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Water Policy Research

HIGHLIGHT

Measuring the Invisible

Exploiting the water-energy nexus to estimate private, urban groundwater draft

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Pumping of groundwater for domestic uses is common across the country. Almost every high-rise, every new housing society and independent houses have a private tubewell that services domestic water requirements. However, none of these private tubewells are registered. As a result, governance institutions and policy makers have no idea about the extent of private groundwater extraction. However, as soon as the owners acquire an electricity connection, they create a surrogate registration which can be used to quantify the extent of private groundwater draft.

The objective of this study is to develop a methodology to estimate urban groundwater withdrawal using data from electricity utilities. We argue that the water-energy nexus can inform groundwater management and governance policies in urban India by producing a rapid, context-sensitive and fairly robust estimate of private groundwater draft. Applying our methodology to selected regions in Gujarat, we find that private groundwater draft represents a significant share of total water consumption in these regions.

Measuring the Invisible

*Exploiting the water-energy nexus to estimate private, urban groundwater draft**

Research highlight based on Cauchois (2015).

1. The Invisible Resource

Groundwater plays a vital role in urban water systems. Most municipalities in the world rely on groundwater; private users too do not hesitate to turn to wells when municipal supply proves unreliable. In India, the number of privately-owned urban wells has soared in the past decades. While low income households rely on tankers, public stand posts and common dug wells, middle and high income households are more likely to have the financial capacity to drill their own bore wells. It has been established that private bore wells are an important source of domestic water in several cities (Anand *et al.* 2005; Raju *et al.* 2008; Daga 2003) and may account for the persistent groundwater stress these cities experience. The stage of groundwater development has reached 864 per cent in Hyderabad, 406 per cent in Chennai, 232 per cent in Gurgaon, 142 per cent in Bangalore, 138 per cent in Delhi and 102 per cent in Ahmedabad (CGWB 2011a; CGWB, 2011b).

Most municipalities fail to acknowledge the important role that groundwater plays in meeting urban water demand (Narain 2012) and/or the risks associated with groundwater over extraction (Table 1). In this context, the Chennai Municipality stands out: it enacted its own groundwater conservation act as early as 1987. Since then, external pressure from the Supreme Court (in the case of Gurgaon) or from state governments (such as Karnataka or West Bengal) has pushed certain metropolises to take action to curb private groundwater draft, via the issuance of permits for new abstraction structures and the registration of existing wells. None of these regulations however, has brought about expected results (Narain 2012; Grönwall 2013). In her study of groundwater regulation in Bangalore, Grönwall (2013) identifies the total absence of data as a major impediment to effective groundwater regulation and governance.

Quantification and monitoring of private groundwater draft is both important and difficult. It is important in order to: [a] manage and respond to groundwater depletion, which plagues many Indian towns and cities; [b] assess water demand accurately at the city-scale; and [c] assess wastewater production and design appropriate wastewater systems. It is difficult since groundwater is an invisible resource. Its domestic exploitation has reached a tremendous scale but this is done within the private space of the residential premise, which conceals it from the inquisitive eyes of the regulator. Effective monitoring requires full cooperation on the part of the users and past experience has shown that this is not a given, be it in Mexico, Spain, or India

Table 1: Risks associated with groundwater over exploitation in urban areas

RISKS	CAUSES	CONSEQUENCES
Depletion	Over-exploitation	- Drying up of existing tube wells; - High failing rate of new tube wells; - Increasing depth of the water table implying extra drilling and pumping costs; - Importation of water at high costs from the hinterlands
Land subsidence	Over-exploitation	- Lowering of the surface; - Cracking, tilting, sinkholes; - Increased vulnerability to floods
Floods	Land subsidence	- Adverse health effects; - Contamination of water; - Damaging of the built environment
Sea water intrusion	Over exploitation in coastal areas	- Long-lasting alteration of water quality
Pollution by contaminating agents (fluoride, arsenic, nitrate etc.)	- Over exploitation	- Long-lasting alteration of water quality; - Adverse health effects, such as gastro-intestinal illnesses, dental and skeletal fluorosis, cancers, poisoning

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(Shah 2009). Existing attempts to assess private groundwater usage in Indian cities are at best vague, and at worst a failure (CGWB 2011a; Grönwall 2013). At the municipal level, little is known about the actual number, let alone the average draft, of private wells and users.

