

# National Aquifer Mapping and Management Programme: A Step Towards Water Security in India



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## 1 Introduction

India's food and drinking water security is largely dependent on the groundwater resources of the country. Besides, groundwater also caters a large component of the industrial demand. As a country, India is the largest extractor of groundwater in the world, with extraction to the tune of 252 billion cubic metre per year (BCM/yr) (Mukherjee et al. 2015; Saha et al. 2017). Presently, about 62% of our irrigation demand and 85% of rural drinking needs are drawn from aquifers. In urban water sector, despite the substantial investment in surface water-based pipe water supply, groundwater is considered as a dependable supplementary source contributing more than 50% of the total demand.

Overall, we are extracting about 62% of the total annual groundwater recharge in our country. However, if the extraction and recharge pattern is examined spatially, about 16% of our administrative blocks (talukas/firkas in certain states) are overexploited (Fig. 1), where extraction of groundwater resource is more than annual recharge (CGWB 2017).

About 65% of the overexploited blocks are concentrated in eight states distributed in the north-western, western and southern parts of India like Punjab, Haryana, Rajasthan, Gujarat, Maharashtra, Karnataka, Tamil Nadu and Telangana. On the other hand, in large swaths of the north-eastern, eastern and central parts of India, groundwater resources are underdeveloped, leaving further scope of further development of groundwater resource.

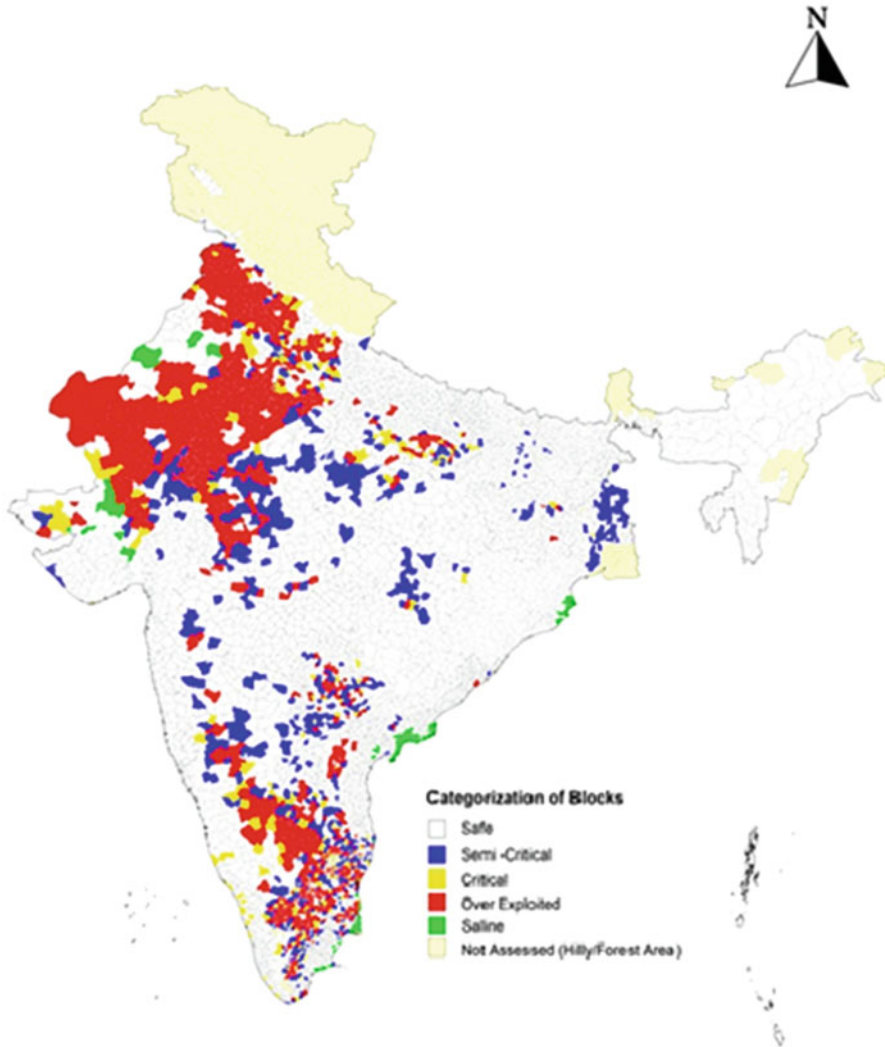
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**Fig. 1** Distribution of overexploited blocks in India. (After Saha and Ray 2019)

With the ever-increasing water demand fuelled by the spiralling population growth, demand for assured irrigation to achieve higher food grain production coupled with the changing lifestyle of an expanding urban population, a thorough assessment and understanding of the water resources is warranted. The dependence on groundwater is likely to increase further in the coming decades as creation of surface water reservoirs would be constrained owing to several pressing issues like availability of suitable sites, problems related to land acquisition, forest- and land submergence-related issues, etc.

