Groundwater Resource and Governance in Kerala
Status, Issues and Prospects

Dr. Ajaykumar Varma

Forum for Policy Dialogue on Water Conflicts in India
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March 2017
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Author: Dr. Ajaykumar Varma

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ACRONYMS

AAR    Annual Average Rainfall
APFAMGS Andhra Pradesh Farmer Managed Groundwater Systems
ARDC   Agriculture Refinance and Development Corporation
CGWA   Central Groundwater Authority
CGWB   Central Groundwater Board
CPCB   Central Pollution Control Board
CRA    Crystalline Rock Aquifers
CWC    Central Water Commission
CWRDM  Centre for Water Resources Development and Management
EPA    Environment Protection Act
GEC    Groundwater Estimation Committee
GoI    Government of India
GoK    Government of Kerala
GPGSP  Gram Panchayat Groundwater Security Plan
GPZ    Groundwater Protection Zone
KSEB   Kerala State Electricity Board
KSLUB  Kerala State Land Use Board
KWA    Kerala Water Authority
MoCI   Ministry of Commerce and Industry
MoEF   Ministry of Environment and Forests
MoRD   Ministry of Rural Development
MoUD   Ministry of Urban Development
MoWR   Ministry of Water Resources
MWRRA  Maharashtra Water Resources Regulation Authority
NABARD National Bank for Rural Development
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>NAGA</td>
<td>Net Annual Groundwater Availability</td>
</tr>
<tr>
<td>NAGD</td>
<td>Net Annual Groundwater Draft</td>
</tr>
<tr>
<td>NEM</td>
<td>North-East Monsoon</td>
</tr>
<tr>
<td>NOC</td>
<td>No Objection Certificate</td>
</tr>
<tr>
<td>NWC</td>
<td>National Water Commission</td>
</tr>
<tr>
<td>PIM</td>
<td>Participatory Irrigation Management</td>
</tr>
<tr>
<td>RBMA</td>
<td>River Basin Management Agency</td>
</tr>
<tr>
<td>RIF</td>
<td>Rainfall Infiltration Factor</td>
</tr>
<tr>
<td>SDG</td>
<td>Submarine Discharge of Groundwater</td>
</tr>
<tr>
<td>SGWD</td>
<td>State Groundwater Department</td>
</tr>
<tr>
<td>SPCB</td>
<td>State Pollution Control Board</td>
</tr>
<tr>
<td>SWM</td>
<td>South-West Monsoon</td>
</tr>
<tr>
<td>TAGR</td>
<td>Total Annual Groundwater Recharge</td>
</tr>
<tr>
<td>TNEA</td>
<td>Tamil Nadu State Electricity Board</td>
</tr>
<tr>
<td>TRA</td>
<td>Tertiary Rock Aquifers</td>
</tr>
<tr>
<td>WALTA</td>
<td>Water, Land and Trees Act</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organisation</td>
</tr>
<tr>
<td>WLF</td>
<td>Water Level Fluctuation</td>
</tr>
<tr>
<td>WQAA</td>
<td>Water Quality Assessment Authority</td>
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<tr>
<td>WRD</td>
<td>Water Resources Department</td>
</tr>
</tbody>
</table>
Foreword and Acknowledgement

The state of Kerala, once considered water rich, is increasingly facing seasonal water scarcity. Multiple reasons including decline of its river systems, loss of large extend of wetlands and paddy fields, increasing demand, over-exploitation of available resources, pollution, etc., have contributed to this scarcity. The Groundwater Resource Potential of Kerala, as per the Groundwater Evaluation Committee (2012) is 6029 Mm³. This is only around 12-13% of the total utilisable water availability in the state. However, groundwater plays a crucial role in meeting the water requirement of the state, especially its domestic water requirement. As per Census 2011, about 62% of the population of Kerala depend on groundwater for the purpose of drinking water. Bulk of this is from around 65 lakh open wells. The Kerala Water Authority reported that during the year 2003, 48% of the then total 45 lakh wells in the state dried up during summer. This percentage must have increased as more and more wells are becoming seasonal.

Dr. Ajaykumar Varma, the author of this report, says, “The hydrological importance of the river systems, wetlands, ponds, tanks, irrigation canals, etc., in sustaining the groundwater system is either not understood or not taken seriously at the grassroots level and, therefore, the environmental abuse on these systems is on the increase. The thick and highly porous and permeable sand bed in rivers is now more or less removed thereby the river bed storage of water for the lean season is almost lost. As a result, the perennial flow in rivers is on the decline and the groundwater level in wells even on the river banks is lowering dangerously. The adverse impact of indiscriminate pumping on the aquifer environment is also on the increase as it is done without any consideration on the safe yield, water quality, recharge, etc.”

The declining quality of groundwater is also a major concern. Various studies suggest that there is bacterial contamination in bulk of the open wells in the state. Studies also confirm localized issues with respect to excessive iron, low pH and excessive fluoride.

The rapidly changing water scenario, especially over the last 35 years necessitates a thorough understanding of the sector, including its river systems, groundwater, and water management practices. It is in this context that the Kerala State Centre of the Forum for Policy Dialogue on Water Conflicts in India (Forum to be brief) decided to bring out a technical report on groundwater situation in Kerala. The Kerala State Centre approached Dr. Ajaykumar Varma, senior scientist at National Centre for Earth Science Studies, Thiruvananthapuram and one of the most knowledgeable persons on groundwater issues in the state, to prepare a report on the groundwater situation in the state that would bring out the present status and critical issues and also suggest ways to address them.

We express our heartfelt gratitude to Dr. Ajaykumar Varma, also a steering committee member of the Kerala State Centre, for agreeing to take up this task on behalf of the Forum and also for doing a thorough analysis of the ground water situation in Kerala and helping us in bringing out this report, despite his pressing engagements. We also express our gratitude to Dr. T.M. Thomas Issac MLA (now the Finance Minister of Kerala) for being part of the consultative workshop that discussed the draft
report. We also thank other dignitaries who participated in the consultative workshop including, Dr. K.N. Nair, Dr. M.P. Parameswaran, Dr. V.S. Vijayan, Smt. Sheela Vijayakumar (Thrissur District Panchayat President), Sri Sudheer Padikkal, Dr. P. Indiradevi, Sri Madhavan Namboothiri, Dr. Abdul Hammed, Sri K.J. Joy, Sri Siddharth Patil, Dr. V.R. Raghunandan, Sri P. Vinodkumar, Adv. K.P. Raviprakash, Adv. Shama Kuriakose, Dr. Bridgit, Smt. Rema. K.Nair, Smt. Bindu Vasumathi, Sri. Sivaraman, Smt. Najuma, Neethu, Sreenath and many others for providing their suggestions and critical feedback on the draft report.

The Secretariat of the Forum has been a constant source of support for us. We thank Sri K. J. Joy for guiding us and for reviewing the draft report more than once. We thank other Secretariat members especially Pratima Medhekar and Sarita Bhagat for their valuable support. We would also like to thank Neeta Deshpande for the copy-editing and Mudra Printers for the layout and publication.

This initiative is supported financially by Arghyam Trust. We express our gratitude to the Arghyam Trust.

The report is a timely one as it is coming out at a time when Kerala is going through severe water scarcity and drought. We do hope this report would prompt different stakeholder like the policy makers, bureaucrats, civil society, Panchayati Raj Institutions and people at large to take timely actions in protecting the groundwater sources and also in streamlining its use in more sustainable and equitable lines.

March 2017

Kerala State Centre of the Forum
Assessment of Groundwater Situation in Kerala

1.1 Introduction

Groundwater resources play a vital role in sustaining livelihoods. The ubiquitous occurrence, reliability and availability in all seasons have made them the primary buffer against drought. They also play a pivotal role in ensuring food security at all levels. Groundwater has an important role in meeting the water requirements of agriculture, industrial and domestic sectors in India. About 85% of India’s drinking water supplies and 60% of its irrigation requirements are dependent on groundwater resources.

If current trends continue, 60% of all the groundwater aquifers of India will be in critical condition by 2032 (World Bank, 2012). India is the largest user of groundwater in the world as it uses an estimated 230 km³ of groundwater per year that works out to be over a quarter of the global total. Groundwater is an annually replenishable resource but its availability is non-uniform in space and time.

Groundwater is a common-pool resource used by millions of farmers across the country. Hence, this resource is managed both by the government and private entities. The nature and relative ease and convenience of decentralised access to groundwater make it the backbone of India’s agriculture and drinking water security. It remains the only drinking water source for most of India’s rural households. With an estimated 30 million groundwater structures, India is fast hurtling towards a serious crisis of groundwater overuse and quality deterioration. The report of the Expert Group on Groundwater Management and Ownership of the Planning Commission (2007) states, that in 2004, 28% of India’s blocks were showing alarmingly high levels of groundwater use. A study under the GRACE satellite mission (NASA) and hydrological models indicated that the northern India region and surroundings lost groundwater at a rate of 54±9 km³/year between April 2002 and June 2008 (Tiwari, Wahr & Swenson, 2009). This amounts to a decline in the water table to the tune of 0.33 metres per annum, and is also said to be equivalent to the contribution from the melting of Alaskan glaciers to the rise in the sea level. This is probably the largest rate of groundwater loss in any region of a comparable area on earth and is attributed to excessive extraction. In addition to depletion, many parts of India report severe water quality problems.

Kerala is a tiny strip of land located at the south-western tip of India between North latitudes 8° 18’ and 12° 48’ and East longitudes 74° 52’ and 77° 22’, occupying only 1.2% of India’s land area. Geographically, it can be described as an elongated strip of land cushioned between the Western Ghats in the east and the sandy shores of the Arabian Sea in the west. Its land area is 38,863 km² with a length of 560 km and width ranging between 11 km and 124 km. Though Kerala forms only 1.2% of the total area of India (3,287,263 km²), 3% of the country’s population inhabits the state.
Groundwater Resource of Kerala

The state is subdivided into 14 districts, 21 revenue divisions, 75 taluks and 1635 revenue villages for administrative convenience and into 152 blocks, 6 city corporations, 87 municipalities and 941 gram panchayats for decentralised governance.

As per the 2011 Census, about 62% of the population of Kerala depends on groundwater for the purpose of drinking alone. The latest estimate (2008-09) of the Groundwater Resource Potential of Kerala by the Groundwater Evaluation Committee (2012) indicates that the total available resource is 6029 Mm³ and the average level of development is 47% annually. The level of development is highest in Kasaragod district (71%) and lowest in Wayanad district (17%). The long-term groundwater levels during the pre-monsoon period show a predominantly rising trend in Kerala. However, the Kerala Water Authority (KWA) reported that during the year 2003, 48% of the total 45 lakh wells in the state dried up during the summer. The hydrological importance of river systems, wetlands, ponds, tanks, irrigation canals, etc. in sustaining the groundwater system is either not understood or not taken seriously at the grassroots level, and therefore the environmental abuse of these systems is on the rise. The thick and highly porous and permeable sand bed in rivers is now more or less removed, because of which the river bed storage of water for the lean season is almost lost. As a result, the perennial flow in rivers is on the decline and the groundwater levels even in wells on the river banks are lowering dangerously. The adverse impact of indiscriminate pumping on the aquifer environment is also on a rise, as it is done without any consideration for safe yield, water quality, recharge, etc. The third party evaluations on groundwater quality in the state highlight widespread contamination. For example, the spatial assessment studies by the Indian Institute of Science (IISc), Bengaluru highlights the prevalence of low pH and faecal coliform bacterial infestation in the groundwater of Kerala (Boominathan et al., 2012).

Various studies by the Centre for Water Resources Development and Management (CWRDM), Kozhikode also highlight that 90% of the open wells in Kerala are subjected to bacteriological contamination. The studies also confirm localised issues with respect to excessive iron and fluoride and low pH (Harikumar, 2016).

The strategies to respond to groundwater overuse and deteriorating water quality must be based on the notion that groundwater is a common property resource. However, the understanding of the occurrence, potential, sustainability, management, etc. of groundwater is very scanty at the local level. The groundwater scenario in the country, in general, and the state, in particular, is marred by various conflicts leading to crisis situations. This implies that a detailed understanding of the groundwater regimes in different hydrogeological settings is a prerequisite for sustainable and equitable management of the resource. Further, reforms are needed as to how we assess the groundwater resources, map aquifers, monitor quality and govern groundwater within a legal and institutional framework.

1.2 Significance of Groundwater

Groundwater is the most abundant source of freshwater on earth, accounting for approximately 97% of non-frozen fresh water. Groundwater sustains ecosystems, maintains base flow of rivers and stabilizes land in areas with easily compressed soils. The natural storage of groundwater buffers the impacts resulting from long-term and short-term climatic variations. Approximately 50% of
the world’s population drinks groundwater every day, especially the rural populations who are located away from water supply infrastructure. Further, groundwater contributes to over 40% of the world’s production of irrigated crops, irrigating nearly 100 million hectares of arable land. Overall, the economic benefits of abstracting groundwater exceed those of surface water per unit volume. This is because of local availability of the resource, reliability during droughts, and the fact that groundwater generally requires little treatment (IGRAC, 2014). The role of groundwater is very significant for achieving universal access to drinking water, sanitation and hygiene as highlighted in the Sustainable Development Goals to be achieved by the year 2030 (Resolution adopted by the General Assembly, United Nations, September 25, 2015).

Groundwater naturally buffers against climate variability and plays an important role in disaster risk management in the case of both floods and droughts (Green et al., 2011; Kløve et al., 2011). It ensures livelihood security across the world, especially in economies that depend on agriculture (Moench, 2002). India is one of the largest users of groundwater for agriculture in the world (Shah, 2009). The data from the 4th Minor Irrigation Census (2006-07) shows that the growing numbers of groundwater irrigation structures (well sand tubewells) in the country added up to 18.5 million in 2000-01 and 19.75 million in 2006-07 of which tubewells accounted for 50% (MoWR, 2007). In all likelihood, the number of groundwater irrigation structures is now around 27 million, with every fourth rural household owning at least one (Shah, 2009). The share of groundwater in the net irrigated area has also been on the rise. Of the addition to net irrigated area of about 29.75 million hectares between 1970 and 2007, groundwater accounted for 24.02 million hectares (80%). The share of tubewells in irrigated areas rose from a mere 1% in 1960-61 to 40% in 2006-07, thereby becoming the largest single source of irrigation water in India. The 4th Minor Irrigation Census (2006-07) also indicated that there has been a decline in the number of dug wells from 96.2 lakh in 2000-01 to 92 lakh in 2006-07. During the same period, the number of shallow tubewells and deep tubewells has increased substantially from 83.5 lakhs and 5.3 lakhs respectively, to 91.2 lakhs and 14.4 lakhs respectively.

The traditional homestead type of habitation in Kerala is generally characterised by a well in each compound to tap groundwater. Therefore, it is estimated that the state has around 65 to 70 lakh wells. The well density in Kerala is very high, of the order of 200/km² in the coastal areas, 150/km² in the midland areas, and 70/km² in the highland regions (CWRDM, 1995), which increases to above 400 wells/km² in certain stretches of coastal areas (CESS, 1995). This must have increased significantly by now. 65% of the rural households and 59% of the urban households depend on wells for the purpose of their drinking water needs (Census, 2011). In addition, 50% of the irrigation requirement is dependent on groundwater (KSPB, 2012). However, the occurrence and availability of groundwater in the state varies considerably across regions.

### 1.3 Source of Groundwater

#### 1.3.1 Hydrological Cycle

The hydrological cycle denotes the circulation of water from the oceans to the atmosphere, the atmosphere to the lithosphere, and lithosphere to the oceans through complex and interdependent processes including precipitation, runoff, groundwater flow, evaporation,
transpiration, etc. (Figure 1.1). The part of the precipitation reaching the ground may be absorbed, evaporated, transpired by plants, or may flow over ground. The water absorbed in the ground infiltrates downward through interstices to reach the saturated groundwater medium. It completes the hydrological cycle by emergence as springs or by subsurface flow into streams and oceans. The region of Kerala flanked by the Western Ghats and Lakshadweep has a characteristic hydrological cycle dominated by high monsoonal rainfall.

Kerala received the highest Annual Average Rainfall (AAR) of 3070 mm among the 35 agro-climatic zones of India based on rainfall data for the last 100 years. There are about 120–140 rainy days, having about 1–2 hours of rainfall on an average. One of the most significant aspects of Kerala’s rainfall is its spatio-temporal variation as depicted in Table 1.1 and 1.2 (Varma, 1999). On an average, Kerala receives about 70% of the AAR during the southwest monsoon (SWM) (June to September), 16% during the northeast monsoon (NEM) (October to December), 1% during the winter (January –February), and 13% during summer months (March to May). Almost 50% of the SWM rainfall occurs during 30–40 hours with an intensity of 50–60 mm per hour. The rainfall intensity recorded at Thiruvananthapuram, Kochi and Munnar during the SWM period is 46–144 mm/hr; 97–223 mm/hr and 44–133 mm/hr, respectively (Sasikumar, Sampath, Vinayak & Harikumar, 2007). Whereas southern Kerala receives almost comparable rainfall during both the monsoons, northern Kerala is devoid of significant rainfall after the SWM. Therefore, northern Kerala experiences water shortage long before the summer sets in.

Figure 1.1 : Hydrological Cycle
The long-term (1871–2008) AAR indicates a very marginal decline over 138 years. During this period, there was a decline of 161mm during the SWM and increase of 101mm during the NEM, 9.9 mm during winter and 45.4 mm during summer. To be more precise, there is a decline of 28.6 mm/decade of rainfall during June, 13.6 mm/decade during July and 2.3 mm/decade during August. In September, there is an increase of 7.5 mm/decade of rainfall. During the NEM from October to December, there is a progressive increase of 7.6 mm/decade of rainfall. During winter and summer, there is very marginal and insignificant increase of 0.63 mm/decade and 3.5 mm/decade of rainfall. However, in recent years (1982-2008), the AAR indicates a marginal increase of 16.7 mm/year. During this period, the marginal decline of SWM rainfall was only 0.009 mm/year, whereas the increase during the NEM was 9.8 mm/year and during the summer was 7.5 mm/year. But during the winter, the AAR showed a marginal decline of 0.739 mm/year (Simon & Mohankumar, 2004; Krishnakumar, Prasad Rao & Gopakumar, 2009; Varma, 2015).

Table 1.1: Spatial variation of rainfall**

<table>
<thead>
<tr>
<th>Physiographic Zones</th>
<th>Rainfall (mm)</th>
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<tbody>
<tr>
<td></td>
<td>South</td>
</tr>
<tr>
<td>Lowland</td>
<td>900</td>
</tr>
<tr>
<td>Midland</td>
<td>1400</td>
</tr>
<tr>
<td>Highland</td>
<td>2500</td>
</tr>
<tr>
<td>Average</td>
<td>1800</td>
</tr>
</tbody>
</table>

Table 1.2: Temporal variation of rainfall**

<table>
<thead>
<tr>
<th>Rainy Season</th>
<th>Rainfall (%)</th>
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<tbody>
<tr>
<td></td>
<td>South</td>
</tr>
<tr>
<td>Southwest monsoon*</td>
<td>54</td>
</tr>
<tr>
<td>Northeast monsoon*</td>
<td>33</td>
</tr>
<tr>
<td>Winter rains*</td>
<td>2</td>
</tr>
<tr>
<td>Summer rains*</td>
<td>11</td>
</tr>
</tbody>
</table>

*Southwest monsoon (June-September); Northeast monsoon (October-December); Winter (January-February); Summer (March-May); Source:** Varma, 1999.

The dense canopy in the state intercepts the rainfall and obstructs it from reaching the ground. The interception rate in the dense forest region is estimated to be about 10%. Such estimates are not generally available for other regions in the state. The rest of the rainfall is subjected to runoff, evaporation, transpiration and infiltration. About 80% of the rainfall in northern parts and 70% of the rainfall in southern parts of the state is transformed to surface runoff contributing to streams, rivulets and rivers. The rest of the rainfall that reaches the ground infiltrates it and partially recharges the groundwater. A part of the surface flow also infiltrates into the ground. Increased density of flora and large spread of water bodies lead to considerable evaporation and transpiration loss from the water regimes. The hourly evaporation rate is about 4–7 mm and 2–3 mm during summer and rainy seasons respectively. It may be noted that a healthy coconut tree
in the coastal sandy region transpires about 60–100 litres of water daily. On an average, about 1415 mm of water is lost annually from the surface water spread, wet soils and near-surface groundwater systems. If one considers the water loss due to evaporation and transpiration, the usable AAR is only 54% (1655 mm). It may be noted that the rate of transpiration and evaporation are on the increase as there is an increase of 0.8°C and 0.2°C respectively in the maximum and minimum atmospheric temperature as observed during the 43 years during 1961–2003 (Iyer et al., 2005).

The recharge in the ground depends on the water surplus of a region and ground conditions for enabling the movement and storage of water underground. On an annual basis, Kerala experiences an overall water surplus. The water surplus is experienced generally during June to November. In the Alappuzha region, water surplus is experienced even during winter to the tune of 80 mm. The regional water surplus in Thiruvananthapuram is 350–500 mm, in Kollam and Punalur is 1000–1500 mm, and in the northern part of the state is up to 2000 mm. However, temporal variation of rainfall leads to a water deficit of 250–300 mm in different months. The water deficit during the period of winter and summer alone amounts to 150 mm. It reduces towards the northern and southern parts of the state and in the coastal regions up to 100 mm. The water deficit increases up to 200 mm during the winter and summer in the southern part of the state (Varma, 2013).

The groundwater recharge from the water surplus depends on the infiltration rate of the surface earth material and porosity-permeability conditions of the aquifers (Varma, 2004). The infiltration rates of different types of surface material in the three physiographic zones of the state are given in Table 1.3. Similarly, some of the important hydraulic properties that govern the storage, movement and yield of groundwater in different subsurface formations are given in Table 1.4.

Table 1.3: Infiltration rates of different surface earth material (in cm/hour)

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Coastal area</th>
<th>Midland</th>
<th>Highland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil in low land</td>
<td>16 – 76.8</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Clayey soil</td>
<td>0.025 – 0.12</td>
<td>1.8 – 8.4</td>
<td>---</td>
</tr>
<tr>
<td>Silty clayey soil</td>
<td>11 – 12</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Silty soil</td>
<td>25 – 46</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Fine loamy soil</td>
<td>---</td>
<td>---</td>
<td>15.6 – 47</td>
</tr>
<tr>
<td>Sandy loamy soil</td>
<td>---</td>
<td>15.6 – 31.8</td>
<td>---</td>
</tr>
<tr>
<td>Laterite</td>
<td>---</td>
<td>4.8 – 47</td>
<td>---</td>
</tr>
</tbody>
</table>


1. Water surplus occurs when the precipitation in a region exceeds evapotranspiration.
2. Water deficit occurs when the evapotranspiration in a region exceeds precipitation.
Table 1.4: Porosity, permeability and specific yield of various geologic formations

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Porosity (%)</th>
<th>Permeability (m/day)</th>
<th>Specific Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>45 – 55</td>
<td>0.00005 – 0.1</td>
<td>1 – 10</td>
</tr>
<tr>
<td>Silt</td>
<td>20 – 30</td>
<td>1 – 100</td>
<td>15 – 25</td>
</tr>
<tr>
<td>Sand</td>
<td>35 – 40</td>
<td>5 – 150</td>
<td>10 – 30</td>
</tr>
<tr>
<td>Gravel</td>
<td>30 – 40</td>
<td>50 – 750</td>
<td>15 – 30</td>
</tr>
<tr>
<td>Sandstone</td>
<td>10 – 20</td>
<td>0.005 – 2.5</td>
<td>5 – 15</td>
</tr>
<tr>
<td>Shale</td>
<td>1 – 10</td>
<td>10-8 – 0.0001</td>
<td>0.5 – 5</td>
</tr>
<tr>
<td>Limestone</td>
<td>1 – 10</td>
<td>Site specific</td>
<td>0.5 – 5</td>
</tr>
<tr>
<td>Fractured crystalline</td>
<td>0 – 10</td>
<td>Site specific</td>
<td>Site specific</td>
</tr>
<tr>
<td>Laterite</td>
<td>Site specific</td>
<td>0.3 – 1.1</td>
<td>Site specific</td>
</tr>
</tbody>
</table>


1.3.2 Terrain Influence on Groundwater

The occurrence and movement of groundwater in a region is mainly controlled by the physiography, geological setting and subsurface features such as aquifer properties. Physiographically, Kerala is divided into Lowland, Midland and Highland regions (Figure 1.2). The lowland falls in the altitude range of 0–7.5 m and occupies an area of 3979 km², i.e. 10.24% of the total area of the state. It is characterised by coastal plains, lagoons and comprises of beaches, dunes, barrier flats, coastal alluvial plains, flood plains, river terraces, and marshes. The midland region falls in the altitude range of 7.5–75 m and occupies an area of 16231 km², i.e. 41.76% of the total area of the state. It consists of dissected peneplains with numerous flood plains, terraces, valley fills and colluviums. At places, this unit abuts the sea without intervening coastal plains. The highland is above an altitude of 75 m and occupies an area of 18654 km², i.e. 48% of the area of state.
The state is drained by 44 rivers, of which 3 are east flowing (Figure 1.3). According to the national norm (Rao, 1979), there are no major rivers in Kerala and only four rivers namely, Chaliyar, Bharathapuzha, Periyar and Pamba fall under the medium river category. Rivers are generally swift flowing having very steep gradients in their higher reaches. Absence of major delta formations is a characteristic of the rivers of Kerala. The general drainage pattern of these rivers is dendritic, although at places they are trellis, sub-parallel and radial. The segments of river courses are nearly straight, indicating structural control, coinciding with the prominent lineament directions (NW-SE and NE-SW). Many of the rivers do not have a continuous flood plain. The river flow is modulated by about 30 reservoirs, mostly located in highlands (KSLUB, 2002; CWRDM, 1995 and 1998). Apart from the 44 rivers, there are few streams with lengths falling short of the 15 km limit set for the categorisation as a river (GoK, 1974; CWRDM, 1998). There are 27 estuaries and 7 lagoons in the state (GoK, 1974; CWRDM, 1995).

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3. Trellis is a drainage pattern when subparallel streams erode a valley along the strike of the less resistant geological formation and the streamlet enter the main stream at approximately 90 degree angle.
Within the physiographic zones, different terrain units influence groundwater. There are 22 terrain units identified in Kerala, the names and aerial coverage of which are given in Table 1.5 (Chattopadhyay & Chattopadhyay, 1995).

A generalised soil map of Kerala (Figure 1.4) indicates six categories of soil, namely laterite, forest loamy, riverine alluvium, coastal alluvium, black soil and red loamy in the order of dominance. Soils are well-drained over 77% of the total geographical area of the state, moderately well drained over 6% area, imperfectly drained over 6% area and somewhat excessively drained over about 5% area. As regards soil depth, 2% of the total geographical area has moderately shallow soil, 2% has moderately deep soil, 25% has deep soil, and 65% has very deep soil.
Texturally, in the lowlands, sandy soil dominates in the beaches and dunes and clayey soils in the runnels. Estuaries and backwaters have loamy and clayey soils with high salt concentrations. Soils of the midland, which are lateritic in nature, are predominantly clayey or gravelly clayey. Soils in the high ranges north of the Palghat gap, excluding the Nilgiris, are clayey to loamy in texture with high amount of organic matter. The medium hills have loamy and clayey soils. Soils of the highland south of Palghat gap have varying textures with high organic matter content (Krishnan et al., 2005). The soil environment of the state favours moderate to high infiltration of water.


Figure 1.4: Soil map of Kerala
Geologically, Kerala preserves the major units of the Archaean continental crust, such as granulites, granites, gneisses and greenstones (Figure 1.5). The southern part of the state exposes migmatised meta-sedimentary and meta-igneous rocks. The rocks in the central part are predominantly charnockites and other gneissic rocks. Towards the northern parts, migmatitic gneisses and occasional patches of granulites, schists and granites are observed. There are also crystalline limestone bands in the northern flank of the Palghat gap (Soman, 1997). The crystalline rocks are associated with lineaments/faults. Both marine and non-marine rocks of the Neogene period fringe the coastal tract of Kerala in two major basins of deposition between Trivandrum and Ponnani and Cannanore and Kasaragod. These sedimentary formations unconformably overlie Precambrian rocks. They include the rocks of Vaikom formation (comprising gravel, sand, grayish clay, carbonaceous clay and lignite), Quilon formation (comprising limestone, sands and clays) and the Warkali Series (comprising clays, lignite, sand, sandy clays and sandstone). Sediments of the Quaternary period (sands, lagoonal clays, shell deposits, teri sands) unconformably overlie the Neogene sediments. The thickness of sedimentary sequence exceeds 600 m in the AmbAlappuzha-Alappuzha region. Laterite, a weathering product of rocks, is widespread over Precambrian and Tertiary sediments in the region with elevations of 600 m and below. Vast dissected laterite mesas are widespread in the northern parts of the state.

### Table 1.5: Terrain units and area

<table>
<thead>
<tr>
<th>No</th>
<th>Terrain unit</th>
<th>Area (%)</th>
<th>No</th>
<th>Terrain unit</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Beach</td>
<td>0.5</td>
<td>12</td>
<td>Fluvio-Lacustrine plain</td>
<td>0.7</td>
</tr>
<tr>
<td>2</td>
<td>Coastal cliff</td>
<td>0.1</td>
<td>13</td>
<td>Basin/waterlogged area</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>Coastal plain</td>
<td>3.2</td>
<td>14</td>
<td>Low rolling terrain</td>
<td>17.2</td>
</tr>
<tr>
<td>4</td>
<td>Coastal plain-laterite</td>
<td>0.3</td>
<td>15</td>
<td>Moderately undulating terrain</td>
<td>21.7</td>
</tr>
<tr>
<td>5</td>
<td>Tidal/mud flat</td>
<td>0.2</td>
<td>16</td>
<td>Highly undulating terrain</td>
<td>15.9</td>
</tr>
<tr>
<td>6</td>
<td>Plain with Paleo strandlines</td>
<td>0.7</td>
<td>17</td>
<td>Hilly area</td>
<td>23.1</td>
</tr>
<tr>
<td>7</td>
<td>Flood plain</td>
<td>3.2</td>
<td>18</td>
<td>Isolated residual hill</td>
<td>0.9</td>
</tr>
<tr>
<td>8</td>
<td>River terrace</td>
<td>0.2</td>
<td>19</td>
<td>Scarp slope</td>
<td>4.2</td>
</tr>
<tr>
<td>9</td>
<td>Alluvial plain-i</td>
<td>0.3</td>
<td>20</td>
<td>Mesa surface</td>
<td>1.3</td>
</tr>
<tr>
<td>10</td>
<td>Alluvial plain-ii</td>
<td>0.7</td>
<td>21</td>
<td>Mesa side slope</td>
<td>0.3</td>
</tr>
<tr>
<td>11</td>
<td>Transitional plain</td>
<td>0.6</td>
<td>22</td>
<td>Hummocky terrain</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23</td>
<td>Water bodies</td>
<td>2.9</td>
</tr>
</tbody>
</table>

*Source: Chattopadhyay & Chattopadhyay, 1995.*
Based on the physiography, terrain conditions and geological characteristics, the state could be divided into six groundwater provinces namely, the coastal sandy belt, coastal alluvial tract, laterite formation, inter-mountain valley-fill area, sedimentary formations, and crystalline terrain. The coastal sandy belt is found all along the coast from Thiruvananthapuram up to Ponnani and further north discretely due to crystalline or laterite promontories. The coastal alluvial tract is found in areas adjacent to the estuaries and river mouths. Both the formations consist of sand, clay and silt. They are differentiated based on the domination of sand or silt in the matrix. Laterite is the most widely distributed lithological unit in the state, especially in the midland region. The undulating topography and vivacious hydrology in the background of ever active tectonics resulted in 44 river basins, 1750 sub-basins and 4452 mini-watersheds providing multitudes of lively valley formations juxtaposed with hills forming inter-mountain valley-fill areas dominated with moderately thick alluvium and colluvium. The portion of the Kerala coast between Thiruvananthapuram and Ponnani is found having a sedimentary basin with four sequences of deposition. The crystalline terrain is weathered, jointed and fractured, the secondary porosity due to which is conducive for storage and movement of groundwater.
1.4 Occurrence of Groundwater

The spatial spread of different aquifers in the state is depicted in the generalised hydro-geological map of Kerala (Figure 1.6). The most widely spread aquifers of the state are the Crystalline Rock Aquifers (CRA). The shallow aquifers of crystalline rocks are made up of highly decomposed weathered zone or partly weathered and fractured rocks. Thick weathered zone is seen along the midland area either beneath the laterites or exposed. In the hill ranges, thin weathered zone is seen along topographic lows and areas with lesser elevation and gentle slopes. In areas along the hill ranges mostly rock exposures are seen. The depth to water level in this aquifer varies from 2 to 16 m below ground level (bgl), and the yield of the well ranges from 2 to 10 m³ per day. The potential fractures in the crystalline rocks are encountered at depths ranging between 60 to 175 mbgl with yield varying from less than 1 to as much as 35 litres per second (lps). It is also reported that compared to the khondalite group of CRAs, more than 40% of the wells in the charnockite suite of CRAs yielded 10 lps or more water (GEC, 2012).

