

WATER MANAGEMENT IN ARKAVATHY BASIN

A SITUATION ANALYSIS

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list of **ABBREVIATIONS**

| | | | |
|--------|--|-----------------|---|
| ASHWAS | A Survey of Household Water and Sanitation | KRWSSA | Karnataka Rural Water Supply and Sanitation Agency |
| AusAID | Australian Agency for International Development | KSPCB | Karnataka State Pollution Control Board |
| BBMP | Bruhat Bengaluru Mahanagara Palike | KRSRAC | Karnataka State Remote Sensing Application Centre |
| BCCI-K | Bengaluru Climate Change Initiative – Karnataka | KUWSDB | Karnataka Urban Water Supply and Drainage Board |
| BDA | Bengaluru Development Authority | lakh | 1 lakh = 100,000 |
| BGL | Below Ground Level | LDA | Lake Development Authority |
| BMRDA | Bangalore Metropolitan Region Development Authority | LPCD | Litres per Capita per Day |
| BOD | Biological Oxygen Demand | MDWS | Ministry of Drinking Water and Sanitation |
| BUMP | Bangalore Urban Metabolism Project | mg/L | Milligrams per Litre |
| BWSSB | Bangalore Water Supply and Sewerage Board | mL | Millilitre |
| Cd | Cadmium | MID | Minor Irrigation Department |
| CGWB | Central Ground Water Board | MLD | Million Litres per Day |
| CMC | Cauvery Monitoring Committee | Mn | Manganese |
| COD | Chemical Oxygen Demand | MoWR | Ministry of Water Resources |
| CPCB | Central Pollution Control Board | MPN/100 mL | Most Probable Number |
| CPHEEO | Central Public Health and Environmental Engineering Organisation | Ni | Nickel |
| Cr | Chromium | NO ₃ | Nitrate |
| CRA | Cauvery River Authority | NRDWP | National Rural Drinking Water Programme |
| crore | 1 crore = 10 million | NRW | Non-Revenue Water |
| CSE | Centre for Science and Environment | Pb | Lead |
| Cu | Copper | SEI | Stockholm Environmental Institute |
| CWC | Central Water Commission | SVARAJ | Society for Voluntary Action Revitalisation and Justice |
| CWDT | Cauvery Water Disputes Tribunal | SWAT | Soil and Water Assessment Tool |
| DMG | Department of Mines and Geology | TDS | Total Dissolved Solids |
| F | Fluoride | TGR | Thippagondanahalli Reservoir |
| FC | Faecal Coliforms | TMC | Thousand Million Cubic Feet |
| Fe | Iron | UfW | Unaccounted for Water |
| GoK | Government of Karnataka | UGD | Under Ground Drainage |
| GP | Gram Panchayat | ULB | Urban Local Bodies |
| GSI | Geological Survey of India | WHO | World Health Organization |
| IDRC | International Development Research Centre | Zn | Zinc |
| IISc | Indian Institute of Science | ZP | Zilla Panchayat |
| kL | Kilolitre | | |
| | | | Unit Conversions |
| | | | 100 million litres per day = 1.29 TMC per year |

1

INTRODUCTION

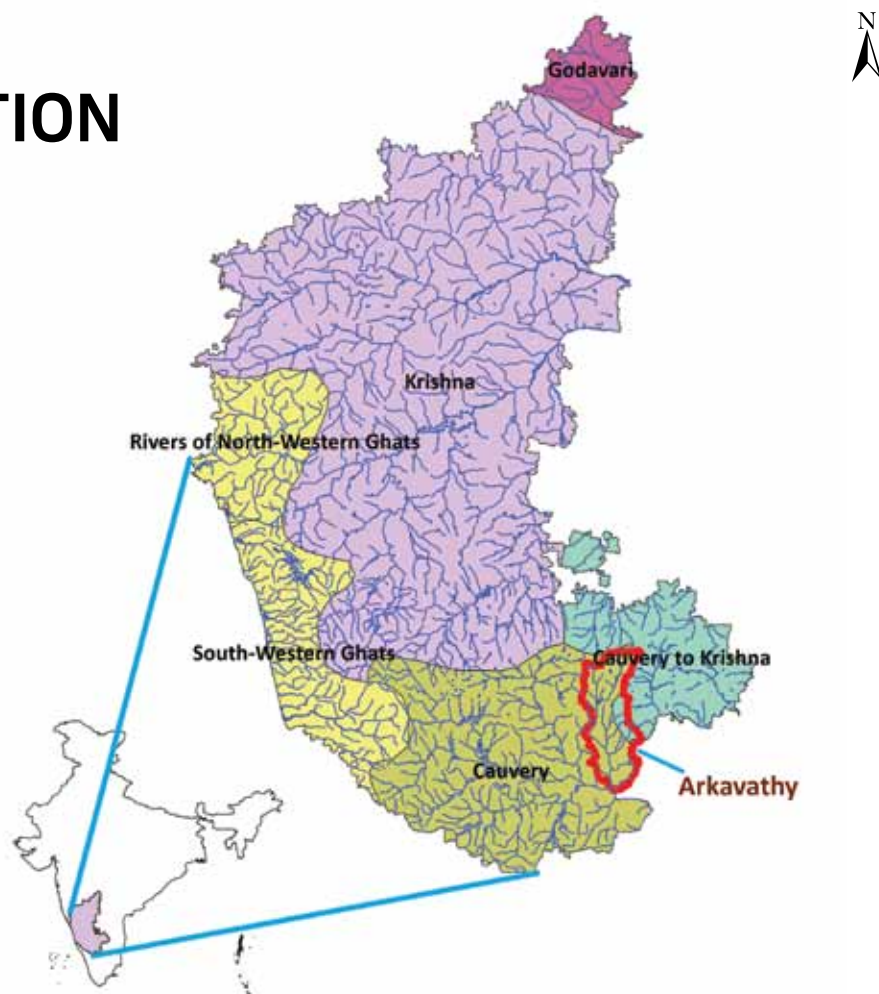


Figure 1: Location of Arkavathy sub-basin within the river basins of Karnataka

The Arkavathy sub-basin, which is part of the Cauvery basin, is a highly stressed, rapidly urbanising watershed on the outskirts of the city of Bengaluru. The purpose of this situation analysis document is to summarise the current state of knowledge on water management in the Arkavathy sub-basin and identify critical knowledge gaps to inform future researchers in the basin.

It is hoped that such an analysis will help those studying or working on water issues in the basin itself, and also provide useful insights for other such urbanising basins.

The Arkavathy sub-basin is located in the state of Karnataka in India (see Figure 1). It covers an area of 4,253 km², and is part of the inter-state Cauvery River basin. The sub-basin covers parts of eight taluka – Doddaballapur, Nelamangala, Magadi, Bangalore North, Bangalore South, Ramanagara, Anekal and Kanakapura within three districts – Bangalore Urban, Bangalore Rural and Ramanagara.

The total population in the sub-basin was 72 lakhs in 2001 and is estimated to be approximately 86 lakhs in 2011. This is distributed approximately 50:50 between urban and rural settlements (although the urban share is growing rapidly), with 33 lakhs from Bengaluru city (more than one-third of Bengaluru's total population). There are also four major Class II towns: Doddaballapur, Nelamangala, Ramanagara, and Kanakapura with populations ranging from 35,000 to 95,000. In spite of rapid urbanisation, there are still 1,107 revenue villages with populations ranging from less than 10 to 6,000¹, and agriculture continues to be the mainstay of a large number of them.

1.1 Hydrological and physiographic context

Originating in Nandi Hills, the main stem of the Arkavathy flows past Doddaballapur town and is joined by the Kumudavathy, Vrishabhavathy, Suvarnamukhi, and

¹ Based on a village layer digitised from Census 2001 district census handbook, and corrected using the latest city/town boundaries.

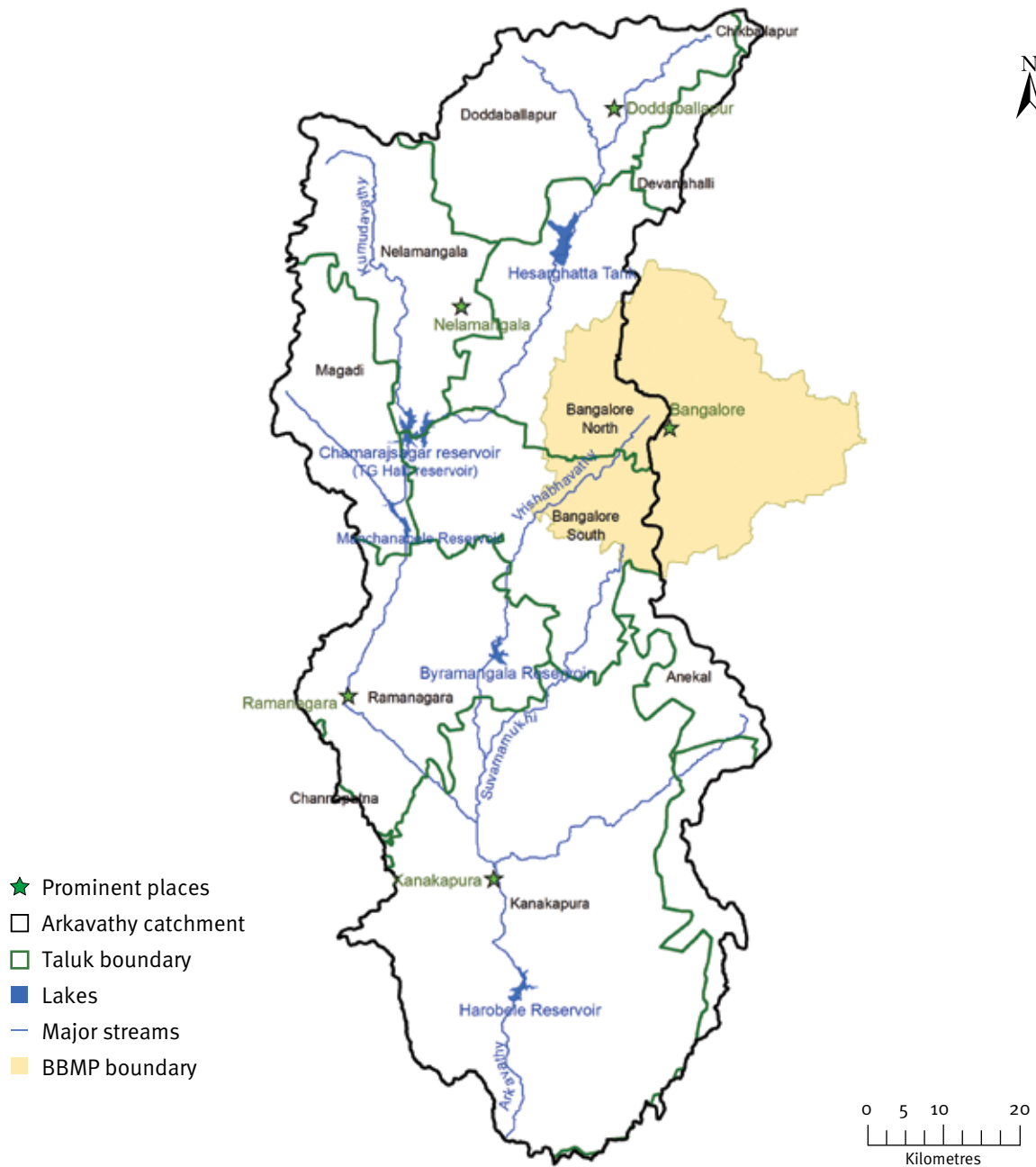


Figure 2: The Arkavathy catchment with major features. (Data source: GSI toposheets, ASTER DEM imagery. Map prepared by ATREE Ecoinformatics Lab)

several smaller streams before it eventually meets the Cauvery (see Figure 2). Of these, the catchments of the Kumudavathy and Suvarnamukhi are largely rural and the Kumudavathy flows only during the wet season. On the other hand, the Vrishabhavathy stream runs through Bengaluru and peri-urban areas, and is now a perennial but highly polluted river, as it acts as a drain for domestic and industrial wastewater.