The Central Ground Water Board (CGWB) does publish groundwater scenarios on a regular basis. However, this information is available at the district or block level only, except for twenty-eight urban centers for which groundwater draft is computed at the municipal level also. For domestic and industrial groundwater use, the following method is employed:

> *"The most commonly used method for computation of irrigation draft is – number of abstraction structures multiplied by the unit seasonal draft. [...] Ground water draft for domestic and industrial needs is computed using the unit draft method and [is] based on consumptive use pattern of the population."*
>
> – (CGWB 2011a, p7)

In other words, CGWB's numbers are computed on population, per capita consumption, and assumptions regarding the number of abstraction structures. This method comes with serious inaccuracies. As we have seen, the number of abstraction structures is a big question mark in cities. In addition, the CGWB relies on official standards to assess per capita consumption, which bear little resemblance to reality and vary largely across cities.

Other methods too have similar limitations, either because they lack accuracy when producing data or because they are not feasible on a large scale. Narain (2012) advises to deduce groundwater use based on the quantity of sewage a city produces. However, reliable data on sewage generation is hardly ever available. Raju *et al*. (2008) and Anand *et al*. (2005) try to assess the number of private wells through systematic survey. However, these methodologies involve significant human capital and time if it is to be replicated in bigger areas. In addition, it gives little tangible information as to the average draft of one domestic borewell.

The present study aims at filling this knowledge gap by proposing a methodology that is able to produce fairly accurate results with minimal effort, so as to be useful to policy makers.

2. Estimating Groundwater Draft Rapidly and Accurately

In order to assess domestic groundwater use, we use electricity consumption as a surrogate. The logic behind the this methodology relies on two basic observations: [a] domestic tube wells, in the formal part of the city, use electric pumps to lift water from the ground; [b] it is possible to segregate electricity consumption of domestic pumps, either by relying on specific water works (WW) tariffs (in Gujarat), or by looking at the contracted load of a domestic connection if there is no specific water works tariffs.

Electricity tariffs are set at the distribution utility level and differ from one state to the other. In Gujarat, because electricity utilities issue specific tariffs for domestic premises and for public or private water works, it becomes relatively easy to compute urban groundwater draft.

2.1 How can electricity consumption inform us about groundwater draft?

To withdraw groundwater, we need β amount of energy within a given period of time. We can establish a simple correlation between electricity consumption and domestic groundwater abstraction, which illustrates the nexus between water and energy:

Groundwater withdrawal (L)=β ×Energy consumed (kWh)

The 'β' factor is not a constant; it varies across pumping systems. Pumping systems vary in size, age, state, efficiency, and depth of the well. Depending on these factors, the above correlation varies accordingly. There might be as many different values for β as there are pumps in Anand. Engineering science teaches us that the different factors impacting for the value of β can be captured using the following equation:

$$Q = \frac{E(kWh) \times 3.6 \times 10^6}{9.81 \times h}$$

Where:

Q = Yearly draft (L)

h = differential head (m) = depth of the bore well + height of the building/reservoir

$E_{(kWh)}$ = Energy consumed yearly (kWh)

Hence, to calculate the total groundwater draft of a city, we need to know the values of the three variables listed below:

- **Units consumed (kWh)** by the totality of the water works connections over a year.
- **Average height of buildings/reservoirs in the city.** For private connections, one can either perform a representative sample survey of buildings' height in the city that is being considered (as we proceed in Anand[1]) or make an assumption, based on the characteristics of the city. In flat, low-density cities such as Mehsana or Anand, we assume an average of 15 meters. In more vertical cities such as Ahmedabad, we take 30 meters as the average height.
- **Depth of the bore well.** The depth depends greatly upon the city in consideration. It can be collected either from households themselves, or by asking drilling companies, or by using data from the Minor Irrigation Census. For Anand, we approached households to determine the average depth of borewells. For other estimates, we used the fourth Minor Irrigation Census, which produces data on the depth of irrigation wells at the district level.

[1]We computed the average height of a building by multiplying its number of floors+1 by 3.1 meters.

Table 2: Model for estimating groundwater draft, using Anand as a benchmark (all units are yearly; water quantity is expressed in million liters unless specified otherwise)

DATA	
Average lift consumption yearly (kwh)	3,331
Private pumps' efficiency (%)	39%
Average number of combined bills (lift + pumps) in WWSP connections (%)	13%
CITY CHARACTERISTICS	
Electricity Data	
Private units of consumption yearly (kwh)	
Number of private connections	
City Characteristics	
Population (source: 2011 census)	
Average depth of borewells (Source: Minor Irrigation Census)	
Average height of buildings (Source: Assumption)	
Total municipal supply from surface water (Source: Municipality)	
Total municipal supply from groundwater (Source: Municipality)	
RESULTS	
Total private groundwater draft	
Share of groundwater in total supply (%)	
Share of private groundwater draft in total supply (%)	
Liters per capita per day (LPCD)	

