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Urban Self-Supply from Groundwater—An Analysis of Management Aspects and Policy Needs

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Abstract: The use of private water wells for self-supply in developing cities has 'mushroomed' during recent decades, such that it is now an important component of total water-supply, but one all too frequently overlooked in official figures. Selected global experience of the phenomenon (from 10 cities in 3 continents) is succinctly summarized, and then analyzed from differing perspectives, before drawing recommendations on priorities for its improved management.

Keywords: urban water-supply; groundwater; private self-supply; management issues

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Citation: Foster, S.; Hirata, R.; Eichholz, M.; Alam, M.-F. Urban Self-Supply from Groundwater—An Analysis of Management Aspects and Policy Needs. *Water* **2022**, *14*, 575. https://doi.org/10.3390/w14040575

Academic Editors: Helder I. Chaminé, Maria José Afonso, Maurizio Barbieri and Francesco De Paola

Received: 23 December 2021
Accepted: 10 February 2022
Published: 14 February 2022

1. Scale of Phenomenon

The use of private water wells for urban self-supply (Figure 1) has 'mushroomed' over the past 20 years or so, especially in South Asia, Latin America, and Sub-Saharan Africa. Recent surveys suggest that private self-supply from groundwater in the urban areas of developing cities is an essential component of total water-supply [1–9], but one that is frequently overlooked in official figures. The phenomenon varies in level with the physical evolution and hydrogeological setting of any given city, but there is convincing evidence of an increasing dependence on private water wells in response to rapid urban population growth and escalating water demand, facilitated by the modest cost of water well drilling.

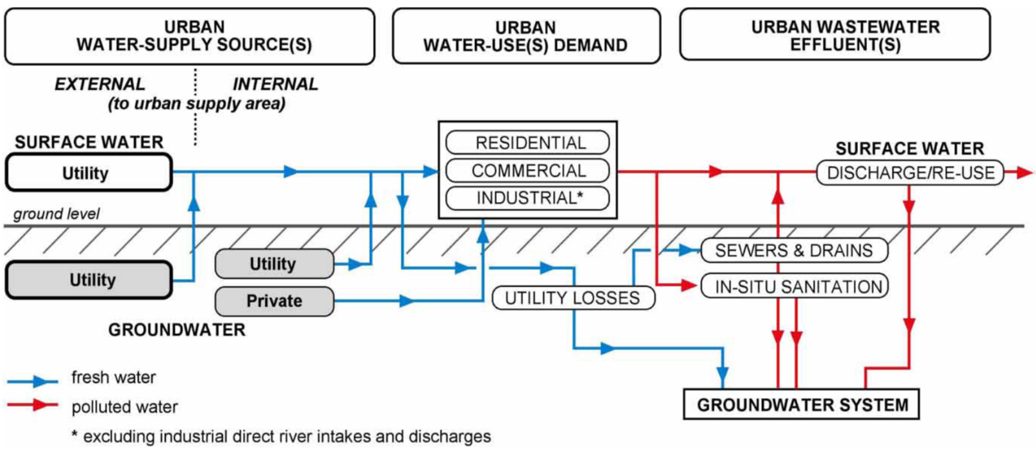

Figure 1. Schematic overview of urban water-supply sources and their interactions [10].

The term self-supply refers to water-supply investments that are financed by users themselves [11], and in developing economies, most self-suppliers use groundwater, and also sell water to neighbors. Self-supply from groundwater provides a rapid solution in areas where it is technically feasible and affordable. Nevertheless, private groundwater use tends to pass under the radar of national water-supply statistics [12], or the phenomenon is not recognized at all by government [3,13].

Private water well construction costs in most hydrogeological settings will be in the range of US$2000–20,000, but are considerably higher (US$30,000–50,000) where deep boreholes (of 200–300 m) are required. Private water well ownership will thus remain mainly the preserve of wealthy individuals or well-organized local communities. Though the practice reduces the pressure on the water-utility supplies, it can also have serious impacts on their cash flows and investment cycles [1,5], and result in inequalities around access to water-supply.