Aquifers are the repository of groundwater. They need to be understood, mapped, measured and monitored for the efficient and optimal use of the available groundwater. Aquifer mapping refers to the entire process by way of which a wholesome

understanding of the aquifers is made. It starts with delineating the aquifers in a three-dimensional environment, characterizing their hydraulic parameters and assessing the availability of groundwater resources and its extraction in an aquifer-specific environment along with the possibility of rejuvenating the depleted resources and chemical characters of groundwater. All these are achieved following the well-laid multidisciplinary scientific approach of investigations, data generation, analyses and synthesis. However, the crux lies in managing the groundwater resources in an efficient and sustainable manner. The management practices to enhance the resource availability as well as for its efficient use are required to be quantified and laid. The key challenge is to limit the total extraction of groundwater within the annual recharge, through a combination of demand and supply side interventions. The supply side interventions are primarily artificial recharge and rainwater harvesting, while the demand side interventions are adopting efficient irrigation practice, crop diversification and cropping calendar change, efficient use of water in industries, curbing wastage of domestic water, etc. However, since the irrigation sector consume more than 85% of total groundwater extraction, the focus remains on efficient groundwater use in irrigation sector.

## **2 History of Hydrogeological Surveys in India**

Since its inception in 1972, Central Ground Water Board, the apex Government of India body for groundwater assessment, monitoring and management in India, has produced a series of hydrogeological maps of different scales based on field investigations. The baseline survey carried out during the initial phase was called systematic hydrogeological survey under which the first approximation of the groundwater resource availability in different parts of the country was assessed. Subsequently, the surveyed areas were revisited every 10 years to assess the changes that took place in groundwater regime including the chemical quality through reappraisal hydrogeological survey. The objectives of the study were to delineate groundwater worthy areas and select the areas or sites for drilling of successful tube wells. The aim was to assist the state governments and the stakeholders to develop the aquifers and derive the maximum benefit therefrom. The maps and wide array of information generated on groundwater potential, hydraulic characteristics and chemical quality of groundwater were refined through subsequent surveys and were compiled at the state level to prepare the state hydrogeological report and state groundwater development plan.

### ***2.1 Aquifer Classification in India***

The first map on hydrogeology was published by the Geological Survey of India in 1969 under the title 'Geohydrological Map of India' on 1:2 million scale. After

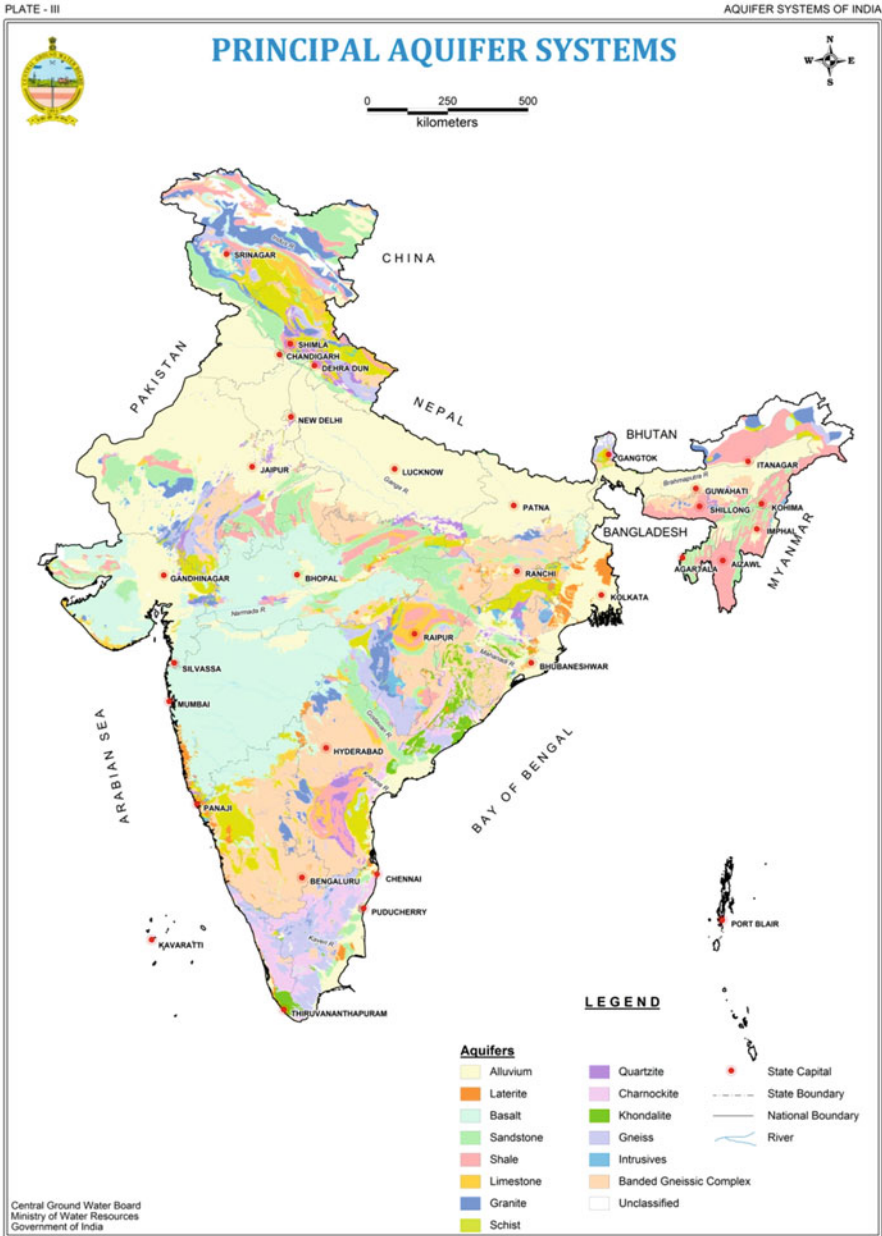
**Table 1** Geographical coverage of different principal aquifers in the country

