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Risks and responses to universal drinking water security

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Risks to universal drinking water security are accelerating due to rapid demographic, climate and economic change. Policy responses are slow, uneven and largely inadequate to address the nature and scale of the global challenges. The challenges relate both to maintaining water security in increasingly fragile supply systems and to accelerating reliable access to the hundreds of millions who remain water-insecure. A conceptual framework illustrates the relationship between institutional, operational and financial risks and drinking water security outcomes. We apply the framework to nine case studies from rural and urban contexts in South Asia and sub-Saharan Africa. Case studies are purposively selected based on established and emerging examples of political, technological or institutional reforms that address water security risks. We find broad evidence that improved information flows reduce institutional costs and promote stronger and more transparent operational performance to increase financial sustainability. However, political barriers need to be overcome in all cases through internal or external interventions that require often decadal time frames and catalytic investments. No single model exists, though there is sufficient evidence to demonstrate that risks to drinking water security can be reduced even in the most difficult and challenging contexts.

1. Introduction

Universal drinking water security is a matter of intensifying concern in industrialized and developing countries as a moral, health and economic imperative. The arguments and rationale for delivering safe and reliable water services on a non-discriminatory basis to everyone on the planet are well rehearsed [1–4]. The

multi-trillion-dollar global costs of both maintaining access for the currently water-secure and providing access to the hundreds of millions of water-insecure are accelerating over time [5,6]. Industrialized countries face enormous rehabilitation costs that are largely hidden, literally underground, which politicians defer to the future, knowing the costs will be higher and the challenges more difficult. For example, only one in three households in the UK has a domestic water supply meter. This is indicative of low political salience related to demand management in a country that once led the world in the development of universal safe drinking water supply [7,8]. The USA faces a stark story of diminishing service delivery, accelerating costs and political somnolence [9]. In developing countries, water supply risks and opportunities will play out amid impacts from population growth, urbanization, environmental degradation and economic development, juxtaposing accelerating urban water demand with stagnating rural water neglect.

We focus this paper on the risks and responses in developing countries where there are high levels of water insecurity, as the nature and scale of the challenge present significant risks to social progress in terms of health, wealth and stability [10–12]. A conceptual framework illustrates how institutional, operational and financial risks to drinking water security shape response patterns and outcomes. The framework is used to examine nine case studies in rural and urban contexts in South Asia and sub-Saharan Africa to evaluate how key elements, processes and practices emerge and reduce risks to universal drinking water security.

In the 1980s, a global strategy to address drinking water security in developing regions was advocated as part of the International Decade of Drinking Water Supply and Sanitation [13]. At the end of the decade, 1.2 billion people lacked access to improved water sources.¹ By 2010, over 780 million still lack access to improved water supplies despite the Millennium Development Goal for safe water access being met at the global level in early 2012—a remarkable and praise-worthy achievement [14]. However, population growth, regional variation in access and monitoring uncertainty on credible metrics of progress make the global fanfare premature. First, population growth effectively led to many regions standing still, or, worse, falling behind, such as in sub-Saharan Africa, which now has an additional 67 million people without improved water services compared with two decades ago. While population growth matters in rural areas served largely by point sources, population growth in urban areas is of greater concern, as it is accompanied by a trend towards smaller, and therefore more, households, with the associated costs of individual piped service delivery provision and maintenance [15]. Second, regional variation illustrates that those regions with a wider set of development, governance and growth challenges have made least progress; in other words, and somewhat predictably, most progress has been made in regions where easier and cheaper gains were to be had, leaving the ‘most in need’ and ‘most difficult to reach’ still (largely) unserved. Third, monitoring progress continues to present significant methodological challenges in determining accurate and comparable metrics of sustainable progress at global and national levels [14]. For example, proxy measures were chosen to determine improved water services based on technology rather than across measured criteria of access (sufficient quantity, acceptable quality, physical proximity, affordability) and reliability (continuity and timing of service). For example, where data limitations are calibrated for water quality variation, global progress inevitably is shown to be declining [3].