Figure 1.6: Generalised hydrogeological map of Kerala

Source: Groundwater Estimation Committee (GEC), 2012.
Laterites are the most widely distributed lithological unit in the state and the thickness of this formation varies from a few meters to about 30 m. The depth to water level in the formation ranges from less than a metre to 25 mbgl. Laterite forms potential aquifers along topographic lows and valleys. The depth to water level in this formation ranges from 2 to 18 mbgl and the yield ranges from 0.5 to 6 m³ per day. The occurrence and movement of groundwater in the laterites are mainly controlled by the topography. Laterite is a highly porous rock formation, which can form potential aquifers along the topographic lows. However, due to the porosity, groundwater is drained from elevated places and slopes at shortest duration after the monsoon, and hence water scarcity is experienced in the elevated places and slopes.

The alluvial deposits form potential aquifers along the coastal plains and groundwater occurs under phreatic and semi-confined conditions in the aquifers. The thickness of this formation varies from a few metres to above 100 m and the depth to water level ranges from less than a metre to 60 mbgl. Filter-point wells are feasible wherever the saturated thickness exceeds 5m. This potential aquifer is extensively developed by dug wells and filter-point wells throughout the state, and the yield ranges from 5 to 35 m³ per day.

Another important groundwater zone is the Tertiary Rock Aquifers (TRA) where water occurs under phreatic conditions in the shallow zone and under semi-confined to confined conditions in the deeper zones. There are four distinct beds in the TRA namely, Alleppey, Vaikom, Quilon and Warkali. These formations, except the Alleppey beds, are seen as outcrops and are lateritised wherever they are exposed. The maximum thickness of tertiary sediments, around 600 m, is found between Karunagapally and Kattoor, where all the four beds are found. Groundwater is commonly developed here through dug wells tapping the sandy zones at shallow depths. The depth to water level in these shallow zones ranges from 3.0 to 27 mbgl and the yield of the wells range from 500 litres per day (lpd) to 10 m³ per day. The Vaikom and Warkali beds are the most potential ones in the TRA. The Alleppey bed is encountered at deeper levels in the coastal tract of Alappuzha and the formation water there is saline. In the Vaikom aquifers, the piezometric level is between 2 and 20 m above mean sea level (msl). The yield of the tubewells in this formation ranges from 1 to 57 lps. This bed forms auto flow zones along the coast between Karunagapally in Kollam district and Nattika and Kaipamangalam in Thrissur district. The water is generally fresh south of Karuvattta in Alappuzha district and in pockets in and around Kochi. Warkali aquifers are the most developed aquifers among the TRA. The urban and rural water supply in the coastal area between Kollam and Cherthala is mostly dependent on this. The piezometric head is about 3m above msl along the eastern part of the sedimentary basin, whereas it is 10 m below msl in and around Alappuzha. The yield of the wells tapping this formation ranges from 3 to 14 lps. The hygrogeological information on Quilon beds is very limited and this formation is considered to be a poor aquifer.

### 1.5 Groundwater Monitoring

Monitoring of groundwater regime over time and space is necessary to gather information on groundwater levels and quality through representative sampling for planning and managing the groundwater resource of the state. This is done by establishing groundwater monitoring network stations to record the response of the groundwater regime to the natural and anthropogenic
stresses of recharge and discharge parameters with reference to geology, climate, physiography, land use pattern and hydrologic characteristics. The natural conditions affecting the regime involve climatic parameters like rainfall, evapotranspiration, etc., whereas anthropogenic influences include, pumpage from the aquifer, recharge due to irrigation systems, and other practices like waste disposal. In Kerala, groundwater monitoring is carried out by the Central Ground Water Board (CGWB) and the State Ground Water Department (SGWD) by establishing 925 and 304 wells, respectively, distributed all over the state (Figure 1.7). The water level is monitored four times in a year during January, April, August and November, while the water quality is monitored in April (Groundwater Year Book, 2012). Among the groundwater monitoring wells of CGWB, 62% are located in the midland region, 18% in the coastal plains, 15% in highland terrain and 5% in the plateau region. The monitoring is carried out for 658 dug wells and 267 borewells. Among the dug wells, i.e. wells located in the phreatic zone, 65% (427) are tapping laterite, 17% (112) tapping weathered/fractured rocks, 15% (99) tapping coastal alluvium and 3% (20) tapping riverine alluvium (GEC, 2012).

Figure 1.7: Location of monitoring wells

2 Groundwater Resource Potential

2.1 Introduction

The occurrence and availability of groundwater vary considerably from place to place within the state depending on the prevailing climate, geomorphological and hydrological conditions. About 88% of the total geographical area of the state is underlain by crystalline rocks devoid of any primary porosity with limited groundwater prospects. In the alluvial formations having multiple aquifer systems, quality is sometimes a constraint for the development of available resources. Increasing population, rapid urbanisation and industrialisation has resulted in increasing use of groundwater resources over the last few decades. Judicious and planned development of groundwater and its scientific management have become necessary to ensure long-term sustainability of this precious natural resource. The groundwater resources of the state are being periodically assessed by the CGWB, jointly with the SGWD and other central government as well as state government agencies, according to the methodology recommended by the GEC constituted by the Government of India (GoI) from time to time (GEC, 1989, 1997, 2005 & 2012; Thambi et al., 1997). Based on these assessments, the salient aspects of the groundwater resources of Kerala are compiled in this chapter.

The first attempt to estimate the groundwater resources of the country dates back to 1979, when the Groundwater Over-Exploitation Committee constituted by the Agriculture Refinance and Development Corporation (ARDC) of the Reserve Bank of India evolved norms and carried out an assessment. Subsequently, the Groundwater Estimation Committee (GEC) headed by the Chairman, CGWB was constituted with the objective of refining the assessment methodology. The GEC formulated a detailed methodology for estimation of groundwater resources in 1984 which was reviewed in 1997 based on the feedback from various agencies, and a modified methodology was formulated in 1997 for computation of groundwater resources. This methodology with minor modifications is currently being used for estimation of the dynamic groundwater resources of the country. Accordingly, groundwater resource potential of the state was assessed in 1989, 1997, 2005 and 2009 by the GEC.

2.2 Groundwater Level during Different Seasons

The groundwater level and its fluctuation mostly depend on the hydro-geological conditions of the area as well as the topography, rainfall patterns, withdrawal, etc. The depth to water level is monitored through 925 monitoring wells distributed throughout the state during the month of April, August, November and January. The water level measured during the month of April is taken as the pre-monsoon water level, and the data of November is taken as the post-monsoon water level on the basis of temporal distribution of long-term rainfall in the state. Generally, the depth
to water level in coastal plains is restricted to 6 mbgl, and in the midland areas with undulating topography, it varies from near ground level to 25 mbgl. In areas of sedimentary aquifers of tertiary age, the water level goes very deep, even to the extent of 55 mbgl. In the highland region, the depth of water level is in the range of a few centimeters to 10 mbgl.

The pre-monsoon water level (during April) in Kerala ranged from a minimum of 0.02 to a maximum of 55.05 mbgl. 88.41% of monitoring wells exhibit water level varying from 0.10-10.0 mbgl. The coastal tracts of Alappuzha, Kollam, and Ernakulam districts and also the eastern parts of the high ranges in Idukki district exhibit shallow water level in the range of 0.2–2.0 mbgl. The areas falling in the midland region generally show water level in the range of 2-10 mbgl. In Kasaragod, Kollam, and Thriruvanathapuram districts, deep water level in the range of 20–55.05 mbgl is noticed in certain pockets where thick lateritic overburden is observed.

During the month of August, the depth to water level varies from a minimum of 0.14 mbgl to a maximum of 25.56 mbgl, but 92.4% monitoring wells exhibit a water level variation between 0.10 and 10.0 mbgl. The well water level in the coastal tracts does not indicate any major change from that in April, but the depth to water level in areas with thick lateritic overburden comes down to 20–26 mbgl.

During the post-monsoon period (November), the depth to water level mostly falls within the range of 0–10 mbgl as shown by 92.8% of the monitoring wells and in certain places up to 53.60 mbgl. Along the coastal tracts of Kollam, Alappuzha, Ernakulam and Thrissur districts and in midland areas of Palakkad districts as well as the northeastern parts of Idukki district, the water level is shallow, less than 2 mbgl during this period. The midland areas generally show water level in the range of 2–10 mbgl, but in the central part of Kasaragod district, the northern parts of Kannur district, and in certain areas of Wayanad district, the water level is in the range of 10–20 mbgl. The areas with thick lateritic overburden in Kasaragod, Kollam and Thriruvanathapuram districts exhibit deep water level in the range of 20–53.6 mbgl as noticed in the pre-monsoon period.

During January, the depth to water level varies from near ground level to 24.70 mbgl, but 90% of monitoring wells exhibit the range of 0–10 mbgl. Shallow water level of less than 2 mbgl is seen along the coastal tracts of Kollam, Alappuzha, Ernakulam and Thrissur districts and in the midland areas of Palakkad district as well as the northeastern parts of the high ranges in Idukki district. The midland areas show water level in the range of 2–10 mbgl. In central parts of Kasaragod district, northern parts of Kannur district, and certain areas of Wayanad district, the water level is in the range of 10–20 mbgl. In Kasaragod, Kannur and Thriruvanathapuram districts, moderately deep water level in the range of 20–22.88 mbgl is noticed in areas with thick lateritic overburden.

2.3 Groundwater Level Fluctuation and Trend

Comparison of the water levels in November with that of April indicates a rise in the range of 0.01–9.97 m in most parts of the state. A decline in water levels is noticed in isolated pockets in the canal command areas of Thriruvanathapuram, Pathanamthitta, Ernakulam and Thrissur districts where the depth of the canals exceeds that of the local groundwater table. A major part of the state recorded a rise in the water level of less than 4 m as revealed by 80% of observation wells. The long-
term fluctuations in groundwater levels in the state have been studied by comparing the pre-and post-monsoon water levels during 2008 with the average fluctuations of the previous 10 years from 1998 to 2007 (GEC, 2012).

The water level fluctuation for the pre-monsoon period (April) between the decadal (1998–2007) mean and that of 2008 indicates that the change in water level is mostly restricted to +2 (rise) to -2 (fall) m as recorded by 89% of the monitoring wells. The rise in water level is predominant, as recorded in about 60% of monitoring wells. The fall in water level is prominently seen in the districts of Kollam, Kottayam, Malappuram, Thrivananthapuram and Ernakulam districts. During the post-monsoon period (November), the comparison of water level between the decadal mean and that of 2008 indicates that the change in the water level is mostly restricted to +2 (rise) to -2 (fall) m as recorded in 96.7% of monitoring wells. Decline in the water level is more pronounced in the southern districts of Kerala, particularly, Pathanamthitta, Idukki, Kottayam, Ernakulam, Alappuzha, Kollam and Thrivananthapuram districts. In Kannur, Kozhikode, Malappuram, Palakkad and Wayanad districts, the rise in the water level is more pronounced.

The time series analysis of the pre-monsoon water levels in the state for the period 1999–2008 indicates that 39% of the groundwater monitoring wells recorded a negligible change in water level in the range of +0.05 to -0.05 m/year. 5% of the monitoring wells recorded a declining trend in the range of 0.05 to 0.1 m/year, and 10% recorded a declining trend above 0.1 m/year. 19% of monitoring wells recorded a rising trend in the range of 0.05 to 0.1 m/year and 26% indicated a rising trend above 0.1 m/year. Therefore, it could be deduced that the water levels during the pre-monsoon period show a predominantly rising trend in the state. The post-monsoon water level trend for the period 1999–2008 indicates that about 40% of the monitoring wells indicate a negligible change in the water level in the range of +0.05 to -0.05 m/year. 15% of monitoring wells recorded a declining trend in the range of 0.05 to 0.1 m/year, and 26% recorded a declining trend above 0.1 m/year. 7% of the monitoring wells recorded a rising trend in the range of 0.05 to 0.1 m/year, and 12% recorded a rising trend above 0.1 m/year. The monitoring wells with a conspicuous falling trend in both pre- and post-monsoon water levels (more than 0.1 m/year) during 1989 to 2005 are listed in Table 2.1.

The maps showing the pre-monsoon water level trend for the period 1999–2008 and the post-monsoon water level trend for the period 1998–2007 are shown in Figures 2.1 and 2.2. The hydrographs of villages in Kollam, Kannur, Wayanad, Kottayam and Palakkad districts are shown in Figures 2.3 to 2.8. From the hydrographs, it is observed that in Edaman village in Kollam district (Dec 79 to Dec 08), Edakad village in Kannur district (Mar 90 to Feb 09) and Vayittri village in Wayanad district (Dec 76 to Dec 08), the water table level is almost stable during the pre- and post-monsoon periods. The hydrographs of Thekethukavala village and Palai village in Kottayam district (Dec 76 to Dec 08) and Chittur village in Palakkad district (Dec 78 to Dec 08) indicate a continuous fall in the water table (ABC Environ Solutions Pvt. Ltd., 2011).
Table 2.1: List of monitoring wells showing falling water levels trend of more than 0.1 m/year for the period 1980 – 2005

<table>
<thead>
<tr>
<th>District</th>
<th>Location</th>
<th>Pre-monsoon trend</th>
<th>Post-monsoon trend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Rise (m/y)</td>
<td>Fall (m/y)</td>
</tr>
<tr>
<td>Kannur</td>
<td>Kannur</td>
<td>0</td>
<td>0.101</td>
</tr>
<tr>
<td>Kannur</td>
<td>Taliparamba</td>
<td>0</td>
<td>0.207</td>
</tr>
<tr>
<td>Kasaragod</td>
<td>Badiadka</td>
<td>0</td>
<td>0.045</td>
</tr>
<tr>
<td>Kasaragod</td>
<td>Bedadka</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kollam</td>
<td>Avaneswaram</td>
<td>0</td>
<td>0.171</td>
</tr>
<tr>
<td>Kottayam</td>
<td>Naranganam</td>
<td>0</td>
<td>0.109</td>
</tr>
<tr>
<td>Kottayam</td>
<td>Velloor</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Malappuram</td>
<td>Kariavattam</td>
<td>0</td>
<td>0.186</td>
</tr>
<tr>
<td>Palakkad</td>
<td>Kozhinjampara</td>
<td>0</td>
<td>0.061</td>
</tr>
<tr>
<td>Palakkad</td>
<td>Palakkad</td>
<td>0</td>
<td>0.185</td>
</tr>
</tbody>
</table>

Source: Shaji, Nayagam, Kunhambu & Thambi, 2008.
Figure 2.3: Hydrograph of groundwater monitoring wells tapping phreatic aquifer in laterites at Edamon, Kollam District

Source: Shaji et al., 2008.

Figure 2.4: Hydrograph of groundwater monitoring wells tapping phreatic aquifer in Laterites at Edakkad, Kannur District

Source: Shaji et al., 2008.
Figure 2.5: Hydrograph of groundwater monitoring wells tapping phreatic aquifer in laterites at Thekethukaval, Kottayam District

Source: Shaji et al., 2008.

Figure 2.6: Hydrograph of groundwater monitoring wells tapping phreatic aquifer in laterites at Vayittiri, Wayanad District

Source: Shaji et al., 2008.
Figure 2.7: Hydrograph of groundwater monitoring wells tapping phreatic aquifer in laterites at Palai, Kottayam District

Source: Shaji et al., 2008.

Figure 2.8: Hydrograph of groundwater monitoring wells tapping phreatic aquifer in weathered crystallines at Palakkad District

Source: Shaji et al., 2008.

4. Phreatic aquifer is the portion of earths subsurface where the water is stored in saturated condition and its upper boundary called water table is having a pressure head equal to atmospheric pressure.
2.4 Groundwater Estimation Procedure

The estimation of groundwater resource potential of Kerala is carried out based on modified GEC-97 norms by the state level committee constituted by the Government of Kerala (GoK) in response to a request of the CGWB, Thiruvananthapuram, based on the direction of the Government of India. This committee consisted of the state level chiefs of Water Resources Department (WRD), CGWB, SGWD, KWA, Agriculture Directorate, Industries Directorate, National Bank for Rural Development (NABARD) and CWRDM. The exercise of resource estimation consisted of the collection, collation, compilation and validation of data pertaining to groundwater from various sources.

Two approaches were recommended for the estimation of groundwater recharge: the Water Level Fluctuation (WLF) method and the Rainfall Infiltration Factor (RIF) method. The WLF method is based on the concept of storage change between various input and output components. Input refers to the recharge from rainfall and other sources and the subsurface flow into the unit of assessment. Output refers to groundwater draft, evapotranspiration, base flow to streams and sub-surface outflow from the unit. Since the data on subsurface inflow/outflow are not readily available, it is desirable to adopt a basin/sub-basin/watershed as the unit for groundwater assessment because the inflow/outflow of groundwater across these units are generally negligible. Accordingly, in the hard rock areas, it is ideal to have the groundwater resources assessment unit as the watershed. In the case of alluvium areas where the watershed-wise data is not available, the administrative block is the desirable assessment unit. In each assessment unit, hilly areas having a slope more than 20% are deleted from the total area to consider the most suitable area of recharge. Further, areas with unusable quality of groundwater are identified and handled separately. The remaining area after discarding the hilly area and separating the area with poor groundwater quality is delineated into command and non-command areas for which groundwater assessment is done separately for monsoon and non-monsoon seasons.

The RIF method essentially uses three parameters, namely the Rainfall Infiltration Factor, Specific Yield and the Unit Groundwater Draft. The GEC recommended values of RIF for various geological formations as 8–12% for alluvium, 6–8% for laterite, 5–9% for weathered granites/gneiss, 4–6% for rocks of granulite facies, and 1–3% for massive/poorly fractured rocks. Similarly, the specific yield of various hydrogeological units are taken as 12–18% for sandy alluvial area, 10–14% for valley-fill formations, 5–12% for silty/clayey alluvial area, 0.2–2% for granites, 2–5% for laterites, 1–4% for weathered granites and gneisses, and 0.2–0.5% for massive/poorly fractured rocks. The groundwater draft for domestic uses is computed based on the 2001 population projected to 2008 and a per-capita requirement of 150 lpd. The fractional load on groundwater is computed based on the extent of surface water supply for domestic use in the assessment unit. The unit groundwater draft for irrigation in different types of wells is adopted from the previous assessment (2004) after modification wherever necessary based on sample surveys. Accordingly, the unit draft values considered for different types of wells are 0.12 hectar meter (Ha.M) for non-energised dugwells, 0.54–2.18 Ha.M for energised dugwells, 2.0 Ha.M for shallow tube/borewells and 0.007 Ha.M for domestic wells used for irrigation.

The rainfall recharge during monsoon computed by the WLF method is compared with recharge figures estimated by the RIF method. Wherever the difference between the two sets of data is more
than 20%, then RIF figure is considered, otherwise monsoon recharge from the WLF method is adopted. While adopting the rainfall recharge figures, weightage is given to the WLF method over the RIF method as the latter is based on ad-hoc norms.

2.4.1 Groundwater Recharge and Availability

As per the GEC reports, the resources assessment during the monsoon season is estimated as the sum total of the change in storage and gross draft. The change in storage is computed by multiplying water level fluctuations between pre-monsoon and post-monsoon periods with the area of the assessment unit and specific yield of the formation. Monsoon recharge is expressed as,

$$ R = (h \times Sy \times A) + DG $$

where, $h$ is the rise in water level in the monsoon season, $A$ is the area of assessment unit, $Sy$ is the specific yield, and $DG$ is the gross groundwater draft.

The monsoon groundwater recharge has two components that of rainfall recharge and recharge from other sources, as represented below:

$$ R(\text{Normal}) = R_{rt}(\text{Normal}) + R_s + R_{sw} + R_t + R_{gw} + R_{wc} $$

where, $R_{rt}$ is the normal monsoon rainfall recharge and $R_s$, $R_{sw}$, $R_t$, $R_{gw}$ and $R_{wc}$ are recharge from seepage of canals, surface water irrigation, tanks and ponds, groundwater irrigation and water conservation structures, respectively.

During the non-monsoon season, rainfall recharge is computed by using the RIF method. Recharge from other sources is then adopted to calculate the total non-monsoon recharge. The total groundwater resource of the assessment unit is the sum of monsoon and non-monsoon recharges. An allowance is kept for natural discharge in the non-monsoon season by deducting 5% of the annual replenishable groundwater resource, wherever the WLF method is employed to compute rainfall recharge during monsoon and 10% if the RIF method is employed. The Net Annual Groundwater Availability (NAGA) is then computed by deducting the Natural Discharge during Non-Monsoon (NDNM) from the Annual Replenishable Groundwater Resource (ARGR).

i.e., $NAGA = ARGR - NDNM$

The Gross Groundwater Draft (GGD) would include the extraction from all existing groundwater structures during the monsoon as well as non-monsoon seasons for the purpose of domestic needs, irrigation requirements and industrial use. While calculating the groundwater recharge in areas with poor quality of water, the normal procedure is adopted whereas for saline areas, the recharge assessment is carried out based on the RIF method. This is due to the non-availability of data there will usually be no observation wells in such areas.

Where the assessment unit is a watershed, the groundwater assessment is converted in terms of an administrative unit such as a block by converting the volumetric resource into the depth unit and then multiplying this depth with the corresponding area of the block. In shallow water table areas, particularly in discharge areas, the rejected recharge would be considerable and the water level fluctuations are subdued resulting in an underestimation of the recharge component. In such areas
where the groundwater level is less than 5 mbgl or in waterlogged areas, the groundwater resource is estimated up to 5 mbgl based on the following equation.

\[
PGD = (5-D) * A * Sy
\]

Here PGD is the Potential Groundwater Recharge, D is the depth to water table below ground level (bgl) in the pre-monsoon season in shallow aquifers, A is the area of the shallow water table zone, and Sy is the specific yield.

2.4.2 Future utilisation of Groundwater Resources

The demand for domestic and industrial water supply is assessed based on the projected population for the year 2025. Future allocation of groundwater resources for utilisation is computed on projected population, fractional load on groundwater, and per capita requirements. The computation is done for two different scenarios as given below.

- Scenario 1 When NAGA ≥ EGDI + CVAD, then allocation for future domestic requirement is taken as CVDU
- Scenario 2 When NAGA < EGDI+CVAD, then allocation for future domestic requirement is taken as NAGA – EGDI or EGDD whichever is more.

Where,

- NAGA=Net Annual Groundwater Availability
- EGDI= Existing Groundwater Draft for Irrigation.
- EGDD= Existing Groundwater Draft for Domestic use
- CVAD= Computed Value of Allocation for Domestic use

Further, the groundwater availability for future irrigation is computed by deducting the projected demand for domestic and industrial use and existing irrigation draft from the Net Annual Groundwater Availability (NAGA).

2.4.3 Stage of Groundwater Development and Categorisation of Assessment Units

The Stage of Groundwater Development (SGD) is the ratio of the Existing Gross Groundwater Draft (EGGD) and the Net Annual Groundwater Availability (NAGA) represented in percentage.

\[
SGD (%) = (EGGD/NAGA) * 100
\]

The categorisation of groundwater assessment units is carried out based on the stage of groundwater development and the long-term trend of pre- and post-monsoon water levels. Accordingly, the assessment units are categorised into four areas, namely, Safe (areas having adequate groundwater potential for development), Semi-critical (areas recommended for groundwater development with caution), Critical (areas recommended for intensive monitoring and conservation measures) and Over-exploited (areas where no further development is recommended till the scenario improves through conservation measures). The details of the criteria for categorisation of assessment units are given in Table 2.2.
Table 2.2: Criteria for categorisation of assessment units

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Stage of Groundwater Development</th>
<th>Significant Long Term Decline</th>
<th>Categorisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre-monsoon</td>
<td>Post-monsoon</td>
</tr>
<tr>
<td>1</td>
<td>&lt;=70%</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes/No</td>
<td>No/Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>&gt;=70% and &lt;= 90%</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes/No</td>
<td>No/Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>&gt;90% and &lt;=100%</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes/No</td>
<td>No/Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>&gt;100%</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes/No</td>
<td>No/Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>


The category ‘To be reassessed’ indicates that the data needs to be checked and reviewed. If there is a contradiction between the groundwater resource potential estimated and the trend of long-term water levels, it is an anomalous situation and therefore requires a review of the groundwater resource computation, as well as the reliability of water level data. The long-term groundwater level data should preferably be for the period of at least 10 years. The significant rate of water level decline may be taken between 10 and 20 cm per year depending upon the local hydrogeological conditions.

2.4.4 Dynamic Groundwater Resource Potential

The groundwater resource potential of the state is computed for each block panchayat by considering it as the assessment unit (GEC, 2012). This is in the absence of watershed-wise data on various components of recharge and discharge. Accordingly, the computation is done for 152 assessment units spread across 14 districts of the state. While carrying out the estimation, the area under command and non-command is not separated due to lack of data. Further, the irrigation projects of Kerala are mostly planned for irrigation of paddy along the topographic lows and the irrigation canals are centrally controlled. Therefore, large areas in the upstream part of the canal do not receive benefits of canal irrigation. In addition, most of the canals are in the midland area with highly undulating topography and therefore, the assessment is carried out by taking all assessment units as non-canal command. However, recharge from canal segments and return seepage from irrigation due to surface water in the command area are incorporated into the computations.

The data required for computation of resources are collected, to the extent possible, with 2008 as the base year and in its absence, data pertaining to the nearest recent period are used. The computation of groundwater draft for irrigation is carried out using data from the 4th Minor Irrigation Census during 2007. Due to non-availability of relevant data for computation of recharge from other sources during the non-monsoon period, data used in the earlier assessment is used.
Based on long-term rainfall data, the monsoon period is considered as May to October and the non-
monsoon period as November to April by the Groundwater Estimation Committee (GEC, 2012). The
method adopted for computation of rainfall recharge during the monsoon season depends on
the Percentage Departure (PD), which is the difference between the recharge computed using the
Water Table Fluctuation (WTF) and the Rainfall Infiltration Factor (RIF) methods. In cases where PD
is between +20 and -20, monsoon rainfall recharge computed by the WTF Method is used.
The number of assessment units where different methods are adopted for the computation are
given in Table 2.3.

Thus, the Total Annual Groundwater Recharge (TAGR) of the state is computed as 6620 Mm³.
Rainfall recharge accounts for 82% of the annual recharge, with the rest coming from other sources
like seepage from canals, return flow from irrigation, recharge from tanks and ponds, etc. The Net
Annual Groundwater Recharge or Availabilityis calculated according to the 1997 norms of the
CGWB by deducting unaccounted losses and natural discharge during the non-monsoon season
from the TAGR. Such losses account for 10% of the total annual recharge in assessment units where
the monsoon rainfall recharge is calculated using the RIF method, and 5% in assessment units
where the monsoon rainfall recharge is calculated using the WLF method.

Table 2.3: Number of assessment units in various districts where different methods are adopted
for estimation

<table>
<thead>
<tr>
<th>No.</th>
<th>Districts</th>
<th>Total no. of assessment units</th>
<th>No. of assessment units in which monsoon rainfall recharge is computed using</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rainfall infiltration method</td>
</tr>
<tr>
<td>1</td>
<td>Alappuzha</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Ernakulum</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>Idukki</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>Kannur</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Kasaragod</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Kollam</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>Kottayam</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>Kozhikode</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>9</td>
<td>Malappuram</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>Palakkad</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>11</td>
<td>Pathanamthitta</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>12</td>
<td>Thiruvananthapuram</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>13</td>
<td>Thrissur</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>14</td>
<td>Wayanad</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>152</strong></td>
<td><strong>114</strong></td>
<td><strong>38</strong></td>
</tr>
</tbody>
</table>


5. In general parlance, the monsoon in Kerala is considered as rainfall from June to November.
2.5 Groundwater Development

Groundwater development is a process by way of which the available resource is extracted for different uses. The available resource is broadly classified as static reserve and dynamic reserve. The static reserve is the groundwater contained within the permanently saturated zone of groundwater reservoir. The dynamic reserve represents the long-term average annual recharge over the static reserve under conditions of maximum groundwater use. The static reserve forms an assured source over which the dynamic reserve is replenished annually. Groundwater development aims to extract only the dynamic reserve, for the resource to be sustainable, except in drought periods when the dynamic reserve may get extracted fully. The groundwater is developed using appropriate extraction structures depending on the quantum of water required, geologic and hydrogeologic conditions and economic considerations. The conventional structures used for groundwater development are dug wells, boreholes, tubewells, filter-point wells, step wells, tunnel wells and spring capping.

2.5.1 Groundwater Abstraction Structures

**Dug wells**

Dug wells are the traditional and most common method for abstraction of groundwater in areas where the water table is shallow. The depth of dug wells varies generally from 2-10 m but in coastal and river beds, it could be less than 1 m and in thick laterite overburden areas, it could be above 20 m. Generally, the wells are of 1.5 m diameter as this provides adequate working space for construction. The higher diameter wells are constructed for greater yield as the storage space increases. Dug wells of more than 15 m diameter are also reported. The performance of dug wells in terms of quantity is largely determined by the aquifer types, and the diameter and depth of the well. Wells with a large diameter and depth expose a greater area for infiltration and fast recharge and provide larger storage spaces. Dug wells are generally protected with a well head, a parapet or apron, to prevent the direct flow of water from the ground surface. The well shaft between the ground surface and water table is sealed with brick or stone masonary or pre-cast concrete rings for preventing collapse or erosion of side walls. If the well shaft portion is a hard laterite or crystalline rock formation, then it is not normally sealed as the chances of collapse are low. The intake portion of the well is the gallery where the infiltrated water from the aquifer is stored. If the aquifer material is hard enough to withstand itself without collapse, as in the case of weathered or fractured crystalline rocks or hard laterite formations, then the side wall of the well intake is left unsealed. Otherwise this portion is protected with slotted concrete rings or masonry walls with intermittent sand and gravel packs for facilitating unhindered seepage from the aquifer formation. The dug wells are easy to construct using local skill and materials and are generally used for small water demands.