The initial private investment in water well construction is usually triggered by a highly inadequate urban utility water-service, and represents a 'coping strategy' to improve water-supply security by multi-residential users, individual properties, commercial premises, and industrial enterprises. In the longer term, the unit operational cost of private water wells is often lower than the cost of an equivalent municipal water-supply on an unsubsidized tariff, and thus, the practice continues as a 'cost-reduction strategy' even when the reliability of the public supply has improved.

2. Selected Global Experience

Profiles of 10 selected cities worldwide (Figure 2) will be included as illustrations of places with an important water-supply component derived by self-supply from groundwater. In some cases, significant progress has been made in exercising management over private water well users, but in the majority of cases, this has not yet been the case.

Figure 2. Location of selected cities whose water-supply has an important private component from water wells.

In Brazil, 172 million people have access to the public water mains, but only 30.4 million (17.7%) are provided by groundwater [14], due to the fact that the largest cities are supplied primarily by surface water. However, 52% of 5570 Brazilian municipalities are supplied either totally (36%) or partially (16%) by groundwater. During 2013–17, Brazil was hit by one of the most severe droughts of the last 80 years, which caused 48% of all cities to declare a water crisis [15], and those cities supplied exclusively by surface water were hit twice as often as those provided by groundwater.

Although official data suggest that surface water is the most used resource in larger cities, it is necessary to assess the role of complementary self-supply from private water wells, which are often irregular or illegal [16], to get the full picture. In Brazil, more than 90% of all groundwater is extracted by private water wells, highlighting the role that self-supply plays in national water security [17], with the following distribution among user types: domestic (30%), agricultural (24%), urban public (18%), and multiple-use (14%). These uses make the value of extracted groundwater US$12 billion, with the 2.5 million water wells valued at more than US$15 billion [18], equivalent to 6–7 years of government investments in sanitation.

For example, in São Paulo (Box 1), the largest urban conglomerate in South America (with over 21.5 million population), though groundwater supplies only 1% of the public water-utility, more than 12,000 private water wells provide 18% of its total demand, and more during crisis periods.

Box 1. São Paulo—Brazil.

São Paulo is home to 21.5 million people distributed across 39 municipalities, and occupies an area of 7946 km^2 with a GDP of US$237 billion/a. Public water-supply is provided to about 95% of the population, mainly by a complex surface-water system producing 5270 ML/d, of which only 1% is groundwater. However, there are more than 12,000 private water wells extracting 950 ML/d (18% of the public supply), and this increased to 25% during the last major water crisis of 2016–2019. Although private self-supply has increased water-supply security, large-scale uncontrolled water well drilling has caused problems, with both the lowering of water-table levels with conflict amongst users, and a significant risk of pollution with many private sources not having regular chemical analysis. The failure to manage groundwater resources is primarily attributed to a lack of appreciation of their importance for water-supply security, and a limited understanding of the conflicts between users. Thus, little pressure is exerted on the water management agencies, who have little incentive to try to regulate thousands of private water well owners.

A similar situation occurs in Fortaleza (Box 2), where many multi-residential apartment blocks take a significant proportion of their water-supply from private water wells [19]. This phenomenon started as a 'coping strategy' during drought when the mains water-supply was inadequate, but continues as a 'cost-reduction strategy' to avoid having to pay the higher water tariffs.

The large city of Recife has a very poor public water-supply (Box 3), and some 6000–8000 private water wells serve 25% of the population of 1.6 million [20]. This situation is replicated in many cities, and even in medium-sized urbanizations such as Bauru (390,000 inhabitants), private water wells meet 18% of the total urban water demand. Private self-supply from water wells must be regarded as essential, given that the public water-supply is limited due to historical scarcity of infrastructure investments. Without the supply produced by private water wells, the water-supply of many cities would collapse in drought periods.

The invisibility of groundwater, when it comes to both human water-supply and environmental features, leads to very inefficient management of the resource nationally. Though laws and regulations are adequate, they are scarcely applied, which means that 88% of water wells are irregular (without an extraction license). This is the result of groundwater users, regulatory agencies, and water well contractors lacking a clear perception of legitimacy and fairness. There is both confusion due to changes in water law, and a predisposition towards law-breaking—perceiving that the benefits outweigh the risks.