Reviewing the reported trends over the monitoring period between 1990 and 2010 in South Asia and sub-Saharan Africa reveals uneven trends (figure 1). First, in urban environments, piped water access on premises has broadly declined over time, with the shortfall largely made up by ‘other improved’² supplies; however, overall performance is effectively flat, with particular concerns for the one in five urban Africans who use ‘unimproved’ water supplies. Second, in rural contexts, South Asia records strong progress particularly in other improved supplies. Progress in rural sub-Saharan Africa has stagnated despite starting from the lowest regional base; one in two people are still without improved water supplies. The net effect is that 38 million *more* rural

¹Improved water sources classified by WHO/UNICEF [14] include (a) piped water into dwelling, yard or plot, (b) public taps or standpipes, (c) boreholes or tubewells, (d) protected dug wells, (e) protected springs and (f) rainwater collection.

²Other improved sources include (b)–(f) detailed in footnote 1.

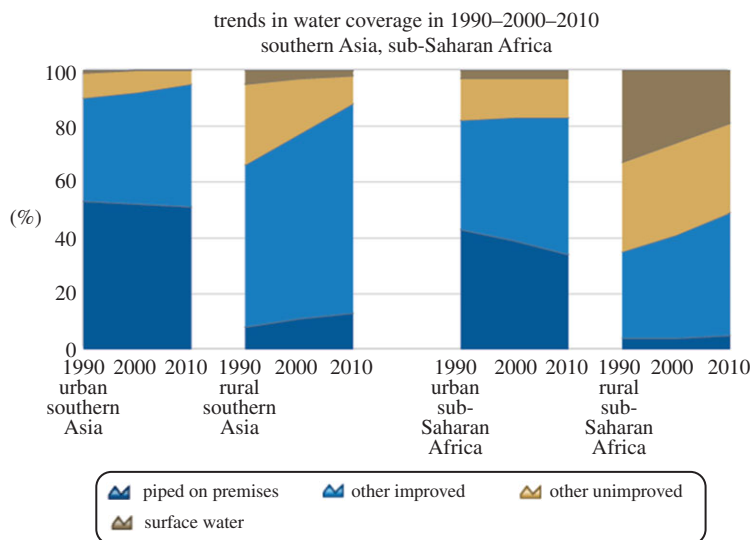


Figure 1. Trends in drinking water access in South Asia and sub-Saharan Africa, 1990–2010 [14]. (Online version in colour.)

Africans do not have access to improved water in 2010 compared with 1990. Despite significant investments and policy reforms, these two key regions should be a major cause for political concern and action; we therefore choose to focus this paper on these two regions.

Drinking water risks manifest in both ‘natural’ forms, such as water quality impacts from fluoride, arsenic or other minerals naturally occurring in the environment, and ‘manufactured’ forms, in relation to human-induced pollution or barriers to access moderated by economic, social or physical determinants. The emergence of a ‘risk society’ [16,17] charts increasing public policy concern with ‘manufactured’ risks and the associated, reflexive responses from society to the hazards that are residual to the wider process of ‘progress’ and modernization. A risk society is not new in manufacturing inequalities to safe and reliable access to all citizens [13]. More recently, societal responses have broadened in the scope of ambition and actors participating, including the Millennium Development Goal for water supply access [18], the Human Right to Water and Sanitation [4] and the World Economic Forum’s concerns of ‘water supply crises’ [12]. Here, we do not focus on the well-established, water quality risk literature [19,20], but examine the under-researched intersection between institutional, operational and financial risks to drinking water security [21]. Established bodies of drinking water supply literature have explored these three domains in alternative and overlapping theoretical and conceptual frameworks of sustainability [22–27], participation [28–32] and governance [33–37]. However, there has been no explicit analysis across domains, nor has risk been applied as a unifying framework, which is a key contribution of this paper.

To illustrate how risks and responses currently interact in drinking water delivery, we outline a conceptual framework (figure 2). Institutional, operational and financial risks vary by the nature of settlement from rural to urban and from scattered to dense settlement typologies [38]. The framework is a reduction of the wider complexity across contexts and time but identifies key elements in each risk domain. Institutional risks refer to separation of powers (policy, delivery and regulation), the degree of autonomy in managing service delivery, accountability and public engagement and support. Across all of these, information systems provide the means to monitor to what extent operational and financial ends are met against process or other benchmarks [21].