**Borewells**

These are narrow wells of 15 cm diameter drilled in crystalline rocks to tap water from weathered zones having considerable thickness and/or fractured zones with high density of fissures. Borewells
are generally drilled using down the hole hammer (DTH) or by augur boring. These wells can collect water from deeper aquifers often up to several hundred meters. The top portion of the borewells are generally protected with a casing of steel or PVC make pipes up to the bottom of the overburden to prevent the collapse of loose soil or rock into the well and also to avoid seepage of water saturated in the surface or near-surface zones. The water from these wells is tapped using submersible pumps and the yield depends on the hydraulic properties of the aquifer. Therefore, the well after construction is subjected to a pump test for determining the safe yield and the extraction from the well is limited to this value.

**Tubewells**

These are narrow wells of diameter 15–30 cm drilled in sedimentary rock formations to tap water from medium to deep aquifers. The tubewells are drilled generally using rotary drilling machines often up to several hundred meters. Auger drilling machines are also used for tubewells, if the aquifer depth is not deeper than around 25 m. Rotary drilling machines use a segmented steel drilling string, typically made up of 6 m sections of galvanised steel tubing that are threaded together, with a bit or other drilling device at the bottom end. The rotary drilling machines are mostly designed to install a steel casing (well assembly) into the well in conjunction with the drilling of the actual bore hole. Air and/or water is used as a circulation fluid to displace cuttings and cool bits during the drilling. Another form of rotary style drilling, termed mud rotary, makes use of a specially made mud (Bentonite clay), or drilling fluid, which is constantly being altered during the drill so that it can consistently create enough hydraulic pressure to hold the side walls of the tubewell. The well assembly is a casing pipe for the entire depth of the tubewell that seal the layers which are unproductive and facilitate seepage of water from the productive layers by providing holes in the casing in the corresponding portion. The well assembly is designed according to the depth and thickness of various aquifer zones determined based on well logging data generated by a geologist based on in situ monitoring of the material drilled out from different depths of the bore and geophysical logging conducted in the well after completion of the drilling.

**Filter-point wells**

These are shallow tubewells that are constructed by driving a small-diameter, perforated tube with a pointed end into friable ground with unconsolidated sand or gravel aquifers using air or water jetting. A filter, or screen, is very often fixed to the lower section of the pipe to filter the sand and other particles and prevent them from penetrating into the well. They are usually used to draw water from shallow depths around 10 m. These are mostly found in the coastal stretches especially in thick sandy horizons.

**Infiltration gallery**

Infiltration gallery is a collector well connected with horizontal perforated or porous pipe surrounded by a gravel filter envelope laid radially in a permeable aquifer with a high water table

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6. A down-the-hole drill (DTH) is basically a mini jackhammer screwed on the bottom of a drill string. The fast hammer action breaks hard rock into small flakes and dust and is blown clear by the air exhaust from the DTH hammer. The DTH hammer is one of the fastest ways to drill hard rock. Auger boring is a technique for forming a horizontal bore hole through the ground by means of a rotating cutting head.
and a continuous recharge with a perennial flow. These are usually laid parallel to river beds at a depth of 3 to 6 m for intercepting and collecting groundwater by gravity flow. Most of the collector wells in rivers for drinking water schemes are infiltration galleries which ensure perennial yield as well as maintain water quality irrespective of the changing quality of river water in different seasons. Infiltration galleries are used in coastal sandy terrains as a safeguard for tapping groundwater without saline water intrusion.

**Tunnel wells**

Tunnel well or *Surangam* is a traditional water management system used to provide a reliable supply of water for human settlements and irrigation in Kasaragod district of Kerala. It is basically a horizontal tunnel dug in the slope of a laterite hill for about 30 to 40 m, which uses gravitational force for extracting the groundwater and collecting it into a storage tank. *Surangams* are considered as a relatively cheaper option in steep hilly terrains with thick lateritic formations. It is reported that there are around 5000 *Surangams* in Kasaragod district of Kerala and Dakshin Kannada district of Karnataka, most of which were constructed during the 1950s (Jayan T.V., The Telegraph, 2012).

The tunnels are generally rectangular or dome-shaped with an optimal height and width which allows a man to work and pass comfortably. The tunnels are made with a downward slope to use the gravitational force for collection of the water percolating outside. During construction, walls are lined to prevent collapse due to loose or soft soil. While an average *surangam* is 26 m deep, *surangams* up to 250 m deep are also reported. Air shafts are provided in longer *surangams* to supply fresh air and expel poisonous gases. The *surangams* are independent or are connected to one another. The water can then be collected by using a temporary small barrier or dam with mud, which can then flow through a plastic or bamboo pipe into a storage pit or tank. After collection of the water in the storage pit or pond, the water is taken to the farms by siphon methods, by creating aqueducts, or by drip or other irrigation methods. One of the problems associated with the *surangams* is water wastage. As water flows out perennially by gravity, the flow could be as high as 600 litres per minute.

**2.5.2. Groundwater Abstraction**

The groundwater abstraction or draft in Kerala is mainly for irrigation and domestic uses. It is reported that Kerala has the highest well density among all the states with about 67 lakh open wells alone all over the state (Harikumar, 2015). However, the data on the number of wells used for domestic purposes alone is not available. Therefore, the groundwater draft for domestic purpose in the year 2008 is estimated based on the population of 2008 projected from the 2001 Census data and assuming the per capita domestic water requirement as 150 lpd. Considering the domestic water supply from surface water sources, the share of groundwater used for domestic purposes is taken as varying from 25 to 100%. Regarding the groundwater draft for the purpose of irrigation, the data on block-wise number of irrigation wells from the 4th Minor Irrigation Census (with 2007 as the base year) is used and it is multiplied with the corresponding unit draft. In the districts of Kasaragod and Palakkad, the number of abstraction structures was considerably lower in the Irrigation Census data compared to that from the data of the Department of Agriculture, GoK, and hence the latter data is used for computation to prevent under-estimation.
The stage of groundwater development (SGD) of assessment units is computed as the ratio of the existing Gross Annual Groundwater Draft for all uses and the Net Annual Groundwater Availability. The projected requirement for domestic and industrial purposes for the year 2025 is also computed using GEC-97 norms. The availability of groundwater resources for future development is computed as the difference between the NAGA and Net Annual Groundwater Draft (NAGD) for all purposes.

### 2.6 Groundwater Resource Potential of Kerala

The data variables used for the estimation of groundwater resource potential of each assessment unit, i.e., block panchayat, is detailed by the Groundwater Estimation Committee in its Report (GEC, 2012). Based on this, the data elements are compiled at the district level and given in Table 2.4. The Total Annual Groundwater Recharge (TAGR), NAGA, SGD and Category of Block with respect to groundwater development for all the block panchayats of the state are drawn from the Report of the CGWB (2012). Based on this data, the Dynamic Groundwater Resource Potential of each district is compiled and given in Table 2.5. As per the computation, NAGA for the entire state as in 2008 is 6029 Mm³. The average NAGA per km² area of the state is 0.213 Mm³, which is highest for Alappuzha with 0.321 Mm³/km² and the lowest for Thiruvananthapuram with 0.140 Mm³/km². The SGD for the entire state is 47%, the minimum value in the state is 17% for Wayanad district, and the maximum value is 71% for Kasaragod district.

### 2.7 Conflicting Scenario in Groundwater Availability

The groundwater resource potential of the state and the stage of groundwater development are estimated for the years 1989, 1997, 2004 and 2009 (Table 2.6). The table also shows the categorisation of blocks as in 2009. Generally, there is a gradual reduction in resource potential from 1989 to 2009 and increase in groundwater development, irrespective of the rainfall as it is not varying significantly. However, the reduction of groundwater resource potential from 1997 to 2009 is almost 10%. The increase in groundwater development is attributable to the increase in the number of wells (both dug wells and borewells) and considerable change in the mode of development from manual drawal to mechanised pumping. In addition, the change could also be attributed to the change in land use pattern due to the filling up of low land and water bodies, abandoning of water bodies, reclamation of paddy fields, and change in agricultural pattern (CGWB, 2006). Further, the reduction in recharge area due to the large scale removal of hills also contributed to the change. Shaji et al., (2008) reported that the groundwater level in some of the blocks shows a sharp decline, sometimes up to 10 cm/year, even though the stage of development of groundwater in those blocks is low. Such blocks are found to have large area under plantation and forest cover, and the wells located in the dense habitation and in cropped areas show a falling trend in groundwater levels. All such blocks with steep declining trend in water level are categorised as semi-critical/critical. The water level decline in these areas is attributed to large withdrawal from limited areas, less facility to store rainwater, and a high base flow consequent to undulating topography with steep slopes.
A graph showing the variation of groundwater resource potential and the stage of development during the four years in 14 districts of the state is shown as Figure 2.9. It shows that the groundwater resource potential is on the decline in all the districts except Thiruvananthapuram and Palakkad. Kollam also showed an increasing trend up to 2004. During the corresponding period, the groundwater development also exhibited significant increase. The declining trend in the resource potential at Idukki and Kannur is very steep, one of the reason for which could be the deteriorated recharge situations. The groundwater development in Palakkad shows significant reduction which probably explains the increase in resource potential at Palakkad, whereas in Kozhikode, the resource potential is on the decline irrespective of considerable reduction in extraction. In Wayanad, there is a steep increase in groundwater development which probably is the cause for gradual reduction in the resource potential. Kasaragod shows significant increase in groundwater use which probably explains the declining resource situation.

**Figure 2.9 Fluctuations in groundwater resource potential and stage of development**

*Source: GEC, 2012.*
Table 2.4: Data variable used for the assessment of Dynamic Groundwater Resource Potential

<table>
<thead>
<tr>
<th>Data elements</th>
<th>KGD</th>
<th>KNR</th>
<th>WND</th>
<th>KZD</th>
<th>MPM</th>
<th>PKD</th>
<th>TCR</th>
<th>EKM</th>
<th>IDK</th>
<th>KTYM</th>
<th>ALPY</th>
<th>PTA</th>
<th>KLM</th>
<th>TVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment area (km²)</td>
<td>1961.30</td>
<td>2967.96</td>
<td>2131.70</td>
<td>2342.30</td>
<td>3125.86</td>
<td>4476.06</td>
<td>2588.93</td>
<td>2148.89</td>
<td>4498.50</td>
<td>2490.60</td>
<td>1414.03</td>
<td>2731.00</td>
<td>2491.08</td>
<td>2192.00</td>
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<td>Non-command area (km²)</td>
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<td>2323.96</td>
<td>1428.70</td>
<td>1661.83</td>
<td>2383.91</td>
<td>3281.34</td>
<td>2588.93</td>
<td>2148.89</td>
<td>1031.86</td>
<td>2368.60</td>
<td>1414.03</td>
<td>1342.23</td>
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<td>2182.00</td>
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<td>0.00</td>
<td>25.0</td>
<td>0.00</td>
<td>30.58</td>
<td>7.00</td>
<td>537.81</td>
<td>0.00</td>
<td>3.56</td>
<td>805.41</td>
<td>443.50</td>
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<td>0.00</td>
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<td>0.00</td>
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</tr>
<tr>
<td>Rainfall (mm)</td>
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<td>2822.50</td>
<td>2122.40</td>
<td>3328.30</td>
<td>2144.80</td>
<td>1883.70</td>
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<td>2874.20</td>
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<tr>
<td>Average pre-monsoon water level (mbgl)</td>
<td>8.46</td>
<td>6.64</td>
<td>5.95</td>
<td>5.27</td>
<td>5.46</td>
<td>5.59</td>
<td>4.75</td>
<td>4.22</td>
<td>5.15</td>
<td>2.35</td>
<td>5.31</td>
<td>6.46</td>
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<tr>
<td>Average post-monsoon water level (mbgl)</td>
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<td>5.46</td>
<td>5.08</td>
<td>4.28</td>
<td>5.20</td>
<td>3.77</td>
<td>4.42</td>
<td>3.73</td>
<td>3.47</td>
<td>4.66</td>
<td>1.58</td>
<td>4.63</td>
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<td>5.13</td>
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<td>Average water level fluctuation (m)</td>
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<td>1.18</td>
<td>0.87</td>
<td>0.99</td>
<td>1.26</td>
<td>1.69</td>
<td>1.17</td>
<td>0.83</td>
<td>0.74</td>
<td>0.49</td>
<td>0.77</td>
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<td>121748</td>
<td>154921</td>
<td>98248</td>
<td>49383</td>
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<td>Specific yield (%)</td>
<td>3</td>
<td>3.78</td>
<td>3</td>
<td>5.50</td>
<td>4.86</td>
<td>2.92</td>
<td>8.29</td>
<td>8.60</td>
<td>2</td>
<td>5.36</td>
<td>15.33</td>
<td>5.11</td>
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<td>8</td>
<td>7.71</td>
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<td>8</td>
<td>8</td>
<td>7.64</td>
<td>9.83</td>
<td>7.56</td>
<td>7.85</td>
<td>7.83</td>
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<tr>
<td>Monsoon draft for industrial purpose</td>
<td>7.765</td>
<td>10.54</td>
<td>115.2</td>
<td>0.515</td>
<td>0.00</td>
<td>240.075</td>
<td>18.490</td>
<td>93.308</td>
<td>6.41</td>
<td>0.00</td>
<td>5.245</td>
<td>0.00</td>
<td>3.961</td>
<td>1.15</td>
</tr>
<tr>
<td>Non-monsoon draft for industrial purpose</td>
<td>7.765</td>
<td>10.54</td>
<td>115.2</td>
<td>0.515</td>
<td>0.00</td>
<td>240.075</td>
<td>18.490</td>
<td>93.308</td>
<td>6.41</td>
<td>0.00</td>
<td>5.245</td>
<td>0.00</td>
<td>3.961</td>
<td>1.15</td>
</tr>
</tbody>
</table>

Where, KGD = Kasaragod, KNR = Kannur, WND = Wayanad, KZD = Kozhikode, MPM = Malappuram, PKD = Palakkad, TCR = Thrissur, EKM = Ernakulam, IDK = Idukki, KTYM = Kottayam, ALPY = Alappuzha, PTA = Pathanamthitta, KLM = Kollam, TVC = Thiruvananthapuram

### Table 2.5: District-wise Dynamic Groundwater Resource Potential of Kerala

<table>
<thead>
<tr>
<th>Data elements</th>
<th>KGD</th>
<th>KNR</th>
<th>WND</th>
<th>KZD</th>
<th>MPM</th>
<th>PKD</th>
<th>TCR</th>
<th>EKM</th>
<th>IDK</th>
<th>KTYM</th>
<th>ALPY</th>
<th>PTA</th>
<th>KLM</th>
<th>TVM</th>
<th>Total</th>
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<tr>
<td>Recharge from monsoon rainfall (MCM)</td>
<td>309.94</td>
<td>452.08</td>
<td>304.30</td>
<td>367.01</td>
<td>465.38</td>
<td>517.80</td>
<td>393.21</td>
<td>162.33</td>
<td>370.74</td>
<td>301.37</td>
<td>207.37</td>
<td>301.98</td>
<td>225.40</td>
<td>4771.38</td>
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<td>Recharge from non-monsoon rainfall (MCM)</td>
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<td>0.00</td>
<td>0.00</td>
<td>54.42</td>
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<td>67.09</td>
<td>103.94</td>
<td>74.21</td>
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<td>6.84</td>
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<td>2.29</td>
<td>3.69</td>
<td>17.42</td>
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<td>0.70</td>
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<td>Total annual GW recharge (MCM)</td>
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<td>531.17</td>
<td>306.98</td>
<td>383.78</td>
<td>531.39</td>
<td>870.95</td>
<td>699.46</td>
<td>615.72</td>
<td>218.38</td>
<td>522.85</td>
<td>483.75</td>
<td>301.61</td>
<td>449.23</td>
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<td>Provision for natural discharges (MCM)</td>
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<td>58.37</td>
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<td>26.50</td>
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<td>479.11</td>
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<td>347.38</td>
<td>484.31</td>
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<td>640.60</td>
<td>557.35</td>
<td>196.55</td>
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<td>284.11</td>
<td>409.27</td>
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<td>109.43</td>
<td>6.52</td>
<td>52.00</td>
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<td>29.92</td>
<td>34.63</td>
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<td>197.85</td>
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<td>135.06</td>
<td>136.67</td>
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<td>279.51</td>
<td>484.17</td>
<td>356.73</td>
<td>239.76</td>
<td>82.98</td>
<td>125.97</td>
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<td>94.24</td>
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<td>17.26</td>
<td>54.61</td>
<td>57.71</td>
<td>60.88</td>
<td>55.69</td>
<td>43.02</td>
<td>42.22</td>
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Where, KGD= Kasaragod, KNR= Kannur, WND: Wayanad, KZD= Kozhikode, MPM= Malappuram, PKD= Palakkad, TCR= Thrissur, EKM= Ernakulam, IDK= Idukki, KTYM= Kottayam, ALPY= Alappuzha, PTA= Pathanamthitta, KLM= Kollam, TVC= Thiruvananthapuram

Table 2.6: Long-term scenario of groundwater resource potential and development in Kerala

<table>
<thead>
<tr>
<th>Districts</th>
<th>Groundwater Resource Potential (Mm³)</th>
<th>Stage of Groundwater Development (%)</th>
<th>Categorisation of Blocks in 2009</th>
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<tr>
<td>T’anantapuram</td>
<td>246</td>
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<td>Kollam</td>
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<td>Pathanamthitta</td>
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<td>Kottayam</td>
<td>447</td>
<td>406</td>
<td>471</td>
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<td>Idukki</td>
<td>561</td>
<td>452</td>
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<td>Trissur</td>
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<tr>
<td>Malappuram</td>
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<td>609</td>
<td>508</td>
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<td>Wayanad</td>
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<td>412</td>
<td>293</td>
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<td>674</td>
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<td>Kasaragod</td>
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<td><strong>Total/Average</strong></td>
<td><strong>6871</strong></td>
<td><strong>6634</strong></td>
<td><strong>6230</strong></td>
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</table>

(OE- Over exploited- SGD above 100%; C-Critical- SGD between 90–100%; SC-Semi-critical- SGD between 70–90%; S-Safe- SGD below 70%)


Irrespective of these ‘not so very serious’ situations in the variation in groundwater resource potential and development, the shortage of groundwater is felt significantly at the local level. The KWA in 2003 reported that 48% of around 45 lakh dug wells become dry during the summer. This phenomena is more pronounced in coastal sandy, laterite and hard rock terrains, where the number of dug wells are maximum. This is mainly due to the summer shortage in wells because of poor aquifer capacity to hold more during the rainy season. This situation is more acute in the northern part of the state as the distributive nature of rainfall is very poor towards the north, though they receive relatively more rainfall compared to the southern part of the state. However, to understand the phenomena and exactly demarcate the localities with poor aquifer potential, the data support is extremely inadequate. As such the rosy picture of groundwater in the state is build based on the water level fluctuation monitored in 941 observation wells spread out in around 30,000 km² area of the state, and it is inadequate to understand the grass-root scenario of the resource potential and development and plan and implement the groundwater replenishment actions. This is a serious lacuna for enabling the local panchayats to implement water conservation programmes aimed at groundwater replenishment.
The water level in a well is hydraulically linked to the surface water domains such as ponds, streams, rivers and other wetlands. The fluctuation of water levels in these structures invariably influences nearby groundwater aquifers. During the monsoon, the surface water resource systems get filled up fully and that in turn pressurises the infiltration into the neighbouring aquifers resulting in their replenishment. Towards summer, the water level in the surface water bodies' declines consistently and in turn reduces the recharge pressure on aquifers. Gradually a reverse flow from the aquifer to the surface water bodies sets in, which may not be very smooth and forceful and depends on the gradient. Therefore, any decline in the water level of surface water bodies does reduce the aquifer pressure and leads to loss of groundwater from the groundwater aquifers.

The sand deposit of rivers having porosity of the order of 30–40% has now got depleted almost completely. This has affected the summer storage of rivers as the sand bed used to facilitate riverine flow during summer, at least marginally. This also increased the groundwater gradient and consequent outflow from the aquifers to the lowered river bed.

In Kerala, the thickness of aquifers is generally limited, more so in silty, laterite and weathered hard rock terrains. Since the permeability of these aquifers is generally low, of the order of 0.1 to 2.5 m/d, the inflow from the aquifers to the wells is relatively slow and thereby the water level in wells goes down quickly on pumping. This enhances the groundwater gradient of the well and as the extraction progresses the top portion of the aquifer is drained fast. If the pumping from the well is repeated continuously prior to the well water level attaining the original level, the top portion of the aquifer remain dry for a long period. Consequently, the possibility of the micro pores of the aquifer getting filled up with tiny grains such as clay is very high. It leads to the blockage of the micro-pores of the aquifer and in turn, leads to the drying up of the aquifer. In the long run, the aquifer potential depletes and well yield reduces or wells become dry.

The sustainability of the groundwater water resource depends on the recharge, which in turn is influenced by the infiltration rate of the soil. In clay dominated soil, the infiltration rate is very low, of the order of 1 mm/hour, whereas in silt dominated soil, it is 150 mm/hour. In sandy terrains, the infiltration rate is maximum of the order of 600 mm/hour or more. Similarly, it is also observed that the infiltration is of the order of 8–12% of the rainfall in loamy soil, 6–8% in laterite soil and 6–8% in rocky terrains with sparse joints and fractures. The infiltration is greatly influenced by the density of vegetation and soil conservation measures. For example, the infiltration rate is almost 4-times higher in dense forest region than that in a ploughed field. The landscape changes and soil loss due to mining of soil, levelling of land etc., and increase in runoff due to deforestation also decreases infiltration and leads to a consequent decrease in groundwater recharge.

2.8 **Static Groundwater Resource**

Apart from the aquifers of the active recharge zone which get charged every year and which constitute the dynamic fresh groundwater resource, estimated as above, there are deeper aquifers below the zone of water level fluctuation. These deeper aquifers of passive recharge zone contain vast quantities of water. The water in these aquifers has accumulated over many years. This water is often called ‘static’ water though in reality it also flows but very slowly. In the alluvial areas, these resources are renewable and get replenished over long periods from recharge areas flanking the
highlands. The in-storage water could also be the fossil water, which is of non-renewable nature (Romani, Sharma & Ghosh, 2007). The tentative estimate of in-storage fresh groundwater in the country is about 10,800 km$^3$, 98% of which is in the alluvial/unconsolidated zones and the rest in the hard-rock terrains (MoWR, 1999). Among the states, Uttar Pradesh (3500 km$^3$), Bihar (2568 km$^3$) and West Bengal (1626 km$^3$) hold 71% of the static resources. Kerala has only 11 km$^3$ (0.10%) of static resource potential, 5 km$^3$ in the alluvial and unconsolidated rocks and 6 km$^3$ in the hard-rock terrains.

The underutilisation of the static water leads to stagnant condition over time which leads to deterioration in quality. Therefore, it is suggested that there is ample scope for development of groundwater from deeper aquifers in states like Punjab, Haryana and Uttar Pradesh where the thickness of the alluvium exceeds 500 m. The underutilisation of groundwater from deeper aquifers has resulted in near stagnant conditions at depth causing the deterioration in quality due to occurrence of calcium bicarbonate type water. This water gradually deteriorates to sodium bicarbonate type with depth, indicating a base exchange between the cations of groundwater and the sub-surface clays. It is possible that such inferior quality water leaks upwards as well as laterally to deteriorate the quality of water in shallow aquifers in extensive alluvial areas.

2.9 Submarine Discharge of Groundwater

Although the coastal zone of Kerala receives abundant monsoon rains, water scarcity is severe in many coastal regions. One of the reasons for the scarcity is the water loss due to quick surface runoff. Another possible cause for the water loss may be the submarine discharge of groundwater (SDG), which has not been subjected to many detailed studies. SDG is defined as the flow of terrestrially derived groundwater and recirculated seawater through the underlying sediments in the seabed into the coastal water. The mechanisms and driving forces for the above two components are quite different: the terrestrial component is driven by the hydraulic gradient of the groundwater in the land, whereas the marine component is controlled by the local oceanographic conditions such as wave set up, tidally driven oscillations, current-induced pressure gradients, and convective circulation of water (thermal or density driven) from the bottom sediments. The discharge of groundwater to the sea along the coastal zone normally takes place as overflow through the unconfined aquifer medium, apart from the natural mechanism of freshwater release from land to sea as base flow with the streams. Further, deeper or confined aquifers forcefully conduct groundwater offshore depending on the hydraulic gradient. Freshwater springs in the sea bottom are common in karst areas. SDG, therefore, is groundwater (fresh or saline or both) that escapes for recirculates from coastal margins into the marine environment, and it commonly occurs as seepage, submarine springs, and tidally controlled groundwater discharge from unconfined and artesian aquifers (Finkl & Krupa, 2003).

The phreatic surface elevation in the coastal zone of Kerala indicates that the groundwater flow and gradient are significant and different from place to place, even though the master gradient is towards the west. The general groundwater gradient for alluvial aquifer varies from 0.00013

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7. Karst is a geological formation consisting of carbonate rocks such as limestones, dolomites and gypsum and is characterised by an underground drainage system with sink holes and caves.
to 0.0053 meter/meter (m/m) and its representative specific capacity\(^8\) is high between 6 to 18.8 \(\text{lpm/m}\) indicating a good yield. The general gradient of the deeper aquifer is found to vary from 0.00053 to 0.0025 m/m (Varma, 1993). Therefore, these conditions could be favoring significant SDG. The geomorphological settings, temporal water quality variations, and subsequent determination of hydrochemical facies provide evidence for explaining the phenomenon of SDG along the Kerala coast. In particular, the indications of streaming potential, inferred interface geometry patterns and truncated lithological layering point to the presence of groundwater discharge across the recognised sections along the Kerala coast (Suresh Babu et al., 2009). Studies also indicate that the SDG in this region is a combination of fresh groundwater and recirculated seawater which is governed by the hydraulic gradient of the adjacent aquifer and varying tidal conditions in coastal waters (Jacob, Suresh Babu & Shivanna, 2009). Further, this study also provides a first-hand estimate of SDG rate as 10.9 ± 6.1 cm/day based on the 222 Rn mass balance investigations in the coastal waters of southern Kerala. Though this estimate is comparable with those reported in the literature, further detailed studies are required to confirm the findings as well as the spatial and temporal variations along the Kerala coast.

### 2.10 Artificial Groundwater Recharge

In the natural process of water cycle, the surface water bodies get recharged from rains which in turn contribute part of it to the groundwater. In the summer season, most of the surface water bodies maintain their flow and water level through contribution from groundwater. Thus the surface water and groundwater are mutually dependent. When their mutual natural balancing is disturbed, due to some form of intervention in nature, the water budget of the area becomes imbalanced. It is in this context that the artificial recharge becomes relevant to restore the natural hydraulic balance and thereby improve the water availability in a region both in terms of quantity and quality. The artificial recharge is carried out by collection and storage of rainwater in reservoirs, wells, ponds or such other structures, and storage of rainwater in subsurface rocks as groundwater for retrieval and replenishment of water bodies in the dry season. The spatial and temporal variation of rainfall in Kerala causes water scarcity in summer and floods during the monsoon. The undulating topography and steep sloping terrain conduct most of the rain water swiftly to lowlands preventing percolation and augmentation of groundwater. Further, groundwater discharge from the phreatic aquifer is very high during and after the monsoons. Therefore, unless the groundwater flow is checked, it is not possible to make available even part of the infiltrated water during the non-monsoon months. Hence, artificial recharge of groundwater and impoundment of subsurface storage assumes great significance in Kerala in the context of water security. However, the methodology to be adopted for recharge differs from place to place depending upon the terrain condition, geology, land availability, nature of use, etc.

Watershed is a natural geographical unit where all the water falling within it, as rain goes out as surface as well as groundwater, flow through a single exit. By regulating inflow into and outflow from the watershed, an underground reservoir can be made to function beneficially just as a surface reservoir. By constructing a sub-surface dam at the exit point of the watershed, a subsurface

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8. Specific capacity of a well is measured as flow (lpm)/ drawdown (meter)
A reservoir could be established which can store the entire water recharged into the groundwater within the watershed area. This simple solution in a high rainfall zone like Kerala will assure the sustainability of the wells, especially dug wells and other extraction structures within the watershed and also facilitate improved base flow of stream. This method could be adopted by large scale consumers like community water supplies, industrial parks, educational institutions, etc. to become self-sufficient in water availability (Thampi, 2015).

The CGWB have estimated the average runoff coefficient in river basins of Kerala as 60%. It means that 40% of the rainfall reaches the groundwater. Therefore, a watershed of 1 ha area in Kerala with rainfall variation of 2000 mm (South) to 3000 mm (North) is capable of providing 8000 to 12000 m³ of groundwater as 60% flows off as surface runoff. If 70% of the infiltration is allowed as losses due to various reasons as well as extraction during the rainy season, 30% of the infiltrated groundwater is available for use during the five dry months, facilitating a withdrawal of 16000 to 24000 lpd for the entire dry season. Along these lines, if a micro watershed of area 300 ha (3 km²) is developed in each panchayat, it is possible to make available 4.8 to 7.2 million litres per day (mld) of water in the dry months which will be sufficient to support the entire population of the panchayat (Thampi P.K., 2015).

There are over 20 successful examples of such interventions reported by Thampi P.K. (2015). The micro-watershed based rainwater harvesting structure in the Film Video Park, KINFRA at Kazhakoottam in the year 2000 generated rainwater storage in the form of an open reservoir on the laterite upland which caters to the entire water requirement of 0.5 mld of the park, as there are no other alternatives for water supply in the park. The institution is depending exclusively on this source for the last 15 years. This is achieved by impounding a seasonal stream having a watershed catchment of 20 ha with an earthen bund and a subsurface dyke both of which uses Low Density Poly Ethylene plastic (500 GSM) as an impermeable barrier. On the upstream side of impoundment a reservoir is established covering an area of 1 ha with a depth of 6 m. All the storm drains in the park area are provided with percolation pits at a 20 m interval to recharge the rainwater falling within the watershed which subsequently moves to the reservoir through the substratum. Water extraction is made through a well reaching to a depth of about 5 m below the reservoir floor. The highlight of the scheme is the fact that the sub-surface dyke is anchored on the impervious white clay layer below the laterite as the basement is over 20 m deep in the area. Another successful example is Ahalia Health Heritage and Knowledge Village, Kozhipara in the Palakkad Gap region where the rainfall is very low, less than 900 mm. The micro-watershed based rain harvesting carried out here turned the area into the largest rainwater harvesting farm in Asia. There are over six rain harvesting reservoirs.