Box 2. Fortaleza—Brazil.

Fortaleza, a city of over 3.0 million population, is situated on a coastal strip underlain by permeable aeolian and fluvial deposits (widely of 30+ m in saturated thickness, and the water-table at 2–15 m depth), which are locally susceptible to sea-water intrusion, and widely vulnerable to pollution. The climate is humid–tropical with an average rainfall of 800–1200 mm/a. Aquifer recharge results from diffuse rainfall recharge, infiltration of surface runoff along riverbeds, profuse leakage of water mains, and ground discharge of wastewater from septic-tanks and cesspits, with groundwater exhibiting some nitrate contamination (15–35 mg NO_3/L) and chloride concentrations of 100–150 mg/L. CAGECE (the water-service utility) provides some 60–70% of the population from surface-water sources (with a 'guaranteed yield' of 570 ML/d), but earlier drought periods (notably 1998) caused near collapse of the mains water-supply, and led some 40–50% of the population, together with commercial water-users, to construct water wells for direct self-supply. A groundwater survey in 2002–2003 inventorized 8950 fully-equipped water wells (compared to about 1700 in 1980), and concluded that:

- **sunk capital in private water wells was at least US$19 million, and probably nearer to US$25 million;**
- **potential groundwater production is about 200 ML/d, representing 36% of total drought provision;**
- **more than 1500 water wells yielding more than 2 m^3/h (0.5 L/s) are effectively outside the law;**
- **groundwater use does not tax resources as a result of mains leakage and wastewater seepage.**

Significant private domestic groundwater use arises as a result of consumers avoiding the use of mains water-supply at prices above the highly-subsidized 'social tariff' (equivalent to US$0.26/$m^3$). This has major financial implications for CAGECE in terms of loss of revenue from potential water sales, difficulties of increasing average tariffs, and resistance to recovering sewer-use charges.

Box 3. Recife—Brazil.

The rapidly-developing Recife Metropolitan Region, a humid region with rainfall of about 2000 mm/a, has a population of over 3.0 million, and a water demand of about 15,000 L/s (including high 'non-accounted for' losses). COMPESA (the state water-service utility) has progressively developed surface water sources, whose capacity reached over 8000 L/s by 2008, but which reduces in severe drought to less than 3000 L/s. Hydrogeologically, the region divides into two areas (north and south) by a major geological lineament, with sharply contrasting groundwater potential on either side. In the south, shallow groundwater is intensely exploited at an estimated rate of 2000 L/s as a low-cost supply for multi-residential properties and hotel facilities by some 6000–8000 private water wells, mainly drilled in response to extreme municipal water shortages during the droughts of 1993–1994 and 1999–2000. In the north, the Beberibe Aquifer of some 200 m thickness dips below younger strata as the coastline is approached, and since 1975, has been widely developed over a 20 km-wide strip by COMPESA to provide mains water-supply, reaching 1500 L/s by 2002. In addition, it is estimated that private industrial water wells are abstracting about 700 L/s, although the depth of the aquifer horizon is such as to have largely prevented residential self-supply from groundwater. The aquifer response has seen drawdowns to around −60 m MSL, although this was not accompanied by any rapid saline intrusion. The Beberibe Aquifer is a good example of a high-yielding groundwater system close to a major urban area, whose geographical extension and regional flow is not sufficient for it to become a 'sole source' of urban water-supply, but whose freshwater storage reserves are large and need to be conjunctively managed to provide increased water-supply security at minimum possible cost.

India is far-and-away the largest user and consumer of groundwater globally, with a total annual extraction estimated to be 245,000 Mm^3/a, but an increasing number (now 29%) of the aquifer units are excessively exploited [21]. Agricultural irrigation (over 75%) is the predominant use, but 85% of the population are believed to rely, directly or indirectly, on groundwater for domestic water-supply, with a total extraction in the range 55–60,000 Mm^3/a.