Operational risks refer to system maintenance, non-revenue water (leaks and theft), performance contracts and service levels, and monitoring systems that relay timely and accurate data into the institutional domain. Financial risks include capital expenditure (CapEx) and operational expenditure (OpEx). Capital expenditure refers to transfers, loans, grants and

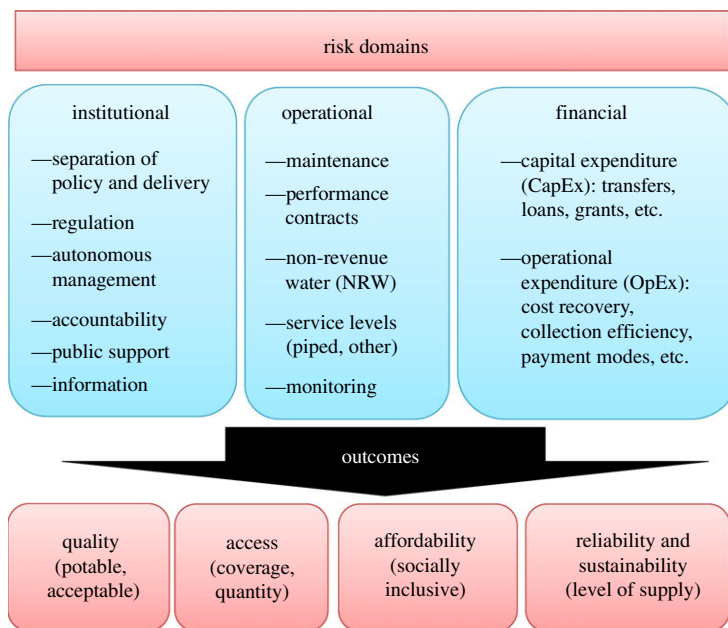


Figure 2. Risk domains and drinking water security outcomes. (Online version in colour.)

other funding sources for major (hard) infrastructure investments in storage, treatment, piped networks, meters and associated costs. Operational expenditure consists of cost recovery, collection efficiency, payment modes and management performance. The risk domains determine drinking water security outcomes across water quality, water access, affordability and reliability criteria [4]. The current state of monitoring globally deals only with the type of water supply infrastructure [14]. Such outcome criteria are aspirational, though examples of monitoring innovations are rapidly emerging to ground data more firmly. We discuss this later. Based on the risk framework, we elaborate in more detail on each risk domain, before applying the framework to the case studies.

2. Risks to universal drinking water security

The three risks listed above are discussed briefly in the context of the well-known impacts of lack of improved water services across health, wealth, time, dignity and associated distributional impacts, particularly for women and children.

(a) Financial risk

Financial risks are illustrated by the global financing gap of over USD 11 trillion between 2013 and 2030 to fund the global water supply and sanitation services infrastructure [6]. The financing gap is composed of new capital expenditure but more significantly of the renewal of existing water supply systems. For example, it is estimated that, in the USA, water supply infrastructure renewal will cost a total of USD 1 trillion between 2011 and 2035 [9]. In Africa, there is a funding gap of USD 16 billion a year just to meet the Millennium Development Goals on water and sanitation, and it is estimated that transforming Africa's water infrastructure (water resources, water supply, sanitation and irrigation) will require an additional USD 31 billion a year together with 'huge efficiency gains' [11]. There are specific regional financial challenges where progress to drinking water security is slowest (Africa), and where demographic change will be most significant (Africa and Asia). Meeting this investment in an affordable way will require extensive long-term, low-interest loans. In the developing world, this is the province of the World Bank

and regional banks, but government initiatives, such as that taken in Malaysia in setting up the Water Asset Management Company (see <http://www.paab.my/>), are also required. Similar access to affordable finance is required in the developed world. This will require the acceptance of higher water charges, which historically politicians have been unwilling to embrace for fear of unpopularity.