S. No	Principal aquifer system	Area (km <sup>2</sup> )	(% of total Area)
1	Alluvium	9,45,754	29.82
2	Laterite	40,926	1.29
3	Basalt	5,12,302	16.15
4	Sandstone	2,60,416	8.21
5	Shale	2,25,397	7.11
6	Limestone	62,899	1.98
7	Granite	1,00,992	3.18
8	Schist	1,40,935	4.44
9	Quartzite	46,904	1.48
10	Charnockite	76,360	2.41
11	Khondalite	32,914	1.04
12	BGC	4,78,383	15.09
13	Gneiss	1,58,753	5.01
14	Intrusives	19,896	0.63

merger of the groundwater wing of GSI with CGWB in the year 1973, CGWB published the 'Hydrogeological map of India' in 1976 on 1:5 million scale followed by its revised edition in 1989. The first edition of the hydrogeological map on 1:2 million scale was published in 1985, and its second edition incorporating the data up to 2001 was published in the year 2002. The state and national level maps were further updated with newer data generated by Central Ground Water Board and State Ground Water Directorates to produce hydrogeological atlas of India on 1:2,50,000 scale (CGWB 2012). This was the first systematic approach to classify the country based on their hydrogeological characteristics using a GIS platform. The country has been divided into 14 principal aquifer systems (Table 1), which is further subdivided into 42 major aquifer systems.

Out of the 14 principal aquifer systems, the largest in expanse is the unit *Alluvium* which denotes the unconsolidated deposits of quaternary age which are either of fluvial, deltaic, lacustrine or Aeolian origin. This unit covers 31% of the geographical area of the country (Fig. 2) and spreads over mainly in the states of Assam, West Bengal, Bihar, Uttar Pradesh, Punjab, Haryana and Rajasthan.

This unit forms the best repository of groundwater and is being extensively exploited depending upon the availability of the resources. Around 35% of the country area is covered by a wide array of hard rock aquifers which includes these aquifer types: gneiss, banded gneissic complex, schists, gneiss, granite-gneiss, quartzites, charnockites, khondalites and intrusives. The aquifer system in these groups are characterized by a two-layered aquifers: a weathered zone (thickness and water holding capacity of which vary as per the aquifer types) underlain by a fractured/jointed aquifer system. The overall groundwater potentiality of aquifers falling in this group is moderate to low and covers a vast swath of central and south India, covering mainly the states of Jharkhand, Chhattisgarh, Madhya Pradesh, Telangana, Andhra Pradesh, Tamil Nadu, Karnataka and Kerala.



**Fig. 2** Principal aquifer systems in India. (After Saha et al. 2016a, b)

The next important principal aquifer system is formed by the Basalts, which hydrogeologically mimics the characteristics akin to the layered alluvial aquifers, yet remains a hard rock aquifer (Saha and Agrawal 2006). In total, it covers ~17% of the

total geographical area and is spread over the states of Maharashtra, Madhya Pradesh, Gujarat, Rajasthan and Karnataka. The overall potential of this unit is moderate to low.

Another prominent aquifer type is Shale, which accounts for about 7% area of the country and is available mostly in Chhattisgarh, Andhra Pradesh, Madhya Pradesh, Rajasthan and in north- eastern states as well as in Himalayan states. The overall aquifer potential is low to moderate; however, depending upon the consolidation and diagenesis of the sediments, the aquifer potential may increase to moderate to high. Limestone aquifer possesses the unique character of holding substantial volume of water in solution cavities. However, this unit covers only 2% of the geographical area and spreads over parts of Chhattisgarh, Andhra Pradesh, Karnataka, Gujarat and the Himalayan states.

### **3 Aquifer Mapping and Management Programme (NAQUIM)**

The ambitious Aquifer Mapping and Management programme, often referred to as Aquifer Mapping in short, was launched in the year 2012 by the Central Ground Water Board (CGWB), under the Ministry of Water Resources, River Development and Ganga Rejuvenation during the 12th Five-Year Plan period (2012–17). The initial analysis reveals that out of 32 lakh km<sup>2</sup> area of the country, mapping is required in 25.9 lakh km<sup>2</sup>. In these parts, the aquifer parameters are such that the aquifers can be exploited provided groundwater resource is available in them and/or groundwater resource can be rejuvenated by artificial recharge and rainwater harvesting.