Virtually all Indian cities have insufficient municipal mains water-supply [22], and their residents have widely adopted self-supply from groundwater as at least a stop-gap solution [23]. The detailed situation in three cities (Box 4, Box 5 and Box 6)—Chennai (Tamil Nadu), Indore (Madhya Pradesh), and Aurangabad (Maharastra)—are presented to illustrate typical trends.

Box 4. Chennai—India.

Chennai is the fourth-largest metropolitan area in India, and its 8.6 million population faced an acute water crisis during 2017–2019. Chennai's four main reservoirs almost dried-up as a result of persistent drought, and by June 2019, combined surface-water storage stood at only 0.1% of total storage, with the water utility only being able to supply 525 ML/d of the total demand of 830 ML/d. Much of the city became totally dependent on groundwater, which is abstracted extensively both within and outside the city limits. Within the city, there are about 420,000 private wells, but due to long-term overexploitation and limited recharge during poor monsoons, the water-table has fallen, causing wells to dry-up and groundwater quality to deteriorate through seawater intrusion. Thus, more than 5000 tankers of 9000 L capacity made 5–6 trips daily to supply groundwater from the surrounding rural areas for both the water utility and private operators at a total rate of 200–300 ML/d. However, a history of inadequate groundwater management has led to conflicts at the urban–rural interface.

Box 5. Indore—India.

Indore is one of India's fastest-growing cities, with a population of about 1.9 million and some 0.5 million households. The Indore Municipal Corporation (IMC) faces major challenges in trying to meet escalating water demand, and currently only achieves 46% water-mains coverage with a supply of about 320 ML/d; it achieves an average supply reliability of about 1 h/day. Of this supply, some 40–60 ML/d is groundwater, but private water wells of residential, industrial, and commercial users extract a further 100 ML/d. Little is known about groundwater quality and any associated risks to public health, but a systematic survey must be an urgent priority for the city. It is estimated that 35–40% of all households rely on private water wells as their main source, with about 150,000 water wells producing some 90 ML/d for this purpose. The associated investment is the equivalent of US$190/household (US$87 million in total), and the unit cost of private groundwater supplies is estimated to be US$0.04/m^3 compared to the water-utility charge of US$0.23/m^3. The estimated operational cost of private water wells is US$1.2–2.0 million/year, which is equivalent to 36% of the annual water-utility revenue, demonstrating the magnitude of the private investment in securing an urban water-supply.

Box 6. Aurangabad—India.

Aurangabad has grown rapidly in recent years to a population of about 1.2 million. In 1998, public water-supply became the responsibility of the Aurangabad Municipal Corporation (AMC), which takes 150 ML/d from a reservoir 45 km away and 180 m lower elevation. This supplements local groundwater sources that can only provide about 15 ML/d. However, shortages of electrical power needed for the high-lift pumping result in very poor service levels (widely, less than 1 h/day), and consequently, most residential properties and commercial premises have resorted to drilling private water wells. The local area has only limited groundwater resources, and the water-table falls from 5 m bgl to more than 10 m bgl in the dry season. Water well capital costs are very low (generally less than US$400), and an expenditure review revealed that private groundwater supplies cost US$0.15–0.25/m^3, compared with tinkered water at US$1.30–1.35/m^3. Consequently, residential and commercial consumers take their water-supply from different sources at different times of year: when available, the highly-subsidized AMC mains-supply at US$0.03/m^3; then, private water wells; and only when these fail in the dry season (April–June) do they use tankered supplies. This represents a coping strategy to reduce the period during which the most expensive water is needed, and as a result, about 60% of the total annual supply is from water wells, 35% from the AMC, and only 5% from tankers.

Bangkok (Box 7), the Thailand capital, is an excellent example of a city, and is driven by an increasing risk of tidal flooding seriously aggravated by land subsidence due to excessive water well pumping. It has struggled with urban groundwater over-exploitation for decades [24], but groundwater stability and an end to further land subsidence was finally achieved around 2005, after greatly enhancing the powers and capacity of the national Groundwater Department (GWD) in defined 'critical zones' as a proactive regulatory agency.

Box 7. Bangkok—Thailand.

