed surface water availability for recharge in Ganga basins given in table 8.21.2.

Table-8.21.2 Basin wise Non-committed Surface Water availability for recharge/ conservation in Uttar Pradesh

Basin	Area(ha)		Non committed surface water availability for recharge/conservation (MCM)
Ganga Basin	Alluvium	Hard Rock	
Basin Total	10362193	716121	5185

8.21.3 RECHARGE STRUCTURES AND COST ESTIMATES

Based on Annual Gross Storage Capacity of Artificial Recharge and Water Conservation Structures and surface water availability the number of structures has been arrived at. The cost of the percolation tanks, recharge shaft/dug well/ tube well recharge has been taken as Rs. 20 lakhs and Rs. 1.0 lakhs respectively, as per the earlier Master plan-2002 and also as per the cost estimates of Minor Irrigation and Ground Water Departments of Govt. of UP, in their ongoing schemes/ projects. The cost of check dam has been taken as per the estimates of Minor Irrigation in the ongoing demonstrative projects.

8.21.4 STATE SUMMARY

A total area of 110783.14 sq.km has been identified as area suitable for recharge and a total tentative cost for constructing recharge/ conservation structures in the region has been estimated as Rs.7629.28 crores. This would envisage recharge/ conservation of 5185 MCM of non-committed water resource available in the region.

Table- 8.21.3 Summary of Recharge Plan for Uttar Pradesh

Area identified for artificial recharge (sq.km)	110783.14
Estimated sub-storage potential (MCM)	57831
Non-committed water resource available for artificial recharge (MCM)	5185
Average annual intake capacity of recharge structure (MCM)	
Percolation tanks	0.2
Recharge Shaft/ Dug Well/ Tube Well recharge	0.06
Check Dam	0.03
Total number of recharge structures required	
Percolation tanks (10% weightage for alluvium; 20% for hard rock)	3022
Recharge Shaft/ Dug Well/ Tube Well recharge(50% weightage for alluvium ; 40% for hard rock)	39638
Check Dam (40% weightage for alluvium; 40% for hard rock)	66285
Cost for construction of artificial recharge structure (Rs. in lakhs)	
Percolation tanks (@Rs. 20 lakhs)	60440
Recharge Shaft/ Dug Well/ Tube Well recharge (@Rs. 1.0 lakhs)	39638
Check Dam (@Rs. 10 lakhs)	662850
Estimated total cost for constructing recharge structures (Rs. in lakhs)	**762928**
Estimated total cost for constructing recharge structures (Rs. in crores)	**7629.28**

8.21.5 ROOF TOP RAINWATER HARVESTING

It has been assessed that roof top rain water harvesting can be adopted in 12 lakh houses, govt. buildings, institutes etc. in urban and municipal areas of the state suitable for artificial recharge in the first phase. It will harness 221.18 MCM rain water to augment ground water resources considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a building having roof and paved area of ~200 sq.m. has been assessed to be Rs12,000/- and for bigger buildings having more than 1000 sq.m. will be Rs. 1.0 lakhs. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs.1968 crores in the first phase considering 5% of the total buildings having larger roofs.

8.21.6 ACTIVITIES OF STATE GOVERNMENT IN RAIN WATER HARVESTING AND ARTIFICAL RECHARGE

In the state of Uttar Pradesh artificial recharge/ water conservation schemes are being implemented since IXth Plan. Various departments like Minor Irrigation Department, State Ground Water Department, Land Development and Water Resource, Rural Development, Agriculture Department and UP Jal Nigam are constructing structures such as check dams (masonry & earthen), construction/ renovation of ponds and other water bodies, roof top rain water harvesting structures, recharge wells. Apart from this these departments are adopting soil conservation measures like contour bunding, peripheral bunding, water harvesting structures which have been observed to be effective water conservation structures also.

The information pertaining to completed/ ongoing/ proposed schemes on artificial recharge or water conservation was obtained from State govt. departments is tabulated below and shows that State govt. departments have constructed number of these structures though not purely for the purpose of recharging ground water in few cases. A total number of 2834 masonry check dams and 14096 earthen check dams have been constructed or proposed to be constructed by these departments in different districts of UP, as per the information available. Roof top rain water harvesting structure has been constructed (or proposed) at 3551 sites in the State. Agriculture department has constructed/ proposed to construct 346 recharge wells at different locations. Construction/ renovation of water bodies are being taken up by various departments at 91900 ponds/ water bodies. The state details are given in table-8.21.4 and district wise proposed plan is given in table 8.21.5.

Table-8.21.4. Summary of recharge structures proposed for construction in Uttar Pradesh by State Government

Sl. No.	Department	Completed / Ongoing/ Proposed AR Structures	Purpose	Cost (Rs. in crores)
1	Minor Irrigation Department (up to 2011)	Check dams- 2772 Ponds - 1164	GW Recharge and water conservation for irrigation	-
2	Awas Bandhu (up to 2009)	Roof top RWH – in 566 govt./ semi-govt. buildings; 2965 buildings (> 200 m^2) Catchment treatment of 191 water bodies covering an area of 1678 ha.	GW Recharge. Utilizing 130901 m^3 rain water	-
3	State Ground Water Department (up to ~ 2009)	Roof top RWH- at 17 sites	GW Recharge	0.76
4	Land Development and Water Resource (DPAP, IWDP) (up to 2004)	Check dam (earthen) – 4928 Ponds – 546 An area of 25000 ha covered under DPAP & IWDP for soil and water conservation	GW Recharge and water & soil conservation	15.0
5	Rural Development (Source: Revenue dept) construction of ponds having areas of 0.5 to 1 ha, 1 to 2 ha & more than 2 ha.	Construction of 84647 ponds.	Water Conservation	-
6	Agriculture Department (up to 2005)	Check dams – 9180 RRR of water bodies - 352 Drains for recycling and recharge - 53.75 km length Recharge wells - 346	GW Recharge and water conservation	-
7	Mistaya Utpadan (up to 2004)	Construction & renovation of ponds – 5000	Water conservation	56.00
8	U.P. Jal Nigam (up to 2004)	Roof top RWH – 3 sites Check dams - 50		-

8.21.7 TOTAL COST

Total cost of the recharge structures and rain water harvesting in Uttar Pradesh is estimated as Rs. 9597.28 crores.

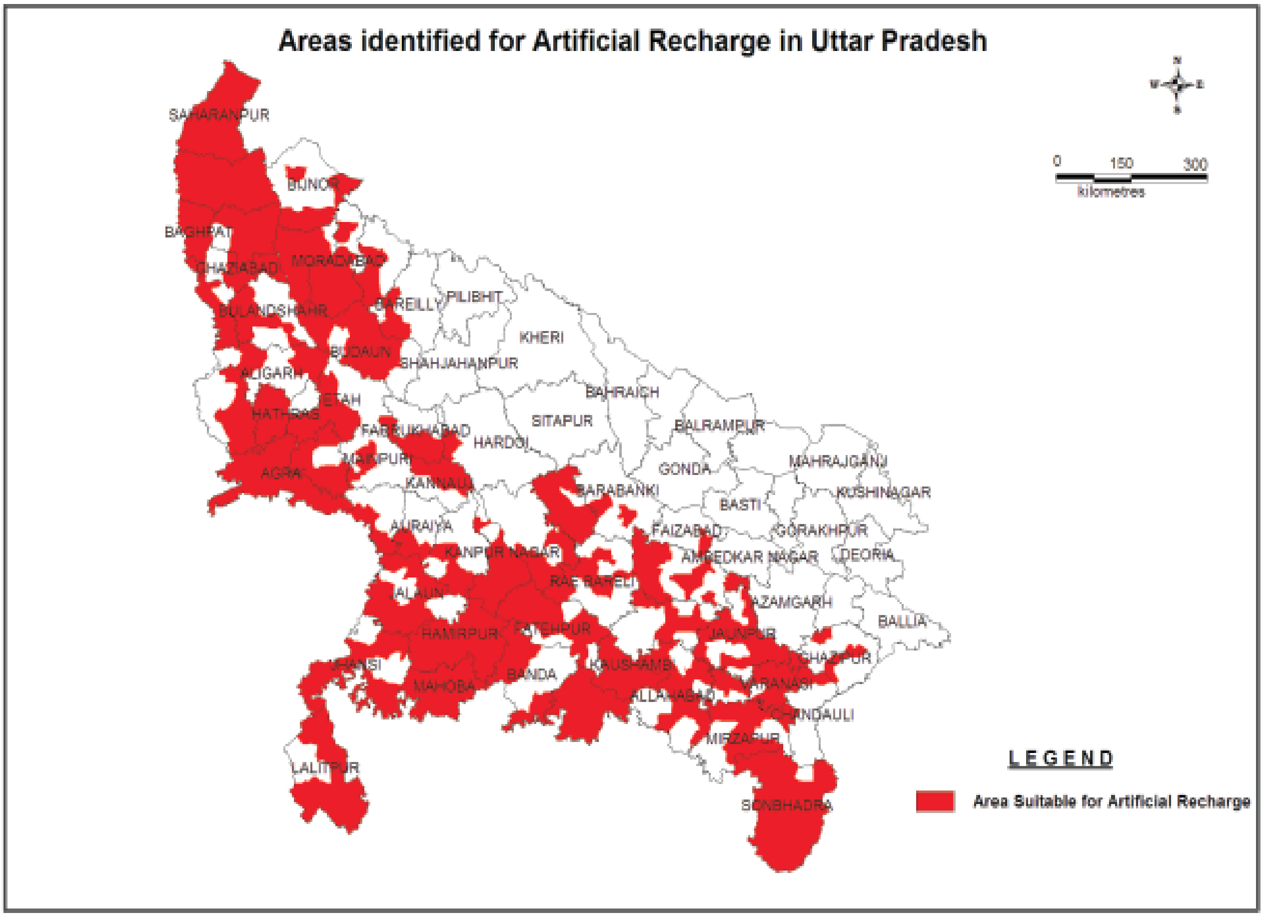


Fig. 8.21.1 Areas suitable for Artificial Recharge in Uttar Pradesh

Table 8.21.5 District- wise Ground Water Recharge Plan for Uttar Pradesh

REGION/ DISTRICT	Area feasible for artificial recharge (ha)		Volume of rechargeable unsaturated zone (MCM)	Surface water required (1.33 * Volume rechargeable) (MCM)	Surface water availability (MCM)	Type of AR structures	No. of struc-tures	Unit Cost of AR Structure (Rs. in lakhs)	Total cost (Rs. in lakhs)	Total cost (Rs. in lakhs)
	Alluvium	Hard Rock								
BUNDELKHAND REGION										
BANDA	235871	280	1896	2521	115	P	114	20.0	2280	18356
						NB/CD/CP	1531	10.0	15310	
						RS/DW/TW	766	1.0	766	
CHITRAKOOT	293219	11121	311	414	357	P	143	20.0	2860	22852
						NB/CD/CP	1904	10.0	19040	
						RS/DW/TW	952	1.0	952	
HAMIRPUR	381337	0	3898	5184	178	P	178	20.0	3560	28476
						NB/CD/CP	2373	10.0	23730	
						RS/DW/TW	1186	1.0	1186	
JALAUN	307940	0	1943	2584	143	P	143	20.0	2860	22926
						NB/CD/CP	1911	10.0	19110	
						RS/DW/TW	956	1.0	956	
JHANSI	365124	35306	894	1189	168	P	167	20.0	3340	26807
						NB/CD/CP	2235	10.0	22350	
						RS/DW/T+W	1117	1.0	1117	
LALITPUR	386740	98939	477	634	218	P	218	20.0	4360	34884
						NB/CD/CP	2907	10.0	29070	
						RS/DW/TW	1454	1.0	1454	
MAHOBA	231810	59090	165	219	108	P	108	20.0	2160	17301
						NB/CD/CP	1442	10.0	14420	
						RS/DW/TW	721	1.0	721	
TOTAL	**2202041**	**204736**	**9583**	**12746**	**1287**	**P**	**1071**	**20.0**	**21420**	**171602**
						NB/CD/CP	**14303**	**1.0**	**143030**	
						RS/DW/TW	**7152**	**10.0**	**7152**	

REGION/ DISTRICT	Area feasible for artificial recharge (ha)		Volume of rechargeable unsaturated zone (MCM)	Surface water required (1.33 * Volume rechargeable) (MCM)	Surface water availability (MCM)	Type of AR structures	No. of struc-tures	Unit Cost of AR Structure (Rs. in lakhs)	Total cost (Rs. in lakhs)	Total cost (Rs. in lakhs)
	Alluvium	Hard Rock								
CENTRAL REGION										
BARABANKI	51400	0	225	300	29	P	15	20.0	300	4454
						NB/CD/CP	391	10.0	3910	
						RS/DW/TW	244	1.0	244	
HARDOI	32030	0	70	93	16	P	8	20.0	160	2466
						NB/CD/CP	217	10.0	2170	
						RS/DW/TW	136	1.0	136	
KANPUR DEHAT	113804	0	1150	1529	51	P	25	20.0	500	7672
						NB/CD/CP	675	10.0	6750	
						RS/DW/TW	422	1.0	422	
KANPUR NAGAR	212229	0	1376	1830	90	P	45	20.0	900	13618
						NB/CD/CP	1197	10.0	11970	
						RS/DW/TW	748	1.0	748	
LUCKNOW	197033	0	772	1027	101	P	51	20.0	1020	15395
						NB/CD/CP	1353	10.0	13530	
						RS/DW/TW	845	1.0	845	
RAI BARELI	215189	0	1011	1345	107	P	54	20.0	1080	16284
						NB/CD/CP	1431	10.0	14310	
						RS/DW/TW	894	1.0	894	
UNNAO	148900	0	643	856	69	P	35	20.0	700	10401
						NB/CD/CP	913	10.0	9130	
						RS/DW/TW	571	1.0	571	
TOTAL	**970585**	**0**	**5247**	**6978**	**463**	**P**	**233**	**20.0**	**4660**	**70290**
						NB/CD/CP	**6177**	**10.0**	**61770**	
						RS/DW/TW	**3860**	**1.0**	**3860**	
EASTERN REGION										
ALLAHABAD	313882	24490	1167	1552	162	P	79	20.0	1580	24487
						NB/CD/CP	2156	10.0	21560	
						RS/DW/TW	1347	1.0	1347	
CHANDAULI	45980	0	125	167	25	P	12	20.0	240	3821

REGION/ DISTRICT	Area feasible for artificial recharge (ha)		Volume of rechargeable unsaturated zone (MCM)	Surface water required (1.33 * Volume rechargeable) (MCM)	Surface water availability (MCM)	Type of AR structures	No. of struc-tures	Unit Cost of AR Structure (Rs. in lakhs)	Total cost (Rs. in lakhs)	Total cost (Rs. in lakhs)
	Alluvium	Hard Rock								
FAIZABAD	27100	0	31	42	15	P	8	20.0	160	2306
						NB/CD/CP	202	10.0	2020	
						RS/DW/TW	126	1.0	126	
FATEHPUR	308997	0	2583	3435	157	P	78	20.0	1560	23734
						NB/CD/CP	2087	10.0	20870	
						RS/DW/TW	1304	1.0	1304	
GHAZIPUR	90886	0	258	343	51	P	25	20.0	500	7693
						NB/C/CP	677	10.0	6770	
						RS/DW/TW	423	1.0	423	
JAUNPUR	279713	0	993	1321	149	P	77	20.0	1540	22662
						NB/CD/CP	1988	10.0	19880	
						RS/DW/TW	1242	1.0	1242	
KAUSHAMBI	174934	0	1446	1923	90	P	46	20.0	920	13691
						NB/CD/CP	1202	10.0	12020	
						RS/DW/TW	751	1.0	751	
MIRZAPUR	232103	51985	682	907	131	P	64	20.0	1280	19799
						NB/CD/CP	1743	10.0	17430	
						RS/DW/TW	1089	1.0	1089	
PRATAPGARH	134085	0	679	904	71	P	35	20.0	700	10720
						NB/CD/CP	943	10.0	9430	
						RS/DW/TW	590	1.0	590	
SONBHADRA	649191	429735	841	1118	373	P	186	20.0	3720	56611
						NB/CD/CP	4978	10.0	49780	
						RS/DW/TW	3111	1.0	3111	
ST. RAVIDAS NAGAR	58009	0	125	166	32	P	16	20.0	320	4846
						NB/CD/CP	426	10.0	4260	
						RS/DW/TW	266	1.0	266	
SULTANPUR	281699	0	1051	1397	153	P	76	20.0	1520	23175
						NB/CD/CP	2038	10.0	20380	
						RS/DW/TW	1275	1.0	1275	
VARANASI	128702	0	643	855	71	P	35	20.0	700	10730
						NB/CD/CP	944	10.0	9440	
						RS/DW/TW	590	1.0	590	

REGION/ DISTRICT	Area feasible for artificial recharge (ha)		Volume of rechargeable unsaturated zone (MCM)	Surface water required (1.33 * Volume rechargeable) (MCM)	Surface water availability (MCM)	Type of AR structures	No. of struc-tures	Unit Cost of AR Structure (Rs. in lakhs)	Total cost (Rs. in lakhs)	Total cost (Rs. in lakhs)
	Alluvium	Hard Rock								
TOTAL	**2725281**	**506210**	**10623**	**14129**	**1479**	**P**	**737**	**20.0**	**14740**	**224275**
						NB/CD/CP	**19721**	**10.0**	**197210**	
						RS/DW/TW	**12325**	**1.0**	**12325**	
WESTERN REGION										
AGRA	402799	5175	6463	8595	163	P	83	20.0	1660	24811
						NB/CD/CP	2179	10.0	21790	
						RS/DW/TW	1361	1.0	1361	
ALIGARH	181116	0	854	1136	69	P	34	20.0	680	10412
						NB/CD/CP	916	10.0	9160	
						RS/DW/TW	572	1.0	572	
AURAIYA	62477	0	218	290	27	P	14	20.0	280	4073
						NB/CD/CP	357	10.0	3570	
						RS/DW/TW	223	1.0	223	
BAGHPAT	134473	0	1688	2245	56	P	28	20.0	560	8465
						NB/CD/CP	744	10.0	7440	
						RS/DW/TW	465	1.0	465	
BAREILLY	81737	0	175	232	48	P	24	20.0	480	7333
						NB/CD/CP	645	10.0	6450	
						RS/DW/TW	403	1.0	403	
BIJNOR	175490	0	710	945	106	P	53	20.0	1060	16116
						NB/CD/CP	1417	10.0	14170	
						RS/DW/TW	886	1.0	886	
BUDAUN	370361	0	1529	2033	172	P	89	20.0	1780	26185
						NB/CD/CP	2297	10.0	22970	
						RS/DW/TW	1435	1.0	1435	
BULANDSHAHAR	178442	0	780	1038	67	P	33	20.0	660	10149
						NB/CD/CP	893	10.0	8930	
						RS/DW/TW	559	1.0	559	
ETAH	214517	0	552	735	84	P	42	20.0	840	12687
						NB/CD/CP	1115	10.0	11150	
						RS/DW/TW	697	1.0	697	