The Arkavathy River feeds a series of cascading tanks and two major water reservoirs (Hesaraghatta and Chamrajasagar) that were once major sources of water to Bengaluru city. Of these, the Hesaraghatta tank is mostly dry, and no longer overflows downstream. The Chamrajasagar reservoir at Thippagondanahalli (and commonly known as TG Halli reservoir), located at the confluence of the Arkavathy and Kumudavathy rivers, still receives some inflow, mostly from the Kumudavathy,

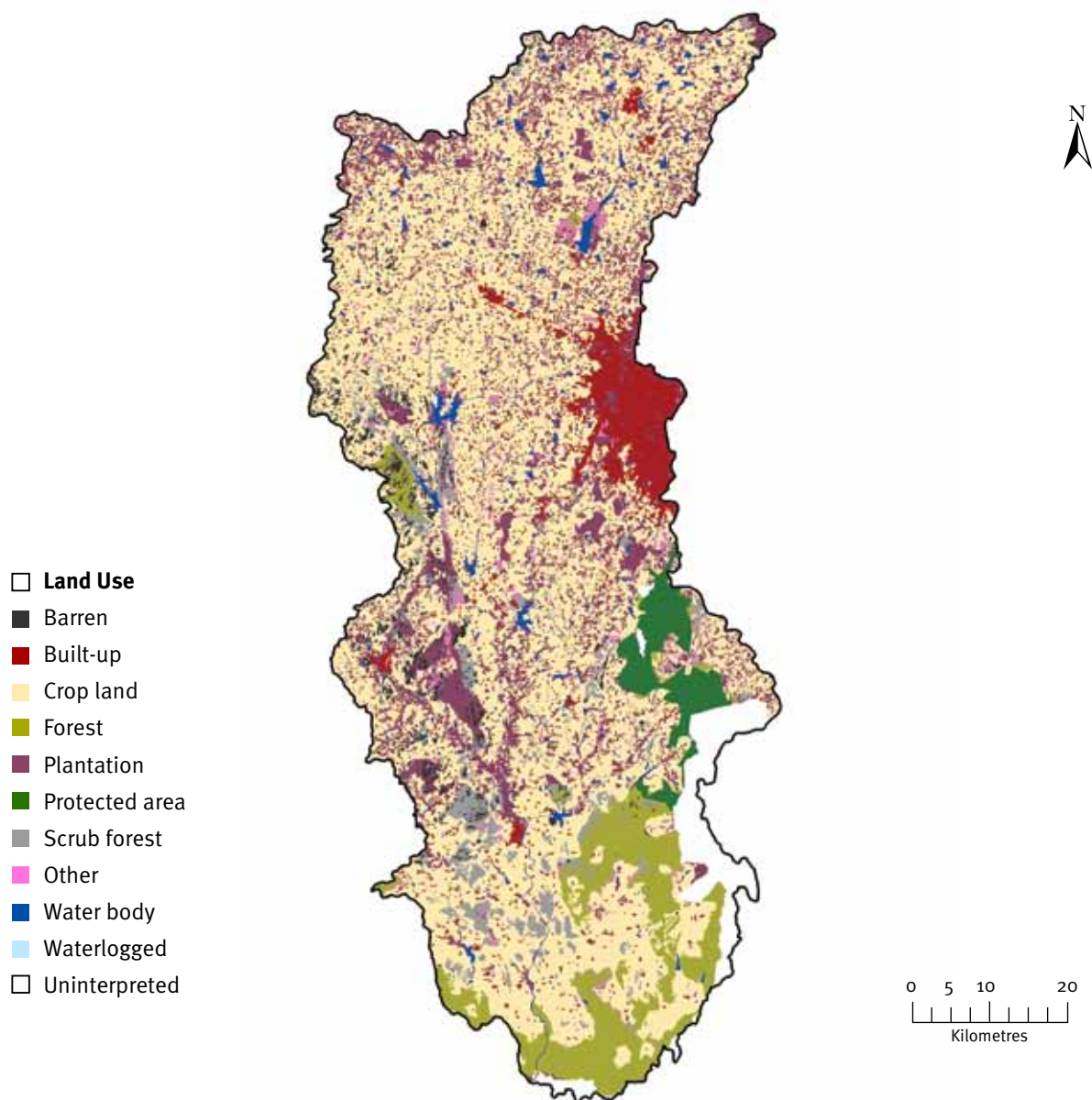


Figure 3: Arkavathy sub-basin land use map for 2003 (Data source: KRSAC. Map prepared by ATREE Ecoinformatics Lab)

but flows have been steadily declining. The reservoir currently supplies about 30 million litres per day (MLD) to Bengaluru, which is far lower than the design capacity of 148 MLD (<http://bwssb.org/water-supply-sources/>). The Manchanbele dam further downstream on the Arkavathy receives additional water from the eastern part of the catchment and serves Magadi town and, occasionally, Ramanagara town.

The Vrishabhavathy, a tributary of the Arkavathy, flows into the Byramangala tank, the water from which, in spite of being polluted, is used for irrigation. The Vrishabhavathy meets the Arkavathy before Kanakapura town. Near Kanakapura and further downstream, the pollutant-laden Arkavathy gets diluted to some extent by other streams, yet remains highly polluted when it joins the Cauvery.

Bengaluru's water supply from the Cauvery Stages 1–4 is drawn from the Cauvery upstream of this sangam.

In terms of hydrogeology, most of the Arkavathy sub-basin is underlain by hard-rock that consists of gneisses and granites. The shallow aquifer consists of the highly weathered zone extending to about 20 m BGL. The fractured zone, extending from 20–50 m, contains joints and cracks, some of which are well-connected to each other and can function as conduits. Yields drop off greatly beyond 60 m. At deeper levels, there are a few joints and fractures that have been enlarged by dissolution and can extend to considerable depths. The Geological Society of India estimates that 96% of the yield comes from the top 60 m (Grönwall 2008).

The land use map for the sub-basin in 2003 shows that cropland and plantations accounted for over half of the sub-basin area, with about 7% being built-up (Figure 3). While we expect the urban area to have grown since 2003 (perhaps even doubled), agriculture and plantations still cover a significant portion of the land area.

1.2 Institutional context

The institutional context of water management in the Arkavathy sub-basin is quite complex. A number of agencies deal with different aspects of water management in different regions, with significant overlap in some cases and significant gaps in others. They are collectively

responsible for enforcement of laws and various government programmes, sometimes with inconsistent mandates. Our current understanding of water governance in the Arkavathy sub-basin with respect to the four objectives identified above is summarised in Table 1.

As seen in the table, the main distribution of responsibilities is along geographical lines: BWSSB is primarily responsible for all aspects of water management in Bengaluru, Karnataka Urban Water Supply and Drainage Board (KUWSDB) along with the respective municipalities in the small towns, and the Gram Panchayats (GP) with the help of specific programmes such as National Rural Drinking Water Programme (NRDWP) in the rural areas. Pollution control

Table 1
Water resource governance in the Arkavathy sub-basin

| Objective | Sector/Source | Context/Agency in charge | | |
|-------------------|------------------|--|--|---|
| | | Bengaluru city | Small towns | Villages |
| Quantity (supply) | Domestic | BWSSB, self and private supply | KUWSDB, CMC self and private supply | GP, KRWSSA and self supply |
| | Industry | BWSSB, self and private supply | KUWSDB, CMC, but largely self and private supply | Self and private supply |
| | Agriculture | — | — | MID & self supply |
| Quantity (sewage) | Domestic | BWSSB | KUWSDB | GP, KRWSSA |
| | Industry | BWSSB | KUWSDB | — |
| | Agriculture | — | — | — |
| Quality | Groundwater | DMG*, KSPCB? | CMC, KSPCB? | DDWS*, KSPCB? |
| | Surface water | BWSSB, KSPCB | KUWSDB, KSPCB | KSPCB, GP |
| Sustainability | Groundwater | BWSSB, CGWB*, Ground water authority, DMG* | KUWSDB, CGWB*, Ground water authority, DMG* | GP/ZIP, CGWB*, Ground water authority, DMG* |
| | Surface water | BWSSB, LDA, BDA, BBMP | KUWSDB, LDA, BMRDA | GP, KRWSSA, CWC* |
| Allocation | Micro/meso-scale | BWSSB | KUWSDB | GP, MID |
| | Macro-scale | Cauvery Water Disputes Tribunal, Supreme Court, CRA, state government, CWC*, WRDO* | | |

* Only monitoring, not enforcement. ? Role of agency is unclear

rests with Karnataka State Pollution Control Board (KSPCB), but it appears to focus on surface water only. Groundwater is monitored by a number of agencies; enforcement remains a problem. Although the landmark Karnataka Groundwater Regulation Act 2011 has been passed, implementation mechanisms have not yet been finalised (Lingaraju, Pers. Comm. 2012).

1.3

Roadmap to this document

In this document, we present this situation analysis by describing the nature of the 'problem' in the Arkavathy sub-basin. We define the problem by identifying four broad objectives of water resources management.

1. To ensure that sufficient quantity of safe, affordable water is supplied to domestic, commercial/industrial/institutional (CII) and agricultural users, as well as left for ecological and environmental purposes.
2. To ensure equitable allocation of water within similar users and fair allocation between different users.
3. To maintain sustainability and resilience of water resources by regulating overdraft.
4. To maintain quality of water in water bodies to sustain public health and environmental amenities.

Then, to the extent these objectives are not met, there is a problem that needs to be addressed. In the following sections, we describe the 'current situation' in the Arkavathy sub-basin as understood in published literature and experts we interviewed. Section 2 discusses the issues of sufficiency of safe, affordable supply. In Section 3, we discuss issues of fairness of allocation. In Section 4, we discuss whether current levels of consumption are sustainable and resilient. In Section 5, we discuss water quality issues. For each issue, we summarise the magnitude and distribution of the problem and then discuss some of the biophysical and socio-institutional determinants. At the end of each section, we highlight the key knowledge gaps that remain to be addressed.

2

SUFFICIENCY OF SAFE, AFFORDABLE WATER SUPPLY

Whether there is sufficient water to meet the current needs of users in the Arkavathy sub-basin and which users face water scarcity, where and when, are usually the first questions raised in water-related discussions. In order to answer these questions, we need to address some conceptual challenges.

First, defining scarcity (or sufficiency) is difficult. Clear quantitative norms exist for domestic users – 55 litres per capita per day (LPCD) in rural areas and 70–100 LPCD for small towns (GoK 2002). But no such norms exist for agricultural or industrial/commercial users or for ecological and aesthetic functions. To avoid getting drawn into debates about how much water is 'enough' or appropriate for industrial/commercial versus agricultural use versus environmental needs, we define 'sufficiency' for non-domestic users subjectively, in terms of whether the water supplied is enough to satisfy current demand.²

Second, scarcity is usually defined as the gap between supply and demand, where supply is usually interpreted as public supply. In practice, water users in the Arkavathy sub-basin access water through multiple sources: public infrastructure, their own wells, and private tanker operators. Owing to the heavy dependence on private sources, whether households obtain enough water depends on how much the public supply agencies are able to deliver, as well as on how much water users can draw

on their own. So, the presence of scarcity does not always imply that the public supply agency is failing; it could also mean that private sources are drying up. Although most researchers and policy makers are aware of this, self- and private supplies are rarely factored into policy discussions.

Third, the issue of scarcity and affordability cannot really be separated. Clearly, water can be purchased from tankers and bottled water suppliers at some price, but beyond a point, the cost of water can compel reductions in water use with negative impacts on household health, force farmers to grow less-remunerative crops, or drive industries out of business. So, we also need to look at scarcity from the economic viability point of view.

With these caveats in mind, in the following section, we discuss water scarcity concerns for each user type and source. We also discuss some of the issues surrounding affordability and cost of supply.

2.1 Urban use – Domestic, commercial and industrial

To estimate the level of water availability or scarcity for urban users in the Arkavathy sub-basin, we have to combine estimates of public supply with private supply, since both are significant.

² This is not to treat current levels of agricultural and industrial activity as sacrosanct, but to use it as one possible level to define sufficiency.

Table 2: Public water supply status in urban bodies in the Arkavathy sub-basin

| Town | 2011 Population | Sources | Quantity (MLD) | LPCD |
|--|-----------------|---|-------------------|------|
| Kanakapura | 59,600 | Cauvery water supply, local borewells | 4.8** | 80 |
| Ramanagara | 95,000 | Backwash from TK Halli, Shimsha borewells | 10 [§] | 95 |
| Doddaballapur | 84,128 | Borewells | 4.98 [^] | 59 |
| Nelamangala | 31,000 | Borewells (design 4.5 MLD) | 1.3 | 41 |
| Bengaluru, plus 9 peri-urban municipal corporations | 9.5 million | Hesaraghatta (design 36 MLD) | 0 | 85 |
| | | TG Halli (design 148 MLD) | 30 | |
| | | Cauvery Stage 1 (150 MLD@source) | 135 | |
| | | Cauvery Stage 2 (150 MLD@source) | 135 | |
| | | Cauvery Stage 3 (315 MLD@source) | 270 | |
| | | Cauvery Stage 4 (315 MLD@source) | 270 | |

Note: MLD = million litres per day; LPCD = litres per capita per day

** <http://www.kanakapuratown.gov.in/ws> § <http://www.ramanagaracity.gov.in/ws>

[^] <http://www.doddaballapurcity.gov.in/ws> Additional information: Feedback Ventures (2009a,b,c)

2.1.1

Urban public supply

Different public agencies supply water to different urban settlements in the Arkavathy sub-basin. Bengaluru Water Supply and Sewerage Board (BWSSB) is the biggest supplier, but it is also the least dependent on local sources. Almost all of BWSSB's water is pumped from the Cauvery River, 100 km away and 500 ft. lower in elevation. The four big Class II towns that lie within the sub-basin have water supply systems managed by the town municipality and/or the Karnataka Urban Water Supply and Sanitation Agency depending on a range of sources for bulk water. Kanakapura town draws its bulk water from BWSSB's Cauvery pipeline and operates only the distribution system. The other three towns – Ramanagara, Doddaballapur and Nelamangala – source, treat and distribute their own water, sourced mostly from municipal borewells. The municipal borewells, subject to electricity availability, pump water to overhead storage tanks, where the water is chlorinated and delivered to users. Additionally, Ramanagara gets a portion of its supply by treating and using the backwash from TK Halli treatment plant, which treats Cauvery water for supply to Bengaluru. Finally, a small quantity of water is exported out of the basin. Water is supplied from Manchanabele reservoir which lies on the Arkavathy River, to Magadi town, which lies just outside the western boundary of the sub-basin.