Greater Bangkok occupies the lower part of the Chao Phrayh Basin, which is underlain by 500 m of interbedded alluvial and marine sediments containing eight semi-confined 'aquifer horizons' (recharged from the north), and overlain by a confining Holocene clay. By 1980, widespread exploitation of groundwater for urban water-supply, mainly by the Metropolitan Waterworks Authority (MWA), reached a level of about 500 ML/d, and caused a groundwater level decline to 40 m bsl, with evidence of significant related land subsidence. The initial approach to reducing groundwater abstraction was to require the MWA to close its water wells in favor of the development of distant surface-water sources, but increased water tariffs triggered a massive increase in private water well drilling. Abstraction reached over 2000 ML/d by the late 1990s, with a further 400 ML/d abstraction by three Provincial Waterworks Authorities (PWAs). The Groundwater Department (GWD) was then given increased power to reduce groundwater abstraction, with the definition of 'critical areas' where water well drilling must be banned, the sealing of water wells in areas with mains water-supply coverage, and licensing/charging for water well abstraction. Charges were raised under two separate components (a 'use fee' and 'conservation fee', each reaching US$0.21/m^3 by 2004). These measures had the positive outcome of controlling groundwater abstraction and reducing land subsidence. There are now just over 4000 licensed water wells operated by around 3000 owners, abstracting about 1600 ML/d (representing 15% of total water-supply). There has been conflict in some districts where the mains water-supply was extended but with high charges (US$0.60/m^3), and these were resolved by allowing private water well users to continue pumping up to 10 years (their next license renewal).

In the last decade or so, the construction of private water wells for urban self-supply has mushroomed in Sub-Saharan Africa [4,12,25–27], but with significant quality concerns in many places [28]. This has occurred equally in cities such as Lusaka (Box 8) and Douala (Box 9), where local aquifers are also in major use by the water-supply utility, as in cities such as Mombasa (Box 10), where the municipal water-supply is imported from distant sources. The driving factors are always the inadequate level and unreliability of the public supply, and the cost advantages to larger domestic water users of self-supply.

Box 8. Lusaka—Zambia.

Lusaka has grown rapidly from 0.5 million in 1978 to 2.8 million in 2018. It has long been dependent on local groundwater for its water-supply. In 2018, the water-utility operated 228 water wells to provide about 140 Ml/d, with river treatment works providing a further 80 ML/d. The water-utility is still plagued by high water losses and poor revenue collection, but has taken a 'pro-poor initiative' by drilling stand-alone boreholes to supply water-kiosks at a subsidized tariff of US$0.25/m^3 (a 40–70% reduction). In addition, there are thousands of private water wells with a total abstraction of up to 300 ML/d. In low-income peri-urban areas, most households still rely on shallow dug-wells where the water-table is less than 3 m depth, but the dolomitic-limestone formation they tap (though high-yielding) is very vulnerable to pollution from urban wastewater and industrial effluents. Pit latrines are the predominant form of sanitation, and in these ground conditions, they are a serious hazard to groundwater quality, and the cause of frequent cholera outbreaks. Some large-scale projects to extend the main sewer network and wastewater treatment capacity are underway, but in the unplanned peri-urban slums, these are difficult and costly to implement.

Box 9. Douala—Cameroon.

Douala, the Cameroon capital on the Gulf of Guinea, has grown very rapidly from about 1.0 million in 1995 to 3.8 million in 2015. The Doula Basin contains thick sedimentary formations, including a semi-confined coarse sandy Mio-Pliocene aquifer (up to 220 m thickness), and the consolidated deeper Continental Terminal aquifer. The climate is hyper-humid (with a precipitation of around 4000 mm/a), resulting in diffuse recharge approaching 1000 mm/a. The Cameroon Water Utility (CAMWater) provides a public supply to about 40% of the urban population, deriving 50% from water wells, and the balance from river treatment works. The rate of groundwater abstraction increased from about 55 ML/d in 1990 to 175 ML/d in 2010. Access to domestic water-supply remains a problem, and the demand is met by private self-supply from shallow water wells and purchase from water tankers. More than 70% of the urban population is served by latrine sanitation, and there is concern about groundwater quality degradation in the upper part of the Mio-Pliocene aquifer, which exhibits a patchy quality, with EC reaching 500–2000 μS/cm (compared to 200 μS/cm in the deeper horizons), but the generally reducing conditions result in the autoelimination of NO_3 and SO_4. In general terms, the hydrogeologic conditions are very favorable for developing new public water-supply wellfields upstream of the city in either the deeper horizons of the Mio-Pliocene and/or the Continental Terminal aquifers.