REGION/ DISTRICT	Area feasible for artificial recharge (ha)		Volume of rechargeable unsaturated zone (MCM)	Surface water required (1.33 * Volume rechargeable) (MCM)	Surface water availability (MCM)	Type of AR structures	No. of struc-tures	Unit Cost of AR Structure (Rs. in lakhs)	Total cost (Rs. in lakhs)	Total cost (Rs. in lakhs)
	Alluvium	Hard Rock								
ETAWAH	79095	0	2006	2668	34	P	17	20.0	340	5132
						NB/CD/CP	451	10.0	4510	
						RS/DW/TW	282	1.0	282	
FARRUKHABAD	87345	0	965	1284	38	P	19	20.0	380	5788
						NB/CD/CP	509	10.0	5090	
						RS/DW/TW	318	1.0	318	
FIROZABAD	199905	0	788	1048	81	P	39	20.0	780	12266
						NB/CD/CP	1081	10.0	10810	
						RS/DW/TW	676	1.0	676	
G B NAGAR	114079	0	348	463	45	P	23	20.0	460	6846
						NB/CD/CP	601	10.0	6010	
						RS/DW/TW	376	1.0	376	
GHAZIABAD	150149	0	779	1036	59	P	30	20.0	600	9015
						NB/CD/CP	792	10.0	7920	
						RS/DW/TW	495	1.0	495	
HATHRAS (MAHAMAYANAGAR)	123244	0	1522	2024	47	P	23	20.0	460	7079
						NB/CD/CP	623	10.0	6230	
						RS/DW/TW	389	1.0	389	
J P NAGAR	211412	0	1185	1575	110	P	55	20.0	1100	16750
						NB/CD/CP	1473	10.0	14730	
						RS/DW/TW	920	1.0	920	
KANNAUJ	99921	0	1074	1429	44	P	22	20.0	440	6624
						NB/CD/CP	582	10.0	5820	
						RS/DW/TW	364	1.0	364	
KASHI RAM NAGAR	23882	0	100	133	9	P	5	20.0	100	1418
						NB/CD/CP	124	10.0	1240	
						RS/DW/TW	78	1.0	78	
MAINPURI	61140	0	472	627	24	P	12	20.0	240	3693
						NB/CD/CP	325	10.0	3250	
						RS/DW/TW	203	1.0	203	

REGION/ DISTRICT	Area feasible for artificial recharge (ha)		Volume of rechargeable unsaturated zone (MCM)	Surface water required (1.33 * Volume rechargeable (MCM)	Surface Water availability (MCM)	Type of AR structures	No. of struc-tures	Unit Cost of AR Structure (Rs. In Lakhs)	Total cost (Rs.in Lakhs)	Total cost (Rs. In Lakhs)
	Alluviam	Hard Rock								
MATHURA	191290	0	1318	1754	64	P	33	20.0	660	9734
						NB/CD/CP	854	10.0	8540	
						RS/DW/TW	534	1.0	534	
MEERUT	221972	0	1356	1804	92	P	46	20.0	920	13957
						NB/CD/CP	1227	10.0	12270	
						RS/DW/TW	767	1.0	767	
MORADABAD	281643	0	1745	2321	147	P	73	20.0	1460	22295
						NB/CD/CP	1961	10.0	19610	
						RS/DW/TW	1225	1.0	1225	
MUZAFFARNAGAR	400043	0	3301	4390	163	P	81	20.0	1620	24645
						NB/CD/CP	2167	10.0	21670	
						RS/DW/TW	1355	1.0	1355	
RAMPUR	83787	0	131	174	44	P	23	20.0	460	6655
						NB/CD/CP	583	10.0	5830	
						RS/DW/TW	365	1.0	365	
SAHARANPUR	333967	0	2319	3084	162	P	80	20.0	1600	24633
						NB/CD/CP	2168	10.0	21680	
						RS/DW/TW	1353	1.0	1353	
TOTAL	**4464286**	**5175**	**32378**	**43063**	**1956**	**P**	**981**	**20.0**	**19620**	**296761**
						NB/CD/CP	**26084**	**10.0**	**260840**	
						RS/DW/TW	**16301**	**1.0**	**16301**	
GRAND TOTAL	**10362193**	**716121**	**57831**	**76915**	**5185**	**P**	**3022**	**20.0**	**60440**	**762928**
						NB/CD/CP	**66285**	**10.0**	**662850**	
						RS/DW/TW	**39638**	**1.0**	**39638**	

8.22 UTTARAKHAND

The state of Uttarakhand, which comprises 13 districts, lies between 28°43’20" – 31°28’00" N latitude and 77°34’06" – 81°01’31" E longitude and has a total geographical area of 53,483 km^2. About 85% of the area of Uttarakhand state is occupied by Himalayan Mountain. Himalayan mountain is represented by NW-SE trending hill ranges which exhibit highly rugged youthful topography.The Great Himalayan range and Tethys are at places covered by snow. Geomorphologically, the area is divided into unit’s like high relief glaciated area, structural hills, denudational hills, dissected fans, river terraces, flood plains etc. The southern boundary of Uttarakhand Himalayas is covered by alluvium of Bhabar and Tarai.

Major part of the hilly area has a slope more than 20%. A slope of the magnitude of this order makes the area unsuitable for groundwater development due to low groundwater potential. Administratively the state is divided into thirteen (13) districts, namely, Chamoli, Uttarkashi, Rudraprayag, Pithoragarh, Pauri, Tehri, Almora, Nainital, Champawat, Bageshwar, Dehradun, Hardwar and Udham Singh Nagar.

In Himalayan Region groundwater mainly manifests in the form of springs. Groundwater mainly occurs under unconfined conditions and the water table follows the topography. The springs are both hot and cold. The hot water springs are generally found in Central Crystalline and are structurally controlled. About 25 hot springs are reported. The temperature ranges between 32^0C and 90^0C. The spring’s discharge ranges from 1 to 10 lps. Out of 600 cold springs 330 are located in crystallines, 180 in quartzites, 50 in shales / slates and 40 in carbonate rocks. The discharge of cold springs ranges from <1 to 30 lps.

The river terraces are most significant repository of groundwater comprising assorted material such as boulder, cobble, gravel, sand and clays. The terrace material has been tapped, at few places, through open wells and bore wells.

In Bhabar zone groundwater occurs under unconfined conditions. Water level is generally deep and observed as deep as 173.71 m bgl at Haldwani. The elevation of water level varies from 250 to 300 m above MSL. The hydraulic gradient is around 3m/km. The yield of the tube wells is observed up to 5540 lpm at a drawdown of 3 to 10 m. The hydraulic conductivity, as deciphered from pumping tests, ranges between 25 and 250 m/day.

Tarai zone is characterized by moist, waterlogged area, which is gently sloping southwards (2.5 m/km). This zone is traversed by numerous perennial sluggish channels rendering the area swampy.

Drainage:

Uttarakhand state has a very prominent drainage system varying from first to fourth or fifth order. The main drainage patterns are dendritic, trellis and rectangular. The drainage of Uttarakhand may be classified into four viz. (1) Yamuna basin, (2) Ganga basin, (3) Ramganga basin and (4) Sarda basin. Each river has a number of tributaries in Uttarakhand Himalaya.

Behavior of Ground Water Level

Depth to water level is monitored with the help of Ground Water Monitoring Stations. These stations are confined to districts Haridwar and Udham Singh Nagar and part of Dehradun and Nainital. The other nine districts of the Uttarakhand state are occupied by lofty Himalayan peaks.

The depth to water level have been categorized (grouped) into five ranges i.e. 0-2 m, 2-5 m, 5-10 m, 10-15 m and 15-20 m. Majority of the monitoring stations (72%) in Dehradun districts falls within the range of 10 to 20 m depth to water levels whereas 27 % falls within the range of 2 to 10 m bgl. District Haridwar shows entirely different behavior, where depth to water level is restricted within 2 to 10 m only during pre-monsoon. In Udham Singh Nagar District, majority of the monitoring stations (75 %) show depth range of 2 to 5m. The station of Nainital always shows ground water level within 5 to 10 m.

8.22.1 WATER LEVEL FLUCTUATION

The water levels fluctuate seasonally in response to varying recharge and discharge. The main sources to ground water recharge in the state are rainfall and return flow from irrigation. The discharge accounts from ground water pumping mainly for irrigation purpose and base flow. The water level fluctuation ranges between –0.39 and 10.80 m. Major part of the area shows water level rise where as rest of the area nearly 40 % shows fluctuation range of 0-2 and 2-4 m. On an average 2 m thickness (fluctuation) has been taken for computation for getting unsaturated volume of aquifer thickness. Locally there are water level declines around Rudrapur, Kichacha and Lalkuan areas.

8.22.2 SOURCE WATER AVAILABILITY:

The four major basins viz. Yamuna, Ganga, Ram Ganga and Sarda in Uttarakhand covers entire area of state .There is enormous quantity of surplus water flows down to the southward plain area .The surplus water usually generated by run-off, base flow and snow melt. The assessment of volume of surface water by such basins has not been quantified due to paucity of data, but it is obvious that rivers, rivulets, streams and nala of Himalayan mountain are very much perennial. Only the first and some time second order of streams are seasonal in nature.

8.22.3 RECHARGE STRUCTURES AND COST ESTIMATES:

Physiographically the major parts of Uttarakhand state is hilly with localized small valleys through which the entire run-off passes .As the area is hilly with high slope the major part of the rainfall is lost as surface run-off. Apart from this the small rivers, nallas also act as carriers for base flow and spring water. In spite of good rain fall in hilly areas there is acute shortage of water especially during the summer. Further availability of water is restricted in these streams only .Thus the water in the streams should be harvested for irrigation and domestic needs through the various structures of rain water harvesting and water conservation measures.

Hydrogeologically, the area has been broadly grouped into hills (10 districts of Uttarakhand) and alluvium area (3 districts). The broad valleys in hilly area are the feasible place for check dam construction where gentle slope (less than 20%) prevails, whereas in the alluvium area (in foothill and beyond southward) check dam and percolation tanks are more appropriate. Roof top rain water harvesting can be adopted in both the terrain; rather this should be given more emphasis on hilly areas specially.

Haridwar and Udham Singh Nagar districts have by and large plain topography. The district Udham Singh Nagar is having very shallow water levels, hence localized artificial recharge structures like percolation ponds/tanks and roof top rain water harvesting are to be adopted.

Almost 95 percent of the rainfall that falls in the catchments area goes out of the state as surface runoff due to high slopes. It is thus important that this runoff is arrested to some extent by constructing gully plugs and contour bunds. These structures arrest the surface runoff, increases the soil moisture, recharge the shallow ground water aquifer and also increase the discharge of springs.

The district wise breakup of the type, number of structures and their cost are shown in table 8.22.1.

8.22.4 IDENTIFICATION OF AREA SUITABLE FOR RECHARGE:

Since 85% of Uttarakhand area is covered by lofty mountains, therefore the areas feasible for artificial recharge is about 15% wherein site specific selection of structures is very important. The villages and agricultural field lying in the wider valleys with gentle slope (less than 20 %) are the only feasible area for artificial recharge structures. On this pretext, district wise identification of area suitable for recharge has summarized in the following paragraphs:

Dehradun: Hydro-geologically, Dehradun valley (Doon) is most feasible area for artificial recharge structures like, recharge shafts and percolation ponds due to the occurrence of unsaturated bouldary formations at shallower depth. Recharge shafts are suitable for artificial recharge to ground water. The recharge shafts will also facilitates in ameliorating water logging in Dehradun urban area. In the recent time, the city of Dehradun is being expanding in full swing, in turn resulting to a concrete apron over the city area. Consequently less and less percolation of rain water occurs. Thus Doon valley is the effective & feasible area for artificial recharge to ground water.

Haridwar: District Haridwar exhibits an entirely different topography and groundwater scenario. The structures feasible, in the fringe area, are gully plugs, gabions and check dams. But in the plain area like Bhagwanpur, Sultanpur, Manglaur, and Bahadrabad, percolation tanks, roof top rainwater harvesting and recharge shafts are feasible.

Tehri: Tehri districts covers the physiographic situation of lesser to greater Himalaya in which the artificial recharge of ground water can be practiced in the villages of Dhanaulti, Narendra Nagar and Pratap Nagar along with the roof top rain water structures in the same town area.

Chamoli: The Tethyan Himalaya falls in the districts of Chamoli are fully covered with the Snow Mountains with parts of Greater Himalayas also covered by snow. Chamoli is also predominantly covered by the narrow valleys of Sarswati, Dhauli Ganga, Rishi Ganga, Birhi Ganga and Pinder River. The suitable sites for recharge structures can be constructed in the villages of Karnprayag, Pokhri, Chamoli, Joshimath, Tharali, and Gauchar.

Pauri: The valley of Nayar, East Nayar and West Nayar are the favorable place for check dam construction whereas roof top rain water structure can be constructed in the villages and towns like Srinagar, Pauri, Satpuli, Lansdowne and Dugadda.

Uttarkashi: North-Eastern part of Uttarkashi district is covered with snow clad mountain. River Yamuna and Ganga (Bhagirathi) originates from Yamunotri and Gomukh area of this district respectively. Their lower reached at Purola, Barkot and Dunda area are somewhat suitable for check dam construction. Roof top rain water harvesting structure can be practiced in Barkot, Dunda and Bhatwari villages.

Rudraprayag: Mandakini is the major river running almost north to south in the middle of district. The district also falls in the Greater Himalaya where steep and narrow gorges are predominant. Only the villages like Augustmuni, Jakholi, Tilwara, Baramwari and Guptkashi can be selected for check dam construction along with harvesting structures.

Almora: Narrow gorges and valleys are predominating in Almora district. However, the valleys of Ramganga, Kosi and Sarju River are the suitable place for check dam construction. Roof top rain water harvesting can be adopted in the township of Ranikhet, Someshwar, Bhikiyasain and Bhanauli.

Nainital: Major part of Nainital district comes under Lesser Himalaya where highest mountain is having altitude of 2591 m. The southern fringe of the district is covered by the Bhabar and Tarai formation which are traversed by numerous north to south flowing streams. Ramnagar, Kaladungi, Haldwani and Chorgalia are the important places where check dam & percolation tanks can be constructed for recharge. Nainital, Bhimtal and Bhowali are the suitable towns for roof top rain water harvesting.

Champawat : Southern part of Champawat district have a east-west running narrow strip of Bhaber and Tarai formation ,especially the area of Banbasa and Tanakpur in which check dam and percolation tanks are very much suitable to construct artificial recharge structures . In the lesser Himalayas Dayuri and Purnagiri temple area are suitable for recharge. Roof top rain water harvesting structures can be suitably constructed in the township of Champawat and Tanakpur.

Pithoragarh: The entire Pithoragarh district comes under Greater and Tethyan Himalayas. Nearly 35/40 % mountains are snow covered where roof top rain water harvesting are the most viable option in these areas. The valleys near Gangolihat, Dewalthal, Thal and Jauljibi are the favorable place for artificial recharge. These places are drained by the streams like Goriganga, Ramganga and Saryu.

Bageshwar: The entire area of Bageshwar comes under greater Himalaya where nearly 10/15% mountains are snow covered. The river valleys of Gomati, Sarju and Ramganga in which villages like Baijnath, Gorur, Kapkot and Khantoli are situated can be selected for check dam construction. These villages are also suitable for roof top rain water harvesting.

Udham Singh Nagar: The entire area of Champawat lying in the Tarai belt in which depth to water level is very shallow in nature except Jaspur and Kashipur area where check dam and percolation tanks are suitable options. The roof top rain water harvesting can be practiced in the entire district.

8.22.5 SUB-SURFACE STORAGE SPACE AND WATER REQUIREMENT:

In Uttarakhand state, except Haridwar and Udham Singh Nagar all other districts exist with highly undulating topography where generally aquifer systems are very much localized. In the outer Himalaya wherever alluvium or valley deposits occurs they are relatively covered by bigger surface area than that of middle Himalayas. The depth to water level in these alluvium domain are very much variable than the plain area of Tarai and beyond in the Gengetic plain. Thus, subsurface storage space is herby generalized for 2m as unsaturated zone. Only for district Udham Singh Nagar storage space has been taken as one meter owing to their shallower nature of depth to water level.

For the seven districts of Garhwal division and six districts of Kumaun division the sub surface storage space has been calculated as 26311 MCM whereas for their saturation, the volume of water required is 6578 MCM.

The volume of source available for recharge has been computed on the basis of 70% of the average rain fall (1500 mm) which is the feasible area only. The area suitable for recharge in the State is given in Fig. 8.22.1.

8.22.6 AREA BENEFITTED

The impact of artificial recharge to ground water will be mainly around the recharge structures due to gradient of water table. The impact will be optimum during post monsoon period and distinct rise in ground water level will be observed in the recharge area as compared to the discharge area. It is estimated

TABLE – 8.22.1 District-wise estimates of Artificial Recharge Structures in Uttarakhand

Sl.No.	District	Area of district (sq. km)	Average post monsoon depth to water (m bgl)	Area feasible for artificial recharge (sq. km)	Volume of unsaturated zone available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of surplus local/distant source available for recharge (MCM)	Types of artificial recharge structures feasible and their numbers	Total costs (unit cost X number) (Rs.in crores)
GARHWAL DIVISION									
1	DEHRADUN	3088	15.00	772	1544	386	810	RS – 150 CD – 100	17.25
2	HARIDWAR	2360	08.00	590	1180	295	619	P – 150 C D– 100	37.50
3	TEHRI	4080	--	1020	2040	510	1071	CD – 200	30.00
4	CHAMOLI	7614	--	1903	3806	951	1998	CD- 200	30.00
5	PAURI	5400	--	1350	2700	675	1417	CD- 200	30.00
6	UTTARKASHI	8016	--	2004	4008	1002	2104	CD- 200	30.00
7	RUDRAPRAYAG	2439	--	610	1210	302	640	CD- 200	30.00
KUMAUN DIVISION									
8	ALMORA	3083	--	770	1540	385	808	CD- 200	30.00
9	NAINITAL	3860	27.00 (part of the area)	965	1930	482	1013	P – 150 CD– 100	37.50
10	PITHORAGARH	7100	--	1775	3550	887	1863	CD – 300	45.00
11	CHAMPAWAT	1781	14.00 (part of the area)	445	890	225	467	P – 50 CD – 150	30.00
12	BAGESHWAR	2302	--	575	1150	287	603	CD – 300	45.00
13	UDHAM SINGH NAGAR	3055	04.00	763	763 (1m)	191	885	P – 100 CD –50	22.50
STATE TOTAL				**13542**	**26311**	**6578**	**14307**	**RS –150 P – 450 C D– 2300**	**414.75**

Unit Cost: Percolation Tank (P) =15.00 Lakhs, Chedk dam (CD)=15.00 Lakhs, Recharge Shaft (RS) =1.50 Lakhs

that influence of recharge scheme as proposed in master plan will be observed in about 13542 sq. km area and it will help to check in decline in water level with the help of 6578 MCM recharge water.

Usually in the broader valleys of Himalayan Mountain and valley bottom, irrigation facilities are scarce during post monsoon period. In these areas of check dam and percolation tank will be beneficial for sustainable irrigation during the lean periodfor existing cropping patteren.

8.22.7 ROOF TOP RAIN WATER HARVESTING:

It has been assessed that roof top rain water harvesting can be adopted in ~ 48250 houses, govt. buildings, institutes etc. in urban and municipal areas of the state suitable for artificial recharge in the first phase. It will harness 13.67 MCM rain water considering normal rainfall for the state and 80% efficiency of the system. The cost of roof top rain water harvesting of a building having roof and paved area of ~ 200 sq.m. has been assessed to be Rs. 12,000 and for bigger buildings having more than 1000 sq.m. will be Rs. 1.50 lakh. The total cost for the roof top rain water harvesting for the state has been estimated to be Rs.68.25 crores in the first phase considering 5% of the total buildings having larger roofs.

8.22.8 ACTION TAKEN BY UTTARAKHAND STATE TO PROMOTE RAIN WATER HARVESTING:

The State Government (Avash and Shahari Vikas) has made rules for compulsory installation of rain water harvesting system and directed to adopt rules in building by-laws. Accordingly, all the development authorities have made partial amendments in the prevalent house building and development bye-laws/ regulations.

109 traditional ponds and 104 percolation tanks have been constructed to conserve water. Besides these schemes basin/ sub-basin catchments programme has been taken up by the project Management unit (PMU) under “Swajal Project” under the catchments areas conservation and management plan (CACMP).

8.22.9 TOTAL COST

Table 8.22.2 gives the summarized cost estimates for various types of structures feasible in Uttarakhand state which works out to Rs. 483 crores.