About 62% of the population in Kerala depends on well water for the purpose of drinking but many of the dug wells that they depend on become dry during the summer season. Considering the acute summer scarcity of water, the Thrissur District Administration under a special purpose vehicle by the name Mazhopolima Monitoring and Coordination Unit (MMCU) implemented a community based well recharge programme in the Manalur gram panchayat of Thrissur District, where the well water is mostly affected by salinity intrusion owing to its proximity to the coastal waters (Raphael, 2015). This programme witnessed a successful shift from the conventional large scale government projects towards a community based small scale eco-friendly project ending dependency on piped...
water supply, tanker lorries, etc. Here, the Mazhapolima project focused its activities on enhancing water security, which witnessed success in the years that followed. Thus, Mazhapolima became the primary fresh water source for many in the panchayat. Convergence of the project with MGNREGS resulted in a much better output, leading to the dynamic spread of the scheme to every nook and corner of the panchayat, thus bringing drinking water prosperity. The methodology involves feeding of roof rainwater to the open dug wells that tends to push back / wash back the saline water from the open dug wells forming a fresh water zone beneath each well. Such massive efforts can reduce saline ingress from the coastal water bodies.
An overview of the groundwater scenario in various districts of the state is compiled based on the institutional contributions mainly by the CGWB, Kerala Region; Kerala State Ground Water Department; CWRDM, National Centre for Earth Science Studies, Geology Department of the University of Kerala, etc. The CGWB brought out a Groundwater Information Booklet of various districts which provided base level information (Joseph, 1993; Thambi, 1993; Nazimuddin & Basak, 1998; Shaji, Anitha Shyam, Chandran & Nayagan, 2007; Balakrishnan & Saritha, 2007; Saritha & Vikas, 2007; Vinayachandran & Joji, 2007; Balakrishnan, 2008; Nayagam, 2008; Sakthimurugan, 2008; Joji, 2009; Chandran, 2009; Vinayachandran, 2009; Sakthimurugan, 2009; Shyam, 2009; Sreenath, 2009; Rani, 2013).

### 3.1 Aquifer Characteristics

The major water bearing formations in Kerala are the weathered and fractured crystallines, coastal and riverine alluvium, valley-fills, laterites over the crystallines and tertiaries and the tertiary formations. The aquifer characteristics as reported in various districts are given in Table 3.1. It indicates that the variation in transmissivity and discharge is significant but the water table fluctuation is only moderate.

<table>
<thead>
<tr>
<th>District</th>
<th>WB Formation</th>
<th>Depth to WT (m)</th>
<th>WL Trend (m/yr)</th>
<th>Discharge (lpm)</th>
<th>Transmissivity (m²/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kasaragod</td>
<td>Crystallines, Laterite, Alluvium</td>
<td>2.39 - 16.11</td>
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<td>--</td>
<td>6.9 - 131.9</td>
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<tr>
<td>Kannur</td>
<td>Crystallines, Laterite, Alluvium</td>
<td>1.75 - 20.48</td>
<td>0.37 - 19.26</td>
<td>0.009 - 0.536</td>
<td>0.009 - 0.499</td>
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<td>Wayanad</td>
<td>Crystallines, Alluvium Valley fills</td>
<td>1.68 - 20.11</td>
<td>0.37 - 19.50</td>
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<td>--</td>
</tr>
<tr>
<td>Kozhikode</td>
<td>Crystallines, Laterite SC Tertiary, Alluvium</td>
<td>2.0 - 16.05</td>
<td>0.38 - 9.0</td>
<td>0.0037 - 0.0339</td>
<td>0.0008 - 0.0168</td>
</tr>
<tr>
<td>Malappuram</td>
<td>Crystallines, Alluvium SC Tertiary, Laterite</td>
<td>3.47 - 15.64</td>
<td>1.37 - 12.78</td>
<td>0.05 - 0.36</td>
<td>0.008 - 0.48</td>
</tr>
<tr>
<td>Palakkad</td>
<td>Crystallines, Laterite, Alluvium</td>
<td>3 - 15.5</td>
<td>--</td>
<td>--</td>
<td>1.39 - 34.72</td>
</tr>
<tr>
<td>District</td>
<td>WB Formation</td>
<td>Depth to WT (m)</td>
<td>WL Trend (m/yr)</td>
<td>Discharge (lpm)</td>
<td>Transmissivity (m²/d)</td>
</tr>
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<tr>
<td></td>
<td></td>
<td>Pr.M</td>
<td>Po.M</td>
<td>Rise</td>
<td>Fall</td>
</tr>
<tr>
<td>Thrissur</td>
<td>Crystallines, Alluvium SC Tertiary, Laterite</td>
<td>1.4</td>
<td>0.59</td>
<td>10.86</td>
<td>0.0028</td>
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<td>12.9</td>
<td>10.86</td>
<td></td>
<td>0.2325</td>
</tr>
<tr>
<td>Ernakulam</td>
<td>Crystallines, Alluvium SC Tertiary, Laterite</td>
<td>0.9</td>
<td>0.55</td>
<td>10.17</td>
<td>NC</td>
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<td></td>
<td></td>
<td>10.58</td>
<td>10.86</td>
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<tr>
<td>Idukki</td>
<td>Crystallines, Laterite</td>
<td>1.14</td>
<td>0.55</td>
<td>8.05</td>
<td>0.01</td>
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<tr>
<td></td>
<td></td>
<td>9.5</td>
<td>8.05</td>
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<tr>
<td>Kottayam</td>
<td>Crystallines, Alluvium SC Tertiary, Laterite</td>
<td>1.11</td>
<td>0.20</td>
<td>10.27</td>
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<td>0.2413</td>
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<td>Alappuzha</td>
<td>Crystallines, Alluvium Tertiary, Laterite</td>
<td>0.72</td>
<td>0.08</td>
<td>6.30</td>
<td>0.05</td>
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<td></td>
<td>12.49</td>
<td>6.30</td>
<td></td>
<td>0.28</td>
</tr>
<tr>
<td>Pathanamthitta</td>
<td>Crystallines, Alluvium Tertiary, Laterite</td>
<td>1.4</td>
<td>0.32</td>
<td>9.54</td>
<td>0.004</td>
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<td></td>
<td>11.43</td>
<td>9.54</td>
<td></td>
<td>0.21</td>
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<tr>
<td>Kollam</td>
<td>Crystallines, Alluvium Tertiary, Laterite</td>
<td>1.67</td>
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<td>22.32</td>
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<td></td>
<td></td>
<td>25.4</td>
<td>22.32</td>
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<td></td>
</tr>
<tr>
<td>T’anathapuram</td>
<td>Crystallines, Alluvium Tertiary, Laterite</td>
<td>1.26</td>
<td>1.05</td>
<td>22.86</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20.34</td>
<td>22.86</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pr.M= Pre monsoon; Po.M= Post monsoon


### 3.1.1 Thiruvananthapuram

The groundwater in Thiruvananthapuram district occurs generally under phreatic condition in crystallines, alluvium, tertiaries and laterites. The crystalline formations here are khondalites, charnockites, migmatites and intrusives. The sedimentary formation comprise the recent alluvium that occur along the coastal plain and in the valleys and are mainly composed of sand and clay, tertiary formation such as Warkali, Quilon and Vaikom beds and the laterites which occur as a capping over crystallines. The recent alluvium, composed of sand and clays, is thinner towards north and the maximum thickness of 18 m is reported at Chackai in Thiruvananthapuram city. In the crystalline and lateritic terrain, the groundwater is developed through dug wells and borewells while along the coastal alluvium and tertiaries, the groundwater is developed through dug wells, filter-point wells and tubewells. The alluvium occurring in the coastal zone, flood plains and intermountain valley fill areas is a very potential phreatic aquifer system and is suitable for dug
wells. The recent alluvium in the coastal tract also supports filter-point wells up to a maximum depth of 10 mbgl, where the saturated thickness exceeds 5 m. These wells have depth ranging from 2 to 6 mbgl with a diameter of about 0.5 to 0.8 m. The average yield of these wells is about 10 to 60 m³/day. The yield of shallow dug wells ranges from 2 to 5 lps. The laterite forms potential aquifers along valleys, break-in-slope regions and topographic lows where the thickness of the saturated zone is significant. They are tapped using large diameter open wells, the yield of which ranges from 0.006 to 0.1 lps. The laterite formations occurring along hill tops and slopes get desaturated at the onset of summer leading to water scarcity during the summer. The wells drilled in sedimentary formations varied from 20 to 109 mbgl which has a yield up to 415 lpm. The transmissivity values vary from 70 to 232 m²/day.

The two crystalline rocks dominant in the districts are khondalites and biotite gneisses. The thickness of the weathered zone is limited in both these formations and the dug wells sustain only in selected places where weathered zone thickness is significant or the weathered zone is underlain by jointed and fractured rock portions. The depth of the wells in khondalites varied from 10 to 201 mbgl and the yield from 30 to 1200 lpm. The transmissivity values here vary from 0.94 to 9 m²/day. The depth of the wells in garnetiferous biotite gneiss varies from 173 to 200 mbgl and the yield from 12 to 420 lpm. The transmissivity values here vary from 0.54 to 17 m²/day. The yield of the borewells tapping the deeper aquifers depends on the intensity of fracturing, type of rocks, subsurface structural controls, etc. In khondalite formations, generally, the increase is substantial only if there are structural controls such as dykes.

3.1.2 Kollam

The groundwater in Kollam district occurs generally under phreatic condition in crystallines, alluvium, tertiaries and laterites. The crystalline formations here are khondalites, charnockites, granite gneisses and intrusives. The shallow aquifers here are the highly weathered zone of crystalline rocks and partly weathered and fractured crystallines, the latter occurring just below the weathered zone. These aquifers are tapped using dug wells and borewells. The yields of the dug wells are of the order 6 to 12 m³/day in general. In the charnockites, the yield of the wells range from 4 to 5 m³/day. The dug wells piercing the weathered charnockites are generally dry during the summer months as the thickness of the weathered zone in charnockites is thin. Among the borewells in the terrain, 5% yield more than 20 lps, 19% yield between 10 to 20 lps and 57% yield between 1 and 10 lps and 19% yield less than 1 lps. The yield of borewells drilled in garnet biotite gneiss is usually higher than that in Khondalite group of rocks, in the absence of structural controls such as dykes.

In laterites, the occurrence and movement of groundwater is mainly controlled by the topography. Laterite forms potential aquifers along valleys and topographic lows where the thickness of the saturated zone is more and can sustain large diameter open wells for domestic and irrigation use. The yield of the well ranges from 0.5 to 6 m³/day. The laterite formations occurring along hill tops and slopes get desaturated at the onset of summer and water scarcity is experienced during summer in such areas. The alluvium is a very potential phreatic aquifer system in Kollam district and is developed extensively by dug wells and filter-point wells for domestic and irrigation needs. The yield of shallow dug wells ranges from 15 to 50 m³/day. The filter point wells are constructed to a maximum depth of 12.0 mbgl and the yield ranges from 20 to 60 m³/day.
The tertiary sedimentary formations include Warkali beds, Quilon beds, Vaikom beds and Alleppey beds from top to bottom. The groundwater here occurs under phreatic conditions in the shallow zone and confined conditions in the deeper zones. Among these, Vaikom and Warkali beds are the potential aquifers whereas Quilon is a poor aquifer and Alleppey beds contain brackish water. Wherever these beds outcrop, groundwater is developed using dug wells with yield varying from 0.5 to 10 m³/day. Vaikom beds are the most potential aquifer system developed extensively in Kollam district using deeper wells. The thickness of granular zones in the formation ranges from 6 to 65 m. The yield of the wells constructed tapping this formation ranges from 0.67 to 36 lps. The transmissivity value ranges from 6 m²/day in the eastern areas to 467 m²/day at Mainagapally and 529 m²/day at Sooranad. The storativity ranges from $2.5 \times 10^{-9}$ to $4.1 \times 10^{-3}$ indicating confined to semi-confined conditions. The specific capacity of the wells ranges between 5.79 and 436 lpm/m. This aquifer is largely developed in and around Kollam for water supply. The type area of Quilon beds is Padappakara near Kollam. The hydrogeological particulars of these beds are very limited. It is not very promising when compared to the underlying Vaikom beds as the thickness of granular zones is only 6-10 m and is composed of fine sand. Warkali bed forming semi-confined to confined aquifers is the most potential extensively developed aquifer in the tertiary sediments. The thickness of the granular zones varies from 5 to 40 m and the yields of the wells range from 3 to 13.7 lps. The transmissivity value ranges from 130 m²/day to 710 m²/day and it is generally minimum around Kollam and maximum at Karunagapalli and increases further towards northern parts.

### 3.1.3 Pathanamthitta

In Pathanamthitta district, groundwater occurs under phreatic condition in the alluvium, laterites and weathered crystallines. It occurs under semi-confined to confined conditions in tertiary sediments and deep seated fractured aquifers in crystalline rocks. Charnockite is the dominant rock type in Pathanamthitta district except in the southern part where gneisses occur. Weathered mantle and partly weathered and fractured zones in the crystallines form potential phreatic aquifer supporting a large number of dugwells. The thickness of the weathered zone in the district ranges from less than 1 m to more than 10 m. The yield of dug wells in hard rock ranges from 5 to 10 m³/day. The yield of borewells in deep fractured rocks widely ranges from 0.5 to 990 lpm with transmissivity ranging from 1.1 to 11.3 m²/day. But barring a few wells, yield of the borewell was mostly less than 180 lpm. The borewells along the NNW-SSE lineament yielded the highest of 990 lpm and the yield of boreholes along the NW lineament is very poor.

In laterites, the groundwater occurs under phreatic condition and is developed through dug wells with a specific capacity ranging from 1.728 to 15.55 m³/day and yield ranging from 5 to 30 m³/day depending on the size and location of the well. The alluvial deposits occur along the north-western portion of the district and groundwater here occurs in phreatic condition. The thickness of alluvium is about 13.7 mbgl and the yield of wells ranges between 10 to 30 m³/day. The tertiary sediments in the district belong to Vaikom bed and have a thickness of 72 m occurring below the alluvium at a depth between 13.7 and 85.7 mbgl in the lowland region of the district. The discharge here is high at 16.76 lps, but the water quality is brackish.
3.1.4 Alappuzha

In Alappuzha district, the crystalline formation is confined to the south-eastern part of the district and is mostly capped by thick laterite formations. The groundwater occurs here under phreatic and semi-confined conditions with low potential fractures having yield ranging from about 60–120 lpm. The recent unconsolidated formation constitutes a major potential phreatic aquifer in the district comprising coastal sands all along the coast and flood plain deposits in the interior Kuttanad area. The discharge in open wells ranges from 11.76 to 12.90 m³/hr. The water level of shallow wells in the coastal region shows a slight rising trend and that of weathered formation shows a falling trend over a decade. The water level in deep wells shows a steady decline of both the pre-monsoon and post-monsoon piezometric level since the last two decades indicating extensive development.

The tertiary formations constitute the major aquifer in Kuttanad and coastal areas of Alappuzha with total thickness of sediments ranging from 90 m to more than 600 m covering an extensive area. They are underlain by crystalline basement and overlain by laterite and unconsolidated sediments. The bottom most unit of the tertiary formations are the Alleppey bed, comprising of highly carbonaceous clay with intercalations of sand. The formation water in this area is brackish. The Vaikom bed overlying the Alleppey bed with thickness varying from 25 to 238 m is the highly potential aquifer comprising of gravel, coarse sand, clay and seams of lignite. They are exposed in the south-eastern part of the district and are highly lateritised. The thickness of the granular zones ranges between 5 and 210 m with discharges in the range of 11 to 96 m³/hr. However, water from Vaikom aquifer in Kuttanad region and in the coastal zone west of Vembanad lake is more mineralised. Some of the tubewells have high discharge of 57.6 to 96.7 m³/hr and the tubewells at Karuvatta, Karumadi, Karthikapalli and Kandiyyur have free flow with water level in the range of 1.44 to 4.29 m above ground level. The transmissivity ranges from 6 m²/day in the eastern recharge area to 3856 m²/day at Karuvatta. Compared to the underlying Vaikom beds, the groundwater potential of the Quilon bed is not very promising. The thickness of granular zones tapped in this aquifer is between 6 to 10 m and is composed of fine sand. The transmissivity of the aquifer is found to be 29.22 m²/day. The Warkali bed overlying the Quilon bed is composed of medium to fine grained sand and is the most extensively developed aquifer in the district. Groundwater occurs in semi-confined to confined conditions with cumulative thickness of the granular zone varying from 6 to 44 m. The aquifer has attained high degree of development in the Alappuzha area and the discharge here is in the range of 6–120 m³/hr and transmissivity ranges between 221 and 712 m²/day.

3.1.5 Kottayam

The hydrogeological units in the district are crystallines, laterites, alluvium and tertiaries. In crystallines, the shallow aquifer consists of weathered and fractured portion of crystalline rocks and their thickness is restricted to 8 to 15 mbgl. The yield of the dug wells in this formation ranges from 2 to 9 m³/day. The deep fractured zone extends up to 112 mbgl and the yield of borewells here goes up to 1730 m³/day (72,000 lph). The transmissivity ranges from 0.48 to 104.8 m²/day. The borewells located in the East-West lineaments are more productive followed by NE-SW, NNW-SSE and NW-SE lineaments. The aquifers here are confined and semi-confined. The laterite formations, extensively seen in the midland region of the district, have an average thickness of 16m. It sustains large diameter dug wells, especially along the valleys and topographic lows where the depth of the
wells ranges from 3.5 to 15.0 mbgl and yield ranges from 0.5 to 6.0 m³/day. The laterite formation along the hill tops and slopes get desaturated at the onset of summer leading to widespread water scarcity.

The recent alluvial formation includes riverine alluvium and valley-fills consisting of black clay, fine to medium grained sand and silt sands. The depth to water level in this formation ranges from a few centimetres to 2.0 mbgl during post monsoon and the seasonal water level fluctuation is from 0.75 to 3.5 m. The yield of wells here ranges from 5 to 20 m³/day. The tertiary sediments in this district are represented by the Vaikom beds exposed in the western part. They overlie the crystalline basalts. Groundwater in this formation occurs under phreatic condition in the shallow zones and confined condition in the deeper zones. It consist of coarse to very coarse sands, gravels and pebble beds with alternating clay layers. Groundwater is developed by dug wells of depth up to 15.0 mbgl. The deeper aquifers are generally brackish except at places like Udayanapuram, near Vaikom.

### 3.1.6 Idukki

The hydrogeological units encountered in the district are laterites and weathered and fractured crystallines. Laterite is extensive in the mid land regions and is generally underlain by lithomarge clay, the thickness of which varies from 0.5 to 4.0 m. Due to the porous nature of laterites, dug wells here get recharged fast. The recharged water also escapes as sub-surface flow leading to the sudden lowering of the water table especially in wells located on topographic highs, ridges and steep slopes. Consequently, the dug wells here dry up in the summer. The shallow aquifers in the laterites are developed through large diameter dug wells with depth ranging from 2.3 to 10.0 mbgl. The depth to water level in these wells during pre-monsoon period is 1.85 to 6.79 mbgl and the water table fluctuation ranges from 0.85 to 3.42 m. The yield of these wells ranges from 3 to 25 m³/day in winter and it reduces to 1 to 10 m³/day in summer. The laterite is generally underlain by weathered crystallines, the thickness of which varies from about 2 to 20 m. The depth of dug wells in these aquifers ranges from 2.0 to 20.7 mbgl with diameter of 1.5 to 4.5 m. In the steep slopes and hilltops, the weathered mantle is very thin or absent and is devoid of perennial phreatic aquifer. The depth to water level in the weathered crystallines ranges from 0.75 to 10 mbgl and water table fluctuation ranges from 0.87 to 4.32 m. The yield of dug wells here vary from 2 to 30 m³/day in the winter period and it reduces 1 to 10 m³/day in the summer period.

The deeper fractured crystalline aquifers are under semi-confined to confined conditions and tapped through borewells with depth ranging from 24 to 200 mbgl. The potential fractures are encountered at depths varying from 10 to 120 mbgl and the depth to water level ranges from 1.98 to 39.30 mbgl. The depth of borewells is comparatively lower in the midland areas of the district, around 60% of the borewells are less than 70 m deep. The thickness of overburden varies from around 1m to more than 20 m. The yield of borewells is generally around 120 m³/day, and varies from around 12 to 1200 m³/day. Only 10% of the wells have discharge more than 240 m³/day. In the post monsoon period, about 70% of the wells shows falling trend in water level in the range of 0.01 to 0.12 m/year and the maximum was shown in the eastern part of the district. The western part of the district shows a rising trend in the range of 0.005 to 0.07 m/year.
3.1.7 Ernakulam

Groundwater in the district generally occurs under phreatic conditions in weathered and fractured crystalline rocks, laterites and unconsolidated coastal sediments. In deep fractured crystallines and tertiary sediments, groundwater occurs under semi-confined to confined conditions. The laterite formation is extensive in the midland region of the district. It is also found in the coastal belt as discontinuous horizons between the recent alluvium and Warkali or Vaikom beds at depths ranging from 20 to 56 mbgl. The laterites are highly porous and permeable and are extensively developed through dug wells in the midland crystalline terrain. The depth of wells in laterite ranges from 3.4 to 14.8 mbgl, and the depth to water level ranges from 1.55 to 11.06 mbgl. The wells located on slopes and elevated areas go dry or have very small water column during the summer season. The yield of wells ranges from 0.5 to 6 m$^3$/day, and it sustains pumping for 3–4 hours a day. The near-surface weathered and fractured crystalline formation also constitutes productive aquifers, especially in the eastern midland and highland region of the district. They are generally tapped using dug wells, the yield of which varies significantly depending on the intensity of weathering and fracturing. In the shallow phreatic zone of these aquifers, the depth of dug wells varies from 3.4 to 14.8 mbgl. The depth to water level in the wells ranges from 1.82 to 12.05 mbgl. The depth of borewells, especially in Charnockite area, range from 131 to 201 mbgl. The fracture zones in the hard rock terrain were encountered at depths ranging from 5 to 194 mbgl with yield ranging from 1 to 22 lps. It is indicated that the wells located in the E-W, NNE–SSW and NE–SW lineaments are more potential than in the NNW–SSW lineaments. The deep fractured rock has transmissivity ranging from 15.64 to 319 m$^2$/day.

The district has extensive alluvial formations all along the coastal belt as well as in the flood plains of rivers. It has sand, silt and clay as constituents depending on the depositional environment and its thickness varies from less than 1 to 54 m, the highest around Kandakadavu. It forms a potential phreatic aquifer and is extensively developed by dug wells and filter-point wells. The dug wells have depths ranging from 2 to 13 m, in general, and the depth to water level ranges from 0.35 to 7 mbgl. The average yield of the dug wells vary from 15 to 20 m$^3$/day. The filter-point wells are common at places where the average saturated thickness of alluvial sand exceeds 5 m and have depths ranging from 5 to 15 mbgl. They have yield ranging from 12 to 18 m$^3$/day.

The sedimentary formations of the tertiary age, comprising Warkali and Vaikom beds are potential aquifers in the district and are tapped using tubewells with depths ranging from 58 to 296 mbgl. The Warkali beds are restricted to the southern coastal belt of the district and its thickness thins out from south to north, from 106.7 m at Chellanum in the south to less than 13 m at Panangad in the north. The Warkali aquifers are composed of fine to medium grained sand and the formation water is found to be generally brackish except in certain pockets in and around the Kumbalangi area. The Vaikom beds are confined aquifers and are generally separated from the overlying Warkali formations and confined by the Quilon beds except in the northern portion of the district, where the Vaikom beds are underlying the coastal alluvium or laterite. The Vaikom beds are composed of thick sequence of coarse to very coarse sand, gravel and pebble beds intercalated with ash and grey clay and carbonaceous clay. They are extensive all along the coast of the district with thickness ranging from 18 m at Panangad in the north to 151 m at Chellanum in the south. The wells, tapping this aquifer with coarse sand and gravel having thickness of 6 to 14 m, yield 1.2 to 10.1 lps of water.
and the transmissivity ranges from 193.6 to 818 m²/day. Some of the wells were flowing wells at the time of construction, but the formation water is generally brackish except in small pockets like Narakal, Subash Park, Naval base and Kumbalangi where the water is fresh.

3.1.8 Thrissur

The weathered and fractured crystallines, laterites and sedimentary rocks constitute the aquifer system in the district. The weathered rock aquifers generally have a thickness ranging from 4.5 m to 21.0 m and the depth to water table here varies from 0.59 to 12.90 mbgl. This aquifer is tapped through open dug wells of 12 m depth and shallow borewells up to a depth of 50 mbgl. In the fractured crystalline aquifers, groundwater occurs under semi-confined to confined conditions and the intersections of fractures are found to be the most potential aquifers followed by E-W and NW-SE fractures. The potential fractures are encountered between 18 to 137 m and the thickness of fracture zones vary up to 10 m. The transmissivity of the aquifer ranges from 22-288 m²/day and the yield of borewells ranges from 43 m³/day to 2100 m³/day.

The most commonly occurring aquifer system in the district is the laterite formation and it forms highly potential aquifers along topographic lows and valleys. These are tapped using dug wells having depth varying from 5.00 to 25.62 mbgl and depth to water table ranging from 0.98 to 24 mbgl. The yield of the wells here ranges from 20 to 40 m³/day. The dug wells tapping the laterites are generally unlined up to the lithomarge clay zone. The wells are lined to avoid caving along the lithomarge zone. Mostly cement rings are used for lining, but lining using bricks or laterite blocks is found more advantageous for quick recuperation of the well.

The alluvium along the river courses, intermontane valleys and coastal plain forms potential aquifers in which groundwater occurs under water table condition. The depth of dug wells located in this formation ranges from 5.00 to 9.00 mbgl, and depth to water table varies from 0.5 to 6.58 mbgl. In the coastal alluvium, where the alluvial thickness is around 15 m, the aquifer is also developed using filter-point wells. The depth of filter point wells ranges from 6 to 10 mbgl of which the saturated sand thickness exceeds five meters. The extraction zone is generally confined to the bottom portion of the well having thickness of 1 to 3 m. The yield of filter point wells ranges from 12 to 18 m³/day.

The tertiary aquifer in the district is represented by the Vaikom formation which contains coarse grained sands, gravel, clay, marl, carbonaceous clay and lignite intercalated with granular formations. The groundwater here occurs under semi-confined to confined condition. The Vaikom formation is found lateritised on the top wherever it is exposed. The thickness of the granular zone in the formation varies from 8 to 30 mbgl, and the aquifer transmissivity ranges from 22 to 105 m²/day.

3.1.9 Palakkad

The valley fills/alluvium, laterite and weathered and fractured crystallines constitute the major aquifers in the district. The alluvium aquifers are developed through dug wells in which the depth to water table ranges from 1–12 mbgl and water level fluctuation is generally high up to 5 m. The yield of dug well ranges from 5 to 20 m³/day. The laterite province is limited in extent and confined
to Trithala, Ottapalam and Pattambi regions. The aquifer sustains dug wells in which the depth to water table ranges from 3 to 11 mbgl and the water level fluctuation varies between 2 to 6 m. The yield of the wells here ranges from 5 to 30 m³/day.

The hard rock province covers 80% of the district and groundwater here occurs in the weathered and fractured portion of the rock, under unconfined to semi-confined condition. The depth of weathering ranges from 10 to 23 mbgl where dug wells and shallow borewells are feasible. The depth of the water table ranges from 5 to 10 mbgl, and the yield varies from 5 to 25 m³/day. Along the fractures/lineaments, borewells are feasible, the yield of which ranges from 43 m³/day to 1650 m³/day. The fractures are generally deep seated and encountered generally within 125 m and in exceptional cases up to 175 m. In the Palakkad gap region, the thickness of weathering is more than 10 m and the yield from this zone is around 173 m³/day. The thickness of weathering and the yield reduces towards the eastern side of the gap region. The depth to the fracture zone also reduces to about 80 to 100 mbgl towards the eastern part of the gap. It is reported that the water level in borewells of the gap region is going down considerably. The yield of borewell here is site specific and relatively better along the E-W and NW-SE fractures. In general, high yielding fractures are rare beyond a depth of 200 m. The area also has dug wells with yield ranging from 5 to 30 m³/day, but many of the dug wells become dry during the summer. It is reported, based on the long-term water table fluctuation data, that the water levels are declining at the rate 0.4 m/year in the eastern part of the gap area. In the rest of the areas, water level decline is less and is in the range of 0.2 to 0.3 m/year. Rising trend is reported in the central western part of the district.

The quality of groundwater is also poor in some pockets as inland salinity is observed within the phreatic zone at places like Nedupeni, Kuduvayoor, Kozhinjampara, Gopalapuram, etc. Fluoride content is found to be higher in borewell and dug well samples in Chittoor and Attapadi regions. The highest fluoride content up to 5.74 ppm is reported from the Kopanur area.

3.1.10 Malappuram

The aquifer system of the district consists of weathered and fractured crystalline formations, laterite, alluvium and tertiaries. Most of the district is underlain by laterites and crystalline rocks of Archaean age. Along the western coastal area, tertiary formations are seen overlaid by recent alluvial deposits. The crystalline group of rocks comprises of charnockite, charnockite gneiss, biotite gneiss, biotite hornblende gneiss and migmatites. A major gabbro dyke is seen trending NW from Cherukara, SW of Perinthalmanna, to NW of Manjeri. The width of the dyke varies from 30 to 50 m. A few dolerite dykes are also seen traversing the basement rocks. Most of the dykes are running in NW-SE direction. Tertiary formations are seen along the western fringe of the district which consists of sandstone and clays with seams of lignite, and they are classified as the Vaikom beds. The tertiary sediments are lateritised at the top. The thickness of this formation is generally less than 75 m. Laterite is the most important lithologic unit of the district and is widely seen almost all along the midland region of the district. The laterite formation is generally thin, of the order 1–3 m, over charnockite rocks and thicker, of the order of 15-20 m over hornblende gneiss rocks.

Groundwater in crystallines occurs under unconfined conditions in the shallow weathered and fractured rocks and under semi-confined to confined conditions in the deeper fractured zones.
The thickness of the weathered rock ranges from 4 to 12 m below ground level (mbgl). Along valley portions in the area, groundwater is developed mostly by means of dug wells with depth varying from 3.5 to 21.2 mbgl. The thickness of the weathered zone here varies from 15 to 20 m and the yields are of the order of 144 to 288 m³/day. The wells located in the hornblende biotite gneiss vary in depth from 6 to 15 mbgl, and the yield here ranges from 96 to 120 m³/day. However, they can sustain pumping only for few hours as the recuperation rate is very poor. Fractured crystalline rocks form potential aquifers which are developed using borewells of depth from 90 to 300 mbgl. The yield of these wells ranges up to 1300 m³/day. The depth of overburden varies from 3–35 m and the water bearing fractured zones are generally encountered at depth ranges of 20–30 m, 40–60 m, 70–80 m, 90–120 m and 150–160 m below ground level. The aquifer transmissivity values are significantly higher for charnockite rock aquifers (30–150 m²/day) than the hornblende biotite gneiss aquifer (5–50 m²/day).