Box 10. Mombasa—Kenya.

Mombasa is a major coastal city, whose population has grown rapidly from 0.4 million in 1989 to 1.5 million in 2018, and is set in a metropolitan area with a population of over 3.0 million. The total water demand is estimated to be in excess of 250 ML/d, but the currently available production capacity of the Mombasa Water Company (MWC) is only capable of meeting 20–25% of this demand. Groundwater provides most of the MWC supply, with the main sources being the Baricho-Sabaki wellfield, 100 km distant, with a design capacity of 95 ML/d (but only delivering 30 ML/d to Mombasa due to offtake by other towns); the Mzima springs via a 200 km pipeline with a design capacity of 35 ML/d, but currently delivering 20 ML/d; the much nearer Tiwi water wells, with a production of up to 10 ML/d; and Marere springs, providing another 5 ML/d. Although not adequately quantified and assessed, the very substantial urban water-supply deficit is met by large-scale water tankering, and by large numbers of uncontrolled shallow private water wells (mainly to 25 m depth in sands requiring well-screens), whose water quality is widely compromised by both wastewater percolation and saline-water encroachment, and is often virtually brackish in character.

3. Analysis from Different Perspectives

3.1. Private Water Well Users

In-situ private self-supply from groundwater is mainly practiced by urban dwellers who have sufficient financial resources (individually or communally) to act unilaterally to secure a more reliable water-supply [5]. Among higher income groups, ownership of a private water well is widely seen as enhancing personal water-supply security in the face of unreliable public water-supplies. Urban properties with water wells, or favorably located for access to groundwater, generally attract a higher market value.

There is a widespread perception that groundwater is of excellent quality, and private water wells are, therefore, reasonably safe. Though there may be some truth in this, there is also increasing evidence of significant pollution [28], and an adequately performing water-utility could offer a supply of more assured quality. On the other hand, the technological and financial inefficiencies of many water-utilities in the developing world leave questions as to whether this can currently be done, and at comparable cost [3,8].

Whether private domestic groundwater use for potable supply presents a serious risk to users themselves will depend on the type of anthropogenic pollution or natural contamination present, and interactions with systems of in-situ sanitation are a particular concern. Some pathogenic microbes, certain synthetic industrial chemicals, and soluble arsenic and fluoride are the greatest hazards. However, there are those who argue that, for some in society, reliable access to any low-cost, parasite-free water-supply is preferable to no water access at all (or use of scarce financial resources on expensive tankered supplies), and that advice on possible use, hazards, and provision of bottled drinking water is a sufficient public-health precaution [9].

3.2. Water-Service Utilities

The existence of groundwater self-supply is of significance to municipal utilities, since it both reduces pressure on (their often limited) water-supplies, and can meet demands whose location or temporal peaks present difficulty for mains water-supply. It is also especially appropriate for uses than are non-quality sensitive.

However, from a water-utility perspective, unregulated private access to groundwater in urban areas also usually means large numbers of richer residents opting to obtain most of their water-supply off-grid. Though this can free up utility water production to meet the needs of lower-income neighborhoods, it will substantially reduce utility revenue collection, and make it more difficult for water utilities to mobilize new investment for water infrastructure and maintain highly-subsidized social water tariffs [1,10]. Moreover, if mains sewerage is (or is planned to be) provided, private water wells will generate additional sewer-flows for which a way will be needed to collect charges (Box 2 and Box 3).

Where the municipal water-supply utility has 'excess developed resources', and is subject to commercial incentives (putting 'financial considerations' before 'social service'), it may well try to market substitution of mains water-supply for private self-supply (to multi-residential properties, and commercial and industrial users, rather than deploying the surplus to improve water-supply to low-income areas). Such action could distort a 'rational policy dialogue'.