The above equation may not produce an accurate estimate of groundwater draft for two reasons. First, in certain residential societies and premises, the electricity consumption of the buildings' elevator and other public lighting fixtures might be included in the water works electricity bill and this may lead to an over-estimation of groundwater draft. Second, the equation assumes that groundwater pumps are 100 per cent efficient, which is not true. In order to address the first issue, we carried out a survey in the city of Anand to determine whether this was a common practice and to estimate the average electricity consumption of an elevator. We found that about 13 per cent of the total waterworks connections have the elevators' consumption included in the electricity bill and that the average annual consumption is 3,331 kWh. To address the second issue, we also estimated the average efficiency of urban water pumps in Anand to be about 39 per cent. Both these findings were then incorporated in our computation of annual groundwater draft.

2.2 An Excel tool to facilitate municipal diagnosis

Overall, this methodology has the advantage of producing a first-cut estimate with minimal effort, since a trip to the local electricity utility shall suffice to produce fairly accurate results. Further, we can facilitate data collection and analysis by designing an easy-to-use excel model. Once the user has entered relevant information regarding the city being surveyed, the total private groundwater draft as well as the share of private groundwater in total supply is automatically computed (see Table 2).

3. Groundwater Dependence in Northern and Central Gujarat

The data on which our results are based was collected from the electricity utilities for central and north Gujarat: MGVCL (*Madhya Gujarat Vij* Company Ltd.) and UGVCL (*Uttar Gujarat Vij* Company Ltd.). The two utilities provided us with data at the circle-level, whose geographical boundaries correspond roughly to those of eleven administrative districts of central and northern Gujarat[2]. Water works Gram Panchayats (WWGP) connections were ignored. Urban population was determined at the district level based on 2011 Census data. We assume that in cities with population less than 5 *lakh*, the inhabitants rely exclusively on groundwater. We applied this model and associated assumptions to municipal supply to test its robustness[3] and then applied it at the district level to obtain regional estimates for private groundwater draft (see Table 3). Official estimates put municipal draft in Ahmedabad and Vadodara at 10,950 and 5,913 ML/year respectively. Thus, using our methodology produces fairly accurate estimates of municipal groundwater draft.

According to a 2004 survey of several Indian cities (Shaban and Sharma 2007), the average consumption of an Indian household is 92 LPCD. How to explain the discrepancies observed in our results across districts regarding the average LPCD? Ahmedabad, Mehsana/Patan districts and Panchmahal/Dahod districts showcase remarkably high LPCD (111, 121 and 130 respectively). Incidentally, they also boast the deepest bore wells of the entire region studied (119, 132 and 105 meters respectively). In such water-scarce areas, using the Minor Irrigation Census to assess the average depth of borewells is likely to lead to inaccuracies. The Minor Irrigation Census has but only one imprecise category for very deep wells, namely deeper than 150 meters. This category does not indicate whether the wells

[2]Namely Ahmedabad, Vadodara, Banaskantha, Sabarkantha, Panch Mahal, Dohad, Anand, Mahesana, Gandhinagar, Patan and Kheda districts.
[3]The share of units dedicated to drainage, pressure and groundwater extraction respectively are determined based on Anand municipal data regarding the total pumps' capacity (HP). Technically speaking, equating load to consumption is a rather eccentric assumption, yet it gives a relatively satisfactory estimate of municipal groundwater draft. We found that about 56 per cent of electricity consumed by municipal waterworks is dedicated exclusively to groundwater draft. Other electricity units consumed are dedicated to drainage or pressure pumps. Our results proved to be quite similar to municipal estimates, which comfort the usability of our methodology.

Table 3: Urban groundwater draft in North and Central Gujarat

District(s)	Ahmedabad – Gandhinagar	Vadodara	Anand	Kheda	Mehsana, Patan	Panchmahal, Dahod	Banaskantha	Sabarkantha	TOTAL
Major City (Population)	Ahmedabad (6,352,254)	Vadodara (1,817,191)	Anand (286,921)	Nadiad (225,071)	Mehsana (190,189)	Godhra (143,644)	Palanpur (140,344)	Himmatnagar (81,137)	
Surface Water (ML)	268,279 (CGWB 2011*a*)	53,217 (Narain 2012)	0	0	0	0	0	0	321,496
Municipal Groundwater Draft (ML)	10,776	5,959	9,149	8,584	8,799	10,067	25,001	10,061	88,398
Private Groundwater Draft (ML)	49,199	8,880	11,899	6,787	15,237	8,582	7,395	2,442	110,422
Share GW/Total Supply (%)	18%	22%	100%	100%	100%	100%	100%	100%	38%
Share Private GW Draft/Total Supply (%)	15%	13%	57%	44%	63%	46%	23%	20%	21%
LPCD (L)	111	88	79	67	121	81	130	88	96