#### ***3.1 Pilot Studies on Aquifer Mapping***

To initiate the NAQUIM programme, CGWB had taken up six Pilot Aquifer Mapping in different hydrogeological terrains spread across the country as below:

1. Alluvial deposits of the Gangetic Plains, Bihar state (AQBHR)
2. Thin alluvial deposits underlying hard rocks, Rajasthan state (AQRAJ)
3. Basaltic rocks, underlain by Gondwana rocks, Maharashtra state (AQMAH)
4. Precambrian hard rocks, Karnataka state (AQKAR)
5. Coastal sediments, Tamil Nadu (AQTND)
6. Aeolian deposits in desert, Rajasthan state (AQDRT)

The location of the pilot study areas is shown on the map depicting the broad hydrogeological framework of the country, delineated on the basis of yield potential of the broad hydrogeological units (Fig 3).

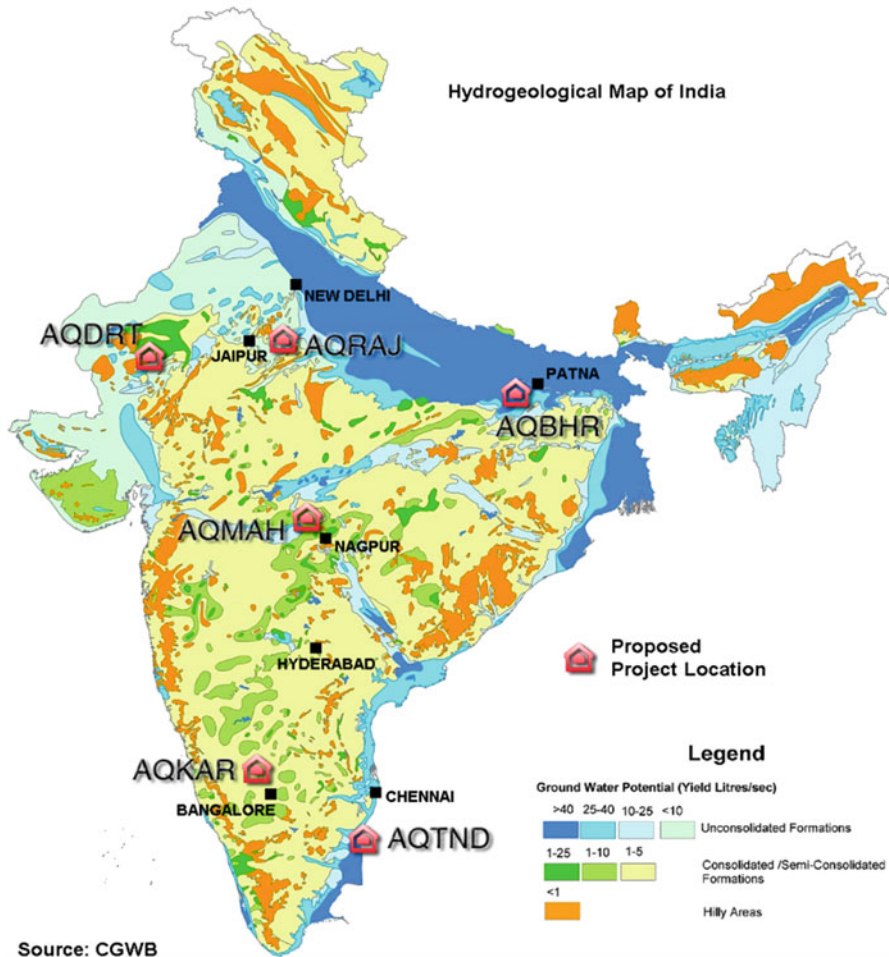


Fig. 3 Location of areas under pilot aquifer mapping. (Ahmed 2014)

The AQBHR represent prolific aquifer system of Indo-Gangetic-Brahmaputra Alluvial System. The AQRAJ represents the marginal alluvial-aeolian aquifers underlain by hard rocks with moderate rainfall, while AQDRT represents an aquifer system deep in the desert areas of Rajasthan. The AQMAH represents a typical trap aquifer underlain by semi-consolidated aquifers of Gondwana rocks, while AQKAR represents the low potential gneissic-granitic-schists-intrusive aquifer combination. The AQTND stands for the good potential coastal aquifers, where a delicate balance exists between freshwater from land and saline water wedge from sea. The objective of the pilot aquifer mapping was to carry out a detailed mapping of aquifers in the selected representative hydrogeological typologies through application of the state-of-the-art investigation techniques like transient electromagnetic, electrical

resistivity tomography, heli-borne dual-moment electromagnetic survey, stable and radioactive environmental isotopes and groundwater flow modelling. Usefulness and applicability of different techniques in different areas have also been studied and protocols developed for applying such techniques at the national level. Each of the area selected for the pilot study represents different hydrogeological framework and groundwater regime behaviour. A brief description of the pilot study areas and the salient findings are given below.