3.3. Water Resource Management

Intensive private groundwater use does not necessarily cause serious resource exploitation problems (such as saline intrusion or land subsidence), because of abundant replenishment from water-mains leakage, in-situ sanitation seepage, and other urban sources [3]. The intensive use of private water wells can also incidentally recover a significant proportion of mains water-supply leakage to shallow unconfined aquifers. However, in those cities where the principal aquifers are significantly confined, sustainability problems may arise (Box 9).

Normally, sufficient groundwater resources are not available within the limits of larger cities to meet fast-growing urban water-demand sustainably (Figure 1). Where high-yielding aquifers are present in the hinterland of cities, the development of 'external wellfields' is an attractive option for water utilities compared to long-distance import of surface-water resources. However, groundwater also remains widely exploited by water utilities through individual water wells scattered around urbanized areas, many without specific protection measures.

4. Balanced Public Policy Formulation

4.1. Resource Stocktaking and Risk Assessment

There is an urgent need to take stock of urban private water well use, and better understand the dynamics of overall investment in water-supply provision and its socioeconomic implications. Public policy needs to be formulated to reconcile the widely differing perspectives of private users and public utilities, and establish how private water well use can be better harmonized with public utility water-supply and sanitation investments [1,7,13,26]. A key question is whether 'off-grid solutions' to water-supply provision have an increasing role to play, despite their potential health risks and lack of economy of scale.

It is important that groundwater resources are used efficiently in developing cities, since they can play a key role in climate change adaptation. In this context, it will be important to manage the large groundwater storage of most aquifers to improve water-supply security. To achieve this the monitoring, the assessment, management, and protection of groundwater must be undertaken, and political and public awareness of the resource must be greatly improved.

The public administration will also need to assess the benefits of private groundwater use in terms of relieving pressure on municipal resources (especially for non-sensitive uses, such as garden irrigation, laundry and cleaning, cooling systems, recreational facilities, etc.), and of guarding against the possibility of groundwater table rebound and associated urban drainage problems should groundwater abstraction radically reduce.

A risk assessment of current private urban water well use practices is a pre-requisite for policy development, and will have various components:

- evaluation of the state of aquifer resources, the risk of saline intrusion or continuous water-level decline, and loss of access;
- appraisal of groundwater quality status, including the types of any aquifer pollution and the hazard associated with any natural contamination (such as arsenic or fluoride);
- audit of sanitary construction standards of private water wells, their mode of use, and the implications in terms of health hazard;

If the assessment indicates a high-level of risk to either groundwater resources and/or water well users, certain actions should be implemented as appropriate to local conditions, including use metering and charging (directly or indirectly) to constrain water well abstraction [3], or issuing health warnings and use advice to private water well operators by declaring sources unsuitable for potable and sensitive uses [10].

Certain tools are useful to guide private investment in groundwater development:

- maps of water well yield potential and reliability, depth to main aquifer horizons, static groundwater levels, groundwater pollution vulnerability, potential contaminant loads, and natural quality hazards;
- protocols for water well design, construction, and operation, and the design and operation of in-situ sanitation (septic tanks and improved latrines);
- order-of-magnitude assessment of the status of groundwater resource abstraction, levels of sustainability, and seriousness of risks associated with persistent excessive abstraction;
- guidelines on groundwater use precautions in relation to quality risks, and procedures for rainwater harvesting and aquifer recharge enhancement at the individual urban plot level.

4.2. Improving Regulation and Monitoring

Some regulation of private self-supply from water wells in urban areas is needed, so as to be able to keep the phenomenon in check [3], but if it is not enforced systematically, it is likely to further distort private use. Moreover, regular quality monitoring would be highly advisable, since, without it, the use of private water wells will be a 'risky business', especially from shallow aquifers as a result of the hazard of their significant pollution from in-situ sanitation, industrial discharges, and chemical spillages.