Laterite constitutes the potential aquifer especially in the midland region and groundwater here occurs under water table conditions. Due to the higher porosity and permeability conditions, groundwater in the laterite aquifers of elevated hills and slopes escapes as sub-surface run-off as the rain recedes. Consequently, majority of wells tapping laterites dry up during the summer months. The bottom part of the wells are mainly constituted of lithomarge clay and become low yielding during peak summer periods. However, in the lower elevations, especially in valley portions, the water table is shallow and appreciable thickness of the saturated zone is available for groundwater development, where groundwater yield is very high, of the order of 192 to 240 m³/day.

The alluvial aquifers in the coastal region are highly potential and are essentially composed of sand, silt and clay. The groundwater here occurs under water table conditions and is developed using dug wells and filter-point wells in areas around Ponnani, Chamravattom, Mangalam, B.P. Angadi, Tirur, Tanur, Parappanagadi and Kadalundi. Riverine alluvium of considerable thickness is seen in and around Thirunavaya and Kuttipuram where groundwater is developed using open dug wells. The valley fill materials also form potential aquifers in all major valleys where the sandy portion is considerable. The dug wells in alluvial deposits vary in depth from 20 to 15 mbgl and the water level ranges from 1.6 to 13.3 mbgl.

3.1.11 Kozhikode

The weathered and fractured crystalline rocks, laterite and alluvium are the major hydrogeological formations occurring in the district. The midland terrain of Kozhikode is generally covered by very porous laterite forming potential phreatic aquifers along topographic lows and valleys. These are developed through open dug wells, the depths of which range between 7.06 and 18.06 mbgl. The depth to water table ranges from 0.33 to 16.86 mbgl and the yield of wells ranges between 5 and 10 m³/day. The alluvium, both riverine and coastal, consists of sand, silt and clay and its thickness varies between 2 and 8 m. The groundwater occurs under phreatic condition and is developed using dug wells and filter-point wells wherever the saturated sand thickness is 4 m or more. The depth of wells ranges between 3.14 and 9.12 mbgl and water table ranges from 0.99 to 6.63 mbgl. The yield of wells here are between 30 and 80 m³/day. The tertiary formations occurring in the district are the Vaikom beds and these are occurring below the alluvium and have been encountered at shallow depths in the narrow coastal strip of the district. The thickness and extent of tertiary beds is very limited with poor groundwater potential.
Groundwater occurs under phreatic condition in weathered crystallines and under confined to semi-confined conditions in deeper fractured crystalline formations. Dug wells are the suitable abstraction structures in the weathered formations and the depth to water level varies from 0.55 to 16.05 mbgl. The yield of dug wells here ranges between 5 and 10 m$^3$/day with pumping duration ranging from less than 1 to 4 hours in a day with further reduction during the summer. The groundwater is abstracted through borewells in deep fractures of crystalline formations. The fracture zones are found up to a depth of 200 m and the potential fractures occur between 10.60 and 169.2 mbgl. The quality of water in hard rock aquifer is good and the yield ranges between 14 to 1470 m$^3$/day. The yield of borewells in hornblende biotite gneiss varies between 14 and 580 m$^3$/day, biotite gneiss varies between 216 and 590 m$^3$/day, and that in charnockite varies between 118 and 410 m$^3$/day. It is reported that the maximum discharge observed in the district is around 1470 m$^3$/day. It is also indicated that the NE-SW fractures in biotite gneisses are the most potential fractures in the district followed by the NS fractures. The overburden thickness is maximum in hornblende biotite gneiss, generally ranging from 10.5 to 30.0 m, in biotite gneiss from 14.50 to 19.50 m and that in charnockites from 8.00 to 20.90 m.

3.1.12 Wayanad

The major water bearing formations in the district are weathered/fractured crystallines, alluvium and valley fills. The thickness of alluvium varies from 3 to 9 m and that of valley fills from 2 to 9 m. In these formations, groundwater occurs under phreatic condition and is developed using dug wells with depths varying from 3.5 to 7.8 mbgl. The depth to water level varies from 0.70 to 3.7 mbgl and the yield ranges from 12 to 240 m$^3$/day with pumping duration ranging from less than 1 to 4 hours in a day.

Groundwater occurs under phreatic condition in weathered crystallines and semi-confined to confined conditions in deep fracture zones. The weathered crystalline aquifers are developed using dug wells and fractured ones using borewells. The depth of dug wells generally varies in the range of 6-10 m with water levels ranging from 3–9 mbgl. The weathered migmatite and gneiss seen along the central portion of the district form moderately potential aquifers compared to the granite around Kalpetta. The depth of dug wells in the migmatite formation generally varies from 14–20 m with water levels ranging from 8–15 mbgl. The weathered gabbro and diorite rocks seen in the northern portion also form moderately potential aquifers, where the depth of wells generally varies from 8 to 12 m and water levels varies from 3 to 7 mbgl. The yield of dug wells in the crystallines varies in general from less than 12 to 144 m$^3$/day and can sustain pumping for a period of from less than 1 to 3 hours in a day.

Deeper aquifers in the crystallines with secondary intergranular porosity and fractures are developed using borewells, the depth of which generally varies from 10 to 100 m with yield in the range of 6 to 528 m$^3$/day. The yield of borewells in charnockites varies between 6 to 70 m$^3$/day and that in diorite and gabbro formations varies from 10 to 528 m$^3$/day. The studies by the CGWB also revealed deep potential fractures between 122 and 140 m along lineaments with maximum yield around 960 m$^3$/day. The over burden thickness is maximum in gneissic areas in central and eastern parts of the district, generally in the range of 20–35 m, and minimum in charnockites, dolerite and gabbro areas on the western and northern part of the district, generally in the range of 15–25 m. The casing depth of borewells generally varies from 3 to 53 mbgl.
3.1.13 Kannur

The hydrogeological units encountered in the district are weathered and fractured crystallines, semi-consolidated sediments equivalent to Warkalis, laterite formations and unconsolidated recent alluvium. The crystallines include charnockites, pyroxene granulites, garnetiferous gneisses, hornblende biotite gneisses and schistose rocks.

The coastal alluvium comprising of sand, silt and clay forms potential phreatic aquifers all along the coast and in the valleys and is extensively developed using dug wells and filter-point wells. The thickness of alluvium is generally low in the district except around Mulappilangad where it is more than 20 m. The depth to water level in the dug wells here ranges from 0.5 to 2.35 mbgl. The terriary, equivalent to Vaikom beds, occur along the coastal region and are found to be lateritised on the top. Very potential aquifers are not found in this district. Laterite is the marker horizon that differentiates between tertiary and recent alluvial sediments and its thickness ranges from 10 to 20 m constituting potential aquifer in the midland regions of the district. The depth of dug wells in the laterite range from 8 to 23 mbgl and the depth to water level vary from 1.5 to 20 mbgl. The yield of the wells ranges from 15 to 30 m³/day.

The weathered and fractured rocks in the crystalline formations form potential phreatic aquifers where the depth to water table varies from 3–13 mbgl. The thickness of weathered zone is in the range of 3 to 20 m and the yield of wells ranges from 10 to 20 m³/day. The recuperation rate of wells is very poor. The degree of weathering is generally low in charnockite areas and the wells located in charnockites vary in depth from 6–13 mbgl. The gneissic rocks are highly weathered and well jointed and form good water bearing zones. The deeper fractured crystalline aquifers are under semi-confined to confined conditions. They are tapped through borewells. The potential fractures are encountered at depth varying generally from 10 to 120 mbgl with discharge ranging 1 to 1200 m³/day.

3.1.14 Kasaragod

The hydrogeological units encountered in the district are alluvium including valley fills, laterites and weathered and fractured crystallines. Coastal alluvium occurs generally as narrow strips and its width increases up to 5 km towards the southern part of the district. The valley fills occur in between laterite hills which are composed of colluvium and alluvium. The water level ranges from 1.3 m to 5.6 mbgl, and the water level fluctuation is in the range of 0.88 to 2.80 m. The yield of wells including filter point wells in alluvium ranges from 10 to 50 m³/day. The dug wells have depth ranging from 3.59 m to 6.74 mbgl and filter-point wells have depth of about 6 metres.

Laterite is the most wide spread and extensively developed aquifer in the district. The depth to water level ranges from 1.6 to 23.90 mbgl, and the water table fluctuation ranges from 0.36 to 6.39 m. Generally large diameter wells are constructed in laterite terrain with depth ranging from 4.84 to 24.76 mbgl and diameter from 2 to 4 m. The yield of wells in laterite ranges from 5 to 60 m³/day during the post-monsoon period, which reduces to 2 to 20 m³/day in the summer. In the northern part of the district, in midland areas a very common groundwater abstraction structure is tunnel wells (locally called Surangam), which are horizontal wells (locally called Adit) with a width of 50 cm to 75 cm and height of around 2 m. The length of tunnel well varies from few metres to 100 m.
Generally the tunnel well starts at the foot hills and cuts across the slope horizontally to have the maximum yield. The yield of tunnel wells varies from 1 to 50 m³/day in the summer.

The weathered crystallines encountered underlying the laterite in the eastern part of the district form aquifers of limited potential sustaining domestic dug wells. The depth to water level ranges from 1.64 to 16.11 mbgl and the water level fluctuation ranges from 0.53 to 5.73 m. The yield of wells ranges from 1 to 10 m³/day in the summer period. In the fractured crystalline aquifer, groundwater occurs under semi-confined to confined conditions. They are tapped through borewells of depths generally ranging from 40 to 120 m and the yield varying from 12 to 1700 m³/day. The NE-SW lineaments, followed by N-S and E-W lineaments are found to be potential in the district. The borewells in the central and northern parts of the district yields comparatively higher discharges.
4 Groundwater Quality

4.1 Introduction

The usability of groundwater is determined by its quality in terms of physical, chemical and bacteriological aspects, which in turn depends on the environment of groundwater occurrence, sources of pollution and level of exploitation. The quality aspect is as important or even more than the quantity as it affects the usability. The groundwater is generally clean, colourless and odourless with little or no suspended matter in most hydrogeological situations and therefore is used directly without treatment. Some of the physical properties that are critical to restrict the usability of groundwater are colour, odour and turbidity. In addition, temperature is another parameter that indicates reactive groundwater regime due to natural processes or external interferences. The chemical quality of groundwater is dependent on its source, geology, climate, environment and use as water is an excellent solvent. Bacteria and micro-organisms are also present in groundwater, some of which are harmless while some are disease-causing, known as pathogenic bacteria. Another quality index of groundwater is biochemical oxygen demand (BOD), which is the amount of oxygen required to cause the biological decomposition of organic matter. In addition to the natural processes and factors that govern the quality of groundwater, the induction of objectionable matter arising from human interferences in the groundwater regime changes its properties, which is known as groundwater pollution. The pollutants are generally the physical characters, ionic matter, organic compounds, organic materials, bacteriological matter and radioactivity.

Groundwater in Kerala, in general, is fresh and suitable for domestic, irrigation and industrial purposes (CGWB, 2012). However, prevalence of water-borne diseases of the gastro-intestinal system, diarrhoea, dysentery, typhoid, worm infestation and infectious hepatitis are attributed to deteriorated quality of drinking water, mostly from wells. There are reports of low pH, high levels of alkalinity, magnesium, hardness, chloride, calcium, total dissolved solids, fluoride, etc. from many places. Most of the reports on groundwater quality are fragmented and are restricted to only specific zones. A representative groundwater quality status for the entire state is generated based on stratified random sampling of groundwater from 98 wells covering all the districts and their analysis for physico-chemical and biological parameters (Boominathan et al., 2012). The summary of physico-chemical and biological properties of groundwater in the state is given in Table 4.1. The parameters exceeding the desirable limit in each district are given in Table 4.2. Overall, the groundwater properties from 90.82% of wells indicated that they are outside the desirable limit with respect to one or more parameters thereby making them unsuitable for drinking without treatment.
About 95% of the observation wells, tapping the phreatic zone, have specific electrical conductance below 500 µS/cm at 25°C. Isolated occurrence of brackish/saline groundwater has been observed, mainly in the coastal districts and in the vicinity of tidal estuaries and streams.

Table 4.1: Summary of physical, chemical and biological properties of groundwater

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<td>Na⁺</td>
<td>mg/L</td>
<td>63.2</td>
<td>28.7</td>
<td>2.6</td>
<td>1203.2</td>
<td>165.2</td>
</tr>
<tr>
<td>K⁺</td>
<td>mg/L</td>
<td>13.6</td>
<td>5.4</td>
<td>0.6</td>
<td>160.7</td>
<td>24.1</td>
</tr>
<tr>
<td>F⁻</td>
<td>mg/L</td>
<td>0.4</td>
<td>0.4</td>
<td>0.2</td>
<td>1.6</td>
<td>0.2</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>mg/L</td>
<td>18.8</td>
<td>9.2</td>
<td>0.0</td>
<td>200.7</td>
<td>30.4</td>
</tr>
<tr>
<td>PO₄³⁻</td>
<td>mg/L</td>
<td>0.1</td>
<td>0.1</td>
<td>0.0</td>
<td>1.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Fecal coliform</td>
<td>MPN/ 100 mL</td>
<td>72.79</td>
<td>17</td>
<td>0</td>
<td>1600</td>
<td>204.48</td>
</tr>
</tbody>
</table>

Note: WT - Water Temperature, TDS - Total Dissolved Solids, EC - Electrical Conductivity, DO - Dissolved Oxygen; and SD - Standard Deviation

Source: Boominathan et al., 2012.

It was found that among 98 samples, only nine samples from Attathodu, Pampa Valley, Athikayam, Vadaserikara, Pandalam (Pathinamthitta district), Kandiyoor (Alappuzha), Kattachal (Kollam), Pazhayidam (Kottayam) and Nedumangadu (Thiruvananthapuram) were within the desirable limit as per Bureau of Indian Standard (BIS) with respect to physico-chemical and biological parameters. The quality of water is outside the desirable limit as per BIS standards at places like Fort Cochin (Ernakulam), Plachimada and Kollengode (Palakkad) and Kodungallur (Thrissur).
4.2 Physico-Chemical Properties

The groundwater in Kerala is mostly acidic in nature (86% of the samples) and the rest alkaline. Almost 62% of the samples were found to have pH varying from 4.32 to 6.46 (less than the desirable limit of 6.5–8.5). The low pH of groundwater is generally attributed to sulphide oxidation (Weiner, 2000), acidic nature of the soil or aquifer characteristics (Harikumar & Kokkal, 2009). The pH could be improved by adding clam or oyster shells to drinking water in wide-mouthed barrels (Bordalo & Savva-Bordalo, 2007). Low pH was observed in Idukki (Rejith et al., 2009), Kottayam (Vijith & Satheesh, 2007) and Muvattupuzha (Gopinath & Seralathan, 2006; Laluraj, Gopinath, Dinesh Kumar & Seralathan, 2006) districts and Kabbini, Periyar and Neyyar river basins (Harikumar & Kokkal, 2009).

Table 4.2 Number of parameters exceeding the desirable limit per district

<table>
<thead>
<tr>
<th>District</th>
<th>No. of samples analysed</th>
<th>No. of samples exceeding the DL with one or more parameters</th>
<th>Parameters exceeding the DL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alappuzha</td>
<td>7</td>
<td>6</td>
<td>pH, NO₃⁻, F⁻, TDS, Sal, MPN</td>
</tr>
<tr>
<td>Ernakulam</td>
<td>8</td>
<td>8</td>
<td>pH, Alk, Har, Ca²⁺, Mg²⁺, TDS, Sal, MPN</td>
</tr>
<tr>
<td>Idukki</td>
<td>5</td>
<td>5</td>
<td>pH, NO₃⁻, Mg²⁺, MPN</td>
</tr>
<tr>
<td>Kannur</td>
<td>5</td>
<td>5</td>
<td>pH, Mg²⁺, MPN</td>
</tr>
<tr>
<td>Kasaragod</td>
<td>11</td>
<td>11</td>
<td>pH, MPN</td>
</tr>
<tr>
<td>Kollam</td>
<td>6</td>
<td>5</td>
<td>pH, Mg²⁺, TDS, MPN</td>
</tr>
<tr>
<td>Kottayam</td>
<td>7</td>
<td>6</td>
<td>pH, MPN</td>
</tr>
<tr>
<td>Kozhikode</td>
<td>7</td>
<td>7</td>
<td>pH, MPN</td>
</tr>
<tr>
<td>Malappuram</td>
<td>6</td>
<td>6</td>
<td>pH, Ca²⁺, TDS, MPN</td>
</tr>
<tr>
<td>Palakkad</td>
<td>8</td>
<td>8</td>
<td>pH, Alk, Cl⁻, Har, Mg²⁺, F⁻, TDS, Sal, MPN</td>
</tr>
<tr>
<td>Pathanamthitta</td>
<td>7</td>
<td>2</td>
<td>pH</td>
</tr>
<tr>
<td>Thiruvananthapuram</td>
<td>7</td>
<td>6</td>
<td>pH, TDS, MPN</td>
</tr>
<tr>
<td>Thrissur</td>
<td>9</td>
<td>9</td>
<td>pH, Alk, Cl⁻, Har, Ca²⁺, Mg²⁺, SO₄²⁻, TDS, Sal, MPN</td>
</tr>
<tr>
<td>Wayanad</td>
<td>5</td>
<td></td>
<td>pH, MPN</td>
</tr>
</tbody>
</table>

Note: Sal – Salinity; TDS – Total Dissolved Solids; Alk – Alkalinity; Har – Hardness; and DL – Desirable Limit; MPN – Most Probable Number

Source: Boominathan et al., 2012.
Generally, the salinity of groundwater is well within the desirable limit (< 500 ppm) in 91% of the samples. However, there are conspicuous anomalies of higher salinity even in wells away from the sea water regime as found in Aluva (2900 ppm) and Kothamangalam (3000 ppm) of Ernakulam district, and Guruvayoor (3180 ppm) and Kodungallur (4310 ppm) in Thrissur district. The samples from Kollengode and Plachimada in Palakkad district, Chavakkad and Kodungallur in Thrissur district and Veeyapuramin in Alappuzha district also showed higher salinity between 600 and 900 ppm. The higher salinity in the wells away from the seawater regime is mainly due to the addition of chlorides for the purpose of disinfection. It is interesting to note that the municipal well in Guruvayoor shows higher salinity whereas a well near the temple shows very less salinity (590 ppm). The influence of sea water is considered as the reason for higher salinity in coastal plain regions.

The total dissolved solids (TDS) was above the desirable limit of 500 ppm in eight samples of Thrissur, four samples of Ernakulam, three samples of Palakkad and one sample each of Malappuram, Alappuzha, Kollam and Thiruvananthapuram districts. The highest value 6060 ppm was found in Kodungallur in Thrissur district. Evaporation, groundwater movement through solute mineral containing rocks, untreated sewage, waste disposals and agrochemicals are the main contributors to the high TDS value. The difference in the taste of non-potable and potable water is often due to the presence of high TDS in water. In addition, certain metals, particularly iron, copper, manganese and zinc also could influence taste (Weiner, 2000). The high TDS values were also observed from coastal plains such as Chavara in Quilon district (Shaji, Nimi & Bindu, 2009) as well as midland and highland from Kabini, Periyar and Neyyar river basins (Harikumar & Kokkal, 2009).

The highest value of magnesium was found in Kodungallur (141.46 mg/L) and it was more than the desirable limit of 30 mg/L in many places at Palakkad. The magnesium in groundwater is mainly from the ferromagnesian minerals in igneous rocks and magnesium carbonates in sedimentary rocks than the anthropogenic sources (Weiner, 2000). Its concentrations beyond 125 mg/L can have a cathartic and diuretic effect (APHA, AWWA & WEF, 1995). Magnesium contamination was found to be more in Palakkad (5 samples), Thrissur (3 samples) and one each in Ernakulam, Idukki, Kollam and Kannur districts. Higher values are reported from Periyar and Neyyar river basins (Harikumar & Kokkal, 2009). It is considered that Mg²⁺ is contributed by the natural processes as the magnesium concentration in most of the samples is within the desirable limit.

The hardness is also within the desirable limit of 300 mg/L in almost 95% of samples studied. The anomalous areas are three spots in Palakkad district and one in Ernakulam and Thrissur districts. The sample from Kodungallur in Thrissur indicated the highest value of hardness (700 mg/L). Certain spots from Kabbini, Periyar and Neyyar river basins also reported higher hardness (Harikumar & Kokkal, 2009). The principal sources of hard water are calcium and magnesium carbonates (Weiner, 2000).

The important constituents contributing alkalinity are bicarbonate (HCO₃⁻), carbonates (CO₃²⁻) and hydroxyl (OH⁻) anions (Weiner, 2000). Alkalinity exceeded the desirable limit of 200 mg/L at Plachimada (340 mg/L) and Kollengode (408 mg/L) in Palakkad and Fort Cochin (352 mg/L) and Kodungallur (304 mg/L) in Ernakulam districts. The alkalinity was also higher in certain locations of the Neyyar river basin (Harikumar & Kokkal, 2009). The strong positive correlation between Ca²⁺, Mg²⁺, HCO₃⁻, alkalinity and hardness indicates that magnesium is the main contributor for alkalinity rather than calcium.
Chloride was within the desirable limit in almost 97% of the samples studied. It exceeded the desirable limit of 250 mg/L at Plachimada (314.35 mg/L) and Kollengode (268.29 mg/L) in Palakkad district and Kodungallur (921.01 mg/L) in Thrissur district. Chloride was also found higher in the coastal tracts of Kerala (Laluraj, Gopinath & Dinesh Kumar, 2005) and certain spots of Kabini and Neyyar river basins (Harikumar & Kokkal, 2009). The chloride in natural waters is due to the weathering of chloride minerals, and higher amount of chlorides in water poses risk to people having heart and kidney problems (Weiner, 2000).

The calcium concentration in groundwater samples are mostly within the desirable limit (75 mg/L) as found in 97% of the samples. The anomalous values are found at Fort Cochin (157.11 mg/L), Ponnani (109.02 mg/L) and Kodungallur (120.24 mg/L). Calcium in groundwater is mainly due to the dissolution of minerals and its higher concentration may increase the risk of kidney stones when exposed for long periods of time (Weiner, 2000).

Generally, the nitrate in groundwater is within the desirable limit of 45 mg/L except in two samples from Kayamkulam (Alappuzha) and Old Munnar (Idukki) having concentration of 45.3 mg/L and 50 mg/L, respectively. Even this is within the guideline value (50 mg/L) of WHO (2008). It indicates that the anthropogenic influence on groundwater is minimal. Fertilisers, animal waste and human sewage are the main sources for nitrates. High concentration (>1–2 mg/L) of nitrate in groundwater may be the result of manure seepage and fertilisers through agricultural activities (Weiner, 2000). High nitrate content causes gastric carcinomas and blue baby diseases/methemoglobinemia in the case of children (Comly 1945; Gilli, Corrao & Favilli, 1984).

The concentration of sulphates is also under the desirable limit (200 mg/L) except a sample from Kodungallur (200.7 mg/L) which is just 0.7 mg/L more than the desirable limit. The sulphates, $\text{SO}_4^{2-}$, are of natural origin and may come from sedimentary rocks, sulphate deposits as gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and hydrate ($\text{CaSO}_4$). According to Weiner (2000), high concentration of $\text{SO}_4^{2-}$ leads to diarrhoea.

The concentration of fluorides in groundwater exceeded the desirable limit (1 mg/L) at Mullackal (1.4 mg/L) and Kalikulam Junction (1.2 mg/L) in Alappuzha district and Kollengode (1.6 mg/L) in Palakkad district. Detailed sampling studies indicated that almost 43% of the samples at Palakkad and Alappuzha (8 samples each out of 37 samples) exceeded the BIS limit for fluoride in drinking water. The fluoride content was reported to be low varying from 0.2 to 0.5 mg/L in about 91.84% of samples. The optimum level of fluoride content (0.6–0.7 mg/L) was reported only in 5% of the samples in Kodungallur (Thrissur), Muvattupuzha and Mattancherry (Ernakulam), Kannimari (Palakkad) and Thiruvallam (Thiruvananthapuram). However, only one sample (Kollengode) was above the guideline value of 1.5 mg/L notified by the WHO (2008). According to Weiner (2000), fluoride comes from weathering of minerals like fluorite ($\text{CaF}_2$), cryolite ($\text{Na}_3\text{AlF}_6$), and fluorapatite ($\text{Ca}_5\text{F}(\text{PO}_4)_3$). Low F– content (< 0.60 mg/L) causes dental caries, whereas high (>1.20 mg/L) fluoride levels cause fluorosis (ISI, 1983). Fluoride contamination was observed by George & Prakasam (2008) in the Edamulackal gram panchayat, Kollam district, Harikumar, Madhavan & Khan (2000) in Thrissur, Palakkad, and Alappuzha districts, and Shaji et al., (2007) in Palghat district.
4.3. Biological Properties

Faecal coliform contamination was found to be highest in Thrissur and lowest in Pathanamthitta. According to the studies of the CWRDM, the biological contamination was mainly due to faecal coliform and faecal streptococcus due to improper disposal of organic garbage or leachates from the tanks or pits (Harikumar & Kokkal, 2009). The studies indicated that the contamination was mainly due to unscientific construction of latrines as evident from 55.5% of water samples. 11.1% samples indicated that the contaminant was due to animal source and 33.3% indicated contamination from both latrine and animal sources. The distance between wells and latrines are highly significant in this context and reduction in contamination level increases with distance in the case of faecal coliform. In general, 46.2% wells located at a distance less than 7.5 m from the latrine pits showed the presence of E. coli, whereas 11.8% wells located at a distance more than 7.5 m from the latrine showed the presence of E. coli. The study revealed that the risk of wells with lining to have presence of E. coli is less than 25%, when compared to wells without lining. The wells with parapets and platforms have significant reduction in contamination as compared to open wells. The wells near double pit latrines and septic tanks showed lower levels of faecal coliform than in wells near single pit latrines. Further, it was also observed that the rainfall prior to the day of sampling appeared to have significant influence on bacterial contamination levels. It was also found that the turbidity and pH of water increased the contamination levels of faecal coliform, faecal streptococcus and E. coli. Increase in temperature appears to increase faecal coliform level but not faecal streptococcus. Higher percentage of wells was contaminated with E. coli in the pre-monsoon than post-monsoon periods. Also, E. coli contamination in the post-monsoon periods is higher than that in the monsoon.

The bacterial contamination in groundwater causes typhoid, diarrhoea, cramps, nausea and headaches (EPA, 2001). A coliform study was conducted in coastal Kerala (Calvert & Andersson, 2000; Laluraj et al., 2005), Kottayam (Panicker, Basi, Alexander & Ravindran, 2000), Kollam (Krishnan et al., 1994) and Thiruvananthapuram (Varghese & Jaya, 2009) districts, Chalakudy basin (Babu et al., 2007), Kabbini, Periyar and Neyyar river basins (Harikumar & Kokkal, 2009).

4.4 Pollution Potential

In general, the quality of groundwater in Kerala is good except for widespread presence of biological contaminants. However, localised water quality problems associated with excess iron, chloride, low pH, excess fluoride, excessive turbidity, etc. are on the increase (Ajithkumar, 2015; Harikumar, 2015; Shaji E., 2015). One of the major concerns is the presence of fluoride in both shallow and deep groundwater aquifers in Alappuzha in coastal sedimentary rock formations and in Palakkad in crystalline rock formations. The dug wells of Palakkad shows high fluoride content up to 5.75 mg/L at Kopanur. The borewells of Palakkad also showed high fluoride content (0.3–3.12 mg/L), the highest reported from Chinnamoolathara. The borewell used for drinking water supply at Eruthenpathy showed higher fluoride content of 1.76 mg/L. The fluoride concentration in both phreatic and deeper aquifers, especially in the eastern part of Palakkad district, is found to be higher. In Alappuzha town, in the deeper aquifers tapping Warkali formations, the fluoride concentration was reported as 1.5–2.6 mg/L. Fluoride content higher than 1 mg/L is reported from 11 wells used for providing drinking water supply to the Alappuzha municipality by the KWA.
As such, Palakkad and Alappuzha are the two hotspots with respect to groundwater quality. In Palakkad, fluoride, calcium, magnesium and chloride are higher than the recommended limits of safe drinking water (BIS level) in 26%, 42%, 74% and 50% of sample, respectively. The sodium concentration is found above the limit for safe drinking water (WHO) in 29% of the samples. Comparatively, the drinking water in Alappuzha is of better quality, but for higher fluoride and iron in 42% and 21% of the samples exceeding the limits set by the BIS.

**Box 1 : Cross Contamination of Wells due to On-Site Sanitation Systems**

In Kerala, with homestead type of habitation, almost all the households have toilets and most of the houses meet their drinking water needs from open dugwells, which are estimated to number around 67 lakh. There are 26 lakh septic tank toilets and 44 lakh leach-pit toilets and these encounter the water table leading to cross-contamination by pathogenic bacteria, viruses, protozoa and several more complex multicellular organisms that can cause gastro-intestinal disorders. Currently, the water is disinfected by chlorination. However, the threat of contamination from the formation of halogenated organic and other toxic compounds cannot be ignored as the potential carcinogenicity of compounds, such as trihalomethanes formed during chlorination of waters containing organic substances, is high. Therefore, it is most desirable to protect the drinking water source from the contaminant source by distancing the structures appropriately to prevent cross-contamination, rather than curing the infected water. The daily per capita contribution of coliform bacteria is estimated to be about 300 billion. A sewage flow of 100 gallons per day per person contains 750,000/ml of coliform bacteria. The natural bacterial self-purification process brings about substantial reduction of coliform bacteria in freshwater, amounting to about 90% in 2 days with only 1% remaining after 4–5 days of passage time as it does not generally multiply after leaving the host organisms. This critical fact has to be taken into account while placing the drinking water and toilet structures.

In an aquifer, the groundwater supply as well as the contaminant transport depends on the porosity and permeability of the medium, enabling movement of water towards an extraction point. The pollutant movement, however, is essentially controlled by dispersion. If a small volume of pollutant is released into an aquifer, it will not retain its fixed volume. As a result of molecular diffusion and, more importantly, mechanical dispersion, the pollutant will spread out to form a plume both along and perpendicular to the flow direction, becoming diluted in the process. The mechanical dispersion arises primarily from the tortuosity of the pore channels or fissures and from the different speeds of groundwater flow in channels or fissures of different widths. Thus the duration of contamination, during which the pollutant is decreasing, is directly linked to the water transit or water residence time between the point source, such as the latrine pits and the sink, such as the wells. The groundwater has wide range of residence times and in unsaturated zones, it is usually weeks to months. Therefore, soil and aquifer characteristics have a major role in the contaminant transport and the distance between well and latrine source is very critical. This, however, varies from place to place depending on the terrain, soil and aquifer characteristics.
Box 2: Abuse of Groundwater Resource at Plachimada

Plachimada, a locality in Palakkad district is known for abuse of groundwater resource. The Coca Cola Factory situated there in an area of about 34 acres of land was drawing water from six borewells and two open wells. The factory, in a report in 2002, stated that the water requirement was 6.35 lakh lpd when operated in full capacity, whereas the normal use was 5 lakh lpd and the waste water release was 1.5 to 3 lakh lpd. The extraction of such huge quantity of water depleted the aquifer and deteriorated the water quality. Many of the borewells and open wells dried up and the salinity, hardness and toxic chemicals (from waste water discharge) in groundwater increased making the water unsuitable for consumption. The sludge from the Effluent Treatment Plant of the factory exacerbated the crisis. Part of the sludge was dumped in landfill sites within the premises of the factory and the rest were trucked out and disposed of in farmlands by impressing upon the peasants that it is good manure. However, the sludge had no nitrogen content but dangerous levels of cadmium and high levels of lead which resulted in nutrient imbalance in the soil and leached into wells. Consequently, the fodder and water in Plachimada and surrounding areas were contaminated with copper, cadmium, lead and chromium more than the admissible level of the WHO. It was also reported that the factory disposed wastewater into the dry boreholes for the disposal of solid wastes that further aggravated the scenario. The studies of Kerala Agricultural University exposed that the fodder, milk, meat and egg samples collected from Plachimada area contained the above elements at toxic levels. In 2003, the District Medical Officer advised the people of Plachimada that the water there was polluted and unfit for consumption. The High Power Committee constituted by the Government of Kerala to assess the extent of damage caused by the Coca Cola Factory at Plachimada in 2010 reported that it caused and contributed to the deterioration of the quality and quantity of groundwater beyond immediate repair and consequential public health problems, displacement and migration of labour and destruction of the agricultural economy of the region. An indicative assessment of the Committee stated that the total loss to the environment was of the order of Rs. 216.26 Crore in terms of agricultural loss (Rs. 86.16 Crore), health damages (Rs. 30 Crore), cost of providing water (Rs. 20 Crore), wage loss and opportunity cost (Rs. 20 Crore) and cost of pollution of water resources (Rs. 62.10 Crore).