### 3.1.1 AQBHR Bihar State

About 520 km<sup>2</sup> is covered in Maner area of Patna district located in the interfluvium of the Sone and the Ganges Rivers (CGWB 2015e). This area represents a type of area of the Indo-Gangetic-Brahmaputra Alluvial Plain holding some of the most potential aquifer systems of the world (Saha et al. 2016a, b). The area is hugely groundwater dependent, and arsenic contamination has been reported from some parts. The study revealed multi-tier aquifer systems made up of quaternary sand within 300 m below ground. The deeper aquifer system is hugely exploited in Patna urban area, located in the study area, apart from excessive dependence on groundwater for meeting the requirements for rural drinking and irrigation purpose (Saha et al. 2014; Dwivedi and Singh 2015; Dwivedi et al. 2015). The recommendations include decongesting the heavy-duty deep tube wells from the urban area to the adjoining demarcated areas with equally prolific aquifers, tapping confined deeper aquifers for potable water supply in arsenic-contaminated areas and recharging the depleted deeper aquifers of Patna Urban area, which are exposed to the surface through a network of palaeochannels, at the southern part of the study area.

### 3.1.2 AQRAJ Rajasthan State

Located in the deep Thar Desert in Ramgarh area, Jaisalmer district, the study area spread over ~675 km<sup>2</sup> (CGWB 2015c). The aquifers are mainly sedimentary rocks of calcareous-argillaceous-arenaceous nature of Tertiary and Mesozoic era. Aquifers are encountered at the depths of 45–70 m and 125–160 m holding brackish water (EC 3500–4000 micromhos/cm). Groundwater level varies from 30 to beyond 100 m bgl at places. The area (some block as a whole) has been categorized under safe category, primarily because of very limited extraction of groundwater. The annual groundwater recharge is ~ 3.44 mm/year constituting only 2% of the annual rainfall (146 mm). Even this meagre resource is brackish in nature due to intrinsic property of the rock formations, thus rendering it unsuitable for use. The management interventions proposed in the desert project area are:

- a) Upscaling the traditional water harvesting system in the area.
- b) Along the Indira Gandhi Nahar Pariyojna (IGNP) canal, freshwater pockets are formed due to seepage from the lined canal which often leads to waterlogging



situation. In such areas, controlled use of groundwater can help mitigate the water crisis.

### 3.1.3 AQMAH Maharashtra State

An area of 360 km<sup>2</sup> has been taken up in Chandrabhaga watershed of ephemeral Chandrabhaga River in Nagpur district (CGWB 2015d). The major part is occupied by Deccan Trap basalt (313 km<sup>2</sup>) of 60–195 m thick, while about 47 km<sup>2</sup> is occupied by Gondwana formation of Permian age. The area receives a normal annual rainfall of 980 mm. Major part of the watershed is having depth of weathering in the range of 3–6 m. Groundwater in Aquifer I generally occurring in the depth range of 20–30 m occurs under unconfined conditions, and in major part of the area, it is occupied by basaltic formation except in the north-eastern part where it is formed of Gondwana Supergroup. Aquifer II which generally extends beyond 30 m bgl is semi-confined to confined in nature. Aquifer III occurs in the Gondwana sediments underlying the trap. The stage of groundwater development is about 80%, and groundwater is mainly used for irrigation purpose (about 5368 ham) out of total draft of 5545 ham. Considering the low potential of the aquifers, the Aquifer Management Plan suggests adoption of unconventional measures like fracture seal cementation (FSC), hydro-fracturing, well jacketing (WJ), borewell blasting technique (BBT), etc. besides taking up normal water harvesting in the area. Model-based evaluation indicates that construction of check dam on Chandrabhaga River would lead to improvement of groundwater availability by 0.29 mcm. Another model-based scenario indicates that construction of 25 recharge wells would enhance annual groundwater recharge by 1.12 mcm.

### 3.1.4 AQKAR Karnataka State

Ankasandra watershed drained by Torehalla stream of Tumkur district spreading over 375 km<sup>2</sup> was selected for the pilot study (CGWB 2015f). The area receives about 680 mm rainfall, while the potential evapotranspiration is more than 1500 mm annually. The area is underlain by hard rocks of Achaean age. The water level is deep and at places is even more than 100 m bgl witnessing a continuously declining trend. The fractured aquifers below the weathered zone, albeit low yielding (3.6–7.2 m<sup>3</sup>/hour), are heavily exploited. Gross groundwater draft for all uses is 3729 ham against a recharge of 1988 ham. However, the extraction is not uniform throughout the watershed, and in some of the villages, there is still scope for further development. Model-based estimate indicates that the available sub-surface storage space for recharging the aquifers so as to raise the groundwater level up to 10 m bgl is 6,39,345 ham. However, in view of the unavailability of surplus water for recharge, it is recommended to import source water from the adjoining areas and recharge them primarily through desilting of existing tanks.

### 3.1.5 AQTND Tamil Nadu

The study area (428 km<sup>2</sup>) falls in Lower Velar Watershed, Cuddalore district (CGWB 2015a). The aquifer consists of regionally extensive sandstones that crop out within the Cuddalore aquifer system which holds huge lignite deposit. The area has following issues:

- a) Heavy and continuous groundwater withdrawal for irrigation
- b) Depressurized hydraulic heads for safe mining of lignite since 1955
- c) Groundwater withdrawal for drinking water supply to Chennai City during lean periods from coastal areas
- d) Threat of seawater intrusion in the event of reversal of hydraulic gradient or by upconing

Four highly potential aquifer systems have been demarcated with present annual groundwater withdrawal of 1213.58 mcm, which is presently safe with no threat of sea water intrusion. However, reversal in hydraulic gradient and consequently sea water intrusion may take place if total annual groundwater extraction exceeds 525 and 700 mcm/yr for Aquifer I (at the top) and Aquifer II, respectively. The present annual groundwater withdrawal from Aquifer III from which considerable pumping (120.8 mcm/yr) is taking place for lignite mining, the safe limit is 500 mcm/yr. Aquifer IV, the deepest, has present pumping of 12.79 mcm/yr mainly for Chennai water supply which can be increased to 550 mcm/yr.