concerned are 160 meters on average (which is our assumption in this study) or closer to 400 meters deep. As a result, we may have underestimated the average depth of borewells in the districts concerned, leading to an overestimation of groundwater draft in the water-scarce areas of Gujarat. A rapid survey on the ground may resolve this problem. In the case of populous Ahmedabad, where groundwater plays but a minor role with respect to total water supply, this inaccuracy does not introduce much bias in our results; increasing the average depth of borewells from the current 119 meters to a hypothetical 300 meters will bring down the LPCD by eight liters only.

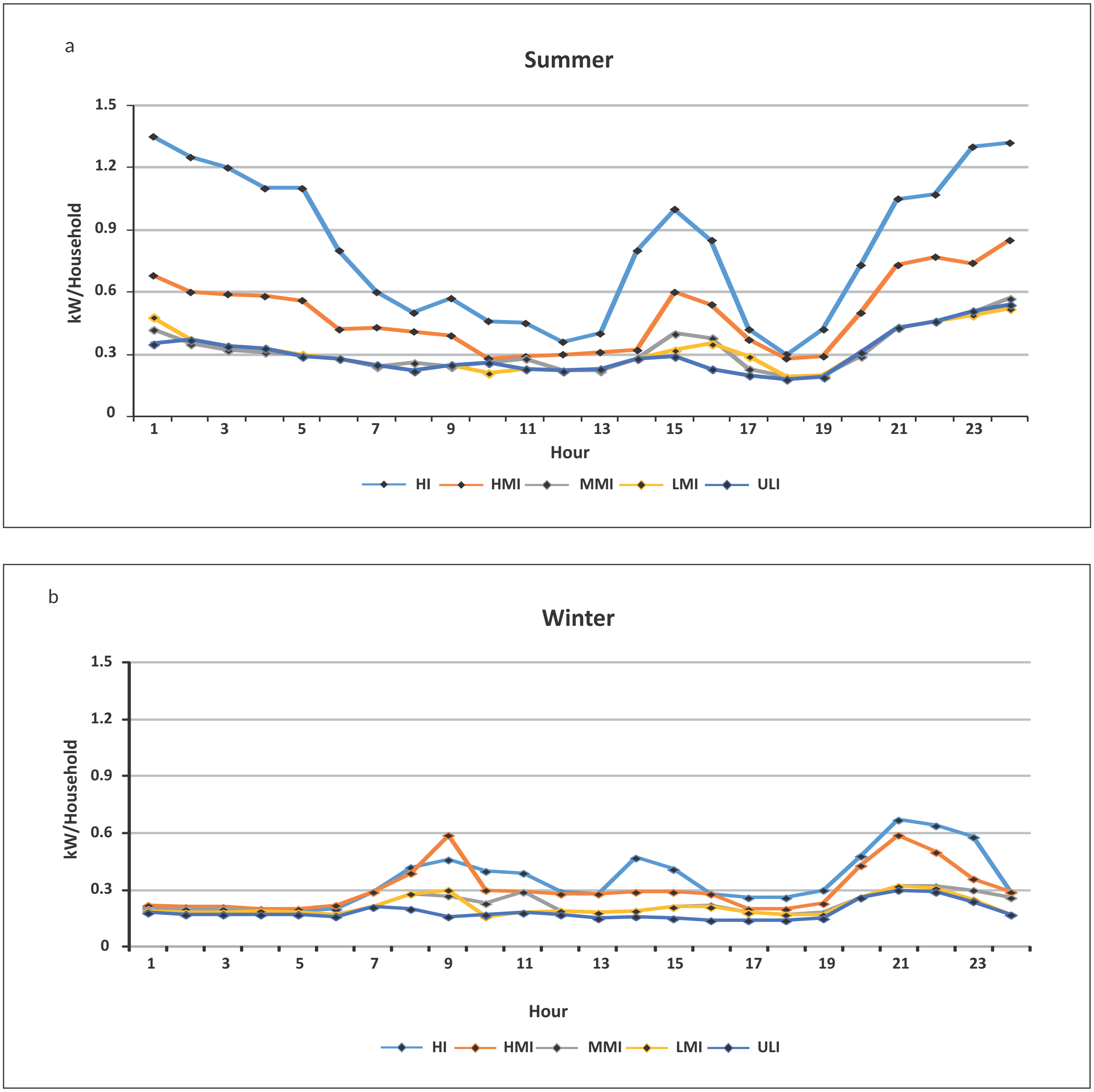
In other districts, the average LPCD is lower than Shaban and Sharma (2007)'s estimate. This is coherent, given that the methodology excludes certain categories of actors. The present results are an under-estimate of actual private groundwater draft. Our starting assumptions, if inaccurate, are all the more likely to affect our results, as Central and Northern Gujarat, with the notable exception of Ahmedabad and Vadodara, consist of a constellation of small towns and cities; light inaccuracies are likely to be amplified by the low density that characterizes most of the urban areas under scrutiny.