Investment needs are compounded by a generally low level of cost recovery, resulting in inadequate maintenance. This neglect leads both to deterioration of the infrastructure and service access, and to the inability of service providers to extend services, particularly to unplanned or expanding urban areas, which limit access to low-income and vulnerable groups. Significant levels of lost revenue limits the ability of urban utilities to meet existing as well as future water demand in cities. The apparent unwillingness to invest in the refurbishment of urban piped networks compared with new water resources suggests that the significance of this risk does not appear to be fully recognized by governments and funding agencies [9]. Unless this underinvestment in existing infrastructure is addressed, there will inevitably be an ongoing spiral of decline where unreliable water service delivery reduces consumers' willingness to pay [39]. Owing to the unreliability and inadequacies of subsidies, sustainable cost recovery is a fundamental condition to ensure financial sustainability to lock-in universal drinking water security [21,40]. A phased transition from subsidies to cost recovery from charges will be required. The need for cost recovery raises the question of provisions for the poor, which is often the stated reason for inadequate cost recovery. Affordability relates not only to the amounts but also to the method of collection. The poor find it difficult to save to pay off accumulated bills, but those other than the destitute are able to pay in frequent but small increments. One option to achieve this benefit is the use of prepayment meters; another is through water payments via the mobile communications sector [41].

In rural areas, waterpoints and small-piped systems are more common. Similar issues of financial risk to those in urban systems apply, as water users appear reluctant to pay, are unable to afford or behave strategically in paying for improved water services [26]. The long-standing paradigm of a demand-responsive approach continues to dominate sector thinking on financing infrastructure and maintenance despite uneven financial performance [22,42].

(b) Operational risk

Operational risks are identified in both urban and rural areas, with demographic growth exacerbating existing low levels of performance. By 2050, Africa and Asia will account for over 70% of the global urban population (*ca* 4.5 billion). Asian cities will be home to 3.3 billion people, and Africa will experience an overall doubling of its population to 2.1 billion, of whom 57% will live in cities [43]. Water service delivery to meet urban population growth will be exacerbated by trends of shrinking household size [15]. Africa will be the only region where the rural population continues to grow by 2050, with a projected 927 million residents, equivalent to half of a declining Asian rural population of 1.8 billion. With rapid urbanization and greater climate variability, there are increasing risks that surface water and groundwater resources, and the means of distributing the additional water, will not keep pace with the growth of rural and urban water demands [44]. Issues about the changing availability of water resources will require wastewater to be regarded as a resource, which introduces additional acceptability and safety risks. Rapid urbanization also increases uncertainties in the design of distribution systems. Risk management approaches are being developed to assist in the decisions to be made on piped system extensions [45].

A major risk to water security is the neglect of existing infrastructure associated with inadequate cost recovery. The result of decades of poor maintenance and virtually no replacement or refurbishment of ageing pipe networks is low pressure and high leakage; the latter is estimated to have an equivalent cost of USD 1 billion per year in selected African cities [11]. One reason for the high leakage losses is rationing urban water supplies by hours per day or week, as unpressurizing and repressurizing of systems accelerate deterioration and introduce the additional risk of ingress of contaminated water [21].

Operational risk in rural areas centres on timely and effective maintenance of both waterpoints and small-piped systems [46]. A review of 23 water and sanitation projects in Angola, Benin, Burkina Faso, Ghana, Nigeria and Tanzania with an investment of over €400 million found that the majority of projects were not sustainable in terms of meeting water user needs [47]. It is estimated that one-third of rural handpumps, which lift locally available groundwater of generally good-quality water at low cost, are not operating at any one time in Africa [48]. The associated investment cost of installing 200 000 pumps that no longer function in Africa is USD 1.2–1.5 billion [49]. Currently, four out of every five people without improved water access reside in rural areas [50]. Minor improvements in operational performance, to keep handpumps working longer, would have a dramatic impact on maintaining and accelerating improved water supplies for rural people.

Benchmarking is a useful tool to enhance water security. Operators can gain much from learning from each other's experience and practice. Benchmarking (process) approaches that provide for a group of water service operators to identify best practice are non-threatening, leading to progressive adoption and service performance improvements over time [21,51]. Once confidence has been gained and sound baseline data have been established, metric benchmarking can be added to show progress period by period, and eventually to introduce an element of performance competition. Competition between area units was used in Uganda to stimulate improved performance [52].