### 3.1.6 AQDRT Rajasthan

The area covers around 600 km<sup>2</sup> in Baswa-Bandikui watershed forming a part of the Banganga river basin in Dausa district (CGWB 2015b). The area is categorized as 'overexploited'. The area receives an annual rainfall of about 660 mm. Broadly two aquifer systems are identified: upper aquifer consists of unconsolidated alternate horizons of clastic sediments like fine- to medium-grained sand, alternating with finer-grained sediments like silt, silty clay and clay. The underlying hard-rock aquifer comprises a slice of weathered zone and lower fractured/crystalline hard rock including quartzites, gneisses, schists and phyllites. The upper aquifer ~60 m thick is heavily exploited and almost gets completely desaturated during the pre-monsoon period (Chatterjee et al. 2018). Groundwater flow modelling forecasts that the present rate of development would lead to drying up of the aquifers. A modelled scenario with a feasible artificial recharge plan shows improvement of groundwater situation in the study area. The recommendations include:

- a) Notification of the Bandikui block for the purpose of groundwater regulation.
- b) Artificial recharge to groundwater through suitable structures.
- c) Use of water efficiency measures like sprinkler and drip irrigation.

### 3.2 National Coverage of NAQUIM

The learning of the pilot aquifer mapping was assimilated to take forward the NAQUIM programme nationwide. As per the approved plan of the Government of India, out of ~25 lakh km<sup>2</sup> mappable area of the country, 8.89 lakh km<sup>2</sup> were to be covered during 2012–2017.

There are four broad sets of activities under the NAQUIM programme:

- a) *Data Compilation and Data Gap Analysis*: Synthesis of existing data collected from various agencies. The useful data were selected and placed in a GIS platform. Available data was compared with the data requirement as per the laid down guidelines for different hydrogeological-type areas through data gap analyses. The quantum of the data to be generated for various work items was determined.
- b) *Data Generation and Integration*: Large array of data were generated by multiple activities such as (i) preparation of lithological log by analysis of drill cut samples from exploratory drilling and geophysical well logging and preparation of geological section to delineate aquifer using lithological log; (ii) determination of hydraulic parameters of aquifers by pumping test; (iii) analysis of groundwater samples for chemical and isotopic composition; (iv) digital analyses of remotely sensed data; (v) geophysical surveys like vertical electrical sounding survey, heli-borne dual-moment electromagnetic survey, transient electromagnetic survey and electrical resistivity tomography; (vi) aquifer-specific water levels; (vii) soil infiltration test and slug test; and (viii) groundwater draft assessment for different formations and aquifers. Upon integrating the data, the aquifer geometry is firmed up by building hydrogeological sections. The aquifers are attributed hydraulic properties, chemical quality, specific water levels, infiltration and percolation capacity, etc.
- c) *Aquifers Map Preparation*: The delineated aquifers are characterized in terms of quality, yield potential as well as sustainability for yield. Delineating principal aquifer, contaminated aquifers, aquifers under stress, recharge mechanism and capacity of the aquifers, etc. The replenishable and in-storage resource estimated for different aquifer systems. The spatiotemporal behaviour hydraulic head in aquifer-specific environment is also established.
- d) *Aquifers Management Plan Formulation*: Sustainable management of groundwater resources with demand and supply side interventions. Quantification of different contemplated interventions. Plan for artificial recharge and possibility of alternate aquifer-based water supply in contaminated areas. Plan for development in groundwater surplus areas.

Initial data analyses revealed that a considerable data gap exists in several parts of the country, for which substantial data is to be generated if timeline of achieving the programme targets is to be adhered. Data generation is required particularly in the field of drilling and construction of wells, conducting pumping tests, geophysical studies and chemical analyses of water samples. As the volume of data required is

beyond the existing capacity of CGWB, it necessitates the requirement of large-scale outsourcing through private and PSU's participation as well as roping in research and academic institutes. In view of these limitations, the target for 2012–2017 was reprioritised from 8.89 lakh km<sup>2</sup> to 5.25 lakh km<sup>2</sup>, targeting the overexploited areas of the country in addition to the Bundelkhand region covering the states of Madhya Pradesh and Uttar Pradesh.