We observe a loose correlation between the size of the major city and private reliance on groundwater, which confirms findings from other studies (Patel and Krishnan 2009). In Ahmedabad and Vadodara, where both the municipalities have almost completely moved away from groundwater sources while expanding the municipal water supply network well beyond national averages, private groundwater draft does not contribute to a large extent in the total water supply. Reliance on groundwater resources is found to be the highest in districts counting medium-sized and growing cities such as Anand, Mehsana, Godhra or Nadiad. The low share of private groundwater draft in Banaskantha (23 per cent) and Sabarkantha (20 per cent) may also be correlated to city size. In both districts, urban areas are like a collection of very small towns of less than 50,000 inhabitants, almost skin to villages. While further research is needed to validate this hypothesis, it might well be the case that, similar to rural areas, residents have not equipped themselves with electric pumps within their premise, especially in these water-scarce areas where drilling a private well represents a substantial investment.

4. Estimating Groundwater Draft outside Gujarat

In other states, there are no separate connections and tariffs for water works connections. However, domestic pumps would still stand out in the official data due to their contracted load, which is higher than other domestic connections. Garg *et al.* (2014) studied the load profile of Gujarati households for various income groups (Figure 1). According to their findings, even AC-equipped high income households do not use more than 2 kW of power at any given point of time. These findings are consistent with our own research. According to officials' personal estimates for the cities of Jaipur, Jaisalmer, Jodhpur, Kota, Anand and

Figure 1: Load profile for income categories during (a) summer and (b) winter.



[HI: High Income; HMI: Higher Middle Income; MMI: Middle Medium Income; LMI: Lower Medium Income; ULI: Upper Low Income]
Source: Garg *et al*. 2014

Hyderabad, households contract 3 kW of load on average for domestic purposes; 6 kW in Bangalore; between 3 and 5 kW in Delhi; up to 10 kW in Chennai. These are adventurous and quick personal estimates from officials; according to secondary data collected for the district of Vadodara, urban domestic connections score an average connected load of 1.31 kW. By contrast, domestic pumps (WW.PR connections) in Gujarat show much higher contracted load on average: 7 kW in water-abundant Anand City, 22 kW in Ahmedabad district, and 10 kW in Vadodara district. This average reaches a dazzling 34 kW in Mehsana. It should be noted that these domestic connections often service an entire society, colony or high-rise apartment building with several inhabitants, and not individual household connections. Therefore, it is possible to segregate domestic connections from water works connections based on their load profile.

5. Conclusion

In the present study, we used the water-energy nexus to compute private, municipal groundwater draft in Central and Northern Gujarat. It produced compelling evidence that private groundwater draft represents a significant share of total water consumption in these regions. Since existing methodologies have failed to produce very accurate data in this regard, this methodology is a first step towards a greater understanding of groundwater patterns of use in urban contexts. Using the water-energy nexus to compute groundwater draft offers local policy makers the capacity to measure rapidly, effectively and fairly accurately at the city level.

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The IWMI-Tata Water Policy Program (ITP) was launched in 2000 as a co-equal partnership between the International Water Management Institute (IWMI), Colombo and Sir Ratan Tata Trust (SRTT), Mumbai. The program presents new perspectives and practical solutions derived from the wealth of research done in India on water resource management. Its objective is to help policy makers at the central, state and local levels address their water challenges – in areas such as sustainable groundwater management, water scarcity, and rural poverty – by translating research findings into practical policy recommendations. Through this program, IWMI collaborates with a range of partners across India to identify, analyze and document relevant water management approaches and current practices. These practices are assessed and synthesized for maximum policy impact in the series on Water Policy Highlights and IWMI-Tata Comments.

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