Table-8.22.2 Summarized cost estimates for various types of structures feasible in Uttarakhand

Type of Structure	Total No. of Structures	Unit cost (Rs. in crores)	Total cost (Rs. in crores)
Percolation Tank	450	0.15	67.50
Check Dam	2300	0.15	345.00
Roof Top Rain Water harvesting structure	48250	0.0012-0.015	68.25
Recharge Shaft	150	0.01.50	2.25
Total			**483.00**

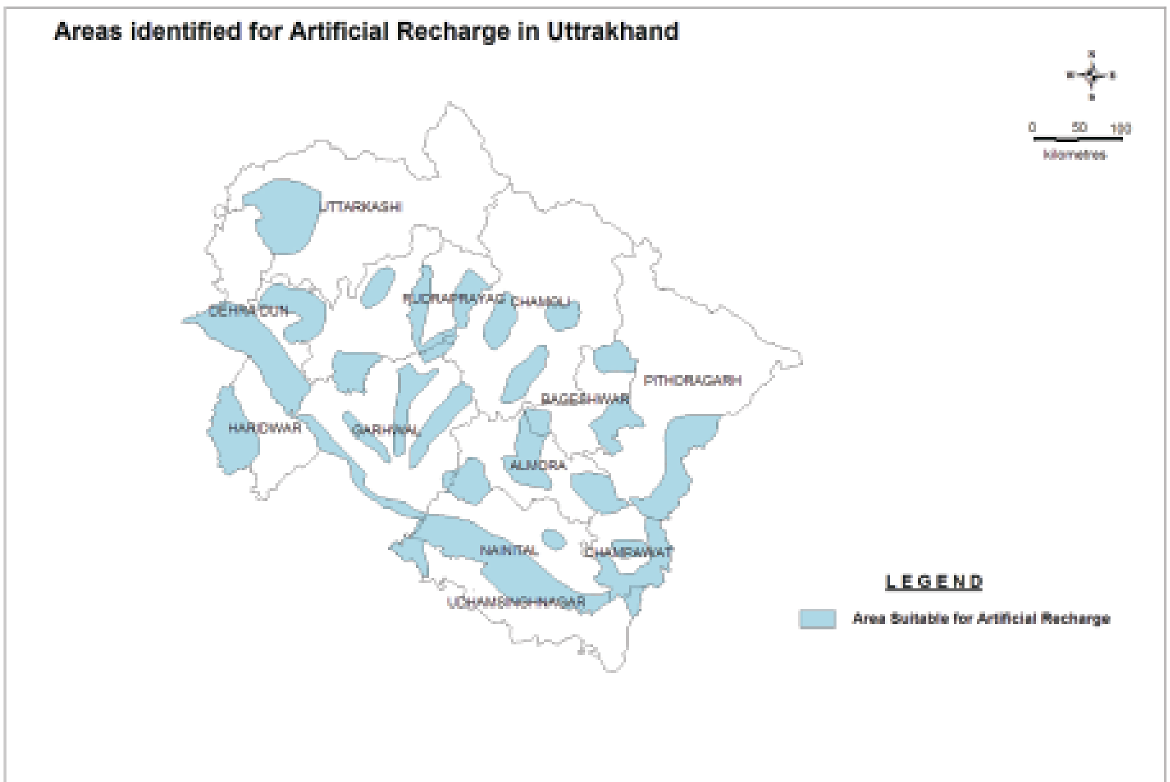


Fig. 8.22.1 – Areas suitable for Artificial Recharge in Uttarakhand

8.23 WEST BENGAL

The State of West Bengal has a total geographic area of 88,752 sq km., and has a population of 91,347,736 as per 2011 census with a population density of 1029 per sq km. The average rainfall in the state is about 1750 mm of which 1250 mm occurs during the period from June to September. While the hilly Himalayan region receives the heaviest rainfall ranging from 2500 to 6000 mm, the southern districts in the plains receive on an average rainfall from 1125 to 1875 mm. There are three major river basins in the State, namely, the Ganga, Brahmaputra and Subarnarekha. The Tista, Torsa, Jaldhaka, etc., are the tributaries to the river Brahmaputra. The Mahananda, Mayurakshi, Ajoy, Damodar, Dwarakeswar, Kasai, Jalangi, Churni, etc. are other tributaries to the river Ganga/Bhagirathi–Hugli river.

8.23.1 IDENTIFICATION OF AREA

Post monsoon average depth to water level maps and long-term trend in water level map has been superimposed over administrative boundary to identify and to prioritize the most feasible area for recharge. The areas considered fulfill the conditions mentioned below.

a) Water levels more than 9 m bgl with or without the falling trend

b) Water levels between 6 and 9 m bgl and declining trend of > 10 cm/yr

c) Area showing water levels between 6-9 m bgl with no declining trend

d) Areas showing water levels between 3 and 6 m bgl and declining trend of > 10 cm /yr

On the other hand the drought prone district underlying by hard crystalline basement rocks, traps and semi consolidated to consolidated Gondwana formations at the shallower depth and lateritic area in Purulia, Western parts of Bankura, Birbhum and PaschimMedinipur district, the area having water level 3-6 m bgl with or without falling trend are considered for recharge.

The coastal blocks in the vicinity of sea in Purba Medinipur and South 24 Pargana district are left beyond the purview of recharge considering the probability of discharge of recharged water in the sea. Depletion in piezometric surface is also found to occur in the urban area of Kolkata city and Haldia Industrial area. The level of ground water development in a block and the categorization are also given due importance while identifying the feasible area in a particular district. An area of 8335.84 sq km in hard rock terrain in parts of four districts and 28394.56 sq km in alluvial area is considered for recharge by suitable proposed recharge structures in West Bengal under this plan (Fig. 8.23.1).

8.23.2 SUB-SURFACE STORGE AND WATER REQUIREMENT

The storage space available for recharge is determined by the average depth of the unsaturated zone below 3 m bgl in each prioritized sectors (average post monsoon water level-3m). The depth of unsaturation beyond 3m is then multiplied by actual area considered for recharge in each sector to determine the net volume of unsaturated volume considered for recharge. An additional area of 10% is added to the feasible area for recharge to arrive at actual area considered for recharge to account for upstream recharge effects depending upon local/regional ground water flow direction. The sub surface storage potential in the state is estimated as 14931MCM.

The volume of water to be added for the optimal recharge of the aquifers in the identified area is calculated by multiplying the available storage space with specific yield value of the particular aquifer materials. After assessing the volume of water required for saturating the vadose zone, the actual requirement of source water is to be estimated.

Based on the experience gained in the pilot/experimental projects implemented in different hydrogeological situations, an average recharge efficiency of 60 to 65% of the individual structure is considered. The volume of source water required for artificial recharge was calculated by multiplying a factor of 1.61 (i.e. reciprocal of 0.62). The gross volume of surface water required, as estimated, for artificial recharge in the state is 17797 MCM. The availability of non committed source water is one of the primary requisite for designing any artificial recharge project. However, the data available of the surplus runoff is only on the basin or the sub basin level, not exclusively for the requirement for the feasible area for the recharge, therefore for the present plan, 70% of the normal average monsoon rainfall receives on actual feasible area for recharge is considered as available non committed surface runoff for that particular area**.**

8.23.3 RECHARGE STRUCTURES AND COST ESTIMATES

Considering the hydrogeological set up of the State, the following artificial recharge / conservation structures are proposed to be constructed for augmentation & conservation of ground water resources.

Type of Terrain		Type of Artificial Recharge Structure proposed
Hard rock & Hilly Areas	1.	Percolation Tanks
	2.	Check dam
	3.	Gabion Structures /Contour bunds
	4.	Sub surface dykes
	5.	Dug well recharge /recharge shaft
Alluvial Areas	1.	Percolation Tanks
	2.	Re-excavation of existing tanks with Recharge Shaft (REET)
	3.	Injection Well
Urban Areas	1.	Roof-top Rain Water Harvesting Structures

The gross storage capacity & percentage of resources allocated for different artificial recharge structures are presented in table 8.23.1.

Table – 8.23.1 Gross storage capacity and percentage of resources allocated for Artificial Recharge Structures, West Bengal

Type of Terrain	Type of Artificial Recharge Structure proposed	Storage capacity of individual structure single filling (MCM)	Resource allocated in percentage of gross proposed water requirement
Hard rock & Hilly Areas	Percolation Tanks	0.5	65
	Check dam	0.05	20
	Gabion Structures /Contour bunds	0.005	5
	Sub surface dykes	0.01	5
	Dug well recharge /recharge shaft	0.05	5
Alluvial Areas	Percolation Tanks	0.5	50
	Re-excavation of existing tanks with Recharge Shaft	0.1	20
	Injection Well	0.3	30

The amount of surface water requirement for artificial recharge is 17797 MCM which is 60% of the estimated non-committed surface run-off (29803 MCM) in the state. Therefore source water availability would not be a problem as per proposed plan.

District wise number of artificial recharge structures has been worked out based on gross storage capacity of individual structure & the allocated resources. The district-wise no. of different type of artificial recharge structures is given in table-8.23.2.

Table – 8.23.2 District-wise number of Artificial Recharge Structure proposed in West Bengal

Name of District	Geology	Surface Water Requirement for recharge (MCM)	Proposed Structures	Source water allotted (MCM)	No of structures
Bankura	Soft/ Alluvial area	238.97	Percolation Tanks	133.23	266
			REET with RS	42.30	423
			Injection Well	63.44	211
	Hard Rock Area	254.51	Percolation Tanks	175.68	351
			Check dam	45.05	901
			Gabion Structures /Contour bunds	11.26	2252
			Sub surface dykes	11.26	1126
			Dug well recharge /recharge shaft	11.26	225

Name of District	Geology	Surface Water Requirement for recharge (MCM)	Proposed Structures	Source water allotted (MCM)	No of structures
Birbhum	Soft/ Alluvial area	1347.55	Percolation Tanks	751.29	1503
			REET with RS	238.50	2385
			Injection Well	357.76	1193
	Hard Rock Area	228.17	Percolation Tanks	157.50	315
			Check dam	40.38	808
			Gabion Structures/ Contour bunds	10.10	2019
			Sub surface dykes	10.10	1010
			Dug well recharge /recharge shaft	10.10	202
Paschim Medinipur	Soft/ Alluvial area	1939.44	Percolation Tanks	1081.28	2163
			REET with RS	343.26	3433
			Injection Well	514.90	1716
	Hard Rock Area	357.43	Percolation Tanks	246.72	493
			Check dam	63.26	1265
			Gabion Structures/ Contour bunds	15.82	3163
			Sub surface dykes	15.82	1582
			Dug well recharge /recharge shaft	15.82	316
Purulia	Hard Rock Area	376.64	Percolation Tanks	259.98	520
			Check dam	66.66	1333
			Gabion Structures/ Contour bunds	16.67	3333
			Sub surface dykes	16.67	1667
			Dug well recharge /recharge shaft	16.67	333
Cooch behar	Alluvial area	19.71	Percolation Tanks	10.99	22
			REET with RS	3.49	35
			Injection Well	5.23	17
Darjeeling	Hilly area	16.09	Check dam	7.12	142
			Gabion Structures/ Contour bunding	7.55	1510
			Dug well recharge /recharge shaft	1.42	142
Hooghly	Alluvial area	2421.99	Percolation Tanks	1135.98	2272
			REET with RS	643.01	6430
			Injection Well	643.01	2143
Haora	Alluvial area	662.61	Percolation Tanks	310.78	622
			REET with RS	175.92	1759
			Injection Well	175.92	586

Name of District	Geology	Surface Water Requirement for recharge (MCM)	Proposed Structures	Source water allotted (MCM)	No of structures
Birbhum	Soft/ Alluvial area	1347.55	Percolation Tanks	751.29	1503
			REET with RS	238.50	2385
			Injection Well	357.76	1193
	Hard Rock Area	228.17	Percolation Tanks	157.50	315
			Check dam	40.38	808
			Gabion Structures/ Contour bunds	10.10	2019
			Sub surface dykes	10 10	1010
			Dug well recharge /recharge shaft	10.10	202
Paschim Medinipur	Soft/ Alluvial area	1939.44	Percolation Tanks	1081.28	2163
			REET with RS	343.26	3433
			Injection Well	514.90	1716
	Hard Rock Area	357.43	Percolation Tanks	246.72	493
			Check dam	63.26	1265
			Gabion Structures/ Contour bunds	15.82	3163
			Sub surface dykes	15.82	1582
			Dug well recharge /recharge shaft	15.82	316
Purulia	Hard Rock Area	376.64	Percolation Tanks	259.98	520
			Check dam	66.66	1333
			Gabion Structures/ Contour bunds	16.67	3333
			Sub surface dykes	16.67	1667
			Dug well recharge /recharge shaft	16.67	333
Cooch behar	Alluvial area	19.71	Percolation Tanks	10.99	22
			REET with RS	3.49	35
			Injection Well	5.23	17
Darjeeling	Hilly area	16.09	Check dam	7.12	142
			Gabion Structures/ Contour bunding	7.55	1510
			Dug well recharge /recharge shaft	1.42	142
Hooghly	Alluvial area	2421.99	Percolation Tanks	1135.98	2272
			REET with RS	643.01	6430
			Injection Well	643.01	2143
Haora	Alluvial area	662.61	Percolation Tanks	310.78	622
			REET with RS	175.92	1759
			Injection Well	175.92	586

In Darjeeling district, springs of varying discharge of 1 lps to 5 lps are found to occur at different altitudes which are in general structurally controlled. The present water requirement of the area is met with spring water only. The spring discharge can be enhanced by proper development of springs by cleaning the spring openings and its channels. By constructing gabion structure / nala bund in the upper reaches of the spring may help in increasing the spring discharge. This area is also feasible for roof top harvesting structures. Details of the proposed structures and cost estimates are given in table- 8.23.3.

Table – 8.23.3 Artificial Recharge Structures & Cost estimate in West Bengal

Type of Terrain	Type of Structure	Total volume of water to be conserved (MCM)	No. of Structure	Unit Cost (Rs. in Lakhs)	Total Cost (Rs. in Lakh)
Hard rock & Hilly Areas	Percolation Tanks	839.88	1679	10	16790.00
	Check dam	222.47	4449	1.5	6673.50
	Gabion Structures /Contour bunds	61.40	12277	0.5	6138.50
	Sub surface dykes	53.85	5385	1	5385.00
	Dug well recharge /recharge shaft	55.27	1218	1.1	1339.80
Alluvial Areas	Percolation Tanks	7956.65	15913	7	111391.00
	Re-excavation of existing tanks with Recharge Shaft	4162.37	41623	3.85	160248.55
	Injection Well	4445.20	14816	2.5	37040.00
Urban Areas	Roof-top rainwater Harvesting Structures	100.8	300000	0.12-1.20	52200.00
Total		**17897.98**	**397360**		**397206.40**

8.23.4 TOTAL COST

The total cost of the artificial recharge structures is Rs. 3972.06 crores in the state.

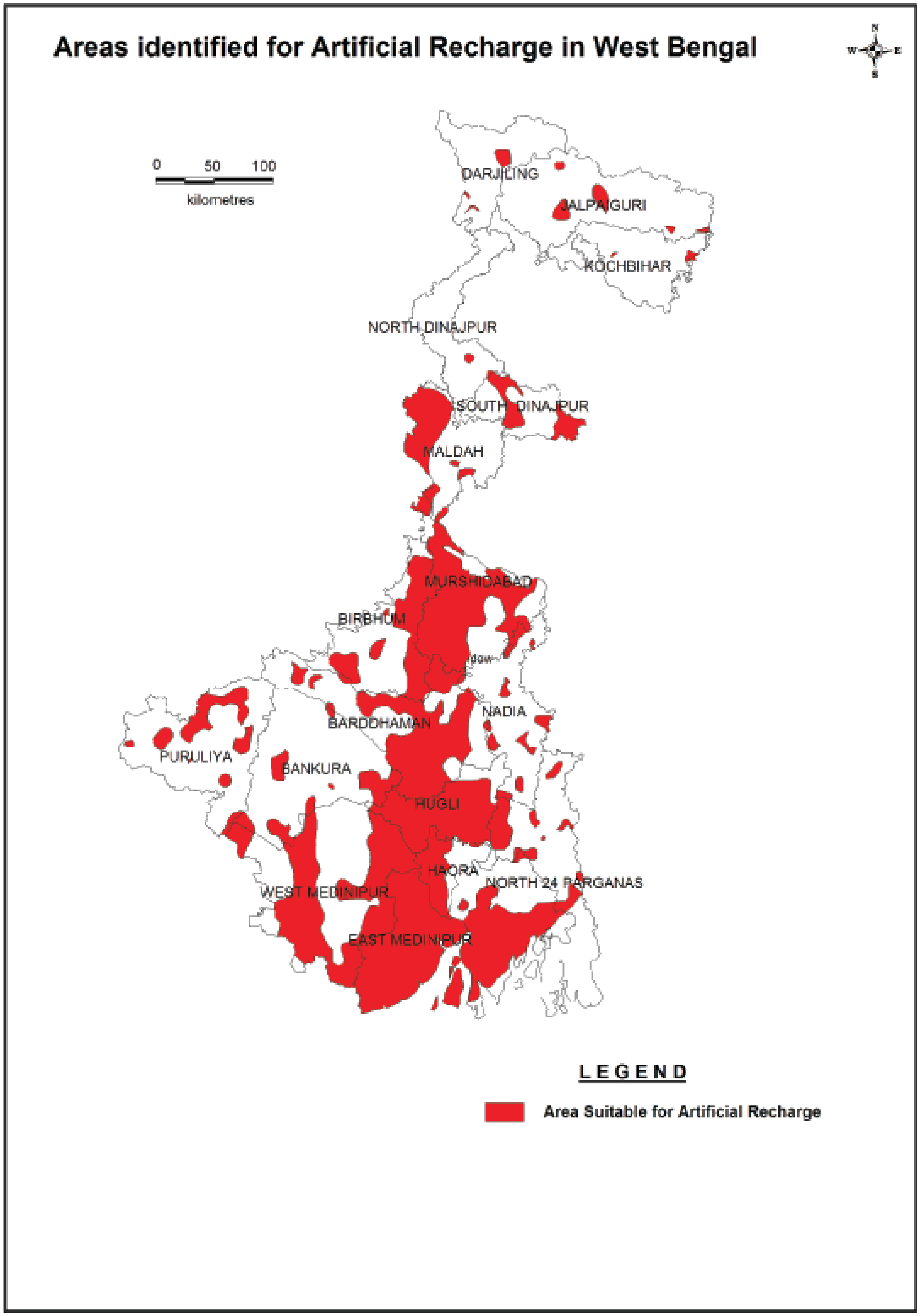


Fig 8.23.1 – Areas suitable for Artificial Recharge in West Bengal

8.24 ANDAMAN AND NICOBAR ISLANDS

Andaman and Nicobar group of Islands is constituted by three districts i.e. 1. North-Middle Andaman District (2) South Andaman from the Northern group of Islands and the southern (3) Nicobar district, separated from each other by the deep sea of 10^o channel. The Andaman group of Islands cover an area of 6340 sq. km. and the Nicobar group 1953 sq. km. Mean annual rainfall of these Islands is over 3000 mm. Perennial streams of the status of major river are absent in the Andaman and Great Nicobar Island. The major perennial streams in South Andaman are Dhanikhari, Protheropore Nala and Pema Nala etc. while in North-Middle Andaman Kalpong nala,Korang nala,Betapur nala, Rangat nala etc are the important perennial streams. In Nicobar South Andaman are all small streams – the Dhanikhari being the largest. In Nicobar District, Galathea and Alexandria rivers, Dhillon Nala, all in Great Nicobar island are the main drainage channels.