The sources and quantities of water supplied to each of the administrative units lying within the sub-basin are shown in Table 2. The data suggest that per capita availability is above the 70–100 LPCD norm for Class 2 towns. However, we do not (as yet) have a breakup of BWSSB supply into wards that lie within the Arkavathy sub-basin, nor is a breakup available in any of the towns for domestic versus commercial/industrial use, nor are leakages and wastage factored into this table. So, for instance, although Bengaluru as a whole shows a level of 85 LPCD supplied, which is already below the 110 LPCD norm, a significant portion of this supply is lost or goes to commercial and industrial establishments, including government institutions. So the actual LPCD received by the domestic user is much lower (although it is then augmented by private borewells and tankers). Moreover, at this gross level of analysis, we are unable to see how much variation there might be within each city/town. Micro-level studies indicate that slums (for instance) receive much lesser water than wealthier neighbourhoods (CSE 2012).

2.1.2

Urban self- and private supply

Groundwater is the other major source of water supply for domestic and CII use in the Arkavathy sub-basin. There is no formal and systematic monitoring of groundwater extraction in urban areas, so we have to rely on a few micro-level or one-off studies.

One of the few city-wide estimates of groundwater extracted from private wells (D'Souza and Nagendra 2011; Suresh 2001) based on a borewell census estimated groundwater abstraction in Bengaluru to be:

1. Private, domestic and industry – 500 MLD
2. Government agencies for domestic use – 33 MLD
3. Private abstraction for the water tanker market – 39 MLD

Thus, total groundwater abstraction for Bengaluru was estimated by Suresh (2001) to be 572 MLD in 2001, an amount that exceeded surface water-based utility supply to the city in that year! In other words, more than half of Bengaluru's water demand was met from local groundwater, with most of it coming from households' own borewells and about 6% from the tanker market. These figures are consistent with estimates by DMG (2011), which estimate groundwater extraction within Bengaluru at 590 MLD. They are also broadly consistent with the pattern emerging from the single ward study conducted in 2004 (Raju et al. 2008). This study reported that 97% of households surveyed were dependent at least partially on groundwater – only 52% used borewells while 45% depended on both piped supply and borewells for their water.

However, there remains considerable dispute over these figures. BWSSB and KUWSSB estimate groundwater extraction in Bengaluru to be much lower. For instance, a consultancy report conducted on behalf of BWSSB estimates groundwater extraction to be as low as 20% of total consumption in 1997/98 (Sinclair Knight Merz and EGIS Consulting Australia, 2001). In the case of the four smaller towns, there are no estimates available for private groundwater extraction.

2.1.3

Summary of urban water scarcity

Based on the above estimations of public and private supplies (adopting Suresh's estimates for the latter as the generous estimate of self-supply), total water available to urban users within Bengaluru for the year 2001 was approximately as shown in Table 3.

This figure of per capita consumption for Bengaluru is somewhat below the Central Public Health and Environmental Engineering Organisation (CPHEEO) consumption norm of 150 LPCD for large metropolitan areas with underground sewerage systems (Mathur et al. 2007), suggesting that Bengaluru was slightly water scarce even after groundwater extraction is considered. Though more recent numbers are not available, we expect that overall the situation has either stayed the same or worsened since 2001. This is because, although more Cauvery water is being delivered to Bengaluru, local sources have dried up and the population has grown

Table 3: Estimating average per capita water use in Bengaluru in 2001

| Water sources | Amount |
|--|-----------|
| Cauvery supply in 2001 | 600 MLD |
| Arkavathy (TG Halli) supply in 2001 | 110 MLD |
| Less losses 42% (Sinclair Knight Merz and EGIS Consulting Australia, 2001) | |
| Total surface water delivery | 412 MLD |
| Total groundwater pumped | 570 MLD |
| Total consumption | 982 MLD |
| Less Commercial, Industrial, Institutional (CII) consumption (20%) | 245 MLD |
| Total use per capita (dividing above by 5.6 million residents in 2001) | 140 LPCD* |

*LPCD = MLD delivered/Population

sharply in the last decade. Furthermore, as mentioned earlier, these average numbers obscure inequities across socio-economic strata. Preliminary field visits suggest that the situation in the smaller towns is somewhat worse, especially in Nelamangala and Doddaballapur.

Estimating the level of scarcity faced by commercial and industrial users is more complicated, not only because there is no simple norm but also because the data are weaker: we do not know the number and types of users within this category. However, it is well-known that many commercial and industrial units receive little or no water at all from BWSSB and have been waiting to be connected for years, and are completely dependent on groundwater (own or purchased). Although water accounts for a small percentage of the costs for these businesses, it nevertheless represents a critical input. If water supply were to be disrupted, the facilities would have to be shut down. By this criterion, many commercial businesses in and around Bengaluru can be described as facing some water scarcity. It is also reasonable to assume that some fraction of these users, as domestic users, face more scarcity during the summer months.

2.2

Rural domestic use

We tried to understand the level of availability/scarcity in rural areas using two publicly available datasets that covered most of the rural portions of this sub-basin. (All other studies were at a much smaller scale.) The Ministry of Drinking Water and Sanitation, Government of India (MDWS) has been implementing the National Rural Drinking Water Programme (NRDWP). This project has

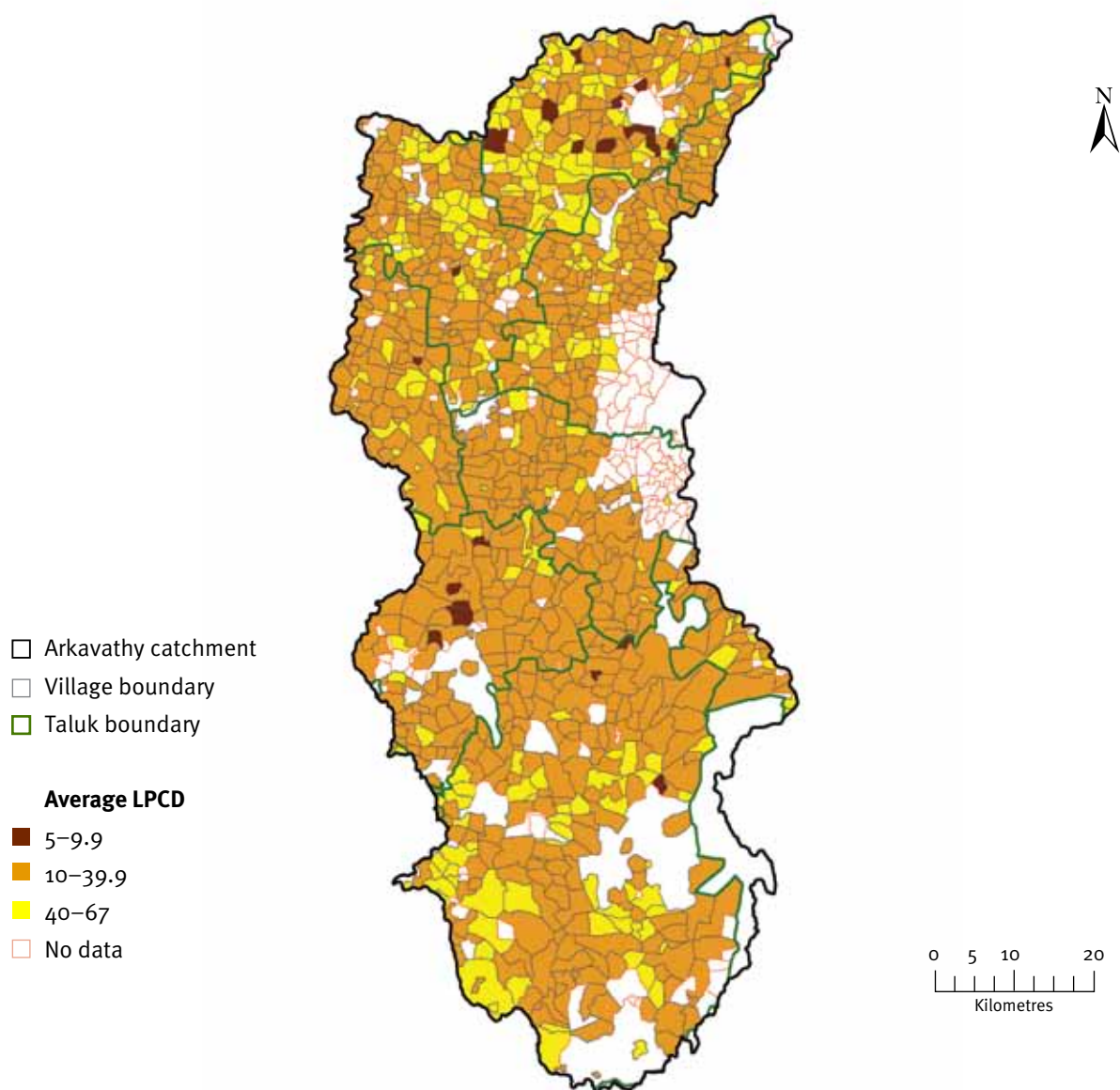


Figure 4: Water supply levels (LPCD) in rural Arkavathy sub-basin. (Data source: NRDWP: <http://indiawater.gov.in/imisreports/nrdwpmain.aspx>. Map prepared at ATREE Ecoinformatics Lab.)

estimated the quantity supplied in each village, which we have mapped (Figure 4). This suggests that most of the watershed is in the 10–40 LPCD range, which is below the Government of Karnataka (55 LPCD) norm for rural areas. The map also suggests that some villages in the north-eastern and south-western portions face lesser scarcity compared to other parts.

However, these figures do not present a true picture of water scarcity for several reasons. First, they only relate to GP water supply schemes and do not include water households may obtain from their own borewells, open wells or other sources. Second, they are most likely to be based on installed capacity, not reflecting actual water

delivered (R. P. Mallick, Pers. Comm. 2012), nor do they account for non-functional wells/pumps or transit losses. These two corrections operate in opposite directions: accounting for self-supply increases the estimate, whereas accounting for actual government delivery lowers the NRDWP estimate. On the whole, this dataset suggests a situation of scarcity for most rural settlements, especially for households that do not have access to private wells. Another dataset that is publicly available is A Survey of Household Water and Sanitation (ASHWAS), a household survey of rural households across Karnataka (indiawaterportal.org; see also (Arghyam 2009)). We obtained data for Bangalore Rural and Ramanagara districts (800 households) and examined the pattern in the quantitative

estimates of water use (total number of pots consumed for all end-uses in the household). These data suggest a much higher level of water consumption: 96–183 LPCD (assuming 1 pot = 12 litres). No clear pattern could be distinguished across the region, partly because the sample covered only a few Gram Panchayats.

Our own field observations are somewhat at variance with the NRDWP data, which suggest that water scarcity is very patchy. On the whole, our observations suggest that the northern portion of the sub-basin experiences less rainfall and higher levels of groundwater depletion, and consequently would be facing more scarcity than villages in the southern portion. The depth-to-groundwater map produced by the Department of Mines and Geology (DMG) also suggests that groundwater is more easily available in the south. In short, no clear conclusions on rural domestic water scarcity emerged from our analysis of secondary data and published literature.

2.3 Irrigation use

Irrigation is a major use of water in the Arkavathy sub-basin; particularly in rural areas. Agriculture remains the mainstay of rural livelihoods in the Arkavathy sub-basin, even though this is changing. As mentioned earlier, more than half of the land in the sub-basin is under agriculture and plantations. From our field visits, we found that groundwater is the primary source of irrigation water in most areas, although some areas such as Doddaballapur taluka have a large number of minor irrigation tanks.

We were unable to find reliable estimates for agricultural water 'scarcity' in Arkavathy sub-basin as there were no studies on peri-urban agriculture. In the northern Arkavathy sub-basin, many irrigation tanks have dried up and the water table has dropped below 500 ft. in places. Here, people reported a shift towards urban land uses and plantation crops – driven in part by water scarcity and in part by industrialisation, urbanisation, changing labour availability, etc. In the southern portion of the sub-basin, water is more plentiful much of it is of poor quality, as it comes from the polluted Vrishabhavathy. Here, farmers reported a gradual shift towards mulberry, fodder and other cash crops.

Thus, on the one hand, although the land under agriculture is decreasing, cropping patterns are intensifying and shifting from cereals to cash crops. On the other hand, drip irrigation is also becoming widespread. The net effect of these trends on user satisfaction or and satisfaction of demand is not well-studied. Also not well-understood is

the seasonal variation and year-to-year variation in water availability. However, except for certain pockets, it is hard to conclude that the availability of water for agriculture has declined as compared to the past.