Endosulfan is a persistent, toxic, broad-spectrum organochlorine pesticide (OCP) used on food and non-food crops. Introduced in the 1950s, it emerged as a leading chemical used against a broad spectrum of insects and mites in agriculture and allied sectors. Endosulphan are toxic and they persist in the environment for a limited period of time and later are subjected to chemical processes of degradation, hydrolysis, oxidation, photolysis, etc. by the ecosystem. In human health assessment studies, endosulfan is shown to have high acute oral and inhalation toxicity as well as dermal toxicity. According to BIS, 2012, the permissible limit of endosulfan in drinking water
is 0.4 µg/L. Since 1954, OCPs like endosulphan are used extensively in India for agriculture as well as in the public health sector. Due to its hydrophobic nature, endosulfan tends to get adsorbed to soil particles, resulting in persistence. The rate of degradation of endosulfan is rather low and often results in the formation of endosulfan sulphate, which is an oxidative metabolite shown to be as toxic and persistent as the parent compound. Pesticide residues in the soil can move from the surface when they dissolve in run-off water, or percolate down through the soil, and eventually reach the groundwater. The pesticides and their transformation products are reported in groundwater from many part of the world.

**Box 3 : Perchlorate Pollution in Keezhmad Panchayat, Ernakulam**

A doctor of the Primary Health Centre, Keezhmad gram panchayat during routine medical check-up found wide spread incidences of hypo-thyroid diseases in the people of Kulakkad colony. He carried out a detailed investigation and found that the well water in that locality contains perchlorate, a dangerous chemical at very high concentration and suspected that it could be from one of the three factories in the vicinity, one manufacturing plywood, other spices and the third making perchlorate (ISRO factory). This analysis of well water samples collected from the localities indicated that the source of perchlorate pollution is the ISRO factory. Further tests indicated that the effluent from the ISRO factory indicated the concentration of perchlorate as 10,000 parts per billion (ppb) and the water from a nearby well indicated a perchlorate concentration of 6116 ppb. Almost 60 people in the locality including two using the well water are reported positive for hypothyroid disease. Perchlorate is a chemical used as rocket fuel. (Ajithkumar, 2015)

In Kerala, endosulfan was applied on cashew plantations extensively in Kasaragod district. A recent study found that combined toxic residues of endosulfan in the sediment and soil samples of selected areas of Kasaragod district are persistent for a period of 1.5–2 years, but the persistence showed variations depending upon the climatic conditions and physico-chemical characteristics like pH, organic matter content and particle size of the soil in the area. In water, it was detected only in 9% of the samples and the repeatability of detection was poor (Harikumar, Jesitha, Megha & Kokkal, 2014). It is also reported that the concentration of endosulfan was decreasing over a period of time. This is because the endosulfan entering into natural water bodies in a gaseous or dissolved phase is assumed to rapidly adsorb to suspended matter. In soil, it is fairly immobile and hence highly persistent. The persistence of endosulfan in sediments is also attributed to their acidic nature, which was reported to be a favourable condition. Majority of sediment samples where endosulfan was detected were rich in organic matter.
Box 4: Pepsi, Palakkad and Pollution

In Palakkad, M/s. Pepsi Company is operating a large scale plant for soft drinks and the raw material is essentially the local groundwater. The process is such that 25% of the extracted water is converted to the product and the rest is discharged as liquid waste and a small portion as solid waste. The company extracts about 78 lakh litre of groundwater per day and the continued operation generates a huge quantum of sludge containing heavy metals which are dangerously stored in the premises of the company in sheds. The effluent from the company used to flow out from the premises and a Joint Parliamentary Committee which visited the company, directed them to stop this. Since then, they are discharging the effluent into a canal of 1 km length spread out in an area of 53 acres within the compound of the company. The company claims that the effluent from the factory is within the stipulated limit of the State Pollution Control Board which is known to be technically correct. For example, the sodium content of the factory effluent shows only 180–200 ppm though the permissible limit is 250 ppm. But as the effluent is continuously discharged into the canal, the pollutant concentration accumulated to very dangerous levels as the sodium concentration was 5000 ppm and potassium concentration was 4000 ppm. This is a very dangerous threat to shallow and deeper groundwater domains of the region (Ajithkumar, 2015).

4.5 Management of Groundwater Quality

The physico-chemical parameters of groundwater in Kerala, in general, are not affected by anthropogenic activities, as evident from the low nitrate and sulphate values. However, the groundwater regime of Kerala, especially shallow aquifers, exhibits low pH and infestation with faecal coliform bacteria, the latter due to unhygienic practices. Therefore, it is necessary to maintain the pH levels within the desirable limit and curb the bacterial contamination. The health hazard due to coliform contamination could be minimised by maintaining better hygiene with good sanitisation facilities and practices such as chlorination, boiling and filtration of drinking water prior to use, constructing the septic tanks away from the drinking water source (well), and establishing systems for septage and faecal sludge treatment systems. Periodical checking of drinking water quality of wells, and checking for leakage from drinking water and septic tank pipelines will ensure safe drinking water. Government, non-governmental organisations, and local institutions can come forward to analyse some important water quality parameters for free to provide a healthy and hygienic environment. Also, conducting awareness programmes to maintain hygienic conditions around drinking water sources by the concerned government, non-government organisations, and local institutions would lead to safer drinking water provisions.

The groundwater samples from Palakkad and Alappuzha districts in Kerala show high fluoride content and according to WHO, the maximum acceptable fluoride concentration in drinking water is 1.5 mg/L. Fluoride is often considered as a double-edged sword because deficiency of fluoride intake leads to dental caries while excess consumption leads to dental and skeletal fluorosis.
Symptoms affecting the soft tissues such as muscles and ligaments are also reported (Kharb & Susheela, 1994). Fluorosis is an important clinical and public health problem and global prevalence of fluorosis is reported to be about 32%. Due to the high toxicity of fluoride to mankind, there is an urgent need to treat fluoride-contaminated drinking water to make it safe for human consumption. The conventional method of fluoride removal includes ion-exchange, reverse osmosis and adsorption. The ion-exchange and reverse osmosis are relatively expensive and therefore, adsorption is considered as a viable method for the removal of fluoride. Adsorption involves the passage of contaminated water through an adsorbent bed, where fluoride is removed by physical, ion-exchange or surface chemical reaction with adsorbent. The tested materials include activated alumina, amorphous alumina, activated carbon, calcite, zeolite clay, kaolinite, bentonite, charcoal, bleaching earth, red mud, etc. Plant materials are reported to accumulate fluoride and hence considered as good defluoridating agents. Studies indicated that Ramacham (Vetiveria zizanioides), Tamarind seed (Tamarindus indica), Clove (Eugenia carryophyllata), Neem (Azadirachta indica), Acacia (Acacia catechu wild), Nutmeg (Myristica fragrans), and coffee husk (Coffea arabica), which are grown indigenously in Kerala, work efficiently to remove excess fluoride content from water. The phosphoric acid activated Vetiver (Ramacham) root showed good adsorption capacity for the removal of fluoride from aqueous solutions than the fresh powdered Vetiver root (Harikumar, Jaseela & Megha, 2012). The percentage of fluoride removal increases with adsorbent dose and time at a given initial solute concentration.

Phytoremediation is proved to be an efficient, economical and ecological alternative to accelerate the removal of endosulfan from water and soil. The aquatic plant species Salvinia molesta proved to be the best variety among different plant species selected for the removal of endosulfan from water and soil. Among terrestrial plant species, percentage removal of endosulfan was found to be higher with tomato. It is reported that the percentage removal of endosulfan by Salvinia molesta was of the order of 97.94 ± 0.33% in 21 days. There are also studies reporting the microbial degradation of endosulfan using Pseudomonas species in 16 days.

The groundwater quality management is all about ensuring the availability of colourless and transparent water without foul smell, bad taste, detrimental chemicals and high acidity or alkalinity. This requires testing of the quality of water periodically and taking corrective measures, if required. The Kerala Water Authority has established water quality testing facilities up to the district level. The State Groundwater Department, Public Health Laboratory, and various Research & Development institutions have advanced water quality testing facilities. However, the awareness among the public to have water quality tested or the attitude of these institutions to provide support to people is not very encouraging. This is very pertinent in a state where more than 60% of the people depend on their own or local source for the purpose of drinking water needs. Therefore, more local initiatives are required for safeguarding wells and other drinking water sources, especially dug wells.

The Local Self Government Institutions were encouraged to take up village level programmes for cleansing the drinking water sources, especially dug wells, since the days of Peoples’ Plan Campaign from the 1990s. This included providing parapet walls, desiltation of wells, periodic disinfection, filtration and aeration of water if required, etc. As a result of the campaign, large number of drinking water sources, especially dug wells, were provided with parapet walls in order to ensure that overland flows and leachates do not flow into wells. The drinking water sources that were subjected
to considerable storage loss due to sediment deposits were subjected to desiltation and cleansing. Further, a massive awareness campaign was taken up to sensitize the people to disinfect the wells periodically, preferably on every Sunday. The method suggested was to use bleaching powder at the rate of 2.5 gm for 1000 litres of well water and a detailed procedure was popularised by a ward level campaign team through house visits. Some of the wells showed increased turbidity, especially when the water level lowered during the summer. In such situations, the households were advised to adopt coagulation sedimentation by adding coagulants such as Alum for removing the solids that cause turbidity. The message was to do the coagulation sedimentation in the stored water, preferably, or within the well, if the situation was acute. It was also advised that normal sedimentation or filtration would be sufficient to clean the water if the turbidity was low. It is known that 90% of the solids get deposited at the bottom within 24 hours if kept undisturbed. Also, the organic load is reduced considerably if the water is kept undisturbed for 5 to 7 days. The filtration normally removes the organic contaminants by 60–75% and reduces the content of iron, manganese, heavy metals, etc. by 30–90%. Some of the wells reported the smell of hydrogen sulphide where the advice was to lay a bed of coarse sand at the bottom of wells and keep charcoal in pouches in water. Some of the well water also indicated higher iron content where aeration is found very effective. The message of the campaign is sustained by many households even today.

4.6 An Innovative Approach to Water Quality Monitoring

The water quality characteristics of aquatic environments arise from a multitude of physical, chemical and biological interactions. The major water pollutants are the organic substances that reach water from various sources including households. Thus, there is a need to generate awareness on the level of contamination, if any, of local water sources and take informed actions to prevent their deterioration. Schools should play a very important role in hygiene education, and with the expertise and facilities at the level of higher secondary schools, they can perform a greater role of advocacy towards environmental upkeep of local water sources. Therefore, the government in 2010, through the Suchitwa Mission, launched a programme to involve Higher Secondary Schools and Vocational Higher Secondary Schools in carrying out water quality surveillance of local water sources making use of their chemistry laboratories. It was decided that the district panchayats, corporations and municipalities will extend support for strengthening the laboratories of these schools. Various governmental and non-governmental institutions with expertise in water quality monitoring were drafted for preparing a handbook containing the policy, action plan and protocol and imparting training to the teachers accordingly. The handbook described the significance of water quality parameters and their desirable limits, sampling and preservation criteria, procedure for analysis, requisites for strengthening the school laboratories, organisational aspects, and database generation and reporting.

The scheme envisaged analysis of water quality at three different levels. The first level is for the primary parameters of pH, conductivity, chloride, hardness (Total), turbidity, total coliform and faecal coliform, which is compulsory. The second level is for the optional parameters of fluoride, nitrate and iron. The third level is for the discretionary parameters of heavy metals and pesticides. The classifications of these parameters into three levels were based on the fact that first level parameters are those which lead to common water quality problems in Kerala and these
parameters could be analysed and monitored by school students with the help of trained teachers and improved laboratory facilities. The optional parameters are fluoride, nitrate and iron, which are specific water quality problems in certain parts of Kerala. Hence they are considered as second level or optional parameters that are to be analysed in specialised laboratories such as that of the Kerala Water Authority, R&D institutions and other such organisations. The third level parameters are heavy metals and pesticides, which could be analysed only in well-equipped referral labs with the help of specific instruments and trained persons.

The laboratories of higher secondary schools were to be strengthened for the primary and optional parameters and the services of referral laboratories were to be utilised for discretionary parameters. The scheme provided a great opportunity for the capacity development of teachers and innovative learning for students including exposure to certain tips to overcome certain common and minor pollution problems of local water sources, mainly dug wells. It provided a great opportunity to generate a massive and continually maintained database on the quality and environmental status of local water sources of Kerala, especially dug wells, through the participation of students, teachers and the local community. However, the programme was initiated only in one school under the Thiruvananthapuram district panchayat and did not sustain as it could not withstand the prioritisation process.
5 Assessment of Laws, Policies and Regulations on Groundwater

5.1 Groundwater Governance

Groundwater is a classic common pool resource with near universal and relatively inexpensive access. As an ‘invisible resource’, its extent and limits are difficult to perceive. In recent years, the development and use of groundwater is changing rapidly, often outside the governance framework. As a result, unrestricted pumping and pollution are threatening the sustainability of aquifers. The allocation and use of groundwater are often not aligned with the social goals of equity, sustainability and efficiency. Hence, improved groundwater governance is an important challenge. Groundwater governance is the process of managing the resource through responsibility, participation, availability of information, transparency, custom, and rule of law. It is the art of coordinating administrative actions and decision making among different jurisdictional levels. It comprises the enabling framework and guiding principles for collective management of groundwater for sustainability, equity and efficiency. Although the governance of groundwater is a significant constituent of overall water governance, the characteristics of groundwater and the way in which it is developed and used merit specific governance provisions.

Of the earth’s water, only 4% is freshwater. Of the total freshwater, over 68% is locked up in ice and glaciers, and 30% in the ground. Therefore, groundwater is a vital component of the world’s freshwater resources (USGS, 2016). Consequently, fresh groundwater is a very precious resource with a unique capability for sustaining populations over long periods without any rainfall. Generally, the quality of groundwater is good and it is considered as a first rated resource that could be economically exploited for water supply and also as input for agriculture and industry. Groundwater conditions show large variations spatially and with respect to a diversity of climatic, socio-economic and political settings, which makes groundwater development, management and governance highly context-specific. The benefits of groundwater development are immense as it supplies drinking water to about half of the world’s population and irrigation water to about 40% of the world’s irrigated land, and is an essential input for many segments of the industrial sector. It plays an important role in the sustainability of wet ecosystems and environmental services. Over time, the rates of groundwater abstraction have increased steadily and as a result, the problems of groundwater depletion, groundwater pollution and associated environmental degradation are becoming common across the globe. In addition, in many countries there are socio-economic problems relating to distribution and equity, efficiency of use, and inter-sectoral allocation. The huge value of groundwater resources, the strong human dependence on this resource, the omnipresent threats to it, as well as opportunities to enhance socio-economic benefits from it require that groundwater resources be governed and managed carefully.
5.2 Status of Groundwater Governance

The status of groundwater governance is characterised by assessing (i) the roles and modes of interaction of actors, (ii) legal, regulatory and institutional frameworks; (iii) development and implementation of policies and plans, and (iv) information, knowledge and science. Groundwater governance is highly diverse and has large gaps in institutional systems and delegation of powers for enforcement. However, two common lessons on groundwater governance are that (i) it depends on management and economic conditions and (ii) it varies with the local needs and environment. Thus, governance has to be tailored to locally relevant issues and challenges like intensive groundwater abstraction and consequent depletion, reducing recharge, seawater intrusion, land subsidence, pollution by inadequate sanitation and wastewater treatment, pollution by industry and agriculture, inequitable allocation, and inefficient use.

The potential actors in groundwater governance are diverse, including the public and private sectors, water users, and society in general. Generally, government agencies have the mandate for groundwater management, but in practice they adopt a top-down regulatory approach and a non-interventionist role. In many parts of the world, low awareness of the importance of groundwater has resulted in the absence of political commitment, low budgets and consequent low management capacity. At the local level, individual stakeholders normally manage the resource as there is no effective cooperation among the government agencies, private sector and other stakeholders. In some places, local interest groups like groundwater users associations are involved in tackling emerging issues but are mostly unsustainable due to the reluctance of government agencies for handholding such initiatives and the failure of the collectives in demonstrating transparency and accountability.

In many developing countries, there are customary laws applied to small scale groundwater abstractions. The significance of this has been largely outdone by massive abstractions of groundwater. Most countries are now adopting modern legislations on groundwater which typically cover ownership and right to its use, protection from pollution, and institutional arrangements for management and regulation. The explosive growth of unregulated groundwater use and the resulting problems have prompted many countries to try to redefine groundwater ownership and use rights. Generally, the responsibility for groundwater management is assigned to public agencies at the national or state level, with water quality often brought under a separate legislation and assigned to a different agency. Regulatory systems typically allocate abstraction licenses and control polluting behaviour. Evidence suggests that the enforcement of laws and regulations on groundwater is generally weak. In many countries, non-compliance is pervasive, and in all regions pollution continues largely unchecked. The problems are weak regulatory capacity and widespread lack of adherence to the objectives and practices of regulation.

Detailed information and knowledge and the science of the groundwater resource are critically important for the management of this ‘unseen’ resource, much more than that of surface water (Groundwater governance, 2015). It is found that inventories of shallow aquifer systems are widespread, but mapping and assessment of larger and deeper aquifer systems are not carried out generally except in more developed countries. The monitoring of physical and socio-economic aspects of groundwater is also important but is not sustained over many years in many of the
less developed countries. Hence, information and knowledge of the resource and its dynamics are usually limited. This hampers the sharing of information and knowledge on groundwater availability and constraints and affect the awareness level and stakeholder participation. Lack of awareness about the multiple functions, opportunities and threats of groundwater is a fundamental cause of inadequate groundwater governance.

5.3 Constitutional Provisions

In the Constitution of India, water, i.e. water supplies, irrigation and canals, drainage and embankments, water storage and water power are included in List II of the Seventh Schedule of the Constitution, i.e. the state list. Therefore, the states are empowered to legislate on these aspects and not the centre. This is true for groundwater management as well. However, groundwater is recognized as a national priority and the central government has set up institutions such as the CGWB for managing groundwater. Though the centre provides guidelines for the regulation of groundwater resources, it is for the states to adopt them with whatever modifications necessary to suit their requirements depending upon the nature of the availability of the resource in the respective states. Accordingly, in 1970, the Government of India mooted the Groundwater (Control and Regulation) Bill through the Ministry of Agriculture which was circulated to all the states with an advice to enact the same into an Act with necessary incidental modifications.

If natural resources of any kind are to be developed in a sustainable manner and their equitable distribution ensured, then the nature of rights to it need to be defined and enforced. It is important to determine whether rights to groundwater use are individual or collective, private or public, usufructuary or riparian, and so on. It is important to identify a practical proposition of the rights to groundwater so as to determine the nature of regulation. In India, as per the Easements Act of 1882, the owner of land owns the groundwater beneath it and has the right to sink a bore hole or a well in his land to extract groundwater. This implies that the right to groundwater is basically an individual right which cannot be infringed on by any external agency, even the state. However, India is a welfare state and therefore major developmental works are undertaken by the state for the benefit of citizens. For example, the benefits accruing from irrigation structures constructed with public money for harnessing and augmenting groundwater through percolation tanks, check dams etc. are enjoyed by the users. Also, English Common Law recognizes the doctrine of riparian rights to regulate proprietary rights to water. Each co-riparian owner has the right to have the water flow pass through his land in the same quantity and quality. There is a duty cast upon the upper riparian owner to see to it that the lower riparians are not denied this right. In Common Law, there is a difference between an underground stream where the riparian right is applicable, and groundwater for which the private right is recognized. The common law was followed in India, but it is unwise to rely upon its doctrines in the changed socio-political scenario. The discourse on rights over water resources, especially over groundwater resources, is very complex and therefore, in the existing socio-economic-political situation, it would be appropriate to consider groundwater as a common property resource which can be regulated by the state as a resource to which individuals enjoy only a positive group right (Devi, 1990). The discussion on the problems and prospects of groundwater law in India reveal the following points:
The problems relating to groundwater use and misuse are divergent in different parts of the country and therefore its regulation has also got to be different.

Even a region or sector specific groundwater law will be inadequate as there are various policies, programmes and laws that influence the utilisation of the groundwater resource. The Acts relating to forests, industrial development, irrigation, electricity, co-operative societies, land distribution, etc. have implications on this resource. This is true for various policies of the government like the Forest Policy, Industrial Policy, Water Policy, etc. Therefore, while enacting a comprehensive legislation to deal with groundwater, it is important to consider first the amendments required for the above mentioned statutes and policies. It means that it would be absolutely necessary to review the existing legislations before making a new law relating to groundwater.

A choice will have to be made on the preference of private or public ownership of wells for extraction of groundwater from the point of view of efficiency and equity. Whatever be the strategy, the regulation of private use is found to be difficult.

It has been seen that ensuring accountability by the state is a difficult task and what is possible is to review the laws and policies which contribute to the deterioration of the resource.

The choice of an effective forum for the settlement of disputes relating to groundwater use is absolutely necessary as the traditional courts are not competent to deal with environment disputes which are complex and therefore, setting up of specialised courts is to be considered seriously.

Based on the above points, it is clear that sustainable development and equitable distribution of groundwater resources can be ensured only if the groundwater is treated as a common pool resource. Only in such a situation, can the intervention of the state, institutionalisation, and community participation be contemplated.

5.4 Central Ground Water Authority (CGWA)

The Central Groundwater Board (CGWB) was constituted as an Authority under Section 3 of the Environment (Protection) Act, 1986 vide notification no. S.O. 38 (E) dated 14.1.97 and subsequent amendments, for the purposes of regulation and control of groundwater development and management under the directive of the Honourable Supreme Court of India in 1996. The main objective of constituting the Board as an Authority was the urgent need for regulating the indiscriminate boring and withdrawal of groundwater in the country. Commensurate with the mandate, the Central Groundwater Authority (CGWA) is undertaking groundwater governance through regulation and control of groundwater development and management in the country, particularly in some of the critical and over-exploited areas, through concerned district administration heads.

The CGWA is regulating the development of groundwater for protecting the fresh water aquifers to meet the drinking and domestic requirements. It has so far notified 839 over-exploited, 226 critical and 550 semi-critical groundwater units from among 5723 assessment units (blocks, mandals, taluks, etc.) based on the evaluation executed in association with the state groundwater
organisations. Further, the state administration of the concerned areas have been issued directives under Section 5 of Environment (Protection) Act, 1986, to ensure that no groundwater development is carried out without prior approval of the CGWA. In case of violations, they have been advised to seal the tubewell or even seize the drilling equipment. Abstraction of groundwater for sale and supply has also been banned in these notified areas. The CGWA is directly regulating the groundwater development in the notified areas of Delhi and Haryana where they are allowing limited permission for construction of new tubewells or replacement of existing tubewells to government water supplying agencies, institutes, hospitals, embassies, etc. to meet their drinking and domestic requirements. The district administration is taking action in case of violations, and the complaints received by the CGWA are forwarded to them for action. Directives have also been issued to group housing societies, institutes, hotels, industries, and farm houses to adopt rainwater-harvesting system in such notified areas. In addition, the CGWA has taken initiative to notify the over-exploited areas in the country where registration of groundwater structures through the state administration is being done. This is with a view to reassess the dynamic and static groundwater resource for confirmation of the status of over-exploitation to enforce regulation in the future. Accordingly, the CGWA has so far notified 162 over-exploited areas in various states for registration of ground water abstraction structures. This is for controlling groundwater development and regulating installation of new groundwater abstraction structures. Directions have also been issued to the states to adopt artificial recharge of groundwater and promote rainwater harvesting in all the over-exploited areas falling under their jurisdiction and ensure inclusion of roof top rainwater harvesting in the building bylaws.

The CGWA is represented in the relevant technical expert committees of the Ministry of Environment and Forests (MoEF) for environmental appraisal of various categories of developmental projects under the provisions of the Environment Impact Assessment Notification. This is to ensure that the approval of the CGWA is obtained prior to the commencement of any industry or such other projects, especially in the regulated domains. Such projects are examined and technical clearances obtained on a case-to-case basis based on the recommendations of regional offices of the Central Groundwater Board. Similarly, the groundwater pollution from geogenic sources, such as arsenic contamination are examined by the CGWA on a case-to-case basis and specific directives are given to the state government for appropriate actions. In order to develop the database on drilling activities being carried out as regulatory measures, countrywide registration of drilling agencies are undertaken by the CGWA. Such a database provides information on the current pace of groundwater development as well as micro-level site specific information on groundwater availability and technology advancement for its development. The CGWA is also rendering active assistance to the Honourable Supreme Court, the High Courts and other designated courts on various legal matters concerning water conservation, which includes among others, highway and flyover projects, and protection of water bodies. The CGWA is also involved in training programmes and awareness building on various aspects of groundwater including rainwater harvesting.

Evaluation of industry and infrastructure project proposals seeking groundwater clearance necessitates constitution of a committee at the district level for receiving and evaluating the project proposals for groundwater clearances. This committee under the chairmanship of the
district collector includes (i) a hydrogeologist of CGWB in charge of the concerned district (ii) a representative of the industry, (iii) a representative of the pollution control boards and other nominees as members. The committee shall meet at least once a month depending on the number of proposals received for examination and forward the same to the CGWA through the regional director after reviewing and incorporating clear recommendations to the CGWA which will be cleared within two weeks of receipt. In case of states where the state authority is functional under the Environment (Protection) Act (EPA) 1986 or appropriate state rules and regulations with an operative system of groundwater regulation, the prevailing authority can suitably adopt these guidelines with necessary modifications as per the local policy. They can issue a no-objection certificate (NOC) with a copy to the CGWA or regional director of the CGWB for avoiding duplication and/or overlap.

5.4.1 Proposal for Restructuring the CGWB

Conflicts over water across uses, across town and country, and across industry and agriculture, have become more and more common. In order to address the new challenges in the water sector, a paradigm shift is required in the management of water resources that occurs on the surface and ground. It is also necessary to plan and act comprehensively for effective utilisation of water for addressing the new national challenges of the 21st century in the water sector. Accordingly, the Government of India has constituted a committee on restructuring the CGWB, established in 1971 and the Central Water Commission (CWC), established in 1945. These two organisations played a stellar role in shepherding India’s water sector over several decades and there is an urgent need to strengthen, restructure and redesign these institutions so that India’s water sector can be provided with competent leadership. The Committee submitted its report, “A 21st Century Institutional Architecture for India’s Water Reforms” in July 2016 (Shah, 2016a).

The Committee recommended a brand new National Water Commission (NWC) as the nation’s apex facilitation organisation dealing with water policy, data and governance and as an adjunct office of the Ministry of Water Resources River Development and Ganga Rejuvenation (MoWR). The Commission is conceived as an institution to function with full autonomy and requisite accountability and deal with hydrology, hydrogeology, hydrometeorology, river ecology, ecological economics, agronomy (with focus on soil and water) and participatory resource planning and management. It is conceived to have a strong regional presence in all the major river basins of India and build, institutionalise and appropriately manage an architecture of partnerships with knowledge institutions and practitioners in the water space, in areas where in-house expertise may be lacking. The NWC is conceived to replace the two institutions, CGWB and CWC.

The key mandate and functions of the NWC includes improvement of water resource management and water use efficiency, giving leadership to the national aquifer mapping and groundwater management programmes, insulating the agrarian economy and livelihood system from pernicious impacts of drought, flood and climate change and moving towards sustainable water security. It also envisages to develop a nation-wide, location-specific programme for rejuvenation of India’s rivers; create an effective promotional and regulatory mechanism that finds the right balance between the needs of development and the environment, protecting ecological integrity of the nation’s rivers, lakes, wetlands and aquifers, as well as coastal systems; promote cost effective
programmes for appropriate treatment, recycling and reuse of urban and industrial wastewater, and develop and implement practical programmes for controlling point and non-point pollution of water bodies, the wetlands and aquifer systems. The commission is also expected to create a transparent, accessible and user-friendly system of data management on water that citizens can fruitfully use while devising solutions to their water problems; operate as a world-class knowledge institution available, on demand, for advice to the state governments and other stakeholders, including appraisal of projects, dam safety, interstate and international issues relating to water, and create world-class institutions for broad-based capacity building of water professionals and knowledge management.

5.5 **Legal Position Regarding Groundwater in India**

Beyond the legal principle evolved by the British courts, which was known as the common law principle, there was no law in India exclusively to regulate or control groundwater use. Common law considered groundwater as part and parcel of the land. The legal consequence of the common law rule is that the owner of the land could dig well(s) in his land and extract as much groundwater he can or wants. The land owner was not legally liable for any damage caused to water resources of his neighbor as a result of his over extraction. This legal principle as seen in the Indian Easements Act, 1886 and customary beliefs were used to derive the ownership and rights of groundwater in India. An ‘easement’ is a right that the owner or occupier of certain land possesses, for beneficial enjoyment of that land, for example, right of way, right to light and air, etc. Section 7(g) of the Indian Easement Act states that every landowner has the right to “collect and dispose” of all water under the land within his own limits, and all water on its surface that does not pass in a defined channel. Therefore, it is considered that the ownership of groundwater is defined based on its source and accordingly, individuals enjoy rights over groundwater which is part and parcel of the land he owns and there is no separate title of ownership over groundwater. Since the right over water is determined by the right over land, landless people have no water rights. A similar feature can be observed in new irrigation laws where only land owners can become members of user associations. The legal position on whether groundwater is a resource meant for public use is fuzzy. As a result, when the Government of Odisha amended their Irrigation Act to assert the right of the state over groundwater, it was challenged in the court.