(c) Institutional risk

There are important risks associated with governance structures across rural and urban water service delivery. These include policy design, service delivery, effective regulation and monitoring of services over time within an accountable and transparent framework that is founded on meaningful public participation [36,37,53].

Traditionally, urban water services have been part of municipal operations. There have been conflicting objectives and targets for water service managers, for example, between revenue collection targets and social service requirements [21]. There can be political interference in water operations, for example, in requiring an increase in staffing to reduce unemployment. In some cities, water operations' accounts were part of general city accounts, adding to a lack of transparency. Local politicians should have responsibility for policies that reflect the needs of the communities they serve. Water service managers should have clear mandates for the implementation of those policies and be held to account for their performance [10,52]. Importantly, both requirements and delivery performance can and should be publicly available information. In Chile, subsidies for low-income groups are handled by local authorities; this avoids conflicts of objectives with water companies able to concentrate on efficient service delivery [21]. The institutional risk is that local politicians remain reluctant to give up the control over operational management to allow essential separation reforms to take place. There is the associated risk of small cities being unwilling to enter into area cooperatives to achieve the economy of scale for management and maintenance. Weak water governance has also been uncovered in water service delivery in rural and urban South Asia, revealing a portfolio of petty practices, from cash incentives for falsifying water meter readings, to collusion in tendering infrastructure contracts or favour-bartering for 'plum' transfers within water service boards [54].

Risks can be mitigated through stronger accountability networks or by increasing the moral cost of corruption or independent scrutiny. This can be in the form of water service regulators or, as in The Netherlands, appointing outsiders with no conflict of interest on supervisory boards. An independent economic water regulator provides for decisions on investment, tariffs and cost recovery to achieve defined policy remits to be determined objectively. This brings realism to what can be achieved and avoids unrealistic expectations. Where politicians have been willing to introduce independent regulation, they have become insulated, partially at least, from unpopular increases of tariffs. Independent regulators are best able to introduce benchmarking schemes. In Portugal, the regulator ERSAR has used performance measures as a means of raising the

performance of both private and public operators [55]. Formal water regulation is one method of increasing public scrutiny and confidence. Others include crowd-sourcing approaches where regulatory structures are weak or absent; one example is 'citizen report cards' where water users self-organize to collate local information and exert pressure from below [37].

One of the key roles of independent regulators is to provide information for the public and to facilitate their participation. Water service operators need the support of the public both in willingness to pay for the service provided, and to assist in operations through reporting water distribution leaks and illegal connections. The risk is that a token approach is taken to participation or that the public is involved only when the service provider wants to do something that may be unpopular, such as build a new reservoir. Experience has shown that active continuous processes of participation are beneficial [21].

3. Risk transformations to universal drinking water security

The selection of case studies is purposively selected, drawing upon the direct knowledge of the authors and the material presented by participants at the University of Oxford's Water Security, Risk and Society Conference, in both the rural and urban water security sessions, in April 2012. We make no claim for the representativity of the examples, but draw upon established case study methodology and comparative analysis to illustrate and systematically explore our conceptual framework [26,56,57]. Limitations to this approach centre on the purposive sampling strategy, which limits wider representativity, and the lack of a coherent sampling strategy to illustrate wider replicability [24,25]. However, given the general unsatisfactory performance of water supply security in South Asia and sub-Saharan Africa [10,11], we trade off methodological flaws against empirical gaps in knowledge. New or under-reported case studies provide new empirical evidence of processes and practices to accelerate universal drinking water supply security.

We now introduce and analyse a range of case studies from developing regions using the risk and response framework to understand how transformations have been achieved across settlement types and differing levels of water supply access.

(a) Transformational changes in urban water services

A major concern and risk to progress is one of complacency or despair in the belief that universal sustainable water services are unobtainable. There are examples that show that, with the key elements of good governance and management in place, service delivery can be transformed, even in developing countries. Case studies of urban water supply systems are now presented, followed by a synthesis on what lessons can be drawn in achieving the required transformation at scale.