2.4 Environmental amenities

An important 'use' of water, particularly in urban areas, is aesthetic and habitat for aquatic biodiversity. The Lake Development Authority recognises that surface water bodies³ play a key function in making urban living pleasant⁴, as well as a habitat to support unique ecosystems that are valued by urban dwellers. For instance, bird watchers reportedly outnumber other types of users in urban Agara Lake (D'Souza and Nagendra 2011). Lake rejuvenation efforts also tout potential flood mitigation benefits if storm water can be channelled into lakes and also the vital hydrological role in recharging groundwater in its lower command areas.

It is clear that the number of lakes in Bengaluru is dwindling and many are drying up, even as the total number of 'lakes' is increasing as Bengaluru expands and swallows up erstwhile irrigation tanks. Overall, one may state broadly that water availability for environmental amenities (most valued in urban areas) is declining. The reasons for this are complex. Some of this is the result of conscious conversion of land use (such as the building of the National Games village). However, conversion is often facilitated by the drying up of the tanks, and the reasons for this are a combination of choking of inlets and pumping of groundwater.

It must also be noted that not all environmental functions are necessarily compatible with each other. Recreational activities such as boating or bird-watching require full lakes, but if lakes are to provide recharge or flood control, they need to be porous or stay empty for most of the time. There is as yet limited understanding of the inflows and storage in such bodies, and of the trade-offs between different uses in the Arkavathy sub-basin.

Similarly, streams and rivers provide habitat for aquatic organisms, and if they dry up or get polluted, this habitat will decline. From that perspective, the flowing water available for environmental aesthetic and biodiversity purposes in the Arkavathy sub-basin has declined sharply; the highly polluted Vrishabhavathy completely violates all norms and it is impossible for most organisms to survive in it. However, given the absence of information on the extent of such amenity use, it is hard to make an assessment of who the winners and losers are

³ Strictly speaking, none of the surface water bodies in the basin qualify as 'lakes' because they are all man-made water bodies, i.e., irrigation tanks created by constructing embankments across streams.

⁴ <http://parisaramahiti.kar.nic.in/role.html>.

and whether the conversion of irrigation tanks to urban amenity lakes counterbalances the decline in any sense.

2.5 Affordability of water supply

If scarcity is determined not just by LPCD, but also by the cost of obtaining the water, what can one say about this (economic) scarcity in the Arkavathy sub-basin? This can be looked at in different ways. For a household, affordability might mean what water at the LPCD norm costs vis-à-vis an average household budget. For agriculture and industry, it may mean whether the cost of water makes those activities unprofitable.

Domestic water is supplied at a base rate of Rs. 6–9/kL for the first 25 kL per domestic connection per month, which equals the LPCD norm (assuming a 5-person household). This amounts to Rs. 150/month/household. This is the highest among most towns in southern India (McKenzie and Ray 2009), but is justified by BWSSB on grounds of the higher cost of pumping water from the Cauvery. Further, given the income levels in Bengaluru, Rs. 150 does not appear to be a huge fraction of an average household's monthly budget.

However, those who do not have BWSSB connections, or have inadequate city supply, have to either pump from own borewells, or pay tankers a much higher rate. In extreme cases, if a household depends only on tanker supplies, its cost of water could be ~Rs. 1,000 per month. Here, a study by Raju et al. (2008) argues that multiplicity of borewells in the same small locality means a 'higher than necessary' cost of water supply, since each individual user is investing in a borewell and pump when there could have been a single common borewell. While no concrete information is available for small towns, we believe the trend is similar there.

In the agricultural sector, impacts of irrigation water scarcity induced by groundwater depletion in hard rock areas of Karnataka (Anantha and Raju 2010) include increased expenditure on deepening wells, increasing pump capacity, frequent replacement of pumps malfunctioning due to voltage fluctuations, etc. In areas suffering from water scarcity, multiple cropping was not possible. In the agricultural sector, impacts of irrigation water scarcity induced by groundwater depletion in hard rock areas of Karnataka (Anantha and Raju 2010) include increased expenditure on deepening wells, increasing pump capacity, frequent replacement of pumps malfunctioning due to voltage fluctuations, etc. In areas suffering from water scarcity, multiple cropping was not possible. Moreover, low economies of scale inhibited the use of new technologies, limiting both crop yields and gains in water use efficiency (Anantha and Raju 2010). Farmers did not get the expected returns from their investments due to high rates of well failure. They were saddled with high

interest rate payments and accumulated debts. The study showed that groundwater depletion impacted both farm productivity and income status of households. Households coped with groundwater depletion using a variety of strategies including

1. Diversification of income sources away from water-dependent, agricultural livelihoods;
2. Drilling deeper bore wells; and
3. Borrowing to cover the increasing cost of irrigation (Anantha and Raju 2010).

Thus, the overall situation today does not represent a picture of acute economic scarcity or non-affordability, although BWSSB, the biggest urban water provider in the sub-basin, clearly charges much higher water rates compared to many other cities. However, there are pockets of physical scarcity (where LPCD falls below the norms), overlaid with pockets of economic scarcity, where households are completely dependent on private sources.

2.6 Institutional analysis of water scarcity

Our analysis of the available literature clearly suggests that there are pockets in both urban and, especially, rural areas where domestic water scarcity is significant. Moreover, a number of households face seasonal shortages. Yet, partly because of the continued availability of Cauvery water, and partly because the government has invested heavily in setting up borewell-based rural water supply infrastructure (without addressing the issue of long-term sustainability), it may be fair to say that the vast majority of domestic users do not experience acute scarcity. Economic scarcity is felt by some commercial and industrial users, and by domestic users who do not have access to city supply or functioning borewells. Some agricultural water scarcity exists in the Kumudavathy and parts of Doddaballapur taluka; but aquatic ecosystem needs are clearly not being met, especially in streams and lakes that are drying up or getting polluted.

The socio-institutional causes of this pattern of scarcity are complex and unclear. Clearly, rural users wield much less political power as compared to the residents of Bengaluru, which is the capital of the state, endowed with an agency exclusively mandated to supply water and sewerage services (BWSSB) and with the power to appropriate water from as far as 100 km away. At the same time, the decisions taken by BWSSB, such as forfeiting budgetary support from the state government and procuring water from so far away, result in high water supply costs that have to be recovered from the consumer, resulting in economic scarcity for some or deprivation of connections for others. BWSSB has also launched some measures towards rainwater harvesting, but it is unclear what (if any) effects it has achieved.

The delicate politicised nature of the negotiations between BWSSB and peri-urban areas (and within these areas) is illustrated by a set of case studies of Tataguni, Doddakallasandra, and Konanakunte villages described by Raju et al. (2004). In Tataguni, an overhead tank, pipelines and private house connections were laid using funds from the Zilla Panchayat. BWSSB refused to undertake responsibility for Operation and Maintenance of the piped network which was poorly constructed. The Gram Panchayat was assigned the responsibility of collecting the money and maintaining the pipes, but at the time of the study, the households were not paying the Gram Panchayat and the Gram Panchayat was not paying BWSSB. Despite years of talks between the Gram Panchayat and BWSSB, the actual water supply arrangement remains informal. BWSSB provides 50,000 litres of water to the village informally due to political pressure, but no formal contract is in place. BWSSB staff operate the connecting valves to the village at their own convenience. Wealthier households closer to the tank (mostly upper caste) receive water and enjoy effective 24/7 supply by collecting water in underground sumps, while those at the tail-end of the piped system, where the Scheduled Caste colony is located, do not receive water. Residents must walk considerable distances to access water from a public tap (Raju et al. 2004).

As far as managing scarcity for environmental amenities and irrigation users is concerned, the existing agencies do not appear to be empowered to manage scarcity. While the Lake Development Authority has been created to rehabilitate and look after lakes in Bengaluru, it is not clear that it has any jurisdiction over the sources of inflow or the authority to regulate groundwater pumping that might be causing reduced inflows. Similarly, the Minor Irrigation Department is unable to regulate pumping that may be reducing inflows into irrigation tanks, and has limited capacity to influence land use change and water diversion upstream.

2.7

Water scarcity: Key knowledge gaps

1. The spatial pattern and extent of domestic water scarcity is still quite unclear. In rural areas, the NRDWP data reflect only installed capacities and do not include self-supply, not to mention, seasonal variation. While overall scarcity in Bengaluru is not so high, pockets of scarcity are not clearly identified and the understanding of scarcity is much weaker for small towns.⁵
2. In the case of agriculture, it is not yet clear to what extent farmers are facing borewell failures and reductions in tank irrigation are being compensated by borewells and by shifts to drip irrigation. Thus, the role of water scarcity (and quality, as the later sections will show) in influencing agricultural cropping shifts (as compared to other factors such as urbanisation) needs to be understood.
3. Little is known about the commercial and industrial use of water, and whether such activities are being seriously affected by the physical or economic scarcity of water.

⁵ The gap in the understanding of water use in Bengaluru is being filled to a large extent by the ongoing BUMP research project (<http://www.urbanmetabolism.in/bump/index.php>).

3

FAIRNESS OF ALLOCATION ACROSS USES/USERS

The second concern is about the fairness of water allocation. Unfortunately, since there are no clear criteria for 'sufficiency' of non-domestic uses; there are also no objective criteria for determining whether water has been fairly allocated across users/uses.⁶ We therefore leave the question of 'how fair current outcomes across users are' unaddressed, and focus on estimating how water is currently allocated, and outlining our understanding of the process through which this allocation appears to be happening. We discuss this across different user groups: domestic versus industrial versus agricultural, upstream versus downstream, and within a particular user category.

3.1 Between sectors – Industrial/commercial, domestic and agricultural users

There is significant competition for particular stocks and flows at specific locations and periods. How much water ends up being allocated depends both on how water is allocated by the public delivery system, and how much water is extracted privately by different users.

At present, there are no formal mechanisms to allocate water rights between agriculture, industry and domestic users. Instead, the mechanisms influencing inter-sectoral allocation are indirect, viz., water pricing, rationing, fencing, licensing, and investment in water infrastructure.

Public-supply: In the case of water utilities, there are typically two mechanisms that govern how much water is 'allocated' to users – pricing and access.

Differential water tariffs across domestic and commercial users: Commercial users in Bengaluru pay 5–10 times higher water rates per kL as compared to domestic consumers. We believe that KUWSDB and other urban local bodies also follow similar tariff structures in the smaller towns.

Access to piped infrastructure: On the one hand, many industrial and commercial consumers have complained about delayed connections to certain areas, even after they have paid their betterment or development charges. On the other hand, certain industries have managed to get a dedicated Cauvery line that bypasses local communities, while others have yet to receive water years after paying for a connection. This amounts to differential access to (reliable) Cauvery water for different consumers.

Thus, it is possible that there is a fair amount of inconsistency even within the commercial sector: a first-come-first-serve policy in some areas, while a few pockets get privileged water supply as compared to others.

Self-supply: In the case of extraction of groundwater, allocation is much less controllable – the user with the deepest well or most powerful pump can usually extract the most. At present, the only legal mechanism to regulate groundwater extraction is the Karnataka Groundwater Act of 2011. The Act requires all new borewell users in notified areas to apply for a permit in which they must specify the purpose of water use. The Groundwater Authority has the mandate to decide how to account for competing uses. In theory, domestic users would be given

⁶ Economists suggest using the marginal economic benefit per unit of water (Rs/kL) to measure whether water is being 'optimally' allocated. In this approach, water should be allocated to those uses which have the highest marginal benefit, till the marginal benefits are equalized across all uses. However, among other problems, this approach has serious equity implications: poorer people may have a lower willingness-to-pay for water because of a lower budget, and certain uses (such as industrial use) may show a higher marginal benefit, but this may not reflect a societal prioritization of the uses water should be put to.

priority; commercial users may not get permission to drill in areas where their use might affect domestic users. However, at this point, neither have rules been notified under the Act, nor have the enforcement mechanisms been finalised. Borewell registration is not linked to any other service that a government can withhold (such as land title or an electricity connection). Some spacing norms are supposed to be in place, but field observations suggest that these norms are not being enforced. Tensions between domestic users and agricultural users are apparent in rural areas, but the response seems to be to dig deeper borewells, i.e., transforming the inter-user issue into an inter-generational issue.

In the case of surface water bodies such as reservoirs, we see evidence of shift in users and management objectives over time. For instance, as Bengaluru has expanded, a number of irrigation tanks have become part of an urban or peri-urban development where surface irrigation is no longer relevant or viable. Over time, these tanks have been converted into 'lakes' and their management has been gradually handed over to the Lake Development Authority or (in the smaller towns) to the Cauvery Monitoring Committee (CMCs). While this can be seen as a conscious recognition of shifting needs, it is unclear how the needs of certain underprivileged users such as fisherfolk are taken into consideration in the shift (D'Souza and Nagendra 2011).