The large majority of private urban water wells are unregulated or completely illegal [17]. If this situation can be regularized, taking advantage of advances in geographical positioning, data capture, and storage systems, it will have a number of benefits:

- urban groundwater users can receive sound information and advice relevant to their use (water well construction standards, pollution risks/alerts, use precautions), and can be protected against the impacts of excessive total abstraction and/or inadequate water well spacing;
- sanitary completion standards of water wells can be improved, and their potential interaction with in-situ sanitation units (latrine, cesspools, and septic tanks) reduced;
- the public administration will be in possession of much better data on private use, which will, in turn, feed into more realistic groundwater resource assessment and municipal water-supply provision;
- public authorities could undertake periodic water analysis as a service to legal urban groundwater users (who, ideally, in return would pay a modest annual 'water resource fee').

The most forthright attempts to regularize the private use of urban groundwater have been in places such as Recife (Box 3) and Fortaleza (Box 2) in Brazil, where the municipal utility has argued for levying of a volumetric water charge in respect to mains sewer use by private water well users. This has resulted in municipal utilities drawing up comprehensive inventories of private water wells on multi-residential, commercial, and industrial properties.

In Fortaleza, charging for sewer use on properties with private water wells is by type/size of property, but in Recife, metering is being introduced for this purpose.

A persistent policy question is under what circumstances do the risks or inconveniences of private residential self-supply in urban areas justify an attempt to ban such use of groundwater. Historically, 'urban groundwater use bans' have been necessarily introduced to address certain specific problems. However, attempts at such bans can be justly criticized because they:

- are unrealistic and, in effect, unimplementable at present;
- could impose intolerable strain on municipal water-supply in some cities;
- do not represent good use of scarce water resources, including the recovery of high levels of physical mains leakage losses;
- run the risk of promoting abandonment of groundwater pumping with water-table rebound, which, in low-lying cities, could imply major disruption and cost.

5. Concluding Summary

Hundreds of millions of urban dwellers worldwide rely on self-supply from private water wells every day. Thus, for local government and municipal water-utilities, finding modalities through which they can find a way of working with, and improving the public health dimensions of, self-supply makes sound sense.

The 'pros' of urban domestic self-supply from groundwater are that it considerably improves water-supply access for some user groups, albeit this only includes the poor, where community action occurs and/or the saturated aquifer occurs at very shallow depth. It also both mobilizes significant private investment in water-supply provision, and incidentally recovers a significant proportion of mains water-supply leakages to the ground.

At a large scale, the 'contras' are that the phenomenon compromises revenue collection, and undermines the investment of municipal water utilities, making it more difficult for them to improve service coverage and quality. Shallow self-supply water wells are also prone to pollution in urban areas from in-situ sanitation, industrial discharges, and accidental spillages.

It is thus very important that urban self-supply from groundwater must not be ignored by the public authorities, and should be systematically included in city-wide surveys and monitoring of water-supply provisions. Policies need to be introduced that encourage municipal water utilities and local government offices to provide services to private water well users in return for formal water well registration and payment of a modest resource fee. Such services need to include periodic chemical analyses to identify pollution hazards or natural contamination, and provide advice on the suitability of the supply for specific uses.

Author Contributions: Conceptualization S.F. 100%; M.E.thodology S.F. 100%; validation S.F. 100%; formal analysis S.F. 40%, R.H. 20%, M.E. 20%, M.-F.A. 20%; investigation S.F. 40%, R.H. 20%, M.E. 20%, M.-F.A. 20%; data curation S.F. 70%, R.H. 10%, M.E. 10%, M.-F.A. 10%; writing—original draft preparation S.F. 100%; writing—review and editing S.F. 70%, R.H. 10%, M.E. 10%, M.-F.A. 10%; supervision S.F. 100%; project administration S.F. 100%. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not appropriate for review of this type.

Informed Consent Statement: Not appropriate for review of this type.

Data Availability Statement: All data used are given in paper.

Acknowledgments: The first author generously acknowledges the excellent dialogue on this topic maintained during 2018–2021 with members of the IWA Groundwater Management Group Steering Committee (which he Chairs) that enriched the content of this paper.

Conflicts of Interest: The authors declare no conflict of interest.

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