(i) Phnom Penh: achieving water security against the odds

Following the fall of the Khmer Rouge in 1993, urban water service performance in Phnom Penh (Cambodia) was at a low ebb; yet in just over a decade, service delivery was acclaimed as the best in class in South Asia. This illustrates a remarkable story of transformation that was built around systematically addressing risks to service delivery [10,58] (table 1). Management was restructured under the highly effective leadership of Ek Sonn Chan, and staff salaries were raised, with bonuses for exceptional performance, but with penalties for 'unacceptable' behaviour. Any member of staff involved in corruption was sacked, reflecting a higher moral cost [54]. The public was consulted throughout, understood the need for charges to cover costs and was encouraged to report leakage and illegal connections. Benefits were widely shared, with 32 out of 38 poor settlements gaining piped water access for the first time; the remaining six settlements were connected to municipal standpipes [10]. There was a specific programme 'Clean Water for the Poor' in which system extensions to poor areas could be funded from revenue, and there were subsidies for connection charges, with the level depending on the level of poverty. The required

Table 1. Phnom Penh urban water performance indicators, 1993–2006.

performance indicator	1993	2006
coverage area (%)	25	90
number of connections ('000s)	27	147
supply duration (hours/day)	10	24
revenue collection (%)	48	99.9
non-revenue water (%)	72	8
staff per 100 000 connections	22	4
financial situation	subsidy	full cost recovery

Table 2. Urban water performance indicators in Uganda, 1998–2011. Exchange rate: USD 1 = 2575 Uganda shillings.

performance indicator	1998	2011
service coverage (% of population served)	48	75
total piped connections	50 826	272 406
new connections per year	3317	25 000
household metered connections	37 217	271 734
staff per 1000 connections	36	6
collection efficiency (%) ^a	60	98
non-revenue water (%)	60	33
metered accounts (%)	65	99
annual turnover (USD million)	8	51
profit ^b (USD million)	–3 (loss)	12 (surplus)

^aBilling revenue collected/bills issued.^bBefore depreciation.

'additional' water had become available from a reduction in leakage. Water bills could and can be paid in instalments, and a progressive tariff with a lifeline tariff for the first band of 7 m³ per month per connection was introduced. It is difficult to imagine a more challenging environment to introduce changes and the political threats to reform that were faced and systematically overcome in a coherent and ambitious programme of transformation. All three water risks were reduced in a coherent approach.

(ii) Uganda: reducing operational risks to drive performance

Uganda's National Water and Sewerage Corporation (NWSC) was transformed from a regional laggard to leader in the space of 13 years through institutional transformations that increased performance [52]. This case study illustrates that, although infrastructure problems have to be addressed, the key requirement is sound institutional governance and good management. The problems faced in NWSC were identified as poor customer service, poor organizational culture, large debts, low cost recovery, high non-revenue water use and corruption among staff. The first step taken was the appointment of a new Management Board with freedom to operate without political interference. The new Managing Director embarked on a series of management reforms to motivate and train staff. One key component was to delegate responsibility to area managers, to give them performance contracts and to stimulate performance competition between areas. The success of the reforms is illustrated by the performance measure improvements (table 2).

It was felt that it was not feasible, because of the financial impact on consumers, to move to full cost recovery quickly, but service charges were increased annually to keep pace with inflation, currency changes and key input price changes. Good use was made of new information technology with the introduction of electronic procurement and mobile water payment options [41]. Mobile water payment options through banks and telephone service providers were introduced, with utility pay points closed, saving over USD 420 000 per year in associated costs [50]. This facilitated improved collection efficiency, made it more convenient and less costly for consumers to pay their bills, and increased revenue.