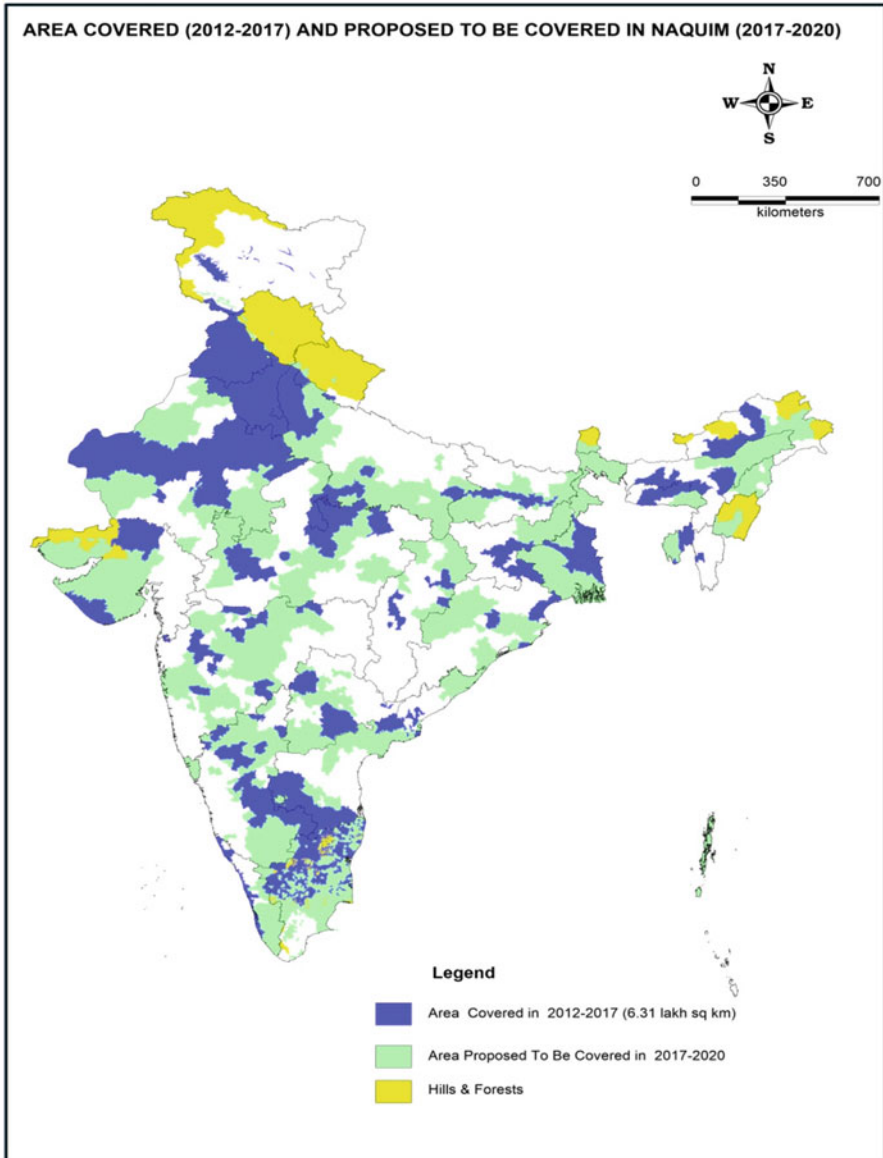
### **3.3 Institutional Arrangement**

To lay the roadmap and provide guidance in executing the programme along with monitoring the progress at the highest level, a *National Inter Departmental Steering Committee* (NISC) has been constituted. NISC is headed by the secretary of MOWR RD & GR, where the central government departments directly or indirectly involved in groundwater and the relevant state departments are also member. In Central Ground Water Board, a *Project Management Unit* (PMU) is formed under the leadership of the member (HQ) to coordinate the execution of the programme through regional offices, as well as to plan and monitor the progress. At the central level, for technical evaluation of the programme outputs, a *National Level Technical Evaluation Committee* (NLEC) has been constituted with domain experts. Considering the important role of the states in taking forward the outputs of the programme, *State Ground Water Coordination Committees* (SGWCC) have been formed in each state headed by the principal secretary of the related department to evaluate the outputs and lay the roadmap for implementing the plans.

Success of the programme warrants involvement of several departments through sharing of data and maps. Agreements have been made with Survey of India and Geological Survey of India for the required toposheets and geological maps. The soil maps and land use geomorphological lithological maps are being obtained from National Bureau of Soil Survey and Land Utilisation Planning and National Remote Sensing Centre. The isotope analyses are being done through Bhabha Atomic Research Centre and National Institute of Hydrology. For groundwater flow simulation through mathematical modelling, it is proposed to rope in the academic institutions with requisite expertise. To begin with, the IIT Kanpur and IISc Bangalore have been involved.

## **4 Outputs and Achievement under NAQUIM**

As part of the programme, an area of 6.31 lakh km<sup>2</sup> has been covered till March 2017. The initial target area for 2012–2017 of 8.89 lakh km<sup>2</sup> was reprioritized to 5.26 lakh km<sup>2</sup> including pilot areas, in view of the rapidly deteriorating groundwater scenario of the country. The focus was given to water-stressed areas in the states of Haryana, Punjab, Rajasthan, Gujarat, Tamil Nadu, Telangana and Bundelkhand



**Fig. 4** Areas covered under NAQUIM Programme till March 2017 and proposed to be covered during 2017–2020

regions in Madhya Pradesh and Uttar Pradesh. Up to March 2017, 6.31 lakh km<sup>2</sup> has been covered, out of which 4.64 lakh km<sup>2</sup> lies in the demarcated prioritized areas, and the remaining 1.67 lakh km<sup>2</sup> is from the remaining parts of India (Fig 4, Tables 2 and 3).