However, strictly speaking, the Indian Easement Act does not allow the owner of a piece of land to “own” the groundwater under the land or the surface water on the land. Instead, he has the right to collect and use the water. However, customarily it is accepted across India that a well on a piece of land belongs to the owner of that land, and others have no right to extract water from the well or restrict the landowner’s rights to use the water. This belief and practice is indirectly supported by various laws such as the Land Acts and Irrigation Acts that list all things on which the government has a right. But these Acts do not mention groundwater. Interpretations of the Transfer of Property Act of 1882 and the Land Acquisition Act of 1894 also support the position that a landowner has proprietary rights to groundwater as it is connected to the ‘dominant heritage’ (land) and cannot be transferred apart from the land.

The common law principle is still a part of groundwater law in India and it will remain so unless state governments make separate groundwater laws. The applicability of the common law principle
on groundwater is being discussed even now as in the case against the Coca-Cola Company at Plachimada in Perumatty Gram Panchayat. The Honourable High Court of Kerala decided on the issue of the excessive exploitation of groundwater by the Coca Cola Company and reiterated that groundwater is a national wealth which belongs to the entire society. It is nectar, sustaining life on earth. Without water, the earth would be a desert. Our legal system —based on English common law —includes the public trust doctrine as part of its jurisprudence. The state is the trustee of all natural resources which are by nature meant for public use and enjoyment. The public at large is the beneficiary of the sea, shore, running water, air, forests and ecologically fragile lands. The state as a trustee is under a legal duty to protect these natural resources meant for public use, which cannot be owned privately. In view of the above authoritative statement of the Honourable Supreme Court, it can be safely concluded that the underground water belongs to the public. The state and its instruments should act as trustees of this great wealth. The state is obligated to protect groundwater against excessive exploitation, and its inaction in this regard will be tantamount to infringement of the right to life of the people guaranteed under Article 21 of the Constitution of India. The Apex Court has repeatedly held that the right to clean air and unpolluted water forms part of the right to life under Article 21 of the Constitution, and the panchayat and the state are bound to protect groundwater from excessive exploitation. This judgement clearly lays down that the state has a right and obligation to restrain use of groundwater if it causes harm to others.

Irrespective of the unclear aspects in groundwater rights and governance, certain regulations are enforced on the use of groundwater. Accordingly, the agencies and their regulatory mandates are given in Table 5.1.

Table 5.1 Regulatory mandates of various government agencies in India on groundwater use

<table>
<thead>
<tr>
<th>No</th>
<th>Agency</th>
<th>Provisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ministry of Water Resource (MoWR)</td>
<td>It is the principal agency responsible for water in India but water pollution does not fall under its purview, nor does the industrial use of water and groundwater.</td>
</tr>
<tr>
<td>2</td>
<td>Ministry of Commerce and Industry (MoCI)</td>
<td>It is concerned with the planning and development of water resources for industrial use. It has no mandate to control or regulate the water use by industries.</td>
</tr>
<tr>
<td>3</td>
<td>Central Ground Water Board (CGWB) / Authority</td>
<td>It is mandated to regulate groundwater quality and quantity in the country, but the background works are not at par with the requirement. It has no mandate to charge industrial groundwater use.</td>
</tr>
<tr>
<td>4</td>
<td>Water Quality Assessment Authority (WQAA)</td>
<td>Frustrated with the multiplicity of agencies, the MoEF and MoWR decided to set up this apex body to compile information on water quality and monitor the functioning of the agencies. But since its constitution, the WQAA has only met twice and no progress has been made on its agenda.</td>
</tr>
<tr>
<td>5</td>
<td>Ministry of Environment &amp; Forests (MoEF)</td>
<td>It is concerned with the quality of surface and groundwater. But it has no mandate to control use of water as raw material, handle water scarcity, nor any power to resolve water conflicts.</td>
</tr>
<tr>
<td>6</td>
<td>Central (CPCB) and State Pollution Control Board (SPCB)</td>
<td>It is mandated to regulate industrial water pollution and charge water cess based on the amount of wastewater discharged by the industries. But its mandate does not include sourcing water from different water bodies.</td>
</tr>
</tbody>
</table>
5.6 Regulation of Groundwater Use

In response to an emerging crisis that threatens the life and livelihoods of millions, the Ministry of Water Resources, Government of India, in 1970, framed a Model Groundwater (Control and Regulation) Bill for adoption by the states. Revised in 1972, 1996 and 2005, the Bill provided the framework to regulate indiscriminate use of groundwater in India. So far, the states of Andhra Pradesh, Assam, Bihar, Goa, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Maharashtra, Telangana, Tamil Nadu, West Bengal, and Union Territories of Lakshadweep, Chandigarh, Dadra and Nagar Haveli and Pondicherry have promulgated the state legislations. The revised version of the central Bill proposes:

- Compulsory registration of borewell owners
- Compulsory permission for sinking a new borewell
- Creation of a groundwater regulatory body
- Restrictions on the depth of borewells
- Establishment of protection zones around sources of drinking water

The Bill mandates (i) periodical reassessments of groundwater potential on a scientific basis, considering quality of water available and economic viability, (ii) regulation of exploitation of groundwater sources so that extraction does not exceed recharge, (iii) development of groundwater projects to augment supplies, (iv) integrated and coordinated development of surface water and groundwater so that they are used conjunctively, and (v) prevention of over-exploitation of groundwater near the coast to stop the ingress of seawater. These mandates are yet to become law in most parts of the country. The implementation of the provisions, in general, is yet to be satisfactory. The basic flaw is that the implementation is entirely in the hands of government authorities and the people as the groundwater users have no role in decision-making or implementation.

Considering this and the recognition of the Supreme Court that water is a fundamental right, the Planning Commission in 2011 prepared a Model Bill for the Conservation, Protection and Regulation of Groundwater. This is also after the Supreme Court has put forward the principle that water, specifically groundwater, is a public trust. It is also realised that the institutional framework should be based on the principle of subsidiarity and framed around existing administrative units of the village/panchayat. The Bill is also framed to ensure appropriate management of groundwater from the local level to the state level. Accordingly, a four level regulatory authority was suggested with (i) Groundwater Committees at the rural Gram Panchayats and Block Panchayats, (ii) Urban Ward
and Municipality level, (iii) District Groundwater Council and (iv) State Groundwater Advisory Council. It is suggested that the Ground Water Grievance Redressal Officer will be the nodal officer for the implementation of the Act. Though the Model Bill is framed in terms of the institutional mechanism, the provision of the fundamental right to water needs policy decisions and changes in the legal status of groundwater. Further, there is doubt about the practicality of the four level regulatory authorities in various states of India, as there will be a large requirement of trained manpower at all levels. There is also no clarity on the mechanism from where authorities created will draw their powers.

5.6.1 Draft Model Bill for Groundwater Regulation, 2016

Considering the unsatisfactory performances of the earlier efforts for regulating groundwater extraction and to restore and ensure groundwater security through the availability of sufficient quantity and appropriate quality of groundwater to all stakeholders in rural and urban areas, a committee was constituted under Dr. Mihir Shah for redrafting the Model Bill. Accordingly, the Committee submitted a draft Model Bill for the Conservation, Protection, Regulation and Management of Groundwater in May 2016 (Shah, 2016b). This bill considered the linkages with various aspects/principles that water is held in public trust, that a river basin approach is needed, that provisions for rainwater harvesting should be elaborate, that the polluter pays principle should be accounted for, that water should be conserved through agriculture practices and land use and that technological developments including those in space technology and information technology are priorities.

In general, the new draft bill is an improvement over the previous ones. It is for the first time that a framework based on the public trust doctrine and the principle of subsidiarity is used for regulating and managing groundwater. The Bill also gives a thrust to quantifying and regulating groundwater use in canal command areas and urban areas. The prevailing serious groundwater crisis due to excessive overdraft and groundwater contamination is addressed in the Bill. The Bill recognises the need for equitable and environmentally sound regulation of groundwater that can contribute to tackling some of the most important challenges including farmer suicides and climate change. The Bill also includes provisions for strengthening of the regulatory powers of gram sabhas, panchayats and municipal bodies related to groundwater in line with Articles 243G and 243W of the Constitution. The institutional mechanism spanning from the ward to the state level and relevant responsibilities are well thought out. The idea of water security plans at the lowest level is crucial for the future which is highlighted rightly. However, there are several concerns that need to be addressed in the current draft.

There is a duplication of effort between the Model Groundwater Bill and the National Water Framework Bill, as groundwater is already covered in the latter by providing additional detail on groundwater aquifer mapping, etc. Though the integration of ground and surface water is repeatedly mentioned as a guiding principle, the Model Groundwater Bill does not mention river basin plans. The inconsistency between these two Bills may lead to the preparation of two sets of water security plans complying with the provisions in the respective Bills. Another important aspect to be addressed is the integration of surface and groundwater on the ground. While the
Bill has articulated the principle of integration well, the practical steps needed for ensuring the integration are missing. It is necessary to institutionalise the scientific norms linking surface and groundwater dynamically both in space and time for achieving integration in practice. The first order streams are increasingly drying up due to groundwater pumping and artificial recharge. This impact has to be mitigated which requires surface flow estimations, an aspect which is not given due consideration in the Bill. The capacity building and operational placements of the institutional mechanism suggested are very crucial and challenging tasks. Therefore, it would have been good to include certain clues as to how the institutional mechanism could be placed. The Model Bill highlights the aspect of groundwater security plans. But this has to be linked to the surface water security plan and vice-versa as well. It is also important to address the water accounting/budgeting aspects under the water security provisions in the Bill. Though the Bill mentions watershed units, the linkages and need for conserving the hydrology and hydrogeology of an area need to be highlighted to visualise the resources conjunctively. It is also important as to how the proposed institutional mechanism could be used for addressing overall water security of an area taking into consideration the surface flows as well. It is important to merge the institutional structures as well as incorporate the considerations of sub-basins and river basins. The Bill should also provide certain directions as to how a water security plan is prepared and their unavoidable components. This will also help in highlighting the importance of groundwater quality which is otherwise largely missing. The concern of point and non-point source pollution of groundwater aquifers is very critical as in the case of surface water, and more importantly, as it has serious consequences for public health due to the heavy dependence on these aquifers for drinking water. The critical importance of groundwater quality is not found adequately highlighted in the provisions of the Bill.

The enforcement provisions of the Bill need more thought from the point of view of the complexities of hydrogeology based on which the grievance redressal system may have to work. Therefore, more clarity in the enforcement and compliance mechanism is unavoidable to operationalise the regulatory provisions. Important climate change considerations and their consequences on the groundwater budget are missing in the Bill. The database on groundwater resources with respect to quantity and quality is critically important for water security. Considering this, the responsibilities for database generation, its storage, retrieval and dissemination need to be brought under the regulatory framework. Overall, the Model Bill is a very positive and important step towards a practical regulatory framework on groundwater. It has seriously considered the aspects of equity, participation and sustainability at the grassroots level, and is based on scientific knowledge. However, in order to apply it in practice at the grassroots all over India, more consultations are necessary for incorporating practical steps.

5.7 Groundwater in the National Environment Policy

The mandate of the Government of India to legislate on groundwater is based on environmental grounds, and therefore, the National Environment Policy has suggested the following action points in relation to groundwater:

- promote efficient water use techniques, such as sprinkler or drip irrigation among farmers
- take explicit account of impacts of electricity tariffs and diesel pricing on groundwater tables
• provide necessary pricing, inputs and extension support to feasible and remunerative alternative crops for efficient water use
• support practices of contour bunding and revival of traditional methods for enhancing groundwater recharge
• mandate water harvesting in all new constructions in relevant urban areas as well as design techniques for road surfaces and infrastructure to enhance groundwater recharge
• support R&D for most effective techniques for removal of arsenic in rural water projects and mainstream their adoption in rural drinking water schemes in relevant areas

5.8 Groundwater in the National Water Policy

The Ministry of Water Resources, Government of India, has laid down policy guidelines and established programmes for the development and regulation of the water resources of the country. The Ministry also assumes responsibility for the overall planning of the development of groundwater resources, establishment of utilisable resources and formulation of policies of exploitation, and overseeing of and support for state level activities for groundwater development and management. Accordingly, the objective of the National Water Policy (NWP) is to take cognisance of the existing situation, propose a framework for creation of a system of laws and institutions, and evolve a plan of action with a unified national perspective. The aspect of groundwater is dealt with in detail in the revised National Water Policy (2012) as given here under:

> Groundwater, though part of the hydrological cycle and a community resource, is still perceived as an individual property and is exploited inequitably and without any consideration for its sustainability. This is leading to its over-exploitation in several areas. Groundwater recharge zones are often blocked. The climate change and consequent increase in sea levels may lead to salinity intrusion in groundwater aquifers in coastal zones. The variability in availability of water, because of climate change, should be dealt with by increasing groundwater recharge and storage.

The policy highlights the need for managing groundwater as a community resource, held by the state, under a public trust doctrine to achieve food security, livelihood, and equitable and sustainable development for all. It suggests that the existing Acts may have to be modified accordingly. The policy also proposes that a portion of river flows should be kept aside to meet ecological needs, ensuring that the low and high flow releases are proportional to the natural flow regime, including base flow contribution in the low flow season through regulated groundwater use. It is further stated that there is a need to map the aquifers to know the quantum and quality of groundwater resources (replenishable as well as non-replenishable) in the country. This process should be fully participatory involving local communities and the same may be periodically updated. The policy recommends that the declining groundwater levels in over-exploited areas need to be arrested by introducing improved technologies of water use, incentivising efficient water use, and encouraging community based management of aquifers. In addition, wherever necessary, artificial recharging projects should be undertaken so that extraction is less than the recharge. This would allow the aquifers to provide base flows to the surface system and maintain
ecological balance. Integrated watershed development activities with groundwater perspectives need to be taken in a comprehensive manner, and conjunctive groundwater use may also be considered for improving the scenario.

The policy suggests that over-drawal of groundwater should be minimised by regulating the use of electricity for its extraction. The policy also proposes to separate electric feeders for pumping groundwater for agricultural use. It recommends the regulation of urban settlements, encroachments and such other developmental activities in the key aquifer recharge areas that pose potential threats of contamination, pollution, and reduction in recharge. The policy recognises that quality conservation and improvements are more important for groundwater, since cleaning up is very difficult. It needs to be ensured that industrial effluents, local cess pools, residues of fertilisers and chemicals, etc., do not pollute groundwater. The policy also recommends the preferable use of surface water in conjunction with groundwater and rainwater for urban and rural domestic water supply. Implementation of rainwater harvesting should include scientific monitoring of parameters like hydrogeology, groundwater contamination, pollution and spring discharges. Tendencies to use excessive water by the industries to avoid treatment or to pollute groundwater need to be prevented.

The policy proposes formulation of appropriate institutional arrangements for each river basin to collect and collate the entire data pertaining to quantity and quality of both surface and groundwater on a regular basis. This is to be implemented to publish water accounts on a daily basis every year for each river basin with appropriate water budgets and water accounts based on the hydrologic balances. In addition, water budgeting and water accounting should be carried out for each aquifer. It is suggested that state water policies should be drafted or revised in accordance with the national policy keeping in mind the basic concerns and principles as well as considering a unified national perspective.

The policy has put forward many contentious issues that need serious public debate. This includes the proposed water pricing, concept of regulatory authority, prioritisation of use, etc. Pricing water without defining and ensuring the right to water will hamper equitable water supply and sustainability of water resources. The concept of regulatory authority is suspected to delink water governance from the democratic process.

5.9 Groundwater in State Environment Policy

The Kerala State Environment Policy of 2009 deals with water resource conservation and management in detail without discussing surface or groundwater separately. It highlights the alarming level of paddy field conversions for various purposes leading to the loss of natural water-conservation domains that replenishes groundwater, and suggests that the highest priority be given to conserve paddy fields and such other wetlands. The policy suggests basin-wise assessment of water availability and its budgeting for various purposes including ecosystem functioning. It also calls for protection of the water resource system from all types of pollution, and suggests that the conservation, recycling and optimal use of water be brought under the local administration with clear guidelines. A state level water literacy mission to educate the public on appropriate utilization and conservation of water as well as implementation of regulatory and promotional measures for the protection of the environment, in general, and water environment, in particular,
are also mooted in the policy statement. However, beyond these customary statements, the State Environment Policy document has consequence neither on the groundwater resource of the state, nor the fragility of the environment. Though the groundwater aquifer system will be affected adversely in the climate change scenario, especially in the coastal regions of the state, no consideration has been given in the policy statement to the imminent changes projected, impacts identified, adaptive measures proposed, and preparedness that the state must demonstrate.

5.10 *Groundwater in State Water Policy*

The annual utilizable groundwater resource potential of Kerala is 6300 Mm³ which is estimated to be 16% of the total utilisable water resource potential of the state. More than 60% of the population depends on well water for their day-to-day requirements. However, the Kerala State Water Policy, 2008 does not give adequate importance to groundwater other than repeating customary statements. The policy highlights the steep decline in groundwater levels at places due to the deteriorating situation in the water environment consequent to landscape and land use changes, deforestation, river sand mining, etc. The lowering of river beds due to excessive extraction of sand beyond the replenishment rate leads to curtailment of the base flows, reversal of groundwater gradient, lowering of the groundwater table, drying up of wells during the summer and enhancement of saline water intrusion. Thus the policy calls for detailed assessment of the characteristics of groundwater aquifers and optimal development of the resource based on proper understanding. It is suggested that the groundwater exploitation by pumping should be regulated based on yield tests of wells. The policy encourages the concept of conjunctive use of surface and groundwater resources to optimise their utilisation. It also suggests efforts for awareness creation and capacity building to understand the complexity and advantages of groundwater development and management. The policy also proposes to promote artificial groundwater recharge measures. Though the policy called for the review and modifications of the provisions and adequacy of the regulations enacted and suggested the enactment of suitable legislations, no such actions followed the policy statements. Though it highlighted water rights, prioritisation of water use, groundwater exploitation, bulk supply, water harvesting, water pricing and subsidy norms, and reconstitution of institutional mechanism as some of the aspects that are to be brought under new enactments, no details are stated in the policy document. As such the State Water Policy of 2008 was inconsequential for the groundwater sector.

5.11 *Groundwater Regulation in Kerala*

The Kerala Ground Water (Control and Regulation) Act, 2002 provides for the conservation, regulation and control of extraction and use of groundwater in Kerala. The Act came into effect in December 2003. The Kerala Ground Water Authority was constituted a month later in January 2004. In order to implement various provisions of the Act, the Government of Kerala brought out the Kerala Ground Water (Control and Regulation) Rules, 2004. These rules provide details of how the various provisions of the Act could be implemented along with necessary formats for applications, acknowledgements, permits, refusal, registration, and certificates. The State Ground Water Authority was further reconstituted in 2005 and 2007. In 2005, the Government of Kerala notified five blocks, namely, Athiyannur, Kodungallur, Chittoor, Kozhikode and Kasaragod
as notified areas. This was to regulate the extraction and use of ground water in these blocks, which were found to be over-exploited by the Ground Water Resource Evaluation Committee constituted by the State Government as per the advice of the Central Ground Water Authority. The act necessitates obtaining permission for any person desiring to dig a well or to convert the existing well into a pumping well, for his/her own or social purpose in the notified area from the Authority before proceeding with any such digging activity or conversion. While granting or refusing the permit, the Authority considers the purpose for which the water is used, other existing users of that locality, availability of groundwater in that area, quality of groundwater in connection with its use, distance between the proposed well and adjoining wells, number of wells in the area, chances for interference with existing wells and pollution, long term nature of groundwater level in the area, and any other relevant factors.

In 2007, the government further notified that every user of groundwater in the state, i.e., those who use groundwater from a pumping well fitted with a pump driven by an electric motor or oil engine for pumping water other than open wells fitted with pumps driven by engine or motor of horse power up to 1.5 and tubewells, borewells and dug-cum-borewells fitted with pumps driven by engine or motor of horse power up to 3, shall apply to the Ground Water Authority for registration as a user of groundwater and for the grant of certificate of registration within one year from the date of this notification, that was February 6, 2007.

The State Ground Water Department conducted district level awareness campaigns for officials, public and non-governmental organisations which mostly ended with district level workshops. Though the Director of the SGWD is designated as the Secretary of the Authority, no effective steps were taken to link all the employees of the SGWD for the implementation of the provisions of the Act except executive orders. Even the executive order was not adequately reviewed or properly followed through. The procedures for granting permits for digging new wells and converting existing wells to pumping wells in notified areas, registration of existing wells as well as users of groundwater in the state, granting permit for digging a well within 30 m of any drinking water source pumped for public purpose, etc. required detailed field level investigations and meticulous data collection and interpretation. Further, very specific conditions and restrictions were to be incorporated in the registration certificate and permit. The rules also necessitated the owner of the well to collect and keep samples of soil, rock and groundwater at different depths while drilling for three months for inspection by the authorities. There were no sincere efforts or pro-active steps to build awareness among the public regarding the importance of these conditions or develop capacity within the SGWD for carrying out such important assignments. As a result, the compliance with various provisions of the Act is very poor based on informal reviews at the state and district levels. There was a very poor response to the registration of wells and users, and only about 31,000 applications, that too mostly from Palakkad district, were received. In Palakkad, the District Collector issued directions to the Kerala State Electricity Board to allocate power based on the details of the water source authenticated by the State Ground Water Department. Though such provisions are not there in the Act, it helped in getting the wells registered. Hence, the response to the registration of wells was relatively better in Palakkad district. The actions taken against the violations of the provisions of the Act were also very limited. The only punitive measures initiated were issuance of a notice and in rare cases intervention by the police.
One of the serious issues with regard to groundwater development in Kerala is the indiscriminate drilling for groundwater development by incompetent agencies. It is also not known as to how many drilling rigs are operated in the state, the actual groundwater development due to these rigs, and their impact on aquifer systems in various groundwater provinces. As such the drilling of bore wells by private drilling rigs are not brought within the purview of the Act. They are not made responsible for filing monthly returns containing drill log details, estimated well yield, recommended capacity of pump and duration of pumping etc. The analysis of the Act also reveals that it does not contain the provisions for the priority principle, polluter pays principle, mandatory preparation of groundwater data of the state, and periodic monitoring of the groundwater situation.

The sinking of borewells by incompetent agencies are not preceded and succeeded by scientific investigation and data collection, as required for finding the most productive aquifer location in a given place. When a borewell is sunk in a spot away from fracture zones, it will be unproductive. As a result, the users on many borewells get cheated on account of poor or no yield. In order to conceal the poor or no yield from the user, the well construction agency lifts the casing pipe above the phreatic aquifer. Thereby the groundwater from the near-surface aquifer flows to the borewell, thus resulting in a temporary small yield from the borewell. The interference of the borewell with the near-surface water table depletes the water available to the nearby dug wells. This may also happen when the sealing of the overburden of a borewell is improper, or when the casing provided for sealing the near-surface aquifers in a borewell is inappropriate. Another damaging activity is to drill a borewell to a depth beyond the thickness of the actual aquifer, which is unnecessary. Sometimes the well yield estimation provided by the drilling company may be wrong leading to over-extraction affecting the well sustainability.

5.12 Regulatory Experiences from Other States

The states have generally exhibited lethargy in legislating groundwater, though the central government repeatedly circulated the Model Groundwater Bill. So far only a few states, particularly those affected severely by groundwater extraction, have opted for legislation. Among them, Punjab is a notable exception, as the state believes that legislation could cause hardship to farmers, and hence favoured alternative strategies focusing mainly on conservation. The commonalities among state legislations include excessive reliance on control mechanisms (permit system), very little emphasis on cooperative management, coercive and heavy-handed penalties in the nature of criminal sanctions, etc. Some states, however, have unique features. For example, Tamil Nadu has a separate legislation for Chennai and its surrounding areas, as distinct from rest of the state. The 1993 Act of Maharashtra focused primarily on drinking water, while other states had a more balanced approach. Maharashtra is also the only state to introduce a regulatory authority separate from the Government. Gujarat made a successful experiment in electricity supply that had a strong bearing on groundwater management without resorting to any dedicated legislation.

Tamil Nadu

The stage of groundwater development in the state is 85%. On the basis of revised norms of groundwater estimation, as of March 2004, the state had 142 over-exploited, 33 critical and 57
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semi-critical blocks out of a total of 385 assessed blocks. Therefore, the groundwater situation in the state is among the worst in the country and is a matter of serious concern. In 1987, the Chennai Metropolitan Area Ground Water (Regulation) Act, 1987 was enacted, and it was amended in 2002. In 2003, the state enacted the Tamil Nadu Ground Water (Development and Management) Act 2003, which is yet to be implemented as the rules are under formulation. The Chennai Metropolitan Area Ground Water (Regulation) Act 1987 (amended as of November 2002) extends to the whole of Chennai city, and specified 302 revenue villages in the surrounding Kancheepuram and Thiruvallur districts. The Act makes it necessary to obtain a permit for sinking wells for permissible use. It is stipulated that contravention of the Act by either an individual or a company entails a fine of Rs. 2000 on first instance and for second and subsequent offences the fine is Rs. 5000 or imprisonment for 6 months. As per this Act, the Court take cognisance of the offence only on a written complaint from the competent authority which has powers to break open and enter the property, seal the well and recover the cost of such action from the violator. The Act stipulated that all the buildings should have a rainwater harvesting facility. It is reviewed that the exploitation of groundwater in the city for commercial purpose has drastically declined after the implementation of the Act in 1987.

The Tamil Nadu Groundwater (Development and Management) Act 2003 extends to the whole state of Tamil Nadu except the areas covered under the Chennai Metropolitan Area Groundwater (Regulation) Act 1987, and is to be implemented by the Tamil Nadu Groundwater Authority. Like the Chennai Metropolitan Area Ground Water (Regulation) Act, 1987, this Act is generally prohibitive in nature and relies heavily on a permit system. An important feature of this Act is that it does not allow the supply of electrical energy from the Tamil Nadu Electricity Board (TNEB) for energising wells sunk in contravention of the provisions of the Act. The Act envisages registration of all wells sunk in the state including notified and non-notified areas. The offences under the act are cognisable and the penalty for failing to comply with it is a fine of Rs.1000 for first offence, Rs. 2000 for a second or subsequent offence, and Rs. 500 per day for continuous contravention of its provisions.

Punjab

Out of the 137 blocks in the state, only 25 are safe; 103 are over-exploited, 5 critical and 4 semi-critical. Punjab state is not in favour of groundwater legislation as it apprehends that such a step will hamper the agricultural sector. Instead, to tackle groundwater over-exploitation, the state is in favour of crop diversification, large scale artificial recharge (through check dams, use of drainage water and rooftop rainwater harvesting), controlled, regulated and metered electricity supply in critical areas, promotion of drip and sprinkler irrigation to conserve water, alteration in the crop calendar (encouraging late sowing of paddy after 16th June to decrease evapotranspiration), etc. The state is also contemplating a complete ban on new tubewells, restricting horse power to 10 HP to prevent tapping of deeper aquifers, replacing old pumps with energy efficient pumps, and conjunctive use of saline and fresh water for bringing down the demand for fresh water.

Andhra Pradesh (Andhra and Telangana)

Though the stage of groundwater development in the states is only 45%, there are 219 over-exploited, 77 critical 175 semi-critical mandals out of 1231 mandals (assessment units) in the state. The Andhra Pradesh Water, Land and Trees Act (WALTA) enacted in the year 2002, aims inter alia, at
controlling and regulating the use of groundwater and propagating tree plantation on farms. The State Government has designated the Commissioner, Rural Development, as the administrator for the purpose of the Act. Some of the critical provisions in the area of groundwater management are the registration of all borewells with concerned Revenue Authorities at the Mandal level, prior permission for digging new borewells, registration of all the rigs with the government, prohibition of pumping of water in certain areas, etc. A notable recommendation of a government constituted Commission on Farmers’ Welfare, the Jayati Ghosh Commission of September 2004, was that the state government should, in the medium term, take over all existing borewells after paying compensation to the current owners and thereafter provide water from these borewells upon payment of the water cess. This, however, was not accepted by the state government.

The Andhra Pradesh Irrigation Development Corporation has implemented a project in collaboration with the Government of Netherlands which envisaged community based usage and management of groundwater (similar to the Kerala Sammoohya Jalasechana Padhathi). The project called the Andhra Pradesh Farmer Managed Groundwater Systems (APFAMGS) aimed at enlightened management of groundwater by farmers emanating from the demystification of the science of hydrology. The project framework was designed in line with the principles put forward by Elinor Ostrom for governing the commons, as well as the defined resource and user characteristics that facilitate self-governance of resources (Ostrom, 1990; Ostrom, 2001). It envisaged participatory actions for monitoring of the hydrological cycle through the measurement of inflows and outflows and the rainfall and water level, preparation of the water budget, digging of community borewells, and collective management and maintenance by groups of farmers. The farmers raised pre-decided crops, allocated water according to the water budget, and regulated water usage through the adoption of gravity based and low cost drip systems. They were also encouraged to grow horticulture crops to save water as well as for drought proofing. The project also implemented the groundwater recharge structure for each borewell and implemented watershed treatment in some areas. The APFAMGS pronounced the project as a successful one and is being promoted for replication elsewhere in the country. Recent field studies, however, indicated that the remnants of practices from the APFAMGS and their likely impacts reflect poorly on the long term sustenance of efforts after the project ended and the local support organisations withdrew (Verma, Krishnan, Reddy & Reddy, 2012). Though the APFAMGS and all similar efforts are successful models on participatory management of common pool resources, the question of whether farmers can willingly, voluntarily and sustainably manage their groundwater resources without long-term external support continues to be relevant.

**Gujarat**

There are 31 over-exploited, 12 critical and 69 semi-critical blocks out of a total of 223 blocks in the state. There is tremendous pressure on groundwater in north Gujarat, Saurashtra and Kutch as the per capita availability in these regions is very low. The maximum decline in the groundwater level in the monitoring wells of the CGWB in over-exploited blocks has been around 3 m per year. At some places, the piezo-metric surface of the deeper confined aquifer has gone down to 130 m. Groundwater is reported to be saline and fluoride contaminated, and the life of a tubewell is only 10 years against a normal life of 30 years. The state has adopted a wide range of conservation initiatives for ensuring sustainability by improving the quantity and quality of groundwater by
recharge through check dams, ponds, tidal regulators along the coast, afforestation, etc. The state restricted electrification of tubewells in over exploited blocks and regulated construction of new tubewells to decelerate the rate of groundwater depletion. By separating electric supply to the domestic and agricultural users through different supply feeders, 24-hour supply was assured for domestic use and 8-hour supply for agricultural use. This has helped in curtailing the excessive pumping of groundwater through illegal means, and enabled more efficient use of groundwater (Ferroni, 2013; Gronwall, J. 2014).

**Maharashtra**

In Maharashtra, 82% of the rural population relies on agriculture. Out of the 318 blocks in the state, 7 are over-exploited, 1 is critical, 23 are semi-critical and 287 are safe. The stage of groundwater development is 48%. It was found that public drinking water supply sources in many parts of Maharashtra were getting affected due to sinking of wells in the close vicinity, and high density and unregulated extraction of water from such wells. This situation made it difficult for authorities to provide the minimum prescribed drinking water to the local population. In order to overcome this situation, increasing and repetitive measures had to be taken to provide dependable and adequate supply of water to many villages, which ultimately led to a huge financial burden on the state. With this background, the Government of Maharashtra enacted and enforced the Maharashtra Groundwater (Regulation for drinking water purposes) Act, 1993, for the limited purpose of protecting the drinking water supply. The main provisions of the Act are prohibition of sinking of wells for any purpose within 500 m of a public water source without prior permission, except by government agencies for the purpose of drinking water, restriction and regulation for extraction of water from permitted wells from time to time depending on the potential of the source to suit the public interest, etc.