3.2 Between upstream and downstream reaches

Upstream users inherently have an advantage in any watershed, which may play out in various ways. In a large river basin such as the Cauvery, upstream users can build dams and reduce flows available to downstream users. In a smaller basin or mill-watershed, upstream small impoundments (such as check dams and nullah bunds constructed under watershed development programmes) may reduce inflows into reservoirs downstream, a possibility suggested from a study in northern Karnataka and which has been a bone of contention between the Minor Irrigation Department and the Watershed Development Department in Karnataka (observed by the first author).

On the one hand, upstream pumping of groundwater and upstream rooftop water harvesting may reduce runoffs and hence streamflow. At the same time, upstream users also have water requirements that need to be met. Thus, determining what constitutes fair allocation between upstream and downstream users is very difficult. Again, we resort to examining this question with reference to the recent past. The question of upstream-downstream water allocation has not received much attention within the Arkavathy basin, although the possibility of upstream pumping or diversions resulting in declining inflows into

Hesarghatta and TG Halli reservoirs has been repeatedly flagged (ISRO and IN-RIMT 2000). The same is true of smaller water bodies such as irrigation tanks, where there is a large amount of anecdotal evidence, including our own field observations, that these tanks are drying up and upstream pumping or watershed development may be contributors to this phenomenon. Systematic investigation of this issue remains to be carried out.

3.3 Between socio-economic groups or locations within the domestic sector

How does water get allocated across different users within a sector? There are three separate issues here: first, whether the pipes are laid and users can access them; second, whether there is water in those pipes and users can afford to pay for it; third, whether the users can make private arrangements to cope with unreliability, which is in turn affected by proximity and availability of the source and ability to pay (Mohan Prabhu, Pers. Comm. 2012).

Infrastructure access: Differences in access to infrastructure determine who receives piped supply and who does not. Public fountains (taps) were once the main source of water for the urban poor, and accounted for almost 34% of the total consumption in 1998. These unmetered connections, largely used by the urban poor, are usually in a state of disrepair due to stolen/damaged taps and broken platforms. Bengaluru Municipal Corporation used to pay BWSSB at the rate of Rs. 2,400 per public fountain per year with BWSSB incurring a further loss of about Rs. 60,000 per fountain (TARU 1998). The AusAID project, public fountain survey estimated that these public fountains were in fact extremely inefficient; much of the water was lost in wastage or leaks.

Since 2002, BWSSB has gradually phased out public standpipes to reduce unaccounted for water (UfW) and make consumers pay for water using a progressive tariff structure. BWSSB has made tremendous strides in improving access to private connections through the creation of the Social Development Unit. There has been the relaxation of the eligibility criterion to obtain private water connections (Connors 2005) and moves to improve participation of local residents in local infrastructure planning processes. However, problems persist in peri-urban areas yet to be connected to the piped mains. Moreover, political interference has led to reinstallation of some public fountains.

Moreover, to our knowledge, no equivalent Social Development Unit exists in the Class II towns. Likewise in rural areas, the location of the public standpipe or pipes may effectively exclude marginalised communities living on the periphery of the village, who must walk a much greater distance to get water.

Water supply differences: Recent pro-poor efforts by BWSSB have greatly improved affordability of water within Bengaluru. Slum dwellers now get water at a monthly tariff of Rs. 48 for the first 8 kL of water, a sum affordable by a large proportion of slum dwellers, who otherwise used to pay much more to private vendors (Grönwall 2008). Although BWSSB has made major strides in improving access to water in slums, these efforts have been largely limited to expanding metered private connections in slums. The recent Excreta Matters Report from Centre for Science and Environment (CSE) clearly demonstrates that distribution of water remains highly inequitable (CSE 2012) with some areas receiving much more water than others in LPCD terms. The Bangalore Urban Metabolism Project⁷ suggests that LPCD delivered varies by as much as 50 and 290 LPCD across wards. Infrastructure disparities, wasteful behaviour on the part of consumers, and political interference, all contribute to disparities in the quantities delivered. Some neighbourhoods receive too much while others get very little and these inequities are 'hard-wired' into the infrastructure.

The location and size of trunk mains and valves often favour wealthier paying customers. However, even within slum communities, there are significant disparities arising from political interference in operating valves (BWSSB, Pers. Comm. 2012). Households with illegal connections and public taps located in a favourable zone (close to a pumping station) have an advantage but also lack the incentive to conserve. They leave their taps open and 'use up' all the water even as others do not get water.

Private coping: Apart from differences in the way infrastructure is developed and operated, poor communities use less water because they have less ability to invest in private water infrastructure. Wealthier consumers typically have in-house piped connections. Moreover, they can install sumps, overhead tanks, and water purifiers which enable them to store and treat water and thus overcome the unreliable intermittent supply. These private coping investments allow such consumers to convert their piped supply to an effective 24/7, high quality supply and thus capture a greater fraction of the supply. In contrast, slum dwellers must collect water from public taps during the hours it is available. Even slum dwellers who have private connections can typically only afford a rudimentary tap outside their houses; and in most cases water is supplied only once or twice a fortnight and the pressure is very low (Grönwall 2008). Poorer consumers must thus wait for water, and carry it back. If supply is infrequent, in dry years, these differences may be exaggerated as poorer households have less ability to dig deeper wells, store water or purchase water from tankers when public supply is curtailed. Often the

poor are affected because borewell-based hand pumps, which require a shallow water table, dry up first.

3.4 Knowledge gaps

1. At a conceptual level, there is little debate and clarity on what constitutes fair or unfair allocation across sectors, or between upstream and downstream users. There is no formal system of water rights, and the National Water Policy gives priority to domestic needs without clarifying what agriculture or industry might be entitled to. Thus, the development of a water rights structure is in itself a major need at this juncture.
2. The lack of knowledge about the relationship between upstream groundwater pumping and changing inflows into tanks or rivers downstream remains a major knowledge gap.
3. To what extent agricultural or industrial pumping is affecting domestic water availability (both in rural and urban areas) is quite unclear. Equally unclear is whether and why some industrial pockets are receiving Cauvery water while surrounding dwellings are not.
4. There are no studies that evaluate trade-offs between the direct use and aesthetic functions of urban water bodies.
5. The absence of disaggregated information on water supply within villages and city wards means that there is limited understanding (beyond individual case studies) of the extent of variation in water availability to domestic users.

⁷ <http://www.urbanmetabolism.in/bump/>

4

SUSTAINABILITY AND RESILIENCE OF SUPPLY

Water is a renewable resource, but current use does affect future availability, particularly in the case of groundwater. Moreover, variations in year-to-year availability (of rainfall and surface water) are high and therefore our capacity to buffer against drought years also needs to be considered. Thus, both sustainability of average use under average conditions, and resilience against major droughts are of concern.⁸

In the Arkavathy sub-basin, there is evidence that both physical and socially acceptable limits to water extraction are being exceeded in several ways, thereby affecting future sustainability and resilience.

Physical limits

- 1) Current surface water sources are drying up.
- 2) Groundwater levels are declining.

Socio-economic limits

- 3) Pumping so much water to Bengaluru from 100 km away results in a high level of electricity consumption, amounting to unacceptable environmental impacts.
- 4) The Cauvery tap is 'drying up', or to be more precise, the amount of water that can be withdrawn from the Cauvery to meet water needs within the Arkavathy sub-basin is going to reach a social limit very soon (viz., the limit imposed by the Cauvery Water Disputes Tribunal (CWDT).

In this section, we describe our current understanding of each of these concerns and present some emerging questions.

4.1

Drying of current surface water sources

In recent years, many of the local water sources in the Arkavathy watershed are seen to be drying up (Figure 5) much faster than predicted for reasons that are not well-understood. The 2001 Sinclair Knight Merz and EGIS Consulting Australia, 2001 report on Bengaluru's water supply sources predicted a decrease in the yield of Hesaraghatta Reservoir to 17 MLD or less by 2025 (compared to the design of 40 MLD), and a decrease in the yield of TG Halli reservoir to 110 MLD or less. In reality, in spite of some measures being taken in response to this report, Hesaraghatta has dried up completely, and TG Halli's yield is only 30 MLD.

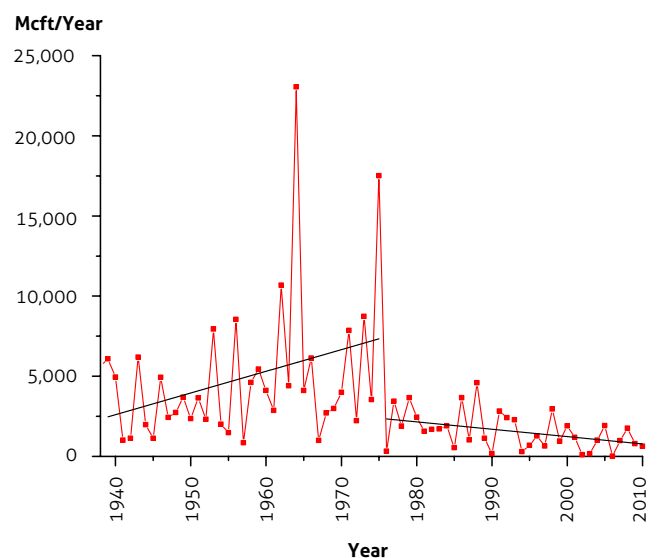


Figure 5: Declining TG Halli inflows into TG Halli Reservoir

⁸There is also the question of resilience against floods, but we have not looked at that aspect here.

4.2

Declining groundwater levels

Studies show that current levels of groundwater extraction are unsustainable. Average groundwater levels have declined in the last 20 years. A recent report by DMG (2011) estimates that groundwater exploitation is occurring at twice the sustainable rates. However, groundwater declines have not been uniform. In peri-urban areas, water levels rose in some areas, as intensive irrigated agriculture was replaced by low-density housing (Murthy 2011). In other areas, as high density urbanisation preceded water supply infrastructure, groundwater pumping resulted in declining water levels. Nevertheless, field observations confirm that the overall trend is of declining water tables. The AusAID report estimates there was a net groundwater depletion of 200,000 ML between 1975 and 2000 for the Bengaluru Metropolitan Area.

4.3

Increasing consumption of electricity

There is no question that the current water supply system of Bengaluru results in an enormously high level of electricity consumption. As the water must be pumped uphill, some 500 m from the Cauvery to reach Bengaluru, electricity costs are the single most expensive line item in BWSSB's budget – comprising up to 65% of its budget. It is estimated that BWSSB's cost of production is Rs. 18/kL, but could be as high as Rs. 40/kL (Grönwall 2008). In addition, consumption of scarce electricity for pumping water such a great distance can be seen as inherently (environmentally) unsustainable.

Simultaneously, there is increasing electricity consumption in pumping from borewells, as the density of wells increases and the groundwater level drops. Estimates of electricity use in groundwater pumping are, however, not yet available.

4.4

Climate challenge to resilience of the system

Climate change may increase the variability of precipitation, making these occurrences more frequent. There is increasing evidence that the earth's climate is changing and this is changing precipitation and temperature patterns in Karnataka (BCCI-K 2011). Although, there are no useful estimates of downscaled climate projections in the Arkavathy sub-basin, it is generally assumed that variability in rainfall is likely to increase. Analysis of rainfall trends suggest that over the last 30 years, monsoonal precipitation has increased, but post-monsoon precipitation has decreased. Moreover, it is possible that rainfall intensities will increase. The main concern is therefore not an overall decrease in rainfall,

but the ability of the system to handle greater variability in, and higher intensity of, rainfall.

4.5

Socio-institutional analysis and response

Local sources drying up: Several reports have speculated on the causes of drying up of TG Halli and Hesaraghatta reservoirs and a few scientific studies are also available; but the question remains unsettled. We could identify six distinct hypotheses advanced in the literature to explain this phenomenon.

1. There has been a substantial increase in land under forest or plantation. This may explain the significant reduction in recharge and therefore surface water yield, at least until the trees mature (Sinclair Knight Merz and EGIS Consulting Australia, 2001).
2. Upstream extraction of groundwater by farms, industries and households has increased greatly in the last two decades. Groundwater levels have declined hundreds of feet, and this may be decreasing run-off, causing first-order streams to dry up (ISRO and IN-RIMT 2000).
3. Channels and tank beds have been encroached upon or fallen into disrepair. As the integrity of the watershed is destroyed, water no longer flows into tanks. Tanks no longer overflow into the Arkavathy River (ISRO and IN-RIMT 2000). The water that would have flowed into tanks collects in ponds and puddles and evaporates, or is transpired by 'non-beneficial' weeds.
4. Illegal sand mining of stream beds is decreasing recharge into aquifers and consequently affecting base flow.
5. Temperature increases due to climate change or urban heat island effects may be increasing evaporation and evapotranspiration.
6. Rainfall magnitudes and/or intensities are changing (ISRO and IN-RIMT 2000), resulting in reduced inflows.