**Table 2** State wise area covered from the Priority areas

S. No	State	Mappable area (km <sup>2</sup> )	Area under priority investigation	Area covered till March, 2017	Number of OE units covered by 2017
1	Andhra Pradesh	130769	28379	39141	44
2	Telangana	103900	26429	22328	7
2	Gujarat	159277	34768	31522	17
3	Haryana	44179	44179	44179	64
4	Karnataka	170703	48294	48311	32
5	Bundelkhand region	66193	66193	27484	9
6	Punjab	50362	50362	50362	105
7	Rajasthan	268378	166911	143275	98
8	Tamil Nadu	104635	45766	45339	314
9	NCR (UP and Delhi)	12283	12283	12283	37
	<b>Total</b>	<b>11,10,679</b>	<b>5,23,564</b>	4,64,224	<b>718</b>

The programme has translated into a number of success stories where the outputs have been adopted and implemented by the stakeholder departments. This unique programme has steered a holistic understanding of the aquifer system and offers a key to managing the precious groundwater resources. The newer insights obtained through programme are:

- **Static resource rapidly diminishing in some prolific aquifers:** Steepening of the declining trend in water levels of some of the prolific aquifer system in North West India, in the states of Punjab and Haryana. This reveals that the annual extraction is outstripping the annual recharge leading to situation of groundwater mining. Such aquifers are to be accorded the highest priority so that groundwater pumpage is reduced significantly coupled with water use efficiency measures so that management of these aquifers can be undertaken in a holistic way.
- **Large aquifer systems can be recharged in an integrated manner:** Traditionally, the recharge efforts in India are disintegrated and specific area centric. Systematic attempt towards large-scale integrated recharge should be taken up in hydrogeologically suitable area, with economic scenario and environmental consideration. Tapi Mega Recharge project benefitting Maharashtra and Madhya Pradesh states is one such big effort to mention, in this direction.
- **Artificial recharge is not an all-weather solution applicable everywhere:** Exemplified by alluvial aquifers in Kurukshetra district of Haryana and Ahmedabad district of Gujarat underlain by hard rock aquifers, demand side managements like crop diversification, micro-irrigation, and laying underground pipelines in place of open channels contribute more in improving the dismal scenario. Scanty source water availability would hinder any large-scale adoption

**Table 3** State-wise area covered other than priority areas

S. No	State	Mappable area (km <sup>2</sup> )	Area covered till March, 2017	Number of OE and critical units covered by 2017
3	Arunachal Pradesh	5461	1965	0
4	Assam	62194	6179	0
5	Bihar	90567	9607	0
6	Chhattisgarh	96000	10619	1
3	Dadra and Nagar Haveli	416	490	0
12	Jammu and Kashmir	9825	8220	0
13	Jharkhand	58417	17693	4
15	Kerala	28088	5200	1
5	Lakshadweep	26	32	0
16	Madhya Pradesh	269746	28080	9
17	Maharashtra	259914	31418	9
18	Manipur	2559	155	0
19	Meghalaya	2758	1627	0
21	Nagaland	2522	400	0
22	Orissa	119728	10193	0
6	Puducherry	463	293	1
27	Tripura	6198	559	0
28	Uttar Pradesh	240928	24401	37
29	Uttarakhand	4993	2811	0
30	West Bengal	71947	8008	0

of artificial recharge in areas of low rainfall and resultant low availability of noncommitted surface water.

- **Protection strategy for arsenic-safe deeper aquifers in the Gangetic plains:** It is well established that the deeper aquifers in the Ganges Basin are free from contamination (Saha 2009; Saha et al. 2010). They are being delineated all along the alluvial patches of the basin. But to keep the lower aquifer arsenic-free, regulated pumping of deeper arsenic safe aquifers should be adopted. In addition to that keeping safe distance between the wells would also help in protecting the arsenic safe zones from the threats of leakance- induced cross-contamination.

## 5 Conclusion

Aquifer Mapping and Management programme launched in India in the year 2012 is dedicated to the cause of scientific management of our groundwater resources. Protection, preservation, and augmentation strategy for our groundwater resources

occurring in the aquifers under different hydrogeological environment calls for a wholesome understanding of the groundwater system. There can't be a one size fits all approach for tackling the groundwater problems owing to the inherent heterogeneity and anisotropy associated with the natural groundwater system, different level of groundwater extraction and contamination affecting various areas. Aquifer appropriate and aquifer-specific action plans for management which is being framed as an output of the NAQUIM programme can help mitigate the groundwater-related issues. The strategy of demand management and supply augmentation or a combination of both with varying weightage will have different results under different hydrogeological conditions and the prevailing stress levels in the aquifers, and therefore the outputs of the NAQUIM are unique and indispensable from the aquifer management point of view. The two important aspects to the success of this programme are (i) scientific part which depends on the accuracy of the data and its meticulous use to prepare the aquifer maps and management plans and (ii) the implementation part which depends on the involvement of the states and various stakeholders including the communities.

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