(iii) 24/7 water supplies in India: demonstration effects to reduce policy risk

A senior Indian government official is reported to have understood 24/7 water services as '7h of water every 24 days' (A. Jalakam 2012, personal communication). This illustrates both the scepticism and despair of achieving continuous piped water services in relation to the current poor level of service delivery in India, and across South Asia [10]. In many parts of the world, it had become standard practice to ration water by rotating supply to zones through systematic valving off parts of the distribution systems. This was done in the belief that there were insufficient water resources to provide supplies 24 h per day. Some observers [21] who had seen intermittent operations first hand were sceptical about the effectiveness of such rationing, were concerned about its likely detrimental impact on distribution systems and promoted the importance of continuous supplies. In Phnom Penh, reducing leakage saved water resources, which allowed system extensions to poor areas. Recent developments in India counter the myth that rationing by hours per day is necessary to share out limited water resources. In practice, such rationing results in greater water losses.

Three 24/7 pilot projects were completed in 2010 in the State of Karnataka, India, which demonstrated the importance of 24/7 in managing water resources and in providing continuous sustainable water services for all [59]. Jalakam [60] discussed the results of the continuous supply demonstration projects in Karnataka to conclude: 'the results have clearly demonstrated that providing continuous water supply does not require more water resources but necessitates an efficient distribution network and a prudent management practice of water loss control'. One hundred per cent coverage was achieved in the 24/7 project areas, and it was found that the poor, many of whom were previously not served by the network, were willing and able to pay for a continuous service. As a result of the success of the 24/7 projects in Karnataka, 24/7 is now the Indian national service-level benchmark and the basis for estimating investment needs. After Delhi's earlier and bitter opposition to 24/7, its civil society groups are now welcoming the proposed implementation [61].

(iv) Metering Mumbai: measuring water consumption to reduce financial risks

Mumbai is one of the world's largest cities, with a population of around 12.5 million served by India's oldest and wealthiest municipality, the Municipal Corporation of Greater Mumbai (MCGM), which was established in 1882. The MCGM faces the challenge of rapid urbanization and uneven development manifested acutely in the ability to provide clean and continuous water in its piped network of 4000 km [62]. On a daily basis, there is an 850 million litre deficit between consumer water demand and supply, which is exacerbated in dry periods. Water access is socially skewed, with over half of the population residing in areas classified as slums where only 5% of households have individual piped connections and the majority share public standpipes. The piped distribution system is in poor condition, with 28 000 leakage incidents a year. The water resource impact (and cost) is unknown, as leakage cannot be measured owing to a lack of district meters. Households, rather than the MCGM, own 90% of household meters, which contributes to limited incentives to repair the 80% that are faulty or not functioning. Piped water is rationed, with 2–4 h of supply per day leading consumers to invest in other water sources and household water storage. In the absence of accurate piped water consumption data, the MCGM has an estimated USD 1.5 billion deficit in late or unpaid water bills [62].

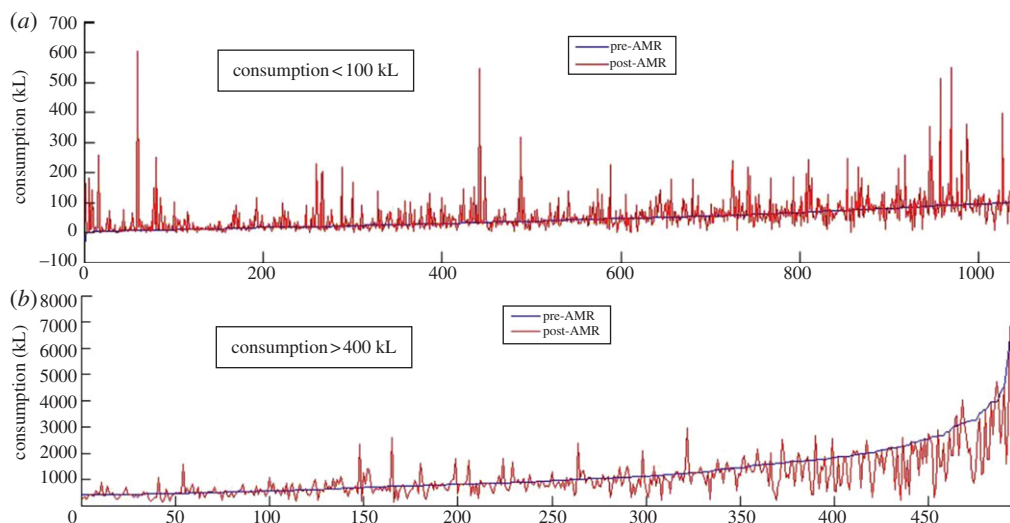


Figure 3. Predicted and measured piped water consumption patterns by (a) low and (b) high groups using AMR technology in Mumbai [62]. (Online version in colour.)