Our examination of these hypotheses and the data presented in the studies mentioned above and discussions with experts suggest that neither sand mining nor temperature increases can cause anything close to the magnitude of decline in inflows that has been observed. Furthermore, the ISRO and IN-RIMT study itself shows that there has been no statistically discernible decline in rainfall, nor have intensities decreased. In fact, if at all, intensities have increased, which should lead to more runoff, not less. Yet, there is no clarity about the extent to which the remaining three factors (plantations, blocking of inlets and groundwater depletion) explain the decline in inflows.

In response to the findings of the ISRO study, some measures have been put in place to halt and reverse the decline of TG Halli reservoir. A 2003 notification⁹ by the government aims to create a protection zone of 10 km around TG Halli reservoir and implement measures to prevent impediments to the flow of water along Arkavathy River. The notification also divides the area into four zones specifying regulated activities and the agencies in charge of regulation. The agencies include BWSSB, Bangalore Development Authority, Nelamangala Planning Authority, Department of Urban Development and Directorate of Municipal Administration. There is no information on how well these measures have been implemented. However, it is clear that despite these measures, TG Halli reservoir remains filled far below capacity.

In addition, there have been several civil society initiatives aiming at river rejuvenation, including some led by NGOs, prominently SVARAJ, and some in the form of network of interest/issue-based groups such as the Save Arkavathy Campaign and Arkavathy Kumudavathy Punarchetana Samithi.

They have been instrumental in influencing government decisions on Arkavathy rejuvenation. Consequently, the state government recently launched an Arkavathy Rejuvenation Initiative in which Rs. 22.43 crore has been sanctioned to revive the Arkavathy, to address the requirements of Bengaluru, as well as provide for the irrigation needs of farmers.¹⁰ Details of this initiative are still emerging. The current focus appears to be on de-silting, redirecting wastewater away from the tank, and clearing encroachments in the inlets and outlets of water bodies.¹¹ The activities undertaken as part of this initiative do not directly address wider problems of upstream groundwater depletion, or plantations; so, it is thus not clear how effective this initiative will be.

Groundwater depletion: Observers of the Bengaluru water situation, such as S. Vishwanath, note that “there is no institutional ‘owner’ or ‘manager’ of Bengaluru’s groundwater”. The Citizens’ Seventh Report on the State of India’s Environment by CSE (2012) that surveyed water supply and sewage management across 71 cities in India, including Bengaluru, affirms this point. The central and state groundwater boards do not play a major role in a city’s water supply; in fact, there is a tendency for water utilities to ignore private groundwater abstraction altogether. In addition to ecological unsustainability of groundwater overdraft, Raju et al. (2008) point out that there is also huge fiscal inefficiency involved in all houses installing their own borewells and pumpsets rather than having (say) ward-level community borewells and pumps. The Karnataka Groundwater Regulation Act

was passed in 2011.¹² A Groundwater Authority has been constituted under this Act, but its rules are yet to be notified. To date, the Authority has met only once and its monitoring and implementation mechanisms have not been finalised. Indiscriminate digging of borewells and pumping of groundwater continue unabated.

A glimmer of hope arises from the few voluntary efforts at the community level. These have managed to set norms where formal legislations and institutions failed. For instance, when the community in Doddatumkuru village off Doddaballapur road found that groundwater levels were decreasing, they decided to voluntarily terminate private water connections and instead set up common pipes in the village centre (field observation, 6 June 2012).

Energy/fiscal unsustainability: The argument against increasing pumping from the Cauvery is partly environmental (energy consumption) and partly fiscal (cost). However, as yet, there is limited acceptance of the environmental or scarce resource argument. It appears that ‘Bengaluru’s domestic water need’ is an argument that trumps everything, even though in reality a significant amount of Cauvery water is used for non-domestic purposes (gardening, government institutions and even commercial establishments). The fiscal argument has also been highlighted, and analysts have argued for more decentralised solutions that would harvest rainwater and store it in lakes (CSE 2012; Suresh 2001). However, the political power of a state capital might make it impervious to fiscal constraints as well.

Limits to water imports: The Cauvery Water Disputes Tribunal award: The Cauvery Water Disputes Tribunal (CWDT) has determined the utilisable waters of the Cauvery to be 740 TMC in a normal year, on the basis of 50% dependability (CWDT 2007). The water is apportioned as follows: 270 TMC to Karnataka and 419 TMC to Tamil Nadu, 30 TMC to Kerala and 7 TMC to Pondicherry. The tribunal also allows a small quantity of water (14 TMC) for environmental protection and ‘inevitable escapages (sic) into the sea’. The allocation is to be enforced in 10-day intervals based on readings at specified measurement points. At present, Bengaluru’s share of the Cauvery is capped at 14.52 TMC, with the assumption that 80% of this will come back to the Cauvery as return flow (CWDT 2007: Volume V, Page 102).

There are therefore several concerns and grey areas.

First, Bengaluru may hit the limit of this allocation very soon: Cauvery Stages 1–4 withdraw 11 TMC; the newly proposed Cauvery Stage IV – Phase 2, would bring the withdrawal to 17 TMC, which is well over what is allowed.

⁹ <http://www.npa.in/not31.htm> (accessed on 18 October 2012)

¹⁰ <http://www.thehindu.com/news/cities/Bangalore/article3541875.ece> (accessed on 18 October 2012)

¹¹ http://www.dnaindia.com/Bangalore/report_arkavathy-rejuvenation-work-will-begin-in-may_1520112 (accessed on 31 October 2012)

¹² http://khanija.kar.ncode.in/DCPublication/Karnataka%20Ground%20Water%20Act%202011_English.pdf

- Second, although the Tribunal's Report has upheld the principle that drinking water must get priority over other beneficial uses of the Cauvery water, it is not clear how this principle is to be enforced once the water is abstracted.
- Third, the Cauvery Water Disputes Tribunal award is unclear on how shortages will be shared in drought years. The CWDT specifies that should the yield of the river be less in a distress year, the allocated shares are to be 'proportionately reduced' among the four riparian parties. Apart from unclear implementation of this concept at the inter-state level, there is a question of how distress sharing is to be implemented within the state. For instance, farmers in Mandya have agitated this year to express that the releases to Tamil Nadu should come out of Bengaluru's share. The same is true of sharing between Bengaluru and other towns such as Kanakapura and Ramanagara that already draw from Bengaluru's share: as they grow, they will demand more water and enter into conflict with Bengaluru residents.
- Fourth, there is no control on the quality of water that is being returned to the Cauvery from Bengaluru (primarily through the Vrishabhavathy), nor is there really any monitoring of whether 80% is going back. Moreover, current return flow includes water pumped from deep groundwater aquifers and used in homes. If this pumping is unsustainable, and a sustainability norm is eventually enforced, the return flow would reduce.
- Finally, the interactions between surface and groundwater have been treated in an inconsistent manner in the CWDT award. The CWDT explicitly recognises the groundwater-surface water link only in the context of the Cauvery delta, where it notes 'as the groundwater in the delta area is replenished by releases from the Mettur, it cannot be considered to be an independent source of irrigation or an alternative means of irrigation' (CWDT: Volume III, Chapter 3). However, the tribunal does not appear to consider the possibility of upstream groundwater extraction affecting stream flows. Indeed, groundwater use elsewhere in the basin is not considered at all. The apportioning formula is applied to each year's yield, as measured by net flows at specified river gauging stations. However, in fact, groundwater pumping and utilisation in the river basin is continuously increasing, which should result in continuous declines in the surface flows even with no change in rainfall. If the CWDT factors this into the apportionment, the allocation to Bengaluru may decline further (as Bengaluru will be seen to have already used up some of its share through groundwater pumping).

Resilience to drought years: There is no systematised plan for drought years. The CWDT has also not clearly stated how allocations will change in drought years. However, the events of 2012 suggest that this issue will

become more and more pressing as increased climatic fluctuations create more frequent or more intense droughts. In 2012, even minimum releases to Tamil Nadu meant significant irrigation cutbacks for Mandya district farmers, who then directed some of their ire at Bengaluru and BWSSB, because Bengaluru's allocation did not change. We are not aware of any contingency plans by BWSSB for a situation where Bengaluru's allocation of Cauvery water is also (say) proportionately reduced in a drought year.

4.6 Knowledge gaps

1. The causes of declining flows in the Arkavathy and TG Halli are yet to be fully understood. There is no scientific consensus on which of the alternative explanations is dominant.
2. The sustainability of groundwater extraction in Bengaluru and elsewhere in the sub-basin has not been understood, beyond the obvious observation of dropping groundwater levels. It is not clear whether and how much water is being pumped from the shallow aquifer versus the deeper aquifer, what the connectivity between these two (or more) aquifers is, and therefore what the recharge rate of the deeper aquifer is or whether borewells are simply 'mining' millennia-old aquifers.
3. Several uncertainties and ambiguities remain in the CWDT Award that require greater analysis and clarification.

5

WATER QUALITY ISSUES IN THE ARKAVATHY SUB-BASIN

People living in the Arkavathy sub-basin depend on groundwater and surface water for their domestic, agricultural, commercial and industrial water needs. Water for different uses tends to be met from different types of sources (i.e., surface versus groundwater) in different locations. Taking this into account, in this section, we analyse concerns of domestic users, irrigation users and the environment (biota in water bodies) separately.

The Central Pollution Control Board of the Government of India (CPCB) has laid down the minimum water quality criteria for each type of use (Figure 6). Both, the types of contaminants that are of concern, and their permissible levels, vary in end-use.

With the above norms in mind, we describe below the present status of water quality in the Arkavathy sub-basin with respect to each use and contaminant.

5.1 Domestic water quality

Domestic water is obtained from surface water (via piped supply schemes) as well as groundwater. The water quality concerns are slightly different for piped supply versus groundwater. Piped water supply that comes from the Cauvery Water supply scheme (to Bengaluru and to parts of Kanakapura and Ramanagara) is free of chemical contaminants to begin with, and is chlorinated at several

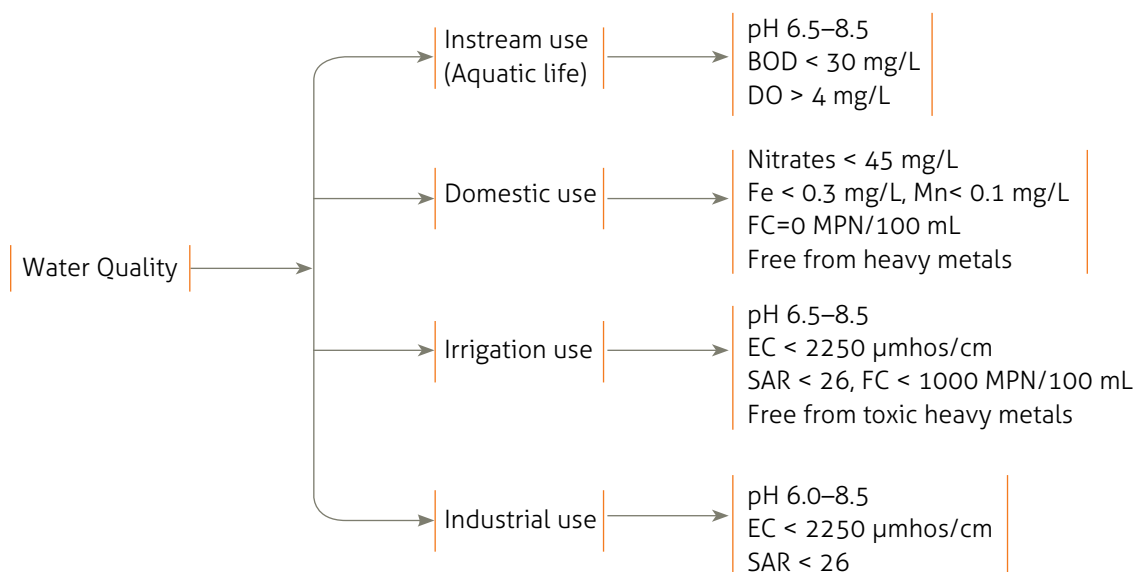


Figure 6: Water quality criteria for different water uses

stages, thereby meeting drinking water standards when it enters the city supply system (BWSSB 2009). However, it may get biologically re-contaminated by leaks, build-up of organisms inside pipes that are only intermittently supplying water, or storage in underground sumps that have not been regularly cleaned. On the other hand, groundwater-based supply faces chances of both chemical and biological contamination. We therefore discuss chemical quality for groundwater supply/users only, and biological quality for both types of water supply situations.

5.1.1

Chemical quality

Regarding chemical quality of water, we shall focus on nitrate and heavy metal contamination.

Nitrates (Permissible limit – 45 mg/L): Nitrate contamination of groundwater is a concern as elevated levels have been detected in samples throughout the Arkavathy sub-basin. Within Bengaluru city, DMG (2011) conducted a groundwater quality survey in 2011, and found that nitrate content was in excess of the permissible limit in 29% of groundwater samples ($n=2209$).