The 1993 Act has not been successful in advancing its prime objective of ensuring protection of drinking water sources. The limited perspective of protecting only the drinking water sources is also a hindrance to achieving the objective of sustainable and equitable use of groundwater among all stakeholders. Further, it has also been found that it is not easy to regulate the extraction of groundwater without involving the local community and sensitising them about the need for cooperative action to ensure groundwater sustainability. These inadequacies have been addressed by promulgating the Maharashtra Groundwater (Development and Management) Act, 2009 which was revised in 2013. The new Act and its revision was to facilitate and ensure sustainable, equitable and adequate supply of groundwater of prescribed quality for various category of users through supply and demand management measures, protecting public drinking water sources, and establishing the State Groundwater Authority and District Level Authorities to manage and regulate the exploitation of groundwater with community participation. The Act provided for the constitution of a Watershed Management Committee at the state and district levels and preparation of the Integrated Watershed Development and Management Plan for giving a thrust to water harvesting and improved recharge as well as for evolving a groundwater use plan linked to the crop plan. The Act also provided for Watershed Water Resources Committees thereby ensuring community participation and enabling democratic decision making as well as enforcement of regulatory provisions based on the groundtruth.
As part of water sector reforms, the Maharashtra government enacted two statutes in 2005, namely the Maharashtra Management of Irrigation Systems by Farmers (MMISF) Act and the Maharashtra Water Resources Regulatory Authority (MWRRA) Act. These were framed to adopt an ‘integrated multi-sector approach’ considering a river basin as a unit of development and participation of stakeholders and users in various aspects of water resources development and management as the principle. The MWRRA established a regulatory mechanism for overseeing the relationship between the service provider and water user entities and also within a water user entity, in terms of determination, enforcement and dispute resolution of entitlements and fixation of water charges. The MWRRA was amended in 2016 by incorporating various provisions including the induction of an expert as a member of the authority with an objective to probably bring in the integration of the provisions in the Maharashtra Groundwater (Development and Management) Act revised in 2013.

A state-wise study of the groundwater situation in pre and post legislation periods reveals that most of the states have only a very short legislative history and therefore, the data/analysis is mostly not available or inadequate for evaluation of effective compliance with the Act. However, based on anecdotal experience, the following observations have been drawn:

- Enforceability of the Act has been a problem and no state has reported the actual number of violations detected and penalty meted out. Even when the legislation is narrowly focused on protecting drinking water sources, enforcement became a huge problem because the supervisory resources are infinitesimally small compared to the number of wells and well owners.

- Undue delay in notifying an area for regulation by the State.

- The study by the Madras Institute of Development Studies in Tamil Nadu has shown that small and poor farmers are affected more by the controls on groundwater exploitation and benefit less from power subsidies as compared to wealthy farmers. Shah and Verma (2008) have noted adverse impact on small farmers who buy water from their neighbours.

5.13 Experience with the Water Market in India

An individual can have access to water from others for a fee in a water market. In India, the water markets are informal and are generally limited to localised groundwater trading between adjacent farmers. The practice is quite common for groundwater because it is a substitute to owning a well. While water markets are widespread in Gujarat, Punjab, Uttar Pradesh, Tamil Nadu, Andhra Pradesh and West Bengal, they are most developed in Gujarat and substantial in the water scarce pockets of Tamil Nadu and Andhra Pradesh for irrigation. The extent of area irrigated through water markets varies across regions and over time depending on a number of factors such as rainfall, groundwater supply, cropping patterns, and the cost and availability of electricity (Saleth, 1994). There is no systematic estimate at the national level of the magnitude of water trading. The area irrigated through water markets has been projected to be about 50% of the total gross irrigated area with private lift irrigation systems (Shah, 1993). Other estimates, using a methodology based on pump set rental data, put the figure at 6 million hectares or 15% of the total area under groundwater irrigation (Saleth, 1999).
Trading of groundwater has no legal basis in India. States, however, have been tolerant of the practice, possibly because of the difficulty in enforcing any kind of restrictions. Besides, it has been serving two useful purposes: promoting efficient use of groundwater and providing poor farmers unable to afford wells an access to water. There is however some evidence of decline in the groundwater table caused by competitive water withdrawal due to intense water marketing activities (Moench, 2002). Besides, there is an equity question; rich sellers can get paid by the very group whose water rights get infringed by the seller’s activities (Saleth, 1994). Gujarat’s Jyoti Gram Yojana, under which feeder separation and limited hours of supply for irrigation have in certain areas reduced the availability of water for farming, has led to an increase in the price of water for their neighbours, particularly poor farmers (Shah & Verma, 2008).

In Kerala, groundwater trading is not reported widely for the purpose of irrigation, whereas it is widespread in tourism and pilgrimage based townships for the purpose of hotels and resorts. However, no systematic study or reports are available on the groundwater markets of Kerala.

### 5.14 International Experience in Groundwater Governance

#### Western United States

The United States (US) has been a pioneer both in facing the environmental fallout of intensive groundwater irrigation as well as in devising ways to minimise or counter its impact. The western US, which has a 150 year history of extensive groundwater irrigation development, has been a fertile ground for technological and institutional experiments in groundwater management. Various states have tried a mix of several approaches to respond to groundwater overdraft, viz. formation of groundwater districts, buying out groundwater rights from farmers, supply of imported surface water in lieu of groundwater pumping, and notification of ‘active management areas’ where a ‘water master’ is appointed to undertake district administrative/legal action by courts.

Management of groundwater depletion in the western US has been centrally about reducing withdrawals, commonly through reducing areas irrigated with groundwater. Colorado decommissioned 1000 irrigation wells by force, and Idaho purchased water rights from irrigators and closed 2000 wells where pumping from increased depths became so expensive. Ironically it cost millions of dollars of tax payer money to buy water rights back that the state gave away for free. Out of the 431 groundwater basins in California, 19 are actually managed with some restrictions on pumping. In the remaining 412 basins, groundwater management is passive involving federal grants to build infrastructure to import surface water and supply it to groundwater users in lieu of pumping. Irrespective of these, the institutional and regulatory actions to improve groundwater governance have not provided results to the desired extent as is evident from widespread falls in groundwater levels in Ogallala aquifer, Kansas, Arizona, etc.

#### Arid Countries

The Sultanate of Oman has successfully combined the demand-side measures to control, protect and conserve water resources with supply side measures to augment the resources for sustainable groundwater management. The former included obligatory registration of all wells, introduction of
well permits, prohibition of wells at less than 3.5 km from the mother-well of a ‘falaj’, filling up of illegally constructed wells, confiscation of drilling contractor’s equipment involved in illegal drilling, a national well inventory, well-metering, well-field protection zoning, water treatment, leakage control, improving irrigation techniques and public awareness campaigns for water conservation. Supply side strategies depended on large recharge dams. The treated waste-water is reused in lieu of groundwater pumping in the Muscat area for watering municipal parks, gardens and roadsides. Public water supply in this capital city is from desalinated sea water.

**Spain**

Spain, like many other countries, provided private property rights over groundwater resources until 1985. The Water Act of 1985, in response to intensive groundwater use, took away groundwater from the private domain and the ownership rights of groundwater were bestowed upon the state. Further, the River Basin Management Agencies (RBMA) were given roles in managing groundwater and finally, they were also vested with the power to grant permits for groundwater use that started after 1985. The RBMA were given authority to declare an aquifer as over-exploited, and thereupon to formulate an aquifer management plan for recovery of the aquifer. It included plans to reduce volume of withdrawals or reject new applications for wells. In addition, groundwater user associations were organised with all users of the aquifer to encourage user participation. Further amendments to the act were made in 1999 and 2001 which emphasised the role of groundwater users in aquifer management.

An evaluation of the current implementation status of the regulation leads to a gloomy picture. Even after 15 years, recording of groundwater rights still remain incomplete, and less than a quarter of all groundwater structures have been registered. This is mainly due to insufficient human resources which has affected well registration as well as monitoring of registered wells. As emphasised in the water law, thousands of small groundwater users’ associations have been formed particularly for management of over-exploited aquifers. However, majority of them are geared towards collective management of the irrigation network, and only a handful have larger mandate of collective management of aquifers. Thus, even in Spain, which has relatively fewer wells, small aquifers and lesser direct dependence on groundwater irrigation, but stronger farmers’ lobbies than South Asia, the implementation of various clauses of groundwater legislation has proved to be very difficult. The studies show that most of the Groundwater User Associations in Spain are defunct and that the water law is widely bypassed.

**Mexico**

Mexico, by formulating the law on the nation’s waters in 1992, declared water as a national property, and it became mandatory for existing users to legitimising their rights through procuring water concessions. The National Water Commission (CNA) has been entrusted with the responsibility of registering water user associations, set up a regulatory structure to enforce and monitor their concessions granted and also to collect a volumetric fee from all users, except small-scale irrigators. Aquifer Management Councils (COTAS) have been promoted by the CNA as user organisation with the objective of managing groundwater. The response to the reforms has been mixed.

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9. An ancient system of water channels known as falaj (plural: aflaj), which often run underground and originate in wells near mountain bases. The aflaj collectively were designated a UNESCO World Heritage site in 2006.
The large industrial and commercial water users have been quick to apply for concession and pay water fees. However, the real challenge has been registering water rights of the agricultural users, who withdraw at least 80% of the total volume of water and monitor their withdrawals. Among agricultural users, the tubewell owners have responded to the law quite positively and have applied for water concessions. The major reason for such compliance has been the ‘carrot’ of subsidised electricity that has been promised to tubewell owners who regularise their connection through registration of the wells with the CNA. This showed that farmers responded well to direct economic incentives. The COTAS have been planned to be involved in technical capacity building, institutional capacity building, creation of local awareness about water issues, and most importantly, creating alternative sources of income through developing various services that water users might value enough to hire and pay. However, it has failed to provide the services that the majority of its potential members (farmers) value the most, i.e., unrestrained access to groundwater. Therefore, most of the farmers are unwilling to become members of COTAS as these institutions have been created to limit their access to water. This shows that passing of laws and executing administrative barriers are not likely to work unless social and economic realities are taken into consideration. Thus Mexico, even with an ambitious water law, is still grappling with basic issues of registered wells and issuance of water permits. Further, a recent move to withdraw the unused portion of water quotas seems to have encouraged farmers to pump more groundwater than they would otherwise have, lest they lose their quotas.

Overall, Spain and Mexico reformed their water laws to make groundwater a national property. However, their success in getting water rights of agricultural users registered has been insignificant and they find it difficult to enforce the new water law even if the number of wells is much less (Spain with 0.5 million wells and Mexico with 0.09 million wells) compared to the situation in India with 19 million wells. The US experience of buying out groundwater rights and supplying surface water by trans-basin diversions has huge cost implications, which is unaffordable in countries like India. The strategy adopted by a small country like Oman by skilfully combining demand side measures to control, protect and conserve water resources with supply side measures to augment the resources has considerable potential for successful replication in India.

In general, the international experiences suggest that in countries where regulation of groundwater development is successful, the groundwater is owned by the state, viz. Israel, China, Australia, Spain, Mexico, some countries in the EU, and USA. Even if it is privately owned, there exist strong laws for reasonable use. In these places the database is very strong and every user needs license/concessions for usage which is closely monitored. Adequate infrastructure and manpower is provided for operationalising such regulatory measures.
6 Way Forward

6.1 Emerging Scenario: Significance, Surplus and Scarcity

The net annual groundwater availability of Kerala is 6029 Mm³ of which only 47% is utilised (GEC, 2012). The level of utilisation varies from a minimum of 17% in Wayanad district to a maximum of 71% in Kasaragod district. There is only one over-exploited block, while there are 3 critical blocks and 22 semi-critical blocks out of 152 blocks and therefore, 83% of the blocks are considered safe. Thus the state level scenario indicates resource surplus. As per the Census 2011, 62% of the population of the state depends fully on well water for their day to day requirement. In the homestead type of habitation in Kerala, every compound has a well and thereby the extraction is widespread through over 65 lakh wells with most of them energised. 48% of the area of Kerala falls under highland, 42% under midland and 10% under lowland. 88% of the state is occupied by crystalline rocks devoid of primary porosity. Therefore, the aquifers are generally thin or spatially limited, and the recharge capacity or water holding capacity is restricted. As a result, they get stressed due to pumping. The deterioration of surface water storages such as rivers, wetlands, ponds, paddy fields, etc. has further reduced the recharge intensity. Therefore, almost 50% of the dug wells in the highland and midland regions of the state go dry during the summer season. The over exploitation of the groundwater in certain hydrological zones has contributed to the permanent lowering of the water table as deep as 10 cm/year. The saline intrusion in the coastal aquifers, especially during the summer season, is also widespread. The cross-contamination of wells due to toilet pits and the infiltration of pollutants from solid waste leachates add to the problem of scarcity. Therefore, the low stage of development of groundwater in Kerala, as reported by the Groundwater Estimation Committee (GEC), 2012 does not indicate the true picture, and the situation is critically poised.

There is hence an urgent need to improve the groundwater resource scenario with respect to its quantity and quality, manage the aquifers so as to maintain their sustainability, and regulate the use so as to ensure equitable availability. The science of groundwater is not well understood and therefore, the fragility of the resource is mostly not considered while planning its development. Therefore, the efforts for the augmentation of the resource and maintaining the pristine nature of groundwater are not adequately and appropriately cared for. The management of groundwater development is a critical factor and has to be based on the aquifer properties and the yield estimates. The effort for mapping and understanding the aquifer properties is totally inadequate for the mostly truncated aquifer systems existing in Kerala, and there are no protocols followed for the estimation of the safe yield of wells. This leads to over-exploitation at the local level and

10. This is mostly drawn from the Draft model bill for the conservation, protection and regulation of groundwater prepared as part of the 12th Plan Working Group of the Planning Commission, Govt. of India, September 2011.
destruction of wells in batches, and such impacts will not have any visibility at the state level till the aquifer is irrevocably destroyed. Though the state implemented a legal framework for controlling and regulating the groundwater domain, it is found totally inadequate to address the challenges of groundwater use and conservation. The overbearing power of landowners on access to and control of groundwater ensures that regulation remains atomised and incapable of tackling over-extraction, contamination, and protection. The direct links between rights to groundwater and land ownership excludes landless people from a stake in groundwater leading to inequality. The existing groundwater legal regime fails to incorporate many of the legal developments that have taken place over the past few decades such as the new water law principles, for instance, public trust, environmental law principles, like the precautionary principle, decentralisation principles embodied in the 73rd and 74th amendments to the Constitution, irrigation mode, a focus on participatory irrigation management, etc. Further, the existing legal frame fails to integrate the fundamental right to water with rights granted to land owners when groundwater is the primary source of drinking water for the overwhelming majority of the population.

Groundwater is a common pool resource, which follows complex dynamics influenced by its hydrogeological characteristics and therefore, a policy or programme focusing on sources (wells), rather than resources (aquifers) cannot lead to sustainability and equity. Therefore, aquifer-based management of groundwater resources needs to be promoted.

6.2 Groundwater Protection and Conservation

Groundwater protection and conservation is necessary at various levels, the highest priority being the areas demarcated as special groundwater protection zones such as the over-exploited and critical zones not only based on the estimated groundwater resource potential but also from the hydrogeological and environmental fragility. It requires the integration of surface water and groundwater and contemplation of groundwater as an ecosystem resource to be accounted for at the micro-watershed level for development planning and management. This necessitates the strengthening of the regulatory powers of gram sabhas, panchayats and municipal bodies related to groundwater in line with Articles 243G and 243W of the Constitution. This is also to empower these bodies to discharge their responsibilities to conserve resources and resolve conflicts, if any, between the users of groundwater as well as between different types of uses recognising the common pool nature of groundwater. Groundwater should be protected and conserved with the objectives of promoting sustainable groundwater use in the public interest on a long term basis ensuring its integrity within the ecosystem and biological diversity and precautionary steps for preventing pollution and degradation of aquifers and also avoiding gender discrimination, inequalities in access to water and adverse environmental impacts. In order to achieve this, effective schemes and measures should be formulated and implemented at the micro-watershed level and integrated at the river basin and state levels.

6.3 Groundwater Rights and Duties

In order to protect the fundamental right to basic water of acceptable quality for leading a healthy and dignified life, it is necessary to refrain from actions prejudicial to the availability of sufficient quantity and quality of basic water. It is also necessary to redefine the legal status of groundwater
Groundwater Resource of Kerala

as a common heritage resource of the people held in trust without ownership by the state, communities or persons, for the use of all, subject to reasonable restrictions to protect all water and associated ecosystems. Thereby, the state is the public trustee of groundwater at all levels and the authority responsible for equitable water allocation and use in the public interest, while promoting environmental values.

6.4 Identification of Groundwater Protection Zones

In order to safeguard the fragile groundwater system of the state, it is necessary to bring in groundwater zoning based on the nature of aquifer fragility, groundwater scarcity and extraction stress. Accordingly, the state could be demarcated into three protection zones to maintain the natural identity of the aquifer and needs of groundwater dependent ecosystems, protect the natural recharge and discharge areas of the aquifer from threats such as physical deterioration, including loss of exposed surface area, change in land-use pattern and causation of chemical and other pollution, and provide the basic water needs and water for livelihood in terms of quality and quantity.

Accordingly, the Groundwater Protection Zone I (GPZ-I) shall include natural recharge areas and discharge areas of an aquifer, which cannot be compromised in any way so as to reduce their natural functions, i.e., recharge to the aquifer and discharge from the aquifer in the form of springs and seeps that feed streams, rivers and wetlands. It should be imposed as a priority in any possible context, whether in mountain areas, in rural or urban settings, or in coastal zones. The protocol for implementing the protection here should include clear rules regarding forestation and deforestation, prohibition of waste disposal, and ban on mining leases. The Groundwater Protection Zone II (GPZ-II) will include those areas that require special attention with regard to artificial recharge of groundwater. These zones will mostly be the catchment areas of percolation tanks, recharge ponds, infiltration tanks and such other measures where water is harvested for recharging aquifers. The Groundwater Protection Zone III (GPZ-III) will include the areas overlying other portions of the aquifer, which are neither natural recharge areas nor natural groundwater discharge areas nor under the purview of artificial recharge zones. These are areas where regulations for groundwater management will have to be executed through appropriate mechanisms like permits, electricity rationing and tariff and community based social regulations passed by the appropriate authority.

6.5 Demarcation of Protection Zones

Groundwater protection zones should be demarcated on the basis of detailed aquifer mapping, which should include clear demarcation of the three types of protection zones and natural groundwater recharge and discharge areas. The aquifer mapping shall also delineate zones where extraction is likely to be the greatest. The protection zones, so demarcated should be declared by the appropriate authorities after notifying it in the Gazette, and discussions at appropriate levels such as the gram sabhas, ward sabhas, gram panchayats, block panchayats, district panchayats, municipal authorities and the state government considering the geographical limits of each of zones. The GPZ-I is considered as a special groundwater protection zone and therefore will be accorded the highest priority in terms of groundwater protection and regulation. No extraction or use of groundwater, apart from use as basic water, will be allowed in the special groundwater protection zones. On the other hand, in GPZ-II and GPZ-III, groundwater should be allocated and extracted in a regulated...
manner, so as to maintain the water balance in the concerned aquifers. In order to achieve this, the Block Groundwater Committee with consent from the concerned Gram Sabha or Ward Sabha should determine the safe yield of any aquifer coming under the purview of the respective protection zones. In areas with severe long-term drought, extraction beyond the annual recharge should be allowed for basic water needs on the condition that in subsequent years of adequate rainfall, additional recharge measures would be taken to compensate the extra withdrawal.

6.6 Prioritisation of the use of Groundwater

The first priority should be that groundwater should meet the right to basic water for the rural and urban population, consistent with the objective of sustaining aquifers and ecosystems indispensable to the long term maintenance of the resource. The primary groundwater uses, besides basic water and ecology, should include direct use of groundwater for livelihoods and municipal use, including public facilities for recreation. The secondary water uses should include commercial activities, including power generation, industry and large scale commercial farms as well as private facilities for recreation. It is also necessary to subject the use or appropriation of water for secondary purposes to an environmental and social impact assessment as it is likely to have significant adverse impacts on local sources of groundwater.

6.7 Institutional Framework

The institutional framework should start with a Gram Panchayat Groundwater Committee constituted by resolution of the Gram Sabha. It should have proportional representation of scheduled castes, tribes and women and also the watershed committee and water user association. The Committee should also include representatives of community-based groups such as self-help groups. The functions of the Gram Panchayat Groundwater Committee should include:

1. Preparation of the Gram Panchayat Groundwater Security Plan (GPGSP) and presentation of the same to the Gram Sabha for approval
2. While preparing the Plan, it should be ensured that it complements and is integrated with other water-related plans, such as drinking water security plans that may be required under other laws or government schemes
3. Implementation of the Panchayat Groundwater Security Plan
4. Determination of groundwater protection zones, with special attention to the delineation of special groundwater protection zones, within the territory of the Panchayat, and adoption of norms for their management and regulation
5. Registration of all wells and other sources such as springs within the Gram Panchayat boundaries for secondary uses
6. Collection of information from all source creation activities, such as drilling of tubewells and construction of open wells by obtaining a log from drilling agencies
7. Regulation of use of groundwater sources within the Gram Panchayat boundaries, especially in terms of delineating protection zones, except domestic wells using motors of 1.5 hp or less
8. The GPGSP should be based on scientific maps and database and contain, besides a description of groundwater aquifers and catchments within the Gram Panchayat area, a statement of rights, duties, management responsibilities, priorities of use and tariffs, if any.

9. The aquifer-based plan should provide for groundwater conservation and augmentation measures, socially equitable use and management of groundwater, and priorities for conjunctive use of surface and groundwater.

10. The GPGSP should be based on the principle that transfers of water outside the area coming under the jurisdiction of the Committee are prohibited, unless the Gram Sabha agrees by a three-fourth majority or a decision to this effect is taken by the Block Panchayat Groundwater Committee or the District Groundwater Council where the basic water needs of other panchayats and municipalities cannot be met without a transfer.

11. The GPGSP should have separate plans for each micro-watershed where there is more than one micro-watershed within the boundaries of the Gram Panchayat. In cases where there is more than one micro-watershed within the boundaries of the Panchayat, the plan shall be integrated at Gram Panchayat level.

12. If any area is declared a groundwater protection zone, the plan should include remedial measures such as prior sanction for extraction or deep drilling; incentives for weaning out water-intensive crops; incentives for the adoption of water-conserving technologies, such as drip irrigation and sprinklers; setting up artificial recharge structures; promoting use of energy-efficient pumps; community based sharing of groundwater; and other measures as may be appropriate to the specific aquifer or the situation under which groundwater overexploitation has occurred.

In similar terms, there should be an institutional set up in all tiers of the government such as the Block Panchayat Groundwater Committee, Ward Groundwater Committee in the urban areas, Municipal Groundwater Committee, District and State Level Groundwater Councils and State Groundwater Advisory Council with pre-defined duties and responsibilities. Similarly, it should also be required to have a scientific support system for operationalising a Groundwater Information and Monitoring System at different layers of the government which will coordinate the preparation of groundwater security plans, assistance to check compliance with groundwater security plans, social and environmental impact assessments, fixing terms and conditions in permits for extraction of groundwater for various uses, periodic preparation and updating of the groundwater database, and evaluating the damages caused by any user of groundwater to individuals, property and the environment.

6.8 Water Harvesting and Catchment Conservation

Rainwater harvesting and catchment conservation should be encouraged as per geological conditions through integration and convergence of all natural resources related developmental schemes and projects. The catchment conservation should be implemented by using appropriate groundwater recharge structures or pits depending on the nature of the terrain/soil and condition/geology of the area.
6.9 **Groundwater Extraction**

The drinking water supply agency extracting groundwater should comply with the provisions in the Manual of Central Public Health and Environmental Engineering Organisation, Bureau of Indian Standards, and specifications or standards adopted by the state government as modified or revised from time to time. The farmers owning or tilling less than one hectare of land for their own livelihood needs should be entitled to use groundwater for irrigation statutorily. The large scale irrigation using groundwater should be based on a permit system allocated by the appropriate authority in consonance with the groundwater security plan. The extraction of groundwater for industrial use or infrastructure projects should be based on permits issued by the appropriate authority. There should not be any permit given for any industrial, commercial or other bulk uses of groundwater in special groundwater protection zones. The permits for industrial, commercial or other bulk uses of groundwater in GPZ-II and GPZ-III should be in conformity with the provisions of the groundwater security plan in the concerned area.

The permits should incorporate binding undertakings by the applicant to take groundwater recharging measures, recycling a prescribed proportion of the extracted groundwater, and treat wastewater to bring it to prescribed standards before it is discharged. The permit granted for a specified purpose should not be used for any purpose other than that for which it has been granted. The permit holder should be prohibited from selling, by whatever name or form, groundwater extracted under the permit to someone else for commercial use and/or gain. The permit should be cancelled on non-compliance with its terms and conditions.

6.10 **Pricing for Industrial Use of Groundwater**

The industrial or bulk groundwater use should be priced and a water rate, as prescribed by the appropriate authority, should be charged. In the case of agricultural use, the input subsidies for water should be continued subject to periodical revision and linked to water use efficiency. The pricing for groundwater used as drinking water should be linked to the water right provisions. There needs to be a detailed and transparent policy for groundwater pricing considering it as a common pool resource to be evolved through a consultative process. Funds collected under this section should be used for groundwater conservation and augmentation activities. The groundwater rate proposed to be charged will be in addition to the water cess under the Water (Prevention and Control of Pollution) Cess Act, 1977. The agencies who are planning reconnaissance, prospecting, general exploration, detailed exploration or mining in respect of any major or minor minerals, including sand mining, must prepare and file a prospecting plan with the appropriate authority of the area concerned, indicating steps proposed to be taken for the protection of surface and groundwater, to minimise the adverse effect of prospecting operations on groundwater and the environment in general.

6.11 **Conjunctive Use of Groundwater and Surface Water**

Conjunctive use of groundwater and surface water should be practised to maximise the economic and environmental effects of ground water and surface water use and also to optimise the water
demand and supply balance in a given irrigation command. Its relevance is increasing as there is a growing demand for adapting to the impacts of accelerated climate change, as the frequency and severity of surface water droughts coupled with growing water demands associated with higher ambient temperatures is on the rise. In reality, the conjunctive use is widely practised on a spontaneous basis, in response to inadequate availability of irrigation canal water and to mitigate crop-losses in a crisis mode. This often leads to the use of large proportion of groundwater even in major irrigation canal commands with little investment on integrated management.

Generally, the responsibility for surface water and groundwater management is divided between multiple agencies, which hamper engineering of opportunities for planned conjunctive use. There is often considerable rigidity and resistance to change in the distribution of surface-water supply, whose rationalisation is a necessary pre-condition for promoting efficient conjunctive use. This rigidity and resistance often relates to a narrow focus on surface water delivery and canal water rostering, with social groups holding tightly onto long-standing entitlements, rather than to absolute water-resource scarcity (Stephen et al., 2010). Some of the issues working against the conjunctive use are:

- Socio-political sensitivity and unwillingness of farmers in areas endowed with surface water to allow canal water to reach less endowed areas
- Inadequate understanding of conjunctive use and the potential role of groundwater by water resource planners, administrators and politicians
- Inadequate knowledge of the degree to which private groundwater use by farmers is practiced, especially in the upper part of irrigation commands/ tailend of commands and their benefits and results
- Ineffective implementation of Participatory Irrigation Management (PIM)

In order to overcome the impediments to conjunctive use, it is necessary to have committed and enforced administration of available surface water resources and incorporation of groundwater users into the existing water users associations. This requires significant strengthening of the institutional arrangements for water resource administration, enhanced coordination among the usually divided irrigation, surface water and groundwater management agencies, and gradual institutional reform learning from carefully monitored pilot projects. The conjunctive use of surface and ground water resources is still in a conceptual stage as far as Kerala is concerned.
References


Directorate of Soil Survey and Soil Conservation (2014). *Generalized Soil Map of Kerala* (Obtained through personal communication by the author)


Additional References


Forum Publications

Books and Reports

- Water Conflicts in India: A Million Revolts in the Making (Routledge)
- Life, Livelihoods, Ecosystems, Culture, Entitlements and Allocations of Water for Competing Uses
- Water Conflicts on India: Towards a New Legal and Institutional Framework
- Water Conflicts in Odisha: A Compendium of Case Studies
- Floods, Fields and Factories: Towards Resolving Conflicts around Hirakud Dam
- Agony of Floods: Floods Induced water Conflicts in India
- Water Conflicts in Northeast India: A Compendium of Case Studies
- Conflicts around Domestic Water and Sanitation: Cases, Issues and Prospects
- Drinking Water and Sanitation in Kerala: A Situation Analysis
- Reform Initiatives in Domestic Water and Sanitation in India
- Right to Water in India: Privileging Water for Basic Needs
- Right to Sanitation in India: Nature, Scope and Voices from the Margins
- Mahanadi River Basin: A Situation Analysis

Policy Briefs

- Towards a New Legal and Institutional Framework around Water: Resolving Water Conflicts in Equitable, Sustainable and Democratic Manner
- Resolving Upstream-Downstream Conflicts in River Basins
- Right to Sanitation: Position Paper of Right to Sanitation Campaign in India
- City Makers and WASH: Towards a Caring city
- Sanitation Rights and Needs of Persons with Disabilities
- Adivasis and Right to Sanitation
- Right to Sanitation: A Gender Perspective
- Dalits and Right to Sanitation
The Forum and Its Work

The Forum (Forum for Policy Dialogue on Water Conflicts in India) is a dynamic initiative of individuals and institutions that has been in existence for the last ten years. Initiated by a handful of organisations that had come together to document conflicts and supported by World Wide Fund for Nature (WWF), it has now more than 300 individuals and organisations attached to it. The Forum has completed two phases of its work, the first centring on documentation, which also saw the publication of ‘Water Conflicts in India: A Million Revolts in the Making,’ and a second phase where conflict documentation, conflict resolution and prevention were the core activities. Presently, the Forum is in its third phase where the emphasis of on backstopping conflict resolution. Apart from the core activities like documentation, capacity building, dissemination and outreach, the Forum would be intensively involved in right to water and sanitation, agriculture and industrial water use, environmental flows in the context of river basin management and groundwater as part of its thematic work. The Right to water and sanitation component is funded by WaterAid India. Arghyam Trust, Bengalure, which also funded the second phase, continues its funding for the Forums work in its third phase.

The Forum’s Vision

The Forum believes that it is important to safeguard ecology and environment in general and water resources in particular while ensuring that the poor and the disadvantaged population in our country is assured of the water it needs for its basic living and livelihood needs. The Forum is committed to the core values of equity, environmental sustainability, efficiency, livelihood assurance for the poor and democratisation.

The Forum’s Mission

The Forum’s mission is to influence policies and actions at all levels and work towards resolving, and preventing water conflicts in an environmentally and socially just manner, and creating awareness for achieving participatory, equitable, and sustainable water use. The Forum aims to carry out these through stakeholder interactions, knowledge creation, policy advocacy, training, networking and outreach.

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