In response to the increasing financial risk of water resource losses and revenue collection, MCGM embarked on a pilot programme in 2010 to replace 129 000 analogue (mechanical) meters with automated meter readers (AMRs). AMRs transmit consumption data via radio frequency or GSM (Global System for Mobile Communications) signal automatically, to be read remotely. Gomes [62] evaluated the change in piped water consumption in two Wards to explore impacts for billing accuracy and revenue collection. In a sample of 4938 consumers evaluated, 45% were classified in a low-consumption band of less than 100 m³ per month and 21% in a high-consumption band of over 400 m³ per month. Results of changes in water consumption patterns show a statistically significant difference in low-consumption users being under-billed and high-consumption users being over-billed (figure 3). AMR technology demonstrates important advantages in improving billing accuracy to address financial risks and improve operational management. However, the research finds that, without wider institutional and governance reform, the potential benefits of smart metering will be limited [62].

(v) Kiamumbi, Kenya: mobile water payments and financial risk

Unpaid water bills cost the urban water sector in Africa around USD 500 million a year—equivalent to 0.07% of the continent's GDP [11]. It is estimated that between 20 and 50% of urban households in Africa with a piped connection fail to pay their water bill [41]. A key reason for low cost recovery is low revenue collection. Payment of water bills to water service offices or through banks can be inconvenient and expensive [50]. Since 2009, at least 22 water service providers (WSPs) in seven African countries have offered the option of paying water bills by mobile money to 19 million customers. Analysis of mobile water payment adoption in four African countries serving over 12 million urban piped water consumers reveals low adoption rates. Only one WSP has achieved over 10% uptake from its consumer base [41]. Key barriers to adoption include delayed reconciliation of billing systems, limited customer awareness, lack of physical proof of payment and convenience of alternative pay points.

All these barriers can be potentially overcome, as exemplified by one small and privately run scheme in Kiamumbi, Kenya, where 85% of customers have adopted a mobile bill payment option [41]. In Kiamumbi, time and cost savings were revealed as principal motivations for mobile water payment adoption, with women benefiting most from time savings. The time saving per transaction was around 1 h, with a cost saving of around USD 0.2 per month. Monthly water

bills were paid around a day earlier for those customers who used mobile money payments most frequently. Furthermore, the likelihood of timely bill payment was statistically higher compared with water users choosing another payment mode, such as the bank. The cost to the WSP was 0.6% of the revenue collected through mobile payments, a small amount in relation to improved cash flow. Mobile water payment systems present a promising approach that can generate benefits for water users, WSPs and mobile network operators. Mobile payments can assist WSPs in reducing the paired risks of financial and operational sustainability. The magnitude of the benefits from mobile water payments will depend on policy action that translates this revenue collection tool into improved water service delivery and access [41].

(b) Transformational changes in rural water services

Over four in five people without improved water services live in rural areas. 'Rural' is an elusive geographical term, which here spans drinking water access via small-piped systems with permanent and high settlement density to remote waterpoints that seasonally serve scattered populations. We attempt to consider the settlement spectrum by evaluating from our purposive sample of water supply initiatives across sub-Saharan Africa and Southern Asia.

(i) Improving the risk calculus for handpump repairs in rural India

If Uttar Pradesh were a country, it would have the second highest number of poor residents in the world at 130 million people, second only to China and higher than Bangladesh, Nigeria, Pakistan and Ethiopia [63]. National drinking water access statistics suggest that four out of five rural people enjoy 'other improved sources', such as handpumps.³ A recent study by WaterAid in Mahoba District, Uttar Pradesh, found that over 7000 community handpumps and 4000 private handpumps were not functional (K. J. Rajeev 2012, personal communication).

The Government of India is responding to these issues through