Table 4: Nitrate levels in groundwater in talukas overlapping with the Arkavathy sub-basin

| Taluka | Nitrates (mg/L) Permissible limit – 45 mg/L |
|-----------------|--|
| Anekal | 4–94 |
| Bangalore North | 7.3–153 |
| Bangalore South | 20–176 |
| Doddaballapur | 1–168 |
| Kanakapura | 0.88–235 |
| Magadi | 5–124 |
| Nelamangala | 7–140 |
| Ramanagara | 1–113 |

(Source: DMG, 2011)

To get a more detailed picture, we have plotted the results of the water quality survey conducted by the National Rural Drinking Water Programme in the map in Figure 7. It shows that villages located in Ramanagara, Magadi, Nelamangala and Doddaballapur taluka are affected by nitrate pollution (upstream and midstream sections of watershed). It also shows a cluster of villages located downstream of Byramangala tank being affected by nitrate pollution, which is not surprising, given that this tank is situated on the highly polluted Vrishabhavathy River. In another study also, nitrate levels

as high as 319 mg/L were observed in the groundwater samples collected downstream of Byramangala tank (Singh et al. 2009).

The ASHWAS survey (ashwas.indiawaterportal.org) included measurement of nitrate levels in hand pump and bore-well water samples from Ramanagara and Bangalore Rural districts. These data are summarised in Table 5. Nitrate levels in all the water samples from Bangalore Rural district were below the permissible value; whereas in Ramanagara district, the nitrate levels in hand pump water and borewell water exceeded permissible limits. This is consistent with the results of the NRDWP data mentioned above.

Table 5: Nitrate levels in groundwater samples from Ramanagara and Bangalore Rural districts

| District | Hand-pump Nitrates range (mg/L) | Borewell Nitrates range (mg/L) |
|-----------------|---------------------------------|--------------------------------|
| Ramanagara | 0–250 | 0–100 |
| Bangalore Rural | 10–20 | 0–25 |

(Source: ASHWAS survey)

While heavy use of fertilisers in agriculture is the major source of nitrate contamination, its presence in groundwater may come about due to either recharge of groundwater by irrigation runoff/return flows/irrigation tanks containing such runoff. However, it is also possible that some nitrate contamination comes from sewage leaking from soak-pits or sewage lines into the groundwater.

Heavy metals (Permissible limit – Cr⁶⁺: 0.05 mg/L and Al³⁺: 0.03 mg/L): Various monitoring studies have been conducted to assess the heavy metal content in the groundwater in and around Bengaluru. Singh et al. (2010) conducted a groundwater quality monitoring study to assess the impact of industrialisation on groundwater aquifer in Bangalore Urban district, collecting and analysing groundwater samples for heavy metals.

Comparison between presence, abundance and frequencies of trace elements in groundwater samples was in the order of Fe (0.084) > Zn (0.072) > Mn (0.068) > Pb (0.045) > Cu (0.041) > Cr (0.035) > Ni (0.033) > Cd (0.021 mg/L). The TDS, Pb, Fe, Mn and Cd concentrations in groundwater samples were beyond the permissible limits prescribed by World Health Organization (WHO).

Two studies (Ramesh et al. 2012; Shashirekha 2009) monitored the level of pollution in groundwater of the Peenya industrial area in the northern Arkavathy basin. The studies found Cr⁶⁺ levels of 16.1 mg/L and 33 mg/L in groundwater samples, respectively. High levels of Al³⁺

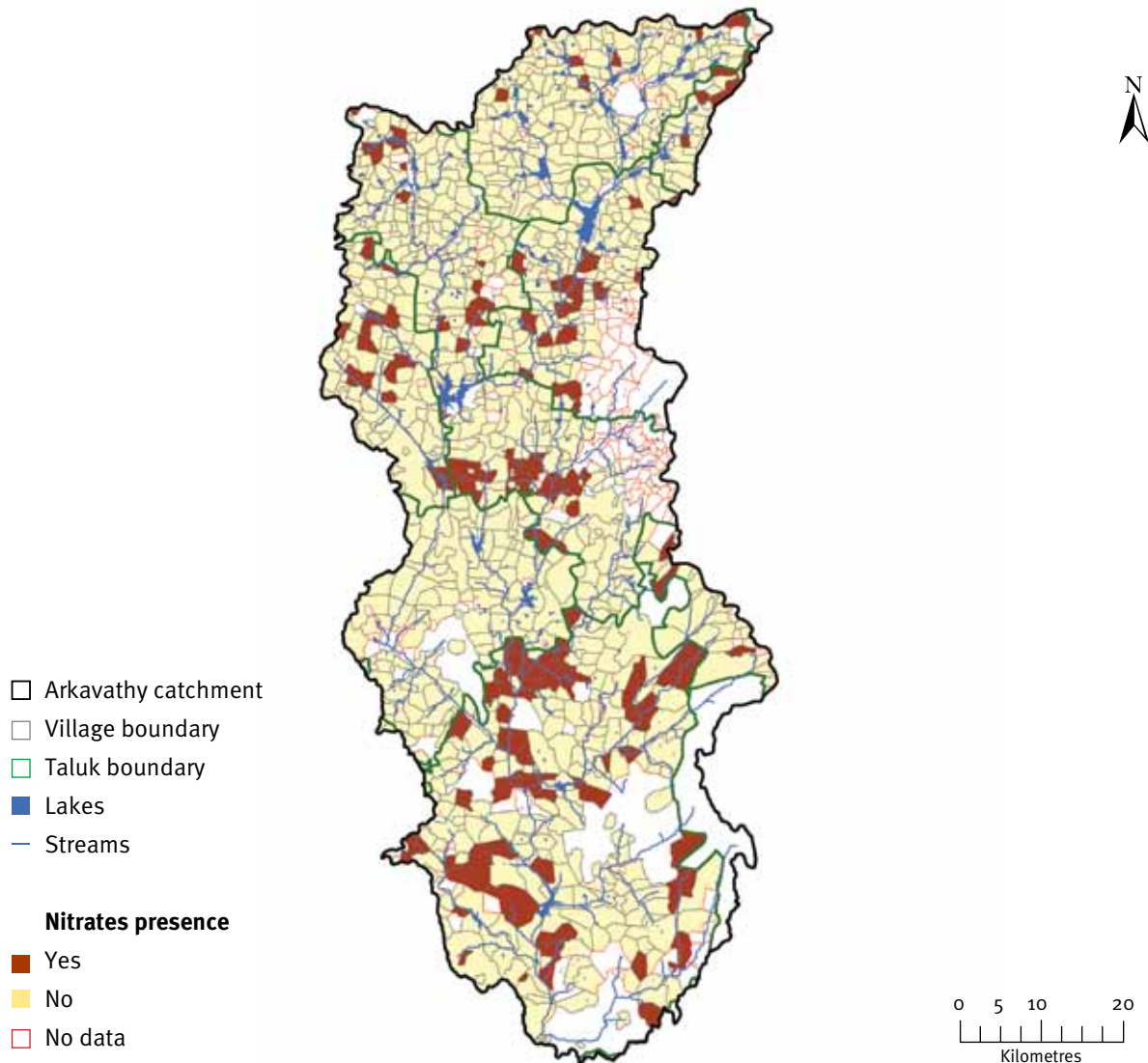


Figure 7: Locations of higher-than-permissible nitrate levels in drinking water supply in rural parts of Arkavathy sub-basin (Data source: NRDWP. Map prepared by ATREE Ecoinformatics Lab)

were also found in groundwater samples of Doddaballapur taluka.

The following reasons have been cited for heavy metal contamination of groundwater:

- Aquifer recharge by poor quality Byramangala tank water
- Poor industrial wastewater management
- Direct pumping of industrial effluents into the abandoned borewells, though these claims need to be supported by scientific data

5.1.2

Biological quality (*Faecal coliforms: Permissible limit: 0 MPN/100 mL*)

Faecal coliforms (FC) are used as an indicator organism to establish pollution levels caused by domestic wastewater. Faecal coliforms are bacteria found in the digestive tracts of animals and humans. They find their way through waste to water bodies and soil matter. The WHO has prescribed the permissible limit for FC levels in drinking water to be 0 MPN/100 mL. The presence of FC in drinking water is associated with various diseases such as gastroenteritis and diarrhoea.

Groundwater: Several studies indicate the presence of total coliforms and FCs in water samples collected from various drinking water sources (borewells, open wells and hand pumps) in the Arkavathy sub-basin (DMG 2011; Jadhav and Gopinath 2010; Prakash and Somashekar 2006; Shankar et al. 2008; Singh et al. 2010). High levels of *E. coli* were also found in groundwater samples both in Bangalore Urban district (DMG 2011) and in the rural districts where all taluka had at least a few hotspots of faecal contamination (Table 6).

Table 6: FC levels in Arkavathy watershed from various studies

| Place | FC levels (MPN/100mL) | | |
|---------------|-----------------------|-----------|-----------|
| | Borewell | Open well | Hand pump |
| Doddaballapur | 0–170 | 270–300 | 17 |
| Peenya | 0–88 | 0–38 | — |
| Kanakapura | ND | ND | ND |
| Ramanagara* | Yes | Yes | Yes |
| Anekal | 0–364 | — | — |

* Qualitative monitoring (presence/absence FC test) by ASHWAS (ashwas.indiawaterportal.org)
ND – No data available

The studies cite the following reasons for presence of FCs in groundwater:

- Groundwater recharge by contaminated lake water
- Lack of proper sanitation facilities
- Non-point sources of pollution (open defecation)

Piped water supply: A recent study conducted by Centre for Sustainable Development (CSD 2012) found that the quality of groundwater and surface water in Bangalore urban area is not fit for human consumption. Despite water treatment, the level of FCs in piped water samples exceeds permissible levels in Bangalore Urban district (Figure 8).

The following reasons have been cited for poor biological quality of piped supply.

- Cross contamination
- Poor personal hygiene
- Bacterial growth within the distribution system (poor maintenance)

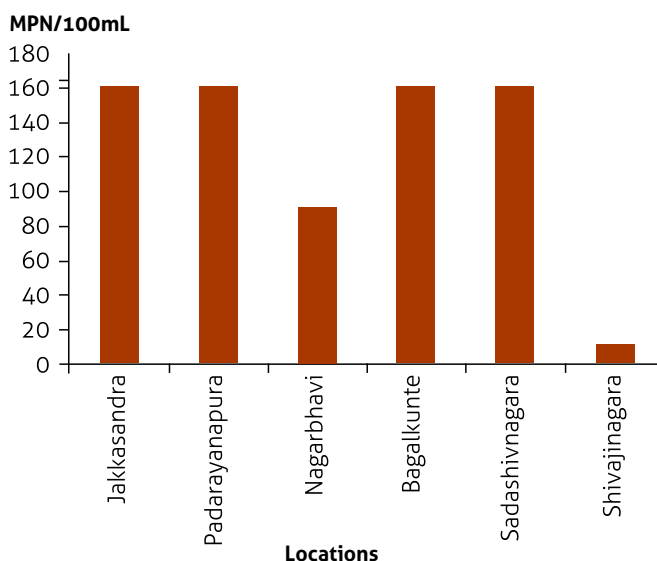


Figure 8: Faecal coliform levels in Bengaluru city (CSD 2012)

(Source: Lokeshwari and Chandrappa 2006, Ahipathy and Puttaiah 2007)

5.1.3

Domestic water quality hotspots

The water quality hotspots are summarised in Table 7.

Table 7: Domestic water quality hotspots in the Arkavathy sub-basin

| Taluka | Contaminant concentration (mg/L) | | |
|--------------------------|----------------------------------|--|------------------------------|
| | Nitrates (mg/L) | Heavy metals Cr ⁶⁺ /Al ³⁺ (mg/L) | Faecal coliforms (MPN/100mL) |
| Anekal | 4–94 | ND | 0–364 |
| Bangalore North | 7.3–153 | Cr ⁶⁺ = 16–32 | 0–88 |
| Bangalore South | 20–176 | Cr ⁶⁺ = 16–32 | 0–88 |
| Doddaballapur | 1–168 | Al ³⁺ = 35 | 0–300 |
| Kanakapura | 0.88–235 | ND | Present |
| Nelamangala | 7–140 | ND | ND |
| Ramanagara | 1–113 | ND | Present |
| <i>Permissible limit</i> | 45 | 0.05 (Cr ⁶⁺) 0.03 (Al ³⁺) | 0 |

ND – No data available

5.2

Irrigation water quality

According to irrigation water quality standards, high Sodium Adsorption Ratio (SAR) in irrigation water negatively impacts soil fertility (SAR>26). In addition,

presence of heavy metals and FCs is known to have significant health impacts. The farmers in the upstream of Arkavathy sub-basin depend entirely on groundwater to meet their irrigation demands. However, the farmers in the downstream of Byramangala tank use both surface water (from Byramangala tank) and shallow groundwater to meet their irrigation demand. According to available literature, groundwater quality in the Arkavathy sub-basin largely meets the prescribed irrigation water quality standards. So, we focus here on the quality of surface water used for irrigation.