Though the development of ground water is in low key, yet the artificial recharge and conservation structures seem to provide a very good mechanism for augmentation of ground water resources in the Islands. Even endowed with high rainfall, quick evaporation losses and proximity to sea facilitate high evapotranspiration, and huge base flow from the aquifers to the sea. To meet the crisis of ground water, artificial recharge structures like percolation tank, cement plug and subsurface dykes as ground water conservation structure appears to be highly useful in the Islands. Presently in many Islands perennial springs ooze through the fractures and topographic lows which cater to a great extent to the village population. Keeping in view the importance of springs, the development of these springs is needed with proper recharge structures and catchment area treatment at appropriate locations, at the upstream of spring discharge.

Depending upon high rainfall in rainy months and scarcity of drinking water in the lean periods (Dec/Jan to April), harvesting of rainwater is very old practice of the Islanders. The tribes in the Islands till date collect rainwater in green coconuts. Recently the Island administrations have started designing the roofs of Govt. buildings for harvesting of rain water from the roof top. This practice may be popularized in the entire districts of Andaman and Nicobar so that an appreciable quantity of rain water may be conserved through properly designed roofs and the water may be conserved for day to day use after rainy season. Similarly artificial recharge through rooftop rainwater harvesting may be implemented in Neil, Havelock, Little Andaman and in parts of South Andaman in Port Blair while in Chowra and Car Nicobar in Nicobar District artificial recharge through rooftop rainwater harvesting may be the best option for sustainable water supply.

Considering all the above modes of augmentation of ground water resources, a Master Plan for artificial recharge to ground water, rain water harvesting and spring development has been prepared (Table-8.24.1 and Fig.8.24.1& 8.24.2). The plan includes spring development (150 nos.), roof top harvesting for houses (1150 nos.), roof top harvesting for Govt./Institutional buildings (50 nos.), check dam/ gabion/nala bund (320 nos.), cement plug (200 nos.), percolation tank (720 nos.) and sub-surface dykes (250 nos.). For construction of all these structures the cost is estimated as Rs.52.02 Crores. Total volume of water may likely to be harvested through these structures would be around 96.20 MCM.

Table – 8.24.1 Cost estimate and Number of Structures proposed in Andaman and Nicobar

Type of structure	No. of structure	Unit Cost (Rs. in lakh)	Total cost (Rs. in lakh)	Total volume of water harvested (MCM)
Spring Development	150	3.0	450	0.45
Roof top rain water harvesting (Houses)	1150	0.50	575	0.55
Roof top rain water harvesting (Govt. & Institutional buildings)	50	4.5	225	0.12
Gabion, Check Dam, Nala bund	320	4.0	1280	32.00
Cement Plug	200	1.5	300	12.00
Percolation tank	720	2.6	1872	1.08
Sub-surface dyke	250	2.0	500	50.00
Total	**2840**		**5202**	**96.20**

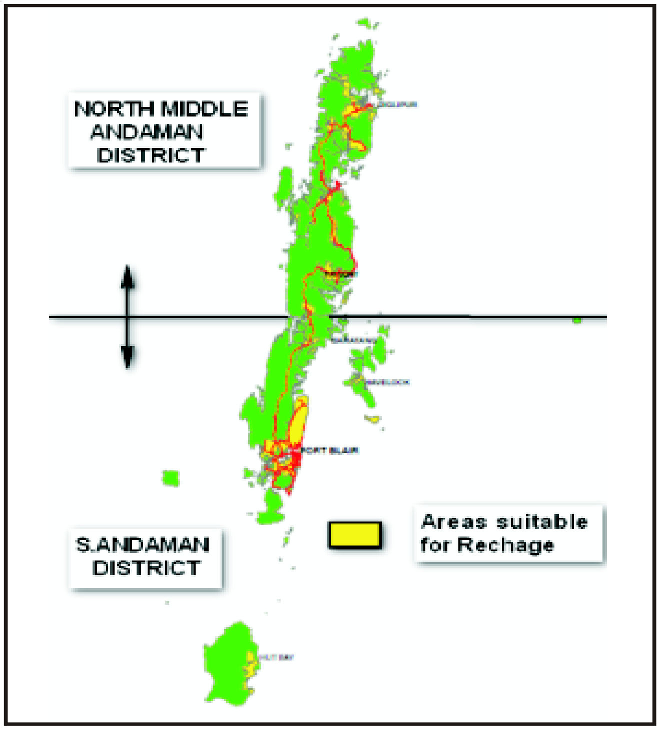


Fig. 8.24.1 Areas suitable for Artificial Recharge in Andaman district

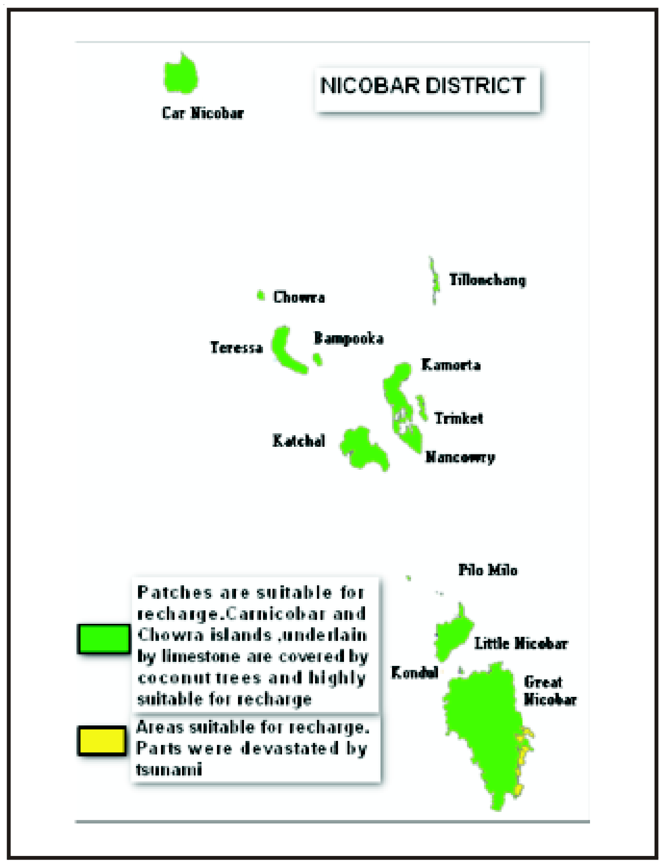


Fig. 8.24.2 Areas suitable for Artificial Recharge in Nicobar district

8.25 CHANDIGARH

Chandigarh is a highly urbanized city and the rooftop of the buildings can be suitably used for artificial recharge of the rainfall falling in Chandigarh. There is lot of green area too and some water bodies that can be effectively utilized for recharging the rainfall runoff. In Chandigarh, there are two distinct aquifer systems – shallow and deep. Shallow aquifer occurs under semi-confined conditions and exists down to 20 to 30 m below land surface. Deep aquifers below 40 m are under confined conditions. The piezometric head of the deep aquifers stands much below the water table of shallow aquifers and thus it can receive water easily on being recharged artificially.

It is estimated that about 30.71 MCM (18.45 MGD) surface runoff is available in the city for recharge to ground water during monsoons from the roads (15.89 sq.km), from rooftops of residential areas (30.19 sq.km) from shopping areas (3.97 sq. km) and public and institutional building (7.94 sq. km). This is almost equivalent to the water pumped out of aquifers and therefore, harvesting and recharging rainwater will go a long way in contributing towards sustainability of water supply. The total runoff generated during an hour of 30 mm of rainfall would be 870000 m^3. As per the prevailing hydrogeological conditions, the most suitable structure for artificial recharge to ground water in Chandigarh UT is trench cum recharge well. The dimensions of the trench would be site specific and will depend on the water availability. A recharge trench of 8 m x 2 m x 3 m capacity with twin recharge wells of 40 – 80 m. depth would store and recharge ~ 100 m^3 of rainfall run off water. It is estimated that a total of 8700 recharge structures would be required to be constructed at an cost estimate of Rs. 652.50 crores at the rate of Rs. 7.50 lakh per structure (table 8.25.1). Rain water harvesting will also address the problem of flooding due to overloading of the storm water drains. Areas suitable for recharge with type of structures is shown in the Fig.8.25.1

Table 8.25.1 - Details of Artificial Recharge Structures in Chandigarh UT

UT name	Area	Average post monsoon depth to water	Area feasible for artificial recharge	Volume of unsaturated zone available for recharge	Volume of water required for recharge	Volume of runoff per hour available for recharge @ 30mm rainfall per hour	Types of artificial recharge structures feasible* and their numbers			Unit cost	Total costs (unit cost x number)
							Type of structure	Recharge capacity per hour per structure	No.		
	(sq.km)	(m bgl)	(sq.km)	(MCM)	(MCM)	(MCM)		(MCM)		(Rs. in lakhs)	(Rs.in lakhs)
Chandigarh	114	4.45	100	145	193	0.87	RS with twin recharge wells of ~70 m. depth	0.0001	8700	7.5	65250

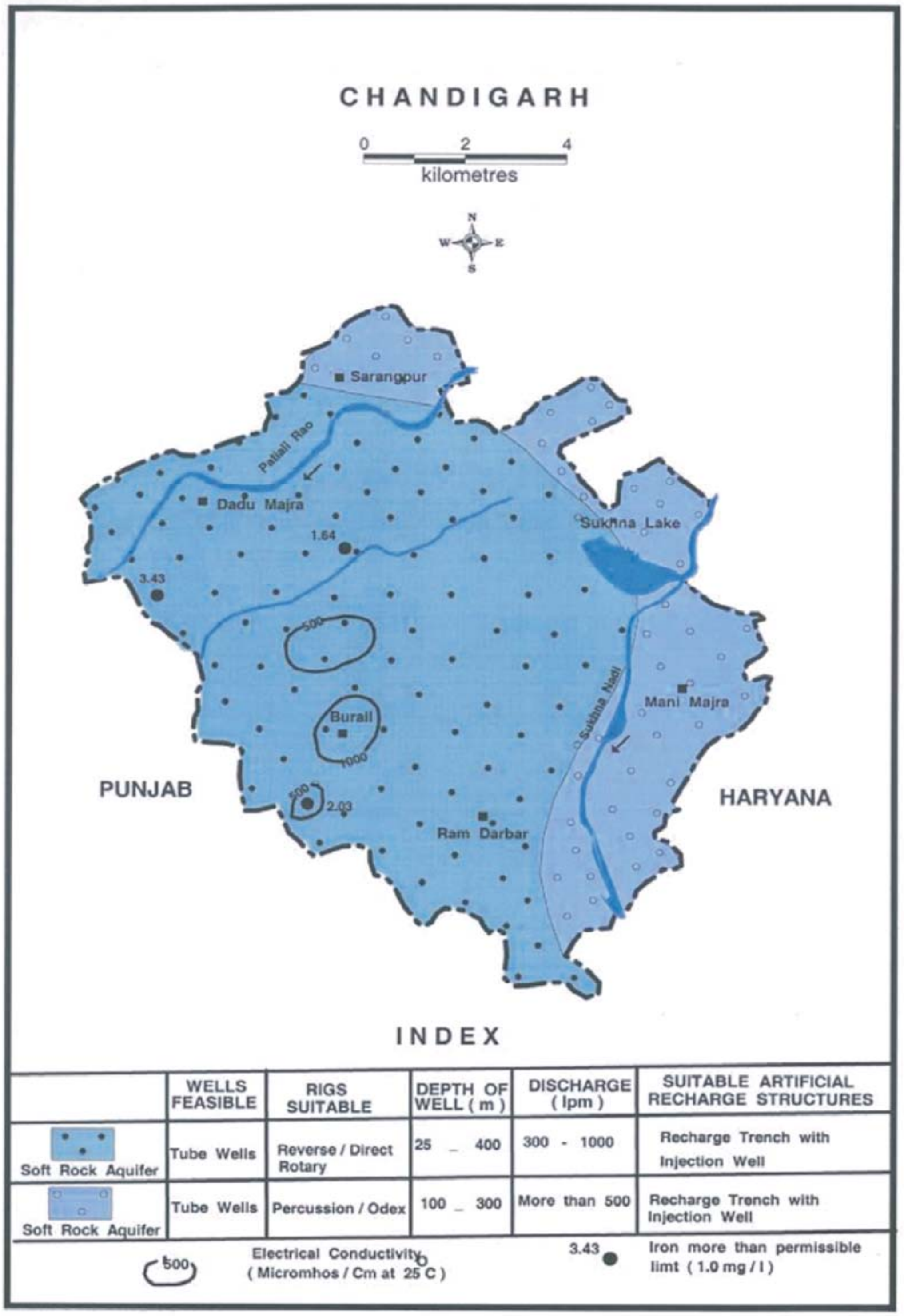


Fig.8.25.1 Areas suitable for Artificial Recharge in Chandigarh

8.26 DADRA AND NAGAR HAVELI

Union Territory of Dadra and Nagar Haveli (DNH) have geographical area of 491 sq. km. The Union Territory comprises of 2 parts namely; (i) Dadra which has only 3 villages and (ii) Nagar Haveli having 69 villages. The Eastern part of the DNH is hilly with elevation ranging from 40 – 400 m amsl. The western part is plain with elevation up to 40 m amsl. The hilly terrain constitutes about 75 sq. km. of the total area. Annual rainfall is about 2311 mm. As per Census 2011, the total population of DNH is around 3,42,853 out of which around 1,83,024 is rural population while 1,59,824 is Urban population. DNH is rich in forest wealth having 53% area under forest. The area is drained by Damanganga river and its tributaries namely Piparia Nadi, Sakartond Nadi and Dudhni Nadi flowing towards west and Dongarkhadi towards east.

The area is underlain by Deccan Trap (basaltic lava flow) and is intruded by dolerite and trachyte dykes. Small and localized patches of alluvium also occur along river's bank. Thickness of alluvium is within 9 m. The average depth to water level is 7.47 to 10.45 m bgl during pre-monsoon. However, during post-monsoon it is shallow and ranges between 3.17 to 8.8 m bgl. The average water level fluctuation is 1.65 to 4.30 m bgl. The pre-monsoon water level rising trend observed in the range from 0.011 to 0.17 m year while the post monsoon decline trend of 0.06 to 0.08 m /year is observed. However, due to shallow depth to ground water (0-3m) and rich forest cover, the possibilities for artificial recharge to ground water are limited.

The population of the UT is widely scattered. There is acute shortage of water in summer in hamlets in spite of copious rainfall. Therefore, roof water harvesting is proposed in 1000 households, institutional and other buildings of the UT. The average cost of roof water collection, transmission and recharge is estimated to be around Rs.15,000/- each. Thus total cost would be about Rs.1.5 crores. There is also need to conserve surface run off near rural water supply schemes supported by check dams/ cement plugs and sub surface dykes at about 50 locations with unit cost of Rs.6 lakhs each. This will cost Rs.3.0 crores. In addition to this, 15 runoff water harvesting schemes are proposed in urban areas of DNH with unit cost of Rs. 2.5 lakhs. This will cost Rs.37.5 lakhs (Area identified for Artificial Recharge to Ground Water is presented in Fig.8.26.1). The total recharge including from roof top rain water harvesting will be 2.94 MCM.

The total estimated cost of the rain water harvesting and run off conservation in the UT of Dadra and Nagar Haveli is Rs.4.875 crores.

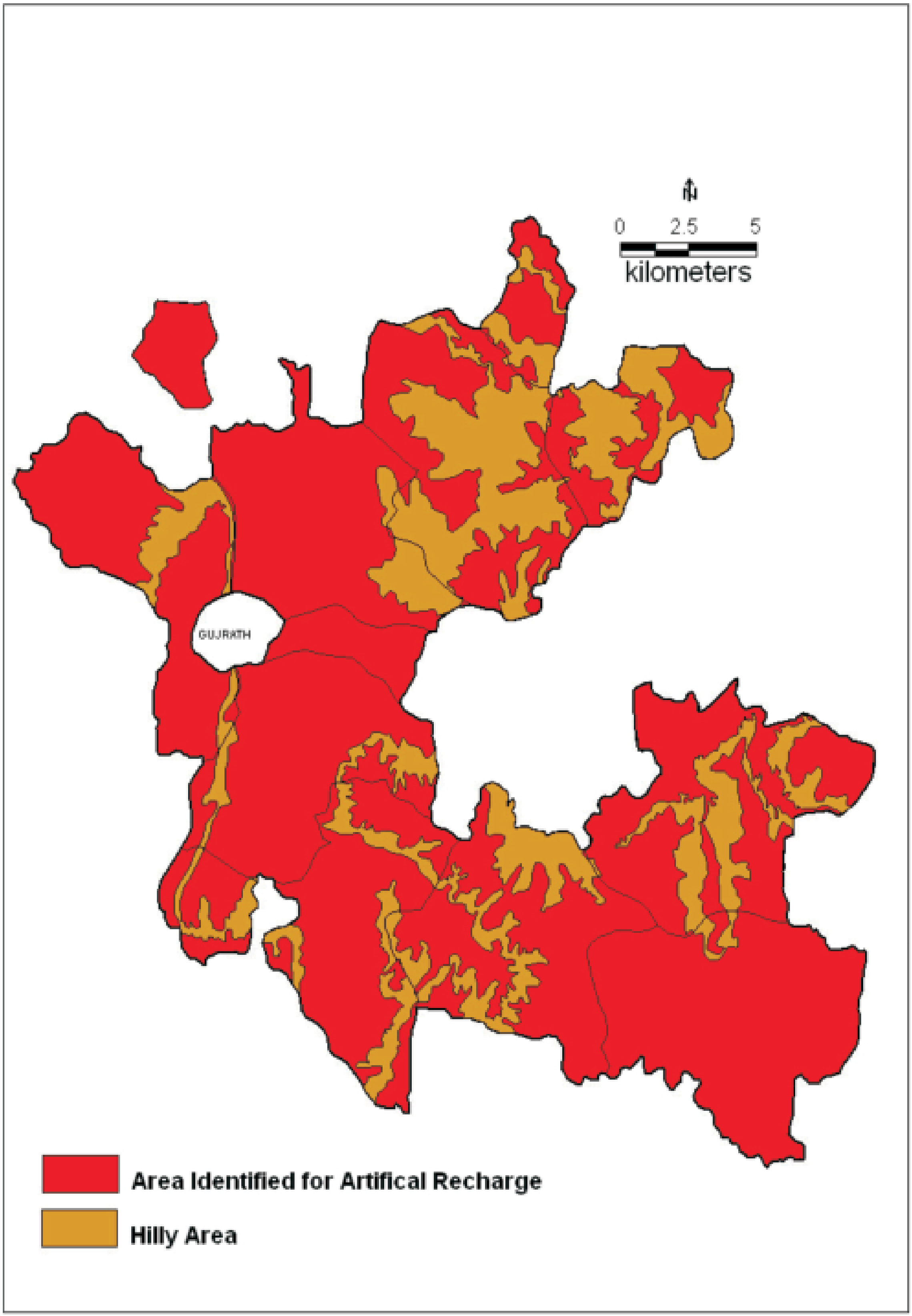


Fig.8.26.1 Areas suitable for Artificial Recharge in UT of Dadra and Nagar Haveli

8.27 DAMAN AND DIU

The Union Territory of Daman and Diu is constituted by two districts, namely Daman and Diu.

Both the districts of Daman and Diu are near Gujarat state, separated by about 700 kms from one another. The district of Daman is situated on the western coast of India between north latitude 20°27' 58" and 20°22' 00" and between east longitude 72°49' 42" and 72°54' 43" . It is surrounded by Valsad district of Gujarat state in North, East and South. Damanganga River passes through middle of Daman district dividing it into two parts namely Moti Daman and Nani Daman. It has total area of 72 sq km; its north to south stretch is 11 kms and width from east to west is 8 kms. The altitude is 12 meters above the sea level. Diu district is an island on southern portion of Gujarat Peninsula. It is joined with Una Taluka of Gujarat State by two bridges over a sea creek. The district of Diu is situated between the North latitude 20°44' 34" and 20°42' 00" and East longitude 71°00' 24" and 70°52' 26" . Its total area is 40 sq km with length from the extremes north and south, measures 4.6 kms and width from east to west measures 13.8 kms. The altitude is 6 meters above sea level. The topography is generally plain. The hillocks attain maximum height of 30 meters. As per census report of 2011, population of Daman is 2,42,911 while Diu Island has population of 52,056 souls. Most of the Diu Island area (44 %) is urbanized with tourism and fishery business while Daman district area is relatively semi urban type and also have fishery and various type of industry as main occupation.

8.27.1 HYDROGEOLOGY AND FEASIBITY OF ARTIFICIAL RECHARGE

The area of Diu Island is underlain by Quaternary formation consisting of Milliolite rocks and stabilized sand dunes. The Milliolite rocks (Lime Stone) form the main aquifer system of the area. Most of the aquifer system down to 6 to 12 m depth below ground level is brackish to saline. The main source of water for both domestic and industries is through piped water supply from inland areas of Gujarat State. The area of Daman is underlain by the Deccan Trap Formation of Cretaceous – Eocene age, which occur as main basement rocks. The area along Damanganga River estuary and Kalu Nadi, Moti Daman part, is overlain by 10 to 18 m thick river terrace type alluvium formation. Like Diu Island, Daman area also has shallow ground water condition with brackish to saline ground water below 10 to 15 m depth. Daman area gets piped water supply from Damanganga Weir projects from inland Vapi area of Gujarat State. For irrigation, canal water is available. Due to limited ground water development, average decadal (2000-09) post-monsoon ground water level in Diu and Daman area is around 3.25 and 3.50 m bgl respectively. The decadal (2000-09) water trend is +0.0067 m / year and +0.0045 m / year for Diu & Daman area respectively.

Taking into consideration of shallow water level condition and more or less, stable ground water condition, area of Diu & Daman are not considered for construction of artificial recharge structures likes percolation tanks & check dams. However, taking into consideration of predominate semi urban and urban types habitat system, roof top rain water harvesting can be implemented for augmenting local ground water resources. The Diu Island gets average monsoon rainfall of 750 to 850 mm while Daman area gets around 1800 to 2000 mm by south west monsoon system during mid June to September / October months. As per 2001 census data number of urban household in Diu and Daman are 6354 & 9422 respectively. Estimating 25% houses are suitable for harvesting and considering 40 sq m area per house, total 1.41 lakh sq m areas is available for roof top harvesting in Diu and Daman. The source water available for harvesting has been taken as 60 % of average annual rainfall of the area, after making allowance for storm rain etc., total source water available for roof top harvesting has been estimated as 0.13 MCM /year. The average cost of making the roof top harvesting arrangements for storing it at surface and recharging to ground water is @ Rs 10,000/- per house. In addition rooftop rainwater harvesting system is also feasible around 100 government and institutional buildings at the cost of Rs 50,000/- each . Thus cost of roof top harvesting for houses of the Diu & Daman is estimated as Rs 4.44 crores (table 8.27.1)

Table 8.27.1: Estimates of Roof Top Rainwater Harvesting in the UT of Daman & Diu

S No	Distract Name	Urban Household Number (Census 2001)	25% of households	Areas of RWH @ 90 % suitable area of avg. 40 sq m area / household (sq m)	Average rainfall of the District (mm)	Volume of rainwater Harvestable (MCM/year)	Cost of RWH @ Rs 10,000 / household and Rs 50,000 others (Rs. in lakhs)
1	Diu	6,354	1588	57,186	800	0.03	158.85
2	Daman	9,422	2356	84,798	1,900	0.10	235.55
3	Institutional & Government Buildings of Diu and Daman		100	-	-	-	50.00
Total						**0.13**	**444.40**

8.28 LAKSHADWEEP

Lakshadweep is the tiniest Union Territory of India and lies about 220 to 440 km from coastal city of Cochin in Kerala. It is an archipelago consisting of 12 atolls, three reefs and five submerged banks. Of its 36 islands covering an area of 32 sq. km., only 10 are inhabited. They are Andrott, Amini, Agatti, Bitra, Chetlat, Kadmat, Kalpeni, Kavaratti, Kiltan and Minicoy. Total population of Lakshadweep is 60650 (2001 Census) with population density of 1895 persons per sq.km. About 49 percent of the population resides in urban area.

The fresh ground water resource of the tiny coral atolls of Lakshadweep, by and large, occurs as lenses floating in hydraulic continuity with seawater. The hydro-geological environment of these islands is complex. The terrain is mostly flat and the surface and near-surface coral medium is porous and permeable. Rainfall, averaging about 1600 mm annually, is the sole source of groundwater recharge in these islands. More than 90 per cent of the potable water supply comes from ground water. Increasing demand for water has resulted in water scarcity in the islands, mainly during summer months. Rainwater harvesting and storage is the most suitable and cost-effective solution to the water scarcity problems in the Lakshadweep islands in view of the limited sub-surface storage available and the shallow water table conditions. The rainfall distribution pattern of the Lakshadweep islands show that the average monthly rain fall is more than 40 mm for eight months a year, from May to December. Further, most of the buildings are tiled roof or RCC roofs and hence ideal for roof water harvesting.

Considering the rainfall pattern, the rainwater harvesting systems may be designed to harvest the rainfall received in any two months of the year, except January, February, March and April to collect and store water enough to meet the requirements of the population for about 100-120 days. In view of the available roof area, social acceptance and the land availability, collection tanks with capacities of 5, 6, 7& $8m^3$ will be ideal for type I, II, III & IV quarters respectively. For type V quarters, two tanks of $5m^3$ each may be constructed. In other buildings like schools, colleges, hospitals, Dak bungalows etc. the tank capacity may be decided as per the roof area and availability of land for construction of tank. For private buildings the collection tanks of $5m^3$ is ideal.

The island wise status of roof water harvesting in operation, future scope and financial out lay required both under private sector and government sector, taking November and December months as the collection period, are worked out and presented in table 8. 28.1. Based on the demand and availability of fund the schemes can be taken up in a phased manner along with other schemes such as desalination using waste heat etc. The cost involved in construction of roof water harvesting structure is around Rs. 12/liter of tank capacity inclusive of eve gutters and fittings, calculated as per schedule of rates for the UT. The total cost of installation of rainwater harvesting systems for disaster preparedness/mitigation in the islands is of the tune of about Rs.30.50 crores.

This will sufficient to meet the drinking water demand for another 120 days at the rate of 8 lpcd for individual households, even if the rainfall during the other four months is not harvested. The advantage of roof water harvesting scheme over the other schemes is that it is self contained and once implemented the individual beneficiary can manage, maintain, regulate and operate according to the requirements. This sense of belonging, independent of government control, makes the scheme more acceptable for private households.

Table 8.28.1 Scope of Rainwater Harvesting in Lakshadweep Island

S. N	Description	Kavaratti	Agatti	Androth	Minicoy	Kalpeni	Amini	Kadamat	Kiltan	Chetlat	Bitra
1	No. of Pvt. buildings	626	600	915	630	485	500	340	310	140	30
2	Roof Area '00 sqm^2	438	406	637	441	340	350	238	217	98	21
3	November Water availability m^3	3130	3000	4575	3150	2425	2500	1700	1550	700	150
4	December water addition m^3	1575	1500	2300	1580	1220	1260	855	780	350	75
5	No. of Govt. Buildings	479	88	114	305	104	148	111	72	87	16
6	Roof Area '00m^2	210	20	34	77	30	36	29	18	21	4
7	Govt storage possibility m^3	3500	550	750	1880	650	910	700	425	520	90
8	Total roof area '00m^2 (2+6)	648	426	671	518	370	386	267	235	119	25
9	Total storage m^3 (3+7)	6630	3550	5325	5030	3075	3410	2400	1975	1220	240
10	December storage m^3	2335	1535	2415	1865	1330	1390	960	845	428	90
11	December storage %	35	45	46	37	43	41	40	43	35	38
12	Existing capacity (m^3) Govt Pvt.	 1840 185	 80 960	 15 0	 1330 375	 360 60	 420 310	 200 45	 60 275	 165 405	 30 145
13	Additional Capacity Possible (m^3) Govt Pvt.	 1660 2940	 470 1940	 735 4535	 550 2775	 290 2365	 490 2190	 500 1655	 365 1275	 355 295	 60 5
14	Cost Rs (lakh) @ Rs.12/Litre Govt Pvt.	 199 353	 56 233	 88 544	 66 333	 35 284	 59 263	 60 199	 44 153	 43 35	 7 1
	Total cost (Rs. Lakh)	**552**	**289**	**632**	**399**	**319**	**322**	**259**	**197**	**78**	**8**

8.29 PUDUCHERRY

Union Territory of Puducherry has four districts namely Puducherry, Karaikal, Mahe and Yanam and its total area is 492 sq. km. Total population of the UT is 12,44,464 (2011 census) and 45% it is engaged in agriculture. Irrigation in Puducherry is mainly through tanks and tube wells.

Puducherry has average rainfall of 1205 mm. Geomorphology of the area is characterized by Coastal Plain, Flood Plains and Pediments. Sandstone and Limestone are main geological formations in the area. Depth to water level ranges between 6 to 35 m bgl. Ground water quality is not potable at places.

As per the water table and vulnerability to sea water ingress, need for artificial recharge is inferred and recharge structures in the UT of Puducherry is proposed and given in table – 8.29.1

Table – 8.29.1: Artificial Recharge Structures in UT of Puducherry

Suitable area for Artificial Recharge (sq.km)	Average Post-monsoon Water level (mbgl)	Volume of unsaturated zone available for recharge (MCM)	Volume of Surplus water available for recharge (MCM)	Volume of water that can be re-charged (MCM)	Proposed number of artificial recharge structures						Total no. of structures feasible
					P	CD/ NBs	RS/ RWs	RT Ws	RTs (kms)	Other Structures	
300	10	252	120	80	30	600	400	500	10	200	1740

Cost of proposed recharge structures (Rs in Lakhs)							Quantum of water recharged through proposed artificial recharge structures (MCM)						
P	CD/NBs	RS/RWs	RTWs	RTs (km)	Other Structures	Total Cost of all structures (Rs. in lakhs)	Sum of P	Sum of CD/ NB	Sum of RS/ RW	Sum of RTW	Sum of RT (km)	Sum of others	Total Quantum of recharge potential created
300	3000	800	1750	90	200	6140	3	12	1	30	30	4	80

Roof top rainwater is proposed to be undertaken in 100 govt./ institutional and 900 private buildings having average cost of @ Rs 1.25 lakhs & Rs. 20,000/- respectively. This will cost Rs. 3.05 crores and it will harness about 0.27 MCM of rain water. Total cost of the recharge schemes proposed in the UT of Puducherry covering mainly Puduchery, Karaikal area and in limited way in Mahe and Yanam is Rs. 64.45 crores.

9.0 OVER VIEW OF MASTER PLAN FOR ARTIFICIAL RECHARGE TO GROUND WATER

The revised Master Plan for artificial recharge to ground water prepared by Central Ground Water Board, aims at providing area specific artificial recharge techniques to augment the ground water reservoir based on source water availability and capability of ground water reservoir to accommodate it. The specific problems in different areas in the states like excessive ground water development resulting in ground water decline, water scarcity due to inadequate recharge in arid areas, low ground water retention in hilly areas despite substantial rainfall, urban areas with limited ground water recharge avenues and related problems of urban pollution, etc., have been considered while revising the Master Plan. To fully utilize the available surplus monsoon runoff in rural areas, emphasis has been given for adoption of artificial recharge techniques based on surface spreading like percolation tanks, nala bunds, sub surface techniques of recharge shaft, well recharge, etc. In urban, hilly and coastal regions, priority has to be given to rain water conservation measures through roof top harvesting techniques etc.

The revised Master Plan, while bringing out the areas suitable for artificial recharge to ground water, prioritizes the areas wherein recharge schemes need to be implemented on priority to ameliorate the water scarcity problems. The proposals and schemes recommended are only indicative which can be modified at later stage of implementation in accordance with changes in ground water regime and cost escalation as well as the impact assessment results.

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 terrains of Jammu and Kashmir, Himachal Pradesh, Uttarakhand and North Eastern States and where the structures are basically proposed to increase the fresh water recharge and improve the sustainability of springs. In case of Islands, freshwater lenses in pockets of higher development are to be protected.

It is estimated that annually about 85,565 MCM of surplus surface run-off can be harnessed to augment the ground water. The surplus runoff available in North Eastern States, Himachal Pradesh and Islands are very high and due to limited space availability for recharge and lack of storage space availability, the surplus run off calculation is not separately given. However, for the stabilization of springs and improving the existing localized ground water extraction areas, few structures are identified which will be executed by considering the local suitability and vulnerability of negative impacts like mudslides/land slides etc.

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 in different states. The revised Master Plan envisages construction of about 1.11crores artificial recharge structures in urban and rural areas at an estimated cost of about Rs. 79,178 crores. 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 (table 9.1). 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 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 North Eastern States, Andaman & Nicobar and Sikkim emphasis has been given for spring development and 2950 springs are proposed for augmentation and development.

The distribution of various types of structures proposed is given in table no 9.1 while state wise number of Rural and Urban structures are given in table 9.2. An overview of the areas identified, extent of recharge feasible from proposed programme, number of artificial recharge structures and cost estimate are illustrated in the table 9.3.

Table-9.1: Master Plan for Artificial Recharge in a nutshell

S. No.	Type of structure	No.of Structures	Range of Unit Cost (Rs. in crores)	Total Cost (Rs. in crores)
1	Check Dam (CD)	2,90,577	0.015-0.50	13457.09
2	Gabion (G)	1,55,394	0.001-0.04	407.22
3	Gully Plug(GP)	6,26,229	0.0015-0.06	1282.40
4	Injection Well(I)	16,235	0.03-0.06	449.16
5	Nala Bund(NB)	4,09,446	0.01-0.08	11113.28
6	Percolation Tank(P)	84,925	0.026-0.41	17225.42
7	Recharge Shaft(RS)	5,90,714	0.006-0.075	15541.43
8	Sub-Surface Dyke(SSD)	8,281	0.01-0.12	329.46
9	Spring Development (SD)	2,950	0.03-0.10	186.50
10	Contour Bund (CB)	1,08,438	0.02	2236.70
11	Roof Top Rainwater Harvesting (RTRWH)	87,66,594	0.001-0.09	16266.14
12	Others	23,172	0.01-0.02	683.00
	Total	**1,10,82,955**		**79177.80**

The number of structures proposed is depicted in Fig.9.0 for comparison of major types and its relative distribution.

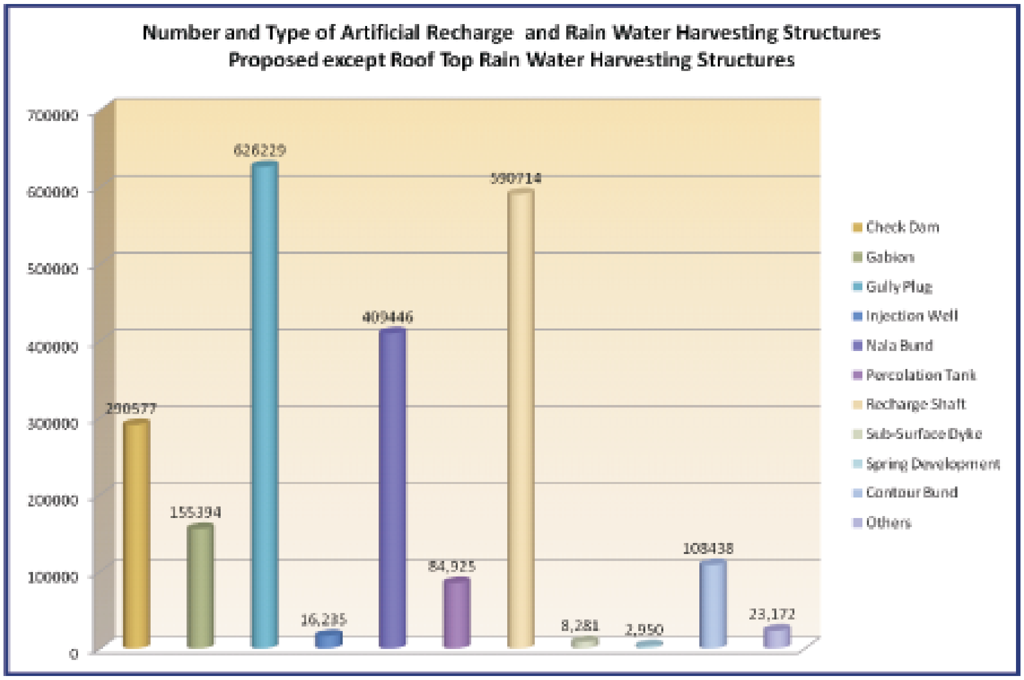


Fig. 9.0-Number and type of Artificial Recharge Structures proposed except roof top rain water harvesting structures.

The percentage distribution of total costs of various types of artificial recharge structures except roof top rain water harvesting is depicted in fig. 9.1

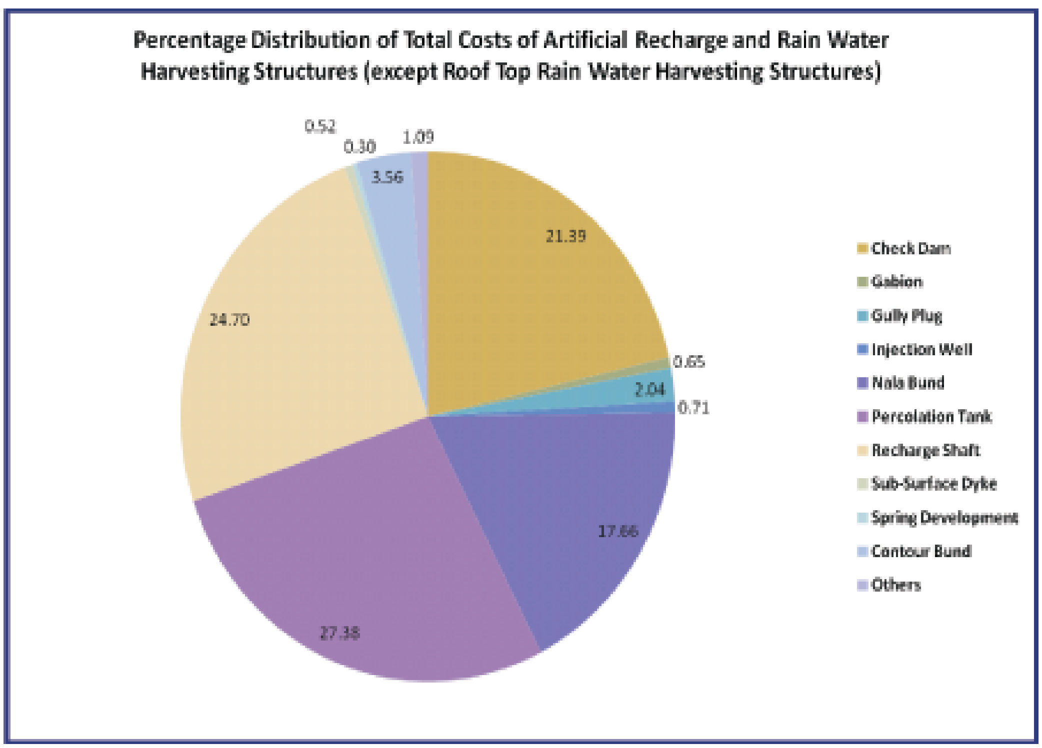


Fig. 9.1-Percentage distribution of total costs of Artificial Recharge Structures proposed except roof top rain water harvesting structures.

Table-9.2 State Wise Rural and Urban Artificial Recharge Structures and cost estimates

S N.	State	Rural		Urban (including habitation)		Total	
		Structure (Number)	Cost (Rs. in crore)	Structure (Number)	Cost (Rs.in Crore)	Structure (Number)	Cost (Rs. in crore)
1	Andhra Pradesh	68625	2703.15	750000	1230.00	818625	3933.15
2	Bihar	2058	128.81	100000	164.00	102058	292.81
3	Chhattisgarh	87202	1856.21	200000	309.00	287202	2165.21
4	Delhi	8	0.40	142850	1097.50	142858	1097.90
5	Goa	1393	83.58	10000	16.40	11393	99.98
6	Gujarat	18775	769.00	500000	725.00	518775	1494.00
7	Haryana	44727	1255.30	376000	1675.00	420727	2930.30
8	Himachal	102328	573.47	50000	82.00	152328	655.47
9	Jammu & Kashmir	1688	168.80	100000	145.00	101688	313.80
10	Jharkhand	26282	1733.34	200000	290.00	226282	2023.345
11	Karnataka	72985	1998.66	700000	1148.00	772985	3146.66
12	Kerala	754427	5457.72	315000	456.75	1069427	5914.47
13	Madhya Pradesh	532724	10717.61	600000	984.00	1132724	11701.60
14	Maharashtra	51157	7926.34	1605670	2765.75	1656827	10692.09
15	NER states	15250	765.90	400000	656.00	415250	1421.90
16	Odisha	5856	525.00	300000	499.50	305856	1024.50
17	Punjab	79924	2021.47	375000	1650.00	454924	3671.47
18	Rajasthan	9603	1566.07	500000	820.00	509603	2386.07
19	Sikkim	1905	54.07	5000	13.25	6905	67.32
20	Tamil Nadu	193574	9284.63	0	0.00	193574	9284.63
21	Uttar Pradesh	108945	7629.28	1200000	1968.00	1308945	9597.28
22	Uttarakhand	2900	414.75	48250	68.25	51150	483.00
23	West Bengal	97360	3450.06	300000	522.00	397360	3972.06
24	Andaman & Nicobar Island	1640	44.02	1200	8.00	2840	52.02
25	Chandigarh	0	0.00	8700	652.50	8700	652.50
26	Dadra & Nagar Haveli	65	3.37	1000	1.50	1065	4.87
27	Daman and Diu	0	0.00	4044	4.44	4044	4.44
28	Lakshadweep	0	0.00	6100	30.50	6100	30.50
29	Puducherry	1740	61.40	1000	3.05	2740	64.45
	Total	**2283141**	**61192.41**	**8799814**	**17985.39**	**11082955**	**79177.80**

Table 9.3- State Wise Summarized Details of Artificial Recharge Structures

S. No.	State /UT	Area (sq.km)	Area feasible for artificial recharge (sq.km)	Volume of unsaturated zone available for recharge (MCM)	Volume of water required for recharge (MCM)	Volume of surplus local/ distant source available for recharge (MCM)	Volume of water to be harnessed (MCM)	Volume of water to be harnessed through RTRWH (MCM)	Types of artificial recharge structures feasible Number	Unit cost (Rs. in crore)	Total cost (Rs. in crore)
1	2	3	4	5	6	7	8	9	10	11	12
1	Andhra Pradesh	275068	43743	340500	10215	2302.97	2302.97	120.53	CD - 28787 P - 3838 RS - 34000 RTW - 2000 RTRWH(H) - 712500 RTRWH(G & I)-37500	CD - 0.05 P - 0.10 RS - 0.02 RTW - 0.10 RTRWH(H)- 0.0012 RTRWH(I) - 0.01	3933.15
2	Bihar	94163	760.3	4406.2	215.9	83.14	83.14	23.13	P - 277 RS - 118 NB - 1663 RTRWH(H) - 95000 RTRWH(G & I)- 5000	P - 0.27 RS - 0.035 NB - 0.03 RTRWH(H) - 0.0012 RTRWH(G & I)-0.01	292.81
3	Chhattisgarh	136034	22401.4	85343.58	2902.72	37783.48	2902.72	52.07	P - 4729 NB & CD - 15862 G - 38062 RS - 28549 RTRWH(H) - 190000 RTRWH(G & I)- 10000	P - 0.20 NB & CD - 0.01 G - 0.001 RS - 0.025 RTRWH(H) - 0.0011 RTRWH(G & I)-0.01	2165.21
4	Delhi	1483	699.86	10153.56	853.83	24.39	24.39	14.69	RS - 17850 CD - 8 RTRWH(H) - 118750 RTRWH(G & I) - 6250	RS -0.05 CD -0.05 RTRWH(H) -0.0012 RTRWH(G & I)-0.01	1097.90
5	Goa	3702	2027	14191	866	528.69	528.69	5.76	Vented Dam - 1393 RTRWH(H) - 9500 RTRWH(G & I) - 500	Vented Dam -0.06 RTRWH(H) - 0.0012 RTRWH(G &I)- 0.01	99.98
6	Gujarat	196024	19407	109668	10708	1483.54	1483.54	110.40	P - 1800 CD - 16975 RTRWH(H) - 475000 RTRWH(G & I) 25000	P - 0.05 CD - 0.04 RTRWH(H)- 0.001 RTRWH(G & I) 0.01	1494.00
7	Haryana	44212	37029	54175	72053	679.26	679.26	187.00	CD - 335 RS - 44392 Rech. Sewage - 1000 RTRWH(H) - 300000 RTRWH(G & I)- 75000	CD - 0.30 to 0.50 RS - 0.025 Rech. Sewage- 0.025 RTRWH(H)- 0.0030 RTRWH(G & I)-0.01	2930.30

1	2	3	4	5	6	7	8	9	10	11	12
8	Himachal Pradesh	55673	2500	105000	1775	1775	1775	13.00	G - 98775 CD/NB -1849 SSD - 347 CD/SSD - 684 RS - 542 I - 131 RTRWH(H) - 47500 RTRWH(G & I) - 2500	G - 0.002-0.003 CD/NB - 0.08 SSD - 0.12 CD/SSD- 0.14 RS- 0.01 I - 0.05 RTRWH(H) – 0.0012 RTRWH(G & I)-0.01	655.47
9	Jammu and Kashmir	222236	5000	185000	1688	29173	1688	12.00	CD - 1000 Pond - 688 RTRWH(H) - 95000 RTRWH(G & I)- 5000	CD - 0.10 Pond - 0.10 RTRWH(H) – 0.001 RTRWH(G & I) 0.01	313.80
10	Jharkhand	79714	7864	24935.16	1414.31	4042	1414.31	47.56	P - 3754 NB - 22528 RTRWH(H) - 190000 RTRWH(G & I)- 10000	P - 0.2775 NB - 0.0307 RTRWH(H) – 0.001 RTRWH(G & I) 0.01	2023.34
11	Karnataka	191791	74007	427424	11367.00	17122	11367.00	167.73	SSD - 271 P - 10166 CD - 59853 PR – 2695 RTRWH(H) - 665000 RTRWH(G & I - 35000	SSD - 0.045 P - 0.075 CD - 0.02 PR – 0.01 RTRWH(H)– 0.0012 RTRWH(G & I) 0.01	3146.66
12	Kerala	38863	10849	42607	1520.00	17678	1520.00	181.44	P - 3109 CD - 3032 SSD - 832 NB - 54957 CB - 106173 I - 45 GP - 586279 RTRWH(H) - 299250 RTRWH(G & I)- 15750	P - 0.20 CD - 0.20 SSD - 0.15 NB - 0.02 CB - 0.02 I -0.05 to 0.08 GP - 0.0015 RTRWH(H) – 0.001 RTRWH(G & I) 0.01	5914.47
13	Madhya Pradesh	308144	119409	16066	21368	15280	15280	103.39	P - 15284 CD - 125019 RS - 125019 NB – 229202 CP - 38200 RTRWH(H) - 570000 RTRWH(G & I)- 30000	P - 0.18 CD - 0.04 RS - 0.006 NB - 0.008 CP - 0.01 RTRWH(H) - 0.0012 RTRWH(G & I) 0.01	11701.60
14	Maharashtra	307713	130011	260022	8474	2846	2846	257.43	P - 9961 CD - 26924 RS (URBAN)- 5670 RS - 772 GP - 1500 NB/CP - 12,000 RTRWH(H) -1520000 RTRWH(G & I)- 80000	P - 0.60 CD - 0.06 RS (UR) - 0.025 RS - 0.025 GP - 0.01 NB/CP - 0.025 RTRWH(H) - 0.0012 RTRWH(G & I) 0.01	10692.09

1	2	3	4	5	6	7	8	9	10	11	12
15	North Eastern States	255083	25508	114786	5600	5600	5600	114.20	CD - 2650 NB - 5100 G - 6100 SD - 1400 RTRWH(H) - 380000 RTRWH(G & I) -20000	CD - 0.15 NB - 0.04 G - 0.004 SD - 0.10 RTRWH(H) - 0.0012 RTRWH(G & I)-0.01	1421.90
16	Odisha	155707	5339	1076.31	1192.05	5538.49	1192.05	76.66	P - 1107 ST - 905 SSD - 871 CB - 2265 Wier - 181 Flooding - 121 IR - 22 RS - 384 RTRWH(H) - 285000 RTRWH(G & I) -15000	P - 0.20 ST - 0.10 SSD - 0.10 CB - 0.05 Wier - 0.05 Flooding - 0.02 IR - 0.05 RS - 0.02 RTRWH(H) - 0.0012 RTRWH(G & I)-0.01	1024.50
17	Punjab	50362	43340	52684	70071	1201	1201	187.00	RS - 79839 CD – 85 RTRWH(H) - 300000 RTRWH(G & I)- 75000	RS – 0.025 CD – 0.30 RTRWH(H) –0.0030 RTRWH(G & I)-0.01	3671.47
18	Rajasthan	342239	160589	2724364	264109	860	860	47.42	P - 3010 Anicut - 860 RS - 5733 RTRWH(H) - 475000 RTRWH(G & I) 25000	P - 0.41 Anicut - 0.0307 RS - 0.0533 RTRWH(H) - 0.0012 RTRWH(G & I)-0.01	2386.07
19	Sikkim	7096	500	1000	277	277	91	186	SD - 1400 G/CD/NB - 180 CP/SSD - 325 RTRWH(H) - 4750 RTRWH(G & I)- 250	SD - 0.03 G/CD/NB - 0.04 CP - 0.015 RTRWH(H) - 0.0020 RTRWH(G&I) 0.015	67.33
20	Tamil Nadu	130058	68839	215937.2	5982.64	712.30	712.30	*	P - 5388 CD/NB - 16163 RS - 154578 RTW - 743 RT(KM)- - 539 FP/RP - 16163	P - 0.20 CD/NB - 0.10 RS - 0.04 RTW - 0.07 RT(KM) - 0.06 FP/RP - 0.02	9284.63
21	Uttar Pradesh	240928	110783	57831	76915	5185	5185.00	221.18	P - 3022 NB/CD/CP – 66285 RS/DW/TW – 39638 RTRWH(H) - 1140000 RTRWH(G & I)- 60000	P - 0.20 NB/CD/CP – 0.10 RS/DW/TW– 0.01 RTRWH(H)- 0.0012 RTRWH(G & I)-0.01	9597.28
22	Uttrakhand	53483	13542	26311	6578	14307	6578.00	13.67	P - 450 CD - 2300 RS - 150 RTRWH(H) - 47500 RTRWH(G & I)- 750	P - 0.15 CD - 0.15 RS - 0.015 RTRWH(H) – 0.0012 RTRWH(G&I)-0.015	483.00

1	2	3	4	5	6	7	8	9	10	11	12
23	West Bengal	88752	36730.4	14931	17797	29803	17797.00	100.80	Hard Rock P - 1679 CD - 4449 G - 12277 SSD - 5385 RS - 1218 Alluvium P - 15913 Tank - 41623 I - 14816 RTRWH(H) - 285000 RTRWH(G& I)- 15000	Hard Rock P - 0.10 CD - 0.015 G - 0.005 SSD - 0.01 RS - 0.011 Alluvium P - 0.07 Tank - 0.0385 I - 0.025 RTRWH(H)- 0.0012 RTRWH(G&I) 0.012	3972.06
24	A & N Island	8293	200	200	95.53	95.53	95.53	0.67	SD - 150 CD/G/NB - 320 P - 720 SSD - 250 CP - 200 RTRWH(H) - 1150 RTRWH(G & I)- 50	SD - 0.03 CD/G/NB - 0.04 P - 0.026 SSD - 0.02 CP - 0.015 RTRWH(H) – 0.005 RTRWH(G&I) -.045	52.02
25	Chandigarh	114	100	145	193	30.71	30.71	0.00	RS - 8700	RS - 0.075	652.50
26	Dadra & Nagar Haveli	491	50	50	2.50	2.50	2.50	0.44	CD/CP - 50 RTW - 15 RTRWH(H) - 950 RTRWH(G & I)- 50	CD/CP - 0.06 RTW - 0.025 RTRWH(H) –0.0015 RTRWH(I) - 0.0015	4.87
27	Daman and Diu	112	10	10	1	0.13	0.00	0.13	RTRWH(H) - 3944 RTRWH(G & I) - 100	RTRWH(H) – 0.001 RTRWH(I) - 0.005	4.44
28	Lakshadweep	32	3	3	0.0327	0.0327	0.00	0.0327	RTRWH(H) - 4576 RTRWH(G & I) -1524	RTRWH(H) – 0.005 RTRWH(G&I) 0.005	30.50
29	Puducherry	492	300	252	80.00	120	80.00	0.27	P - 30 CD/NB - 600 RS - 400 RTW - 500 RT(KM) -- 10 Others - 200 RTRWH(H) - 900 RTRWH(G & I) - 100	P - 0.1 CD/NB - 0.05 RS - 0.02 RTW - 0.035 RT (KM) - 0.09 Others - 0.010 RTRWH(H) – 0.0020 RTRWH(G&I)0.0125	64.45
Total		**3287263**	**941541**	**4889072**	**594314**	**194534**	**83320.11**	**2244.60**			**79177.80**

P- Percolation tank	***I-Injection well***	***GP-Gully Plug***	***RT- Recharge Trench***
CD- Check dam	***SSD-Sub-Surface dyke***	***RTW- Recharge Tube Well***	***FP/RP- Farm Pond/Recharge Pit***
NB-Nala Bund	***G- Gabion***	***PR-Point Recharge***	***DW/TW- Dug Well/Tube Well Recharge***
RS- Recharge Shaft	***CB- Contour Bund***	***IR- Induced Recharge***	***CP- Cement Plug***
SD- Spring Development	***ST- Storage Tank***	***RTRWH(H) - Roof top Rainwater harvesting(House)***	***RTRWH(G&I) - Roof top Rainwater harvesting(Government & Institutional building)***

* Govt. of Tamil Nadu has implemented RTRWH in the state through the Ordinance No. 4 of 2003 promulgated on 21.07.2003

10.0 ROAD MAP OF IMPLEMENTATION

The implementation of the revised master plan at estimated cost of Rs. 79,178 crores is proposed with the participatory approach of State and Central Government agencies, Industries, NGO's, VOs, community and research institutions. The Revised Master Plan envisages the optimal level of harnessing rain water harvesting in the country with a projection of the total present cost for completing the required structures. The priority areas are identified in water scarcity and water quality problem areas in various hydrogeological terrains. The high rainfall areas in the country have water scarcity in summer months and low rainfall areas are prone to water scarcity for the entire year. The need for implementing the rain water harvesting scheme is not only widely discussed in many forums and but also debated by the stake holders and unfortunately, the implementation is not to the desired level. The technical issues are also addressed in many seminars and institutions but same is yet to be translated into effective recharge program in ground. Also, the integrated approach with concerned agencies are not effective in many areas However, the demonstrative artificial recharge structures implemented by CGWB through various state agencies in an integrated manner during XI five year plan period has proved to be successful. The implementation of the scheme involves number of agencies/resources persons and site selection is to be done based on technical feasibility. The present activities under various schemes are to be properly integrated before taking new works. The entire recharge to ground water program is planned to be completed in 10 years time, i.e. the twelfth and thirteenth plan period itself. Presently, various schemes are taken up under following programmes.

- Watershed development
- Bharat Nirman
- Irrigated Agriculture modernization, water bodies restoration and management project (IAMWARM)
- Drought prone area programme (DPAP)
- National Watershed Development programme for rain fed areas (NWDPRA)
- NABARD assisted rainwater harvesting programme for augmentation of ground water recharge
- Rehabilitation of tanks identified by MLAs
- Command area development & Water Management program
- Mahatma Gandhi National Rural Employment Guarantee programme (MGNREGA)
- Water conservation in reserved forest area
- Dug well recharge program by NABARD and State agencies in seven States
- Local area development programme of M.P & M.L.A

There are many more state and central as well as Corporate Social Response (CSR) program and aided projects particularly in the drought prone and disaster prone areas implemented over years. The communities also have the traditional RWH systems for storage of runoff in surface for direct use however with time the need for recharge in aquifer system has gained priority. Some of the conservation and recharge schemes make conflicts within the stake holders and there are number of irrigation tanks in southern states which are converted into recharge systems by desilting and plugging the traditional tank irrigation sluices. Hence, the basic approach of beneficial use of rain water in surface or sub-surface needs participatory community approach. The technical input in the form of GIS layers for locating recharge structures are executed in some states and the duplication of work by different agencies is also reported and hence optimum additional structures only recommended in the plan. The non filling of non system tanks even in good monsoon period in parts of the hard rock terrain is inferred as the result of deficient soil moisture situation and deeper water table thereby the generation of runoff is negligible. Such areas are identified and the surplus run off available in part of watershed is considered for the natural flow downstream and additional structures are feasible only by transporting surplus water from adjoining watersheds and or diversion of flood water by a dedicated canal system. The micro level planning by state with district level data base is essential for actual formulation of schemes and only broad outline of the physical and financial targets for implementation in the coming ten years are indicated in the plan.

10.1 CGWB SCHEME FOR XII PLAN PERIOD

It is recommended to consider a new scheme of artificial recharge under central sector scheme for the XIIth plan period with an outlay of Rs 5000 crores with Rs 500 crores in first year, 1000 crores each in second and third year and 1250 crores each in fourth and fifth year. It will be a 100 % central assistance to innovative schemes in identified areas for total water resources improvement in terms of quantity and quality. The prioritized areas include: the areas notified by CGWA (Presently 82 nos) which have to be brought back into safe level for de-notification, areas identified for registration where stage of development is very high, coastal aquifers having threat of sea water ingress and other specific stress areas identified. As per latest ground water resource assessment on 31st March, 2009 out of the 5842 assessment units in the country, 802 units have been categorized as 'Over-exploited', 169 are critical, 523 units are semi-critical. The areas which fall in these categories which require urgent interventions by artificial recharge, are located in states/UTs such as Andhra Pradesh (falling in districts Anantapur, Chittor, Kadapa, Karimnagar, Kurnool, Medak, Mehboobnagar, Nizamabad, Prakasham, Ranga Reddy, Warangal, East and West Godvari), Delhi (All districts except North and Central Delhi), Haryana (falling in districts Bhiwani, Faridabad, Gurgaon, Kaithal, Karnal, Kurukshetra, Mahendragarh, Panipat, Rewari, Sonepat, Sirsa and Yamunanagar), Kerala (falling in districts Trivendrum, Kasargod and Ernakulam) , Karnataka (falling in districts Banaglore-Rural & Urban, Belgaum, Chitraduga, Kolar, Tumkur), Punjab (falling in districts Amritsar, FategarhShib, Jalandhar, Kapurthala, Ludhiana, Manssa, Moga, Nwanshahr, Patiala, and Sangrur), Tamil Nadu (falling in districts Coimbature, Dharmapuri, Dindigul, Krishnagiri, Nagapattinam, Namakkal, Salem, Theni, Tiruvallur, Tiruvannamalai, Tuticorin, Vellore, and Villupuram), Uttar Pradesh (falling in districts Agra, Budaun, Baghpat, Barielly, Hatras, JyotibaPhule Nagar, Moradabad, Saharanpur), West Bengal (falling in districts Murshidabad and Nadia), and Union territories of Puducherry and Diu. The recharge schemes proposed in respect of over-exploited sedimentary aquifers like Neyveli aquifer, Tiruvandanai aquifer in Tamil Nadu, Rajahmundry sandstone in Andhra Pradesh, deeper aquifers (below 120 m depth) in notified area of Haldia, West Bengal, deepeer aquifers of Punjab and Haryana require multi agency recharge projects with international agency support also. Site selection should be taken up duly following hydrogeological conditions and design components of storage system and recharge methods.

The experience gained by demonstrative artificial recharge projects indicates the limited benefit from the check dams in comparison to percolation ponds and desilting of tanks. The prevailing working condition of many recharge structures is not satisfactory and the O&M cost is not available with the local bodies for repairs. Also, providing additional structures like recharge shafts in ponds and recharge bore wells in check dam , farm pond etc will have effective recharge and the total watershed approach for such works were experimented successfully in Karuvattar watershed, Namakkal district, Tamil Nadu and such schemes are proposed in various states. The salient features of such completed schemes like Gangavalli block inTamil Nadu, Injection well in Neyveli area, Water shed improvement in Karuvattar watershed, Recharge in Palla area, New Delhi, project in Lucknow can be replicated in other parts of the country.The thirteenth plan period should have additional Rs10,000 crores worth activity in similar pattern.

10.2 COMMUNITY PROGRAM

Part of the proposed recharge structures has to be implemented by the community in coming 10 years with formation of watershed wise beneficiary committee and getting fund under state sector with 10 % contribution from the community in the line of other state sector schemes like RRR work. An amount in the order of 20,000 crores should come from the state sector and community, particularly for the O & M cost of existing and new recharge structures to be created in rural areas.

Roof top rain water harvesting should be made mandatory for urban and peri-urban areas by involving urban bodies & communities. In Tamil Nadu, roof top rain water harvesting has been made mandatory. In Andhra Pradesh also, construction of rain water harvesting pit is made compulsory for issuing building plan. Similarly many states have made such provisions. As per the status of enactment of RTRWH by various states, it is mandatory for roof areas of 100 sq.m / 200 sq.m or above. As roof top harvesting from individual houses and recharge to ground water is the best option available, it is suggested for even small roof top of 50 to 100 sq.m. In order to mitigate liquid and solid waste disposal problems, appropriate measures are being taken up for protecting the existing water bodies and aquifers by harnessing rain water from roofs. Roof Top Rain Water Harvesting from cluster of houses will be more effective than adopting in individual houses, particularly in case of urban areas. The state-wise roof top rain water harvesting proposal for urban areas is to be covered under community program.

10.3 INDUSTRIES

The estimated cost of about 20,000 crores should be spent by the industries particularly who are using the ground water as raw material and also for commercial use. CGWA has already given guidelines for the implementation of RWH by industries, infra structure development agencies and mining industry that are seeking NOC for new projects or for expansion program and same should be made mandatory for the existing industries also. In case there is no scope for artificial recharge in plant area due to geological conditions like lack of weathered thickness as well as occurrence of saline aquifer, where the recharged water can not be economically drawn from the aquifers, the storage in surface is the best option for direct use. However, on case to case basis, the industry is to be given mandatory instructions to harvest rain water and recharge to ground water, atleast 2 % of total water pumped. Such recharge can be taken within the factory premises or at least in the watershed/sub basin within the respective state to improve overall ground water scenario in the state. There are many industries viz. thermal plants/steel industry and other water intensive industries, tapping ground water to the tune of 40-50 MCM per year from river sources. Such industries should be given mandate for harvesting rain water and recharge ground water system which will pave way for improving ground water situation in the entire region.

10.4 CENTRAL/ STATE GOVERNMENT SCHEMES

Presently, number of state and central government programs have regular budgetary program for water harvesting, water conservation and sustainability of water sources for drinking water supply. The major works are carried out by Forest Department, National Rain Fed Authority, Agriculture departments, Drinking Water Supply departments, Panchayat Raj Institutions under MGNREGA work in particular, Drinking Water supply Department of GOI under Drinking Water Mission for sustainability of sources like Oorani (pond), head works. A district level co-ordination committee under District Collector and select funding Agency as well as implementing agency as members, is recommended to have an overall monitoring of the recharge program in accordance with the master plan and in an affective scientific and participatory approach. The estimated work of Rs. 24,178 crores in ten years for specific recharge to ground water in accordance with the periodic assessment of the need and priority in the districts are recommended.The cost escalation with time can be monitored and the ground water development and land use pattern change with time, the impact of climate change and its ground reality can be periodically reviewed by the district, state and national level ground water development and management committee.

The broad outline recommended for implementing the Revised Master Plan of artificial recharge to ground water in the country will ensure the optimal recharge to ground water system in the country and improve the water resources sustainability to various uses.

Annexure I-A

CONCEPT PAPER ON COMPREHENSIVE NATIONAL RECHARGE PROGRAMME IN THE COUNTRY

The dependency on groundwater has increased many folds during the recent years and the groundwater extraction for irrigation, domestic and industries have resulted in lowering of water levels, long-term water level declining trend and even drying up of wells. In order to regulate the groundwater development, Central Ground Water Board in association with State Ground Water Departments has computed Dynamic Groundwater Resources and categorized blocks as Over Exploited, Critical, Semi Critical and Safe.

Central Ground Water Board had also taken up Pilot Artificial Recharge studies under Central Sector Schemes to augment the groundwater resources during VIII, IX & X Plans. The pilot schemes which were mostly point recharge program, have been executed through the State Agencies and NGOs with technical and financial support of Central Ground Water Board. With the experience gained in Central Sector Scheme, it was felt that artificial recharge schemes taken up with scientific approach in a compact area could bring in more benefit and accordingly "Demonstrative Projects on Artificial Recharge to Groundwater" was envisaged as a pilot study, in over exploited blocks of the country.

Based on the Groundwater Resources Estimation, Central Ground Water Authority has notified areas for registration of groundwater abstraction structures and regulation of groundwater extraction. Demonstrative Projects on Artificial Recharge to groundwater have been taken up in selected notified blocks in the country to improve the overall groundwater situation in the block. One such study taken up in Gangavalli block of Salem district in Tamil Nadu has proved the success of integrated scientific approach by state agencies and also the constructive response from local people. The lessons learnt also include the need for long term maintenance strategy and resolving the local disputes created by vested interest people. The reluctance of the common people in participation in the recharge program is a social constraint which has to be removed by mass awareness program and participatory approach in decision making on the type of structures as well as its location and maintenance. The philosophy of de-notifying the area due to improved ground water situation can be initiated by ensuring the application of modern irrigation practices and stabilizing the draft component also to change the "Over exploited" categorization to "Safe" category. Keeping this objective of increasing the recharge and reducing the draft, the line departments have to initiate action plan. The best option lies in improving the recharge component in any well defined administrative or natural boundary (Block/ Water shed) by an integrated scientific approach with people participatory program. Such program also needs to include cost effective structures and best practices possible without deteriorating the existing surface and ground water resources in terms of quantity and quality.

Central Ground Water Board had formulated a Master Plan for the whole country to recharge the shallow aquifer. The criteria considered for the selection of sites were as given below

- Post monsoon water level (>3 m bgl) & Declining long term water level trend (>0.1m/year)
- Post monsoon water level (>9 m bgl) with either rising or declining long term water level Trend
- Availability of uncommitted surplus run off

On the basis of experience in pilot studies under Central Sector Schemes, check dam and percolation ponds were suggested as recharge structures. However, the experience had shown that these structures in combination with recharge wells would be more effective in recharging the aquifers. The desilting of the existing structures may be given priority over new structures. Further, check dam should be the last option and if necessary, it may be combined with recharge wells. The funding from various State and Central agencies is utilized for augmentation of groundwater resources. The existing programmes under Central & State Assistance are as follows.

1. **Watershed Development** in which check dams and contour bunding etc are made which indirectly augment groundwater

2. **Bharat Nirman** in which water bodies are renovated to augment irrigation potential, which incidentally increase the recharge to groundwater.

3. **IAMWARM (**Irrigated Agriculture Modernization, Water Bodies Restoration and Management Project) whose objective is to improve the irrigation service delivery & augment the productivity by effective water management. This covers the whole ambit of irrigation system, which would indirectly benefit the groundwater system.

4. **Drought Prone Area Programme**, whose objectives have undergone change from modification of infrastructure to creation of rainwater harvesting and overall economic development through watershed activities.

5. **NWDPRA (National Watershed Development Programme for Rain fed Areas)**

6. **NABARD assisted Rainwater harvesting Programme for augmentation of groundwater recharge**

7. **Rehabilitation of tanks identified by MLAs**

8. **Command Area Development & Water Management Programme**

9. **NREGP (National Rural Employment Guarantee Programme)**

10. **Water Conservation in Reserved Forest Area**

11. **Dug Well Recharge Progamme by NABARD and State Departments in seven states.**

12. **Local Area Development Programme of M.P.& M.L.A**

The schemes mentioned above show that though Governments have taken initiatives to improve the water resources and in particular groundwater, the efforts are uncoordinated and their impacts are not in desired magnitude. The structures have become ineffective either due to non-maintenance after construction or due to defective designs. Thus, there is a need to have a holistic view while planning the artificial recharge schemes and dovetail the existing programmes to augment the groundwater resources so as to make the precious resources sustainable.

It is also noticed that there are small fresh water lenses which may not show the continuous decline in level or the pre monsoon water level may be less than 9 m where the artificial recharge is more essential. The post monsoon level may be also less than 3 m and the quality of ground water needs improvement by rain water dilution. In order to accommodate more micro-level issues, it is mandatory to consider the local ground slope, rainfall pattern, soil cover, lithological disposition and prevailing ground water development scenario as well as water quality aspects of the surface and sub-surface water resources. In order to give more thrust on the long term benefit, the surplus run off consideration in a basin needs micro level catchments analysis to know the most critical locations of water deficiency and the nearest area of surplus run off. The local precipitation and also transported water needs to be considered in totality for the recharge scheme. The existing natural and man-made structures and their effectiveness in ground water recharge needs scrutiny before taking new ones. It is possible to repair and renovate existing stricture at less cost than adding a new one. Also, rehabilitation of the defective design with suitable modification is more economic option. Hence, a holistic scientific and social approach is desirable for the revision of master plan for the local level to the country. The approach should be from the local level to country than the reverse one as made earlier.

Hence, there is an urgent need to revise the guidelines in the formulation of the artificial recharge schemes so that artificial recharge would be a part of Sustainable Management. The guidelines which can be used in the formulation of scheme proposal can be enumerated as follows.

1. Criteria for selection of priority area

- Area characterized by declining post monsoon long term water level trend
- Area characterized by deeper post monsoon water level – Relative magnitude to the local environment than the earlier criteria of 3 m.
- The area having high stage of groundwater development (OE, Critical)
- The aquifer under stress needs to be considered for artificial recharge & priority to be given for recharging at the recharge area of the confined aquifer, viz., crystalline-sedimentary contacts, palaeo-channels, beach terraces, upstream side of fractures/lineaments.
- The coastal aquifers vulnerable for the sea water ingress

2. Unit for formulation of Master Plan

It was envisaged in the earlier plan that the unit for formulation of the schemes inhard rock area be watershed and sedimentary be basin/sub-basin. Though, the unit for computations for formulation may be retained as in the earlier Master Plan, it would be better to convert the same to Block/Mandal, District and state while formulating the scheme so as facilitate easier funding from administrative point of view. The design criteria and priority areas and guidelines for preparation of Master Plan can be worked out for different agro-climatic and ground water development units of the country, viz., hard rock areas of Peninsular India, Coastal aquifers, Hilly regions of west coast, North eastern region, Himalayan region, Gangetic plain , Desert regions of Western India .

3. Feasibility of using transported water for Artificial Recharge Schemes.

The earlier Master Plan had been prepared considering only the available uncommitted surplus run off realized through rainfall. In the places, where there is a greater demand but characterized by lesser rainfall or absence uncommitted surplus run off, diversion from surplus area or even recharging of treated water need to be considered.

4. Database on available structures to be created.

The database on existing artificial recharge structures are to be created and a nodal department may be identified by respective State Government for maintaining and updating of the database. The existing structures created by different agencies along with their capacity would assist in determination of available uncommitted surplus run off. In addition, this data can also be utilized to refine the groundwater resources estimation.

5. To consider the management of demand on groundwater while formulating Artificial Recharge Schemes.

- Dovetail all the water resources development and conservation projects taken up by both State and Central Governments and integrate the augmentation of groundwater resources, wherever feasible.
- Identify the areas not suitable for groundwater development and exclude them from artificial recharge schemes and in such areas create alternative sources to meet the demand.
- Recharge Schemes for the area having brackish water problems.
- Bio-drainage programmes having water level up to 3 m bgl
- Diversion of flood water and use of treated water for artificial recharge schemes in places of low availability of source water.
- The Master Plan for artificial recharge to be made on watershed basis for hard rock terrains and sub basin wise for sedimentary terrains and may be translated on administrative units for execution.
- Bottom to top approach in working out the need and implementation is desirable to that of the top to bottom target oriented approach. In other words, the number of structures from Block to District to State to National Level should be compiled.
- Artificial Recharge Schemes should be implemented in the entire country in the phased manner by giving annual work programme within the framework of Master Plan of the country
- The guidelines for the preparation and prioritization of the Master Plan for the various regions of the country will have many common factors but for the convergence on the type of priority to be fixed and nodal agency for preparation of the Master Plan and role and execution of project by line departments and other stake holders. The project formulation can be always given to an independent agency / consultant who will not have any component of execution for unbiased approach, better transparency and credibility. The different executing agencies may use the master plan as a guideline and based on the priority and fund allotted by government, the recharge program is taken up with proper Operation and Maintance mechanism.
- The manual on artificial recharge prepared and made available in the website will be the basic guideline for the selection criteria of structures. The refinement of the design to meet the local condition can be made by resource persons and the periodic impact assessment of the completed structures should for the base for fine tuning the design criteria and development of new site specific, optimum cost designs.

Annexure- I B

GUIDELINES FOR REVISION OF CGWB MASTER PLAN OF ARTIFICIAL RECHARGE

The Master Plan on Artificial recharge (2002) had been prepared for the whole country taking the regional database for the formulation. It was based on the assumptions that the surplus monsoon runoff available in a basin is available uniformly throughout the basin where as it is not uniform in space and time. This availability so worked out was for the entire sub basin and not exclusively for the requirement of the identified areas for artificial recharge. The source water availability for identified areas for artificial recharge was apportioned from total water availability in the basin. Hence it is imperative that estimation of surplus monsoon run off in space and time for each basin / sub basin/unit is a pre-requisite for actually taking up any Artificial Recharge project.

However, the actual estimation of surplus run off is made complex by the following –

- Actual available monsoon runoff in space and time is highly variable.
- There are instances of monsoon rains of higher intensity generating substantial quantity of runoff, which have to be considered depending upon facilities to arrest or store in the areas where recharge schemes are to be taken up.
- In hard rock areas, where the watertable is shallow and immediately after the rains, the water level comes up and stabilises in due course of time. The recharge from rainfall thereafter only generates rejected recharge, which goes out as baseflow and joins the river/stream courses. This quantity becomes substantial in later part of the monsoon.

Thus, need has been felt that formulation of Master Plan should address realistic natural conditions / boundaries and administrative needs. More emphasis should be made on demand side of ground water while taking up any artificial recharge scheme – thus taking a holistic view involving all linked parameters – such as improvements in agricultural practices etc. This will decrease stress on ground water regime as a twin pronged strategy for bringing change in the ground water scenario of a particular area, which is the ultimate objective. It is also imperative that the thrust should be from State Government so that the Master Plan for artificial recharge would include not only the hydrogeological parameters, hydrological database but also the socio political considerations of the respective States. As State agencies would be involved in the actual execution, this would eventually result in proper execution of the Master Plan as per the need of the respective States.

The Master Plan should basically address the three following points-

- Need for artificial recharge (The area should not be considered if there is no need)
- Scope for artificial recharge (The availability of source water and ability of the groundwater system to accept the recharge should be ensured)
- Anticipated benefits from the artificial recharge program

Thus the crux of the issue is to identify the critical areas and thereafter provide appropriate designs for effecting artificial recharge to groundwater.

Identification of Critical Areas

The area suitable for groundwater development can be considered for artificial recharge, while the areas not suitable for groundwater development due to quality problem should also be identified and surface storage is preferable in such areas. The area suitable for groundwater development would depend on groundwater potential, which indirectly depend on hydrogeology of the area. Thus the hydrogeology of the area would be the foremost criteria in identifying the area suitable for groundwater development.

Within the areas suitable for artificial recharge, priority areas have to be identified to formulate artificial recharge schemes. The priority can be assigned to an area on the basis of the following.

- Areas notified under State & Central Groundwater Authority
- Area showing declining water level trend during post monsoon
- Areas having higher Stage of groundwater development (>90%). The priority can be assigned to an area in the descending order of Stage of Development (from highest to lowest)
- Water logging conditions with water level less than 3m below ground level, where Bio-drainage is necessary.
- Area having water quality issues like brackish water in coastal and inland areas.
- Vulnerable aquifers with declining pressure heads.

Designs of Artificial Recharge Structures

The designs of artificial recharge structures depend on terrain conditions and the scope of artificial recharge. The various factors need to be considered in the design of the artificial recharge structures are listed below.

- Terrain specific designs, viz., Hard rock areas of Peninsular India, Coastal aquifers, Hilly regions of West coast, North eastern region, Himalayan region, Indo-Gangetic plain and Desert regions of Western India.
- Rural and Urban areas should be treated as separate entities and the designs need to accommodate the inherent properties of these environments.
- Ability of the system to accept the recharge (available sub surface storage, aquifer parameters)
- Availability of source water considering the catchment area for each structure and uncommitted surplus run off into the catchment area and quantity of committed run off to be allowed out to downstream side.
- In case of non-availability of source water in the priority area, design of structures should also provide for transfer of water from water surplus area to water deficit area.
- Treated water for artificial recharge also should be kept as one of the options in water deficit areas.

Artificial Recharge to Groundwater

It is proposed that artificial recharge to groundwater may be taken up as two pronged strategy viz., Point Recharge Schemes and Aquifer Recharge Schemes.

Point Recharge Schemes

In the earlier Master Plan (2002), on the basis of groundwater levels and availability of source water, Point recharge schemes were considered and accordingly designs for different structures were made. A broad framework of recharge structures such as Check Dams, Percolation Ponds, Recharge wells, Contour Bunds etc were considered for scheme formulation as given below:–

S. No.	Name of State	Type and Number of Artificial Recharge Structures	Cost of Plan (Rs. in crores)		
			Rural	Urban	Total
1	Andhra Pradesh	3800 Percolation Tanks 11167 Check dams Rain Water Harvesting in Urban Area.	1229	468	1697
2	Bihar & Jharkhand	2695 Percolation Tanks 9483 Nala Bunds 1303 Contour Bunds 1630 Recharge Shafts	644	330	974
3	Chhattisgarh	648 Percolation Tank 2151 Nala Bund /Cement Plug /Check dam 2582 Gravity Head / Recharge shafts 7740 Gully plugs, Gabion structures	223	51	274
4	Delhi	23 Percolation tanks 23 Existing dug wells 10 Nala Bunds 19216 Lateral trench with recharge wells 2496 Roof top rain water harvesting	232	25	257
5	Goa	1410 check dam / KT weirs 10,000 Roof top rain water structure	63	10	73
6	Gujarat	4942 Percolation Tanks with Recharge Tubewell 13210 Check dams Rainwater Harvesting (4.5 lakh houses)	1155	450	1605
7	Haryana	15928 Recharge Shafts and Recharge Trenches Roof Top Rain Water Harvesting (1.7lakh house)	159	173	332
8	Himachal Pradesh	1000 Sub surface dykes 500 Check dams 300 Revival of Ponds 500 Revival of spring 2000 Roof top harvesting structures	458	7.5	465.5
9	Jammu & Kashmir	500 Sub surface dykes 336 Revival of Kandi Ponds Roof top harvesting (1.5 lakh houses)	234	12.5	246.5
10	Karnataka	1040 Sub Surface Dams 5160 Percolation Tanks/ Desilting of old Tanks 17182 Check dams 8.3 lakh rooftop rain water harvesting with Filter bed	1233	499	1732
11	Kerala	4312 Check dam 7181 sub surface dykes 10780 gully plugs 10780 nalah Bunds Roof Top Rainwater Harvesting (0.7lakh houses) Runoff water harvesting (1200 structures)	1221	57	1278

S.No.	Name of State	Type and Number of Artificial Recharge Structures	Cost of Plan (Rs. in crores)		
			Rural	Urban	Total
12	Madhya Pradesh	5302 Percolation Tanks 20198 Nala Bunds/ Cement Plug/Check dams 23181 Gravity Head / Dug wells / Tubewells/ Recharge Shafts 69598 Gully Plugs, Gabian Structures.	1909	244	2153
13	Maharashtra	8108 Percolation Tanks 16598 Cement Plugs 2300 Recharge Shafts,Urban schemes of Roof Top Rain Water Harvesting (8.78 lakh houses) 3500 Run off Harvesting	2000	562	2562
	North Eastern States				
14	Arunachal Pradesh	500 Check dams 1000 Weirs 1000 Gabian Structures 480 Roof top harvesting 300 Development of Spring	87	7	94
15	Assam	250 Check dams 500 Weirs 1000 Gabian Structures 600 Roof top harvesting 250 Development of Spring	49.5	9	58.5
16	Manipur	300 Check dams 500 Weirs 500 Gabian Structures 300 Roof top harvesting 150 Development of Spring	48.5	4.5	53
17	Meghalaya	300 Check dams 600 Weirs 600 Gabian Structures 300 Roof top harvesting 200 Development of Spring	53.5	4.5	58
18	Mizoram	500 Check dams 1000 Weirs 1000 Gabian Structures 300 Roof top harvesting 200 Development of Spring	82. 0	4.5	86.5
19	Nagaland	500 Check dams 1000 Weirs 1000 Gabian Structures 300 Roof top harvesting 200 Development of Spring	82.0	4.5	86.5
20	Tripura	300 Check dams 500 Weirs 1000 Gabian Structures 240 Roof top harvesting 100 Development of Spring	47	3.5	50.5
21	Odisha	569 Percolation Tanks 761 Converted Percolation Tanks 698 Sub Surface Dykes 809 Nala Contour Bunds	414	100	514

S.No.	Name of State	Type and Number of Artificial Recharge Structures	Cost of Plan (Rs. in crores)		
			Rural	Urban	Total
		679 Check Dam weir 1981 Water spreading / flooding 668 Induced recharge 334 Recharge shafts Roof top harvesting (1 lakh)			
22	Punjab	40030 Recharge shafts and Recharge Trenches 12800 Roof Top Harvesting structures in Urban area	400	128	528
23	Rajasthan	3228 Percolation Tanks 1291 Anicuts 2871 Recharge shafts Rooftop Rainwater Harvesting structure (4 lakh houses)	740	400	1140
24	Sikkim	2100 Spring Development 2500 Cement Plugs/ Nala Bunds 5300 Gabian Structures 69596 Roof Water Harvesting	103	70	173
25	Tamil Nadu	8612 Percolation Ponds 18170 Check Dams 5 lakh rain water harvesting structure	2086	300	2386
26	Uttar Pradesh & Uttarakhand	4410 Percolation Tanks 12600 Cement Plugs (Check Dams) 2,12,700 Recharge Shafts Roof top rain water harvesting structures (10 lakh)	3561	600	4161
27	West Bengal	11200 Percolation Tanks with shaft 3606 Gabian structure 1054 Nala Bund/ Cement Plug 1680 Re-excavation of tanks 500 Desiltation of village pond 1000 Spring Development 70 Sub Surface Dykes. 1500 Roof Top Harvesting for Calcutta & Darjeeling	1333	7·5	1340·5
28	Andaman & Nicobar Islands	145 Spring Development 270 Cement Plugs 38 Percolation Tanks 150 Sub surface dykes 2600 Roof Top Harvesting	23	13	36
29	Chandigarh	597 Recharge shafts, recharge trenches, Check dams and Gabian structures.	0·6	5·4	6
30	Dadra & Nagar Haveli	50 Check dams / cement plugs 58 Sub surface dykes 1000 houses rain water harvesting	2	1	3
31	Daman & Diu	100 Nala bund/check dams 2000 Roof top rain water harvesting structures	-	15	15
32	Lakshadweep	1000 roof top rain water harvesting structures	-	10	10
33	Puducherry	5 Percolation Tanks 14 Recharge pit 20 Check Dams 40 Desilting of ponds 10 Nala bund, 20 Desilting/Recharge wells. Rainwater harvesting 10,000 houses	2.2	10	12.2

GRAND TOTAL Say Rs. 24,500 Crores

In view of the water scarcity, many States with their own fund or with central assistance, executed fairly good number of point recharge schemes in last few years. The proposed number of structures given in the earlier master plan (2002) will be reduced in tune with the number of executed schemes. However, the financial outlay may be more or less same due to cost escalation. Hence, it is proposed that the existing Central assistance schemes & State sponsored programmes can dovetail their programmes to suit artificial recharge to groundwater requirements in their priority areas. The number of structures can be refined to suit the priority of the respective States. The programmes can be executed through Panchayat Raj Institutions, NGOs and other State agencies taking the guidelines from the earlier master plan (2002). In addition, construction of structures under Local Area Development Fund of Member of Parliament & Member of Legislative Assembly in consultation with local District Authorities should also be dovetailed.

CGWB has brought out a Manual on Artificial Recharge to Groundwater on the basis of the experiences in formulating and executing artificial recharge schemes in the country under VIII, IX & X plan periods. The designs of the various structures given in the manual can be referred and modified if necessary to suit the terrain conditions.

It is also suggested that a scientific database be created on the existing artificial recharge structures and a nodal department nominated by respective State Government be entrusted with for coordinating the artificial recharge schemes being executed through myriad of Central and State schemes. The Nodal Department also should first create a scientific database and periodically update the database. This will not only assist in estimation of surplus uncommitted run off in area but also aid in the refinement of groundwater resources. The schemes for point recharge should be developed from Block level to District and then to State. The State governments also may propose on the basis of their own priority so as to ensure more critical areas initially.

Aquifer Recharge Schemes

It is also felt that in addition, artificial recharge to groundwater may be taken up in major stressed aquifers in the country, which would rejuvenate the aquifers to make them sustainable to meet the future demand and also emergent situations like tsunami, flood and drought etc. For example in Tamil Nadu, potential Cuddalore Aquifer, Orathanadu Aquifer, Tiruvadanai Aquifer etc can be recharged by diverting flood waters or transported surplus from rivers using new advancements in technology. Central Ground Water Authority and state ground water authorities have notified few blocks/areas for registration and regulation. The deeper aquifers of Haldia in West Bengal are increasingly affected by increased ground water pumping by industries. Large scale recharge to confined aquifers in the belt is essential. Similarly, Quilon and Alleppey areas of Kerala are having number of deep tubewells, which may fail due to sea-water ingress. Such aquifers need proper protection and remediation, if need be. Many sedimentary aquifers are under stress condition in parts of West coast and East coast need recharge schemes. Similarly, other states might be having similar potential aquifers that are being highly developed and such aquifers may be rejuvenated using artificial recharge techniques. Such attempts need participation of national and International institutions in project mode, which can be implemented by MoWR as National projects for sustainable management of ground water resources of India.

It is proposed that these aquifers may be identified jointly by CGWB & respective State agencies and aquifer mapping be attempted to decipher the aquifer geometry with the demarcation of recharge and discharge areas. A group of experts from Central & State agencies may be constituted to formulate major scheme proposals to recharge these aquifers. The source water can be either from the catchment or from transport of source water from water surplus areas. Diversion of floodwater can also be attempted through man-made waterways, which would also be beneficial in averting the flood damage recurring every year.

The recharge using canals/drains (exclusively) in overexploited areas with deeper water levels such as in parts of Punjab, Haryana and Rajasthan from Himalayan rivers/tributaries can be worked out. Similarly possibilities of transporting water from shallow aquifers lying near active floodplains to water deficit areas should be explored. In the state of Haryana, recharge to deeper aquifers can be taken up using defunct tubewells lying next to augmentation canal using spare monsoon water. Such major aquifer recharge and aquifer remediation of identified zones throughout the country is likely to cost around Rs 30,000/-crores that needs fine tuning by respective states.

Most of the recharge schemes languish after completion is because of poor or no maintenance. This reduces effectiveness of recharge schemes to a great extent within few years of construction. Main reason for this is large quantity of silt that comes with rainwater. Moreover technology to exclude silt in running water before recharge should be developed. Thus, it is very important to keep separate funds under operation and maintenance every year after construction. The recharge schemes should be maintained by a separate wing of state specially entrusted with this activity.

It is proposed that each scheme proposal be accompanied with Detailed Project Report (DPR) and a broad guideline for the preparation of DPR is given below.

1. Introduction
2. Background Information on the area giving hydrometeorology, hydrology & Hydrogeology
3. Need for Artificial Recharge

   Scope for Artificial Recharge including source water availability and ability of aquifer to accept the recharge
4. Justification of the Scheme
5. Proposed Structures
6. Cost Estimates
7. Tentative Accrued Benefits
8. Time Schedule
9. Executing Agency Details
10. Operation & Maintenance of the Structures
11. Proposal for Impact Assessment Study by an Independent Agency

ANNEXURE

I Detailed Cost Estimate

II Time Schedule of Execution

III Certificate of Undertaking from the Executing Agency

IV Certificate of Undertaking for Operation & Maintenance

Post Execution

There should be a provision to hand over the structures to Panchayat Raj Institutions/linked department for post maintenance. A definite budget provision for Operation and Maintenance of artificial recharge structures should be made and it may be collected from the beneficiaries on Own & Operate basis.

It is also proposed that an impact assessment study be made on the impact of these artificial recharge schemes to study the efficacy of these techniques. In addition, the knowledge sharing of the impact will also ensure the active participation of beneficiaries in operation and maintenance.

Annexure- I C

DRAFT GUIDELINES FOR CONVERTING OVER-EXPLOITED BLOCKS TO "SAFE" CATEGORY TAKING INTO CONSIDERATION ASPECTS OF WITHDRAWAL, RECHARGE, WATER USE PRACTICES ETC.

Ground Water Resource Estimation of the country as per GEC-1997 norms was conducted. The blocks where the annual ground water recharge is less than the ground water draft for all uses have been categorized as 'Over-Exploited'. The stage of ground water development has been expressed in percentage. As per GEC-97, if the stage of ground water development of a particular block is more than 100% and the long term water level trend shows a declining trend, the block has been categorized as over-exploited. These blocks all over the country have been identified and need special attention as far as ground water resource management is considered. In order to tackle the problem one must try to understand the cause behind the overexploitation of ground water resource, which can be due to one of the following:-

A. Draft from ground water is mainly to meet irrigation demands

B. Draft from ground water is mainly to meet drinking/domestic demands

C. Draft from ground water is mainly to meet industrial requirements

D. Draft from ground water is for a combination of one or more of above mentioned factors

Once the real cause has been identified, the restoration of the overexploited block can be initiated tackling the root cause. Besides the above, water use practices and socio-economic nature of area have to be well understood. The approach to bring overexploited block to safe category will be area specific depending on the magnitude of above-mentioned causes. The block wise detailed approach should be as follows:-

Blocks where draft from ground water is mainly to meet irrigation demand

In most parts of country blocks that have been categorized as overexploited are due to agricultural needs of the local farmers as per current farming practices. The steps need to be initiated in following manner in these blocks:-

It has been observed that it is very difficult to change the current farming practices that envisages shift from water intensive crops to less water consuming crops for one or other reason. Nevertheless efforts should be continued towards that approach by providing farmers better crop remuneration in any form, better marketing of agriculture produce, more minimum support price etc. However, more emphasis should be on demand side management of ground water resources.

Numerous studies have been conducted by various agricultural universities to devise ways and means to reduce water demands of mainly crops like paddy and sugarcane among other crops. It has been proved that paddy requires 30-40% less water if proper new techniques of plantation are adopted. Adoption of such techniques can reduce the water demand significantly. Take for example case of a block where stage of ground water development is say 140 %, and if less water can be applied for irrigation due to innovative techniques, draft from ground water can be considerably reduced. Thus adopting water saving on-farm techniques will reduce demand for ground water by 35 %. This will result in lowering the ground water development considerably. However, return flow from applied irrigation will also stand reduce and it is estimated that the block will come out of the overexploited category. Moreover, successful implementation of farmers participatory approach and R&D activities in improvising irrigation efficiency can further ease pressure on demand side.

In addition to above, efforts have to be done to tackle the supply side of ground water management by adopting artificial recharge techniques. Quantum of additional recharge has to be assessed utilizing surplus water from all available sources such as surplus monsoon run-off, pond water etc. Area suitable for artificial recharge has to be identified and Recharge to the aquifers is increased using appropriate techniques in a cost effective manner to maximize the output. In the example as discussed above, where the stage of ground water development has come down to 100 % from 140% by adopting on-farm management techniques, it is estimated that supply has to be increased by about 40%, which is spread equally through out the area under consideration to bring it to safe category as per GEC-97.

Blocks where draft from ground water is mainly to meet drinking / domestic demands

There are few blocks that have become overexploited due to huge demand due to domestic needs. Such situation exists around major towns and metropolitans. These towns depend largely on ground water to cater for their requirements. State public health departments responsible for water supply should adopt management of water resources while pumping ground water. Water conservation measures are required to be taken in conjunction with a strategy of reducing demand. Following steps are needed to be initiated in these areas to overcome the precarious situation:-

- Recharge to ground water using monsoon runoff from rooftop rain water should be given top priority. No water falling on hard tops should be allowed to go waste as runoff.
- Residents should be made aware of the shortage of drinking water and its consequences by adopting awareness programmes.
- All the major towns generate huge quantities of sewage water, which can be treated using appropriate technology and put to use for other purposes than drinking. This will surely reduce stress on fresh ground water as part of management on the supply side. Studies should be taken up to observe the impact of such approach on the ground water system.
- Bulk users should be charged with appropriate rate based on consumption pattern.

Blocks where draft from ground water is mainly io meet industrial demands

There are certain industrial belts in the country, which are consuming huge quantities of ground water resulting in steep water level decline in the immediate vicinity of the area. In the ground water resource estimation whole of the block has been considered while only localized pockets are severely affected due to large scale ground water pumping. However, the other part is suffering due to ground water mining and resultant environmental degradation due to failure of shallow wells. Another major problem emerging from the industrial belt is ground water pollution and resultant damage to fresh water aquifers. It has been observed that generally industrial areas are near to either agricultural areas or large population resides nearby. It is suggested that these areas be identified and ground water resources be computed separately excluding agricultural and domestic areas. In case any industrial belts are causing severe ground water decline flowing steps should be initiated to overcome the problem

- The industrial belt should be notified for ground water regulation measures as directed by Central Ground Water Authority from time to time.

- The industries existing in the industrial belts should be asked to adopt rainwater harvesting measures so that maximum rainwater is utilized for ground water recharge.
- In case industries are drawing water from shallow aquifers and deeper aquifers exist in the area, necessary directions should be issued to draw water only from deeper aquifers.

Blocks where draft from ground water is mainly to meet the miscellaneous demand

There are few blocks in the country where there is no specific industrial belt but large number of small scale industries does exist. These small scale industries pump large quantity of ground water for their industrial requirements. The typical example in this case can be of Ludhiana City. Large number of local and migrant population is engaged in such industries and is dependent on ground water resource only for their daily needs. Thus, domestic and industrial requirements put together have created a scenario where stage of ground water development has reached alarming proportions. It is necessary to organize the small scale industry by shifting them first as done in NCT Delhi where all industries inside the residential areas have been shifted to cities outskirts in a very systematic way. Effluent and sewage treatment plants be put in place and industrial requirement be supplemented using treated water. The industries and residential areas should be asked to adopt rainwater harvesting measures so that maximum rainwater is utilized for ground water recharge and category of the block is reversed from Over-exploited to Safe.

According to GEC-97 computations as on March, 2004 it is observed that the stage of ground water development of Over-exploited blocks vary greatly from near 100% to more than 300%. Hence it is very important to priorities these blocks so that things improve in phased and systematic manner.

The Over-exploited blocks can be further put into sub-groups as follows:-

I. Stage of ground water development is more than 200%.

II. Stage of ground water development is 150% - 200%.

III. Stage of ground water development is in the range of 100% - 200%.

In the first phase, priority should be given to those blocks where stage of ground water development has reached more than 200% followed by other categories.

References:

1) Manual on Artificial Recharge of Ground Water (1994)

2) National Perspective Plan for Recharge to Ground Water by Utilizing Surplus Monsoon Runoff (1996)

3) Guide on Artificial Recharge to Ground Water (1998)

4) Master Plan for Artificial Recharge to Ground Water in India, Govt. of India, Ministry of Water Resources, CGWB, New Delhi- February, 2002

5) Dynamic Ground Water Resource of India (As on March, 2004), Govt. of India, Ministry of Water Resources, CGWB, New Delhi -2006

6) Manual on Artificial Recharge to Ground Water , Govt. of India, Ministry of Water Resources, CGWB, New Delhi – September, 2007

7) Manual on Artificial Recharge of Ground Water (2009)

8) Select Case Studies “Rain Water Harvesting and Artificial Recharge (2011)

9) Dynamic Ground Water Resources of India (As on March, 2009), Govt. of India, Ministry of Water Resources, CGWB, New Delhi – 2012.

CONTRIBUTORS

Committee Members

Dr. N.Varadaraj, Regional Director, CGWB, SR, Hyderabad	Chairman of the Committee
Sh. Manoj Srivastava, Regional Director, CGWB, WR, Jaipur	Member
Dr. K.M. Najeeb, Regional Director, CGWB, SWR, Bangaluru	Member
Sh. Sanjay Marwaha, Suptdg. Hydrogeologist, CGWB, NR, Lucknow	Member Co-ordinator

Principal Contributors

All Regional Directors, CGWB

Other Contributors

Sh. Anoop Nagar, Suptdg. Hydrogeologist, CGWA, New Delhi

Sh. G.Sudarshan, Suptdg. Hydrogeologist, CGWB, SR, Hyderabad

Sh. Y. B. Kaushik, Scientist-D, CGWA, New Delhi

Dr. S. K. Gupta, Scientist-D,CGWB, New Delhi

Dr. P.N. Rao, Scientist-D,CGWB, SR, Hyderabad

Sh. S.K.Juneja, Scientist-D,CGWB, New Delhi

Sh. S.K.Sinha, Scientist-D,CGWB, Faridabad

Sh. G.Y. Setty, Scientist-C, CGWB, SR, Hyderabad

Dr. S. Subrmanian, Scientist-C, CGWB, SECR, Chennai

Sh. M. K. Garg, Scientist-B, CGWB, New Delhi

Sh. P. Yadaiah, Assistant Hydrogeologist, CGWB, New Delhi

Overall Supervision and Guidance

Sh. Sushil Gupta, Chairman, CGWB, Faridabad

RECYCLE
REUSE
RECHARGE

केन्द्रीय भूमि जल बोर्ड
जल संसाधन मंत्रालय
नई दिल्ली
दूरभाष : 011- 23383561, 26175362
ई मेल : cgwb@nic.in
वेब साईट : www.cgwb.gov.in

Central Ground Water Board
Ministry of Water Resources
New Delhi
Tel. : 011-23383561, 26175362
e-mail : cgwb@nic.in
website : www.cgwb.gov.in