Faecal coliforms : Monitoring studies conducted in the Arkavathy sub-basin indicates the presence of FCs in water samples both from Byramangala tank and Arkavathy River downstream of Kanakapura town (CPCB 2012; Prakash and Somashekar 2006; Singh et al. 2009). According to CPCB guidelines, if the water is used for restricted irrigation, FC levels should not be greater than 100,000 MPN/100 mL and, if used for unrestricted irrigation, FC levels should not be greater than 1,000 MPN/100 mL. FC levels greater than 1,000 MPN/100 mL in Arkavathy River indicates that the water is not suitable for unrestricted irrigation (CPCB, 2012), and thereby poses risk to public health. Discharge of treated and untreated domestic wastewater into the Vrishabhavathy was identified as the main reason of faecal contamination.

Heavy metals: Heavy metals in surface water enter the food chain through irrigation, thereby causing a risk to public health. In addition, continued exposure to heavy metals, especially chromium could result in allergic dermatitis (skin reactions). A water quality guideline for Cr⁶⁺ of 0.008 mg/L in irrigation water is recommended for the protection of agricultural crop species (CCME 1999). Table 8 summarizes the levels of heavy metals detected in the water samples from Vrishabhavathy river, Bellandur lake and groundwater samples in Vrishabhavathy Valley. The heavy metal levels in surface water (Vrishabhavathy river, lakes) as

well as in the groundwater samples exceeded the irrigation water quality standards, thereby posing greater health risk to public.

Villagers in Veerapur village, located downstream of Doddaballapur town, experienced poor water quality in the irrigation tank due to wastewater discharges from the textile industries located upstream of the tank. The irrigation water quality hotspots in Arkavathy sub-basin are summarised in Table 9.

Table 9: Irrigation water quality hotspots

| Taluka | Concentration* | |
|--------------------------|-------------------------------|------------------------------|
| | Heavy metals (mg/L) | Faecal coliforms (MPN/100mL) |
| Doddaballapur | ND | Yes * |
| Kanakapura | 0.03–0.04 | 0–5000 |
| Ramanagara | ND | Yes * |
| <i>Permissible limit</i> | <i>Cr⁶⁺(0.008)</i> | <i>1000</i> |

ND – No data available

* Information gathered during preliminary field visit

5.3 Aquatic life and ecosystem services

Aquatic life typically occurs in two kinds of water bodies: flowing rivers and lakes/reservoirs. In the Arkavathy sub-basin, the Arkavathy itself, although once a perennial river, now flows primarily during monsoon season in many reaches, till it is augmented by the Vrishabhavathy and Suvarnamukhi. On the other hand, the Vrishabhavathy has become fully perennial because it carries the 'return flow' of Cauvery water in the form of Bengaluru's effluents. As a result, it is a highly polluted water body, as shown by several studies. The water quality of Vrishabhavathy River, upstream of the Peenya Industrial estate is good, classified as Category A (CPCB) with maximum DO levels of 7 mg/L. As the river flows through the city, its DO levels fall to 0 mg/L

Table 8: Heavy metals in surface water (and groundwater) in Arkavathy sub-basin

| Location | Cu (mg/L) | Fe (mg/L) | Zn (mg/L) | Cr (mg/L) | Pb (mg/L) | Cd (mg/L) | Mn (mg/L) |
|--------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Site 1 (V-river) | 0.02 | 0.16 | 0.03 | 0.03 | 0.07 | 0.01 | 0.32 |
| Site 2 (V-river) | 0.04 | 0.52 | 0.09 | 0.03 | 0.07 | 0.01 | 0.33 |
| Site 3 (V-river) | 0.05 | 0.41 | 0.04 | 0.03 | 0.08 | 0.01 | 0.50 |
| Site 4 (V-river) | 0.04 | 0.56 | 0.05 | 0.04 | 0.02 | 0.01 | 0.56 |
| Bellandur lake | 0.012 | 1.08 | 0.132 | 0.006 | 0.009 | 0.0007 | |
| Groundwater (n=30) | 0.041 | 0.084 | 0.072 | 0.035 | 0.045 | 0.021 | 0.068 |

(Source: Ahipathy and Puttaiah 2007; Lokeshwari and Chandrappa 2006)

(Ahipathy and Puttaiah 2006). The authors reported high BOD (37 to 737 mg/L) and COD (125 to 1451 mg/L) values along Vrishabhavathy River. The river water quality in the midstream and downstream reaches belongs to Category E and is unable to support any form of aquatic life.

On the other hand, the Suvarnamukhi and Doddahalla tributaries contribute much cleaner water to the Arkavathy, as they flow through rural areas. No studies are available on the exact level of water quality in these tributaries. Nevertheless, after these tributaries join the Arkavathy, the pollution from the Vrishabhavathy gets diluted (also because most of it is trapped in the Byramangala reservoir), but again it is not clear what the water quality is, south of Kanakapura town. In short, while aquatic life is drastically curtailed in the Arkavathy (western arm) because of water scarcity, and destroyed by heavy pollution in the Vrishabhavathy, some aquatic life exists in areas downstream of Kanakapura town.

In the case of standing water bodies, i.e., irrigation tanks and urban lakes, several studies show that the latter (primarily those within Bengaluru city) have been contaminated by sewage. Consequently, aquatic and bird/reptile life forms have surely been affected, although no studies seem to exist on the extent of impact of such pollution.

5.4 Health and economic impacts of poor water quality

It would be natural to assume that the extensive water quality problems documented above have led to significant health, economic and social impacts. However, these linkages are poorly documented or understood.

One of the few epidemiological studies in Bengaluru (Jadhav and Gopinath 2010) points to the complexities of linking water quality to health, due to other complicating factors. But rigorous epidemiological studies, particularly in rural areas, seem to be completely absent. However, two hotspots were clearly identifiable from field visits: areas downstream of Doddaballapur town and Byramangala reservoir. Additionally, one study of water pollution in the Byramangala command area (Nagaraj and Chandrashekar 2005) suggests significant impacts. First, crop yields are reported to be much lower than earlier (62% less for paddy and 47% for sugarcane), the paddy straw is not palatable, and the rice fetches a 20% lower price. Second, farm workers exposed to direct contact with the polluted water reported several health problems, including dermatitis, skin rashes and gastrointestinal problems. Women were doubly affected as they had to (on average) walk for 1.5 km and spend 2 hours fetching potable water. Third, since the livestock consumed contaminated water, the quality of milk declined – consumers complained of odour and quick spoiling.

Bullocks, cows and buffaloes reportedly suffered from dehydration, skin irritation and oedema.

Poor water quality in the sub-basin has also been shown to have adverse health impacts on the urban population. A study (Ahipathy and Puttaiah 2007) was conducted on the impacts of toxicity of Vrishabhavathy river water and sediments on growth of crops and vegetables such as French beans. The analysis (summarised in Table 8) showed that the heavy metal content in plant leaves and beans were above detectable limits, but less than permissible limits and therefore safe for human consumption at the time of the study (Ahipathy and Puttaiah 2007). However, a similar study on Bellandur Lake, found that the vegetables, fodder, etc. irrigated by lake water contaminated with industrial and domestic pollution contained heavy metals that exceeded permissible levels. Heavy metals such as Fe, Zn and Cd levels were also detected in cow's milk from the impacted area (Lokeshwari and Chandrappa 2006).

In the absence of controls, however, the quantitative estimates of impact may be somewhat unreliable, but that there is a negative impact is incontrovertible.

5.5 Institutional analysis and individual coping responses

In this section, we discuss responses of formal institutions and individuals to water quality problems.

Formal responses: The KSPCB is the main agency responsible for maintaining environmental water quality. However, part of the pollution problem stems from lacunae in institutional jurisdictions. We identify three: first, KSPCB can only enforce effluent quality standards if a manufacturing unit is registered with it or the unit comes to KSPCB's notice in some way. Second, KSPCB's powers over public water utilities are limited. It can only enforce effluent water quality released from wastewater treatment plants; but cannot easily address dumping of untreated sewage due to inadequate infrastructure. Third, KSPCB's focus has tended to be on surface water. Groundwater studies have been done for specific neighbourhoods, but groundwater is not systematically monitored.

For registered units, KSPCB staff sample effluents and can order the plant shut if pollution levels are exceeded. Typically, a unit needs to get registered with KSPCB to get an electricity connection. Often industries will approach them for clearance certificate, at the time of regularisation. If the industry has a zoning violation (e.g., they have existed for 20 years, informally in a zone which is residential or has recently become residential), KSPCB can force them to relocate to an industrial park, which would then have a better effluent treatment facility.

The problem is that some units never trigger the 'power connection clearance'. In the instance of cottage industries, which do not require a separate power connection, the case may come to the notice of the KSPCB either due to a complaint filed by neighbours (KSPCB has a separate complaint cell to handle such complaints) or via a Public Interest Litigation filed by a community group, or while independently investigating the cause of a major pollution event. For e.g., a massive fish die-off in Lalbaugh over 15 years ago led the KSPCB via a storm water drain, to a group of home-based dyeing units. Eventually, KSPCB relocated these units to Apparel Park near Doddaballapur where they are served by a Common Effluent Treatment Plant (CETP). Very rarely are polluting units completely overlooked by KSPCB. Most of these units occur in clusters and generally face harassment from the surrounding neighbours and usually come to KSPCB looking for a solution (KSPCB, Pers. Comm. December 2012)

A trickier situation is when the polluter is a public water utility such as BWSSB or a municipal water department. For instance, the water quality of the Vrishabhavathy River is clearly very poor. However, the wastewater treatment plants located in the Vrishabhavathy valley currently treat only 20% of the total sewage generated; 80% of the sewage is released untreated into the stream. Moreover, only some of the treatment plants have secondary treatment capability (TARU 1998). Another problem is sewage infiltration into storm water drains and vice-versa caused by illegal connections, damage to existing sewers, laying of main sewers in the natural drains where they are difficult to access and maintain, and removal of covers and dumping of solid waste into manholes. However, KSPCB has no control over this. KSPCB does not have a formal role in a city's water supply system; so it cannot force BWSSB to install sewage treatment plants. In the case of BWSSB and peri-urban towns such as Ramanagara, KSPCB has tried various punitive actions to bring the water utility to comply with sewage treatment norms – but often gets pressured politically to use a softer approach or give the utility more time to comply.

At the same time, KSPCB appears to focus only on surface water quality. Groundwater quality is 'nobody's business' (CSE 2012). Many departments including Central Ground Water Board (CGWB), KA Department of Mines and Geology (DMG) and Department of Drinking Water Supply (DDWS) monitor groundwater quality, but have no mandate to trace causes or to take punitive or corrective action.

Informal (NGO) responses: Even though formal institutions are inadequate, there have been some civil society initiatives aiming to control industrial pollution through community mobilisation, organising meetings, protests, etc. An example is the efforts of Janajagruti Samiti in mobilising local communities against industrial effluent discharge by garment export units such as Go-Go in Bashedhalli industrial area in Doddaballapur and litigation on pollution (Dominic 2002).

5.6 Key knowledge gaps

1. The link between water quality and water quantity in the Arkavathy basin has not been fully established.
2. The causes of observed patterns of pollutants are yet to be fully understood; for e.g., whether nitrate contamination is from domestic or agricultural sources.
3. The links between contamination and public health problems are yet to be established, viz., which segments of the population are directly consuming contaminated water and whether these have manifested in public health impacts such as cancer clusters.

6

CONCLUDING REMARKS

We have attempted to review and summarise the state-of-the-art facilities regarding water resource management in the Arkavathy sub-basin. The water management 'problem' was defined using a four-dimensional framework of water scarcity, fairness, sustainability and water quality. We find that, on all dimensions, there are significant issues. While scarcity is not immediately apparent to many domestic users, the problem has already affected rural pockets, and commercial and industrial users. Similarly, there are a few major water quality hotspots in the sub-basin, water use is clearly not sustainable, and distribution among users is also not always fair. A number of studies examining these dimensions attest to these findings. Perhaps least well-understood are the specific locations and communities affected by rural water scarcity, the extent to which groundwater is being mined, and the impacts on aquatic ecosystems. Also poorly understood is the water budget for the region vis-à-vis imports from the Cauvery, an aspect that will become important as the Cauvery award is implemented.

At the same time, there are major gaps in our understanding of the causal pathways of many of these outcomes. For instance, in spite of commissioned studies, the causes of the TG Halli reservoir drying remain unclear. This is related in part to the generally poor understanding of linkages between groundwater and surface water and between shallow and deeper aquifers. The implications of these for sustainability of groundwater are also not understood. Likewise, the

sources and contamination pathways of heavy metal pollution in the Vrishabhavathy and of nitrate pollution in areas are poorly understood.

Given these gaps in our understanding of the biophysical pathways, the socio-economic causes of scarcity, pollution and unsustainability are then difficult to trace in specific terms. Nevertheless, the general picture is that of water agencies focusing on immediate supply solutions rather than long-term sustainability, groundwater extraction being completely unregulated, inter-user norms and priorities being unclear, the implications of the CWDT award yet to sink in, and the incapacity of the pollution control board to enforce effluent control norms against a city of the size and power of Bengaluru. We believe that an integrated effort at understanding and solving these problems is essential, requiring close collaboration between researchers, state agencies and civil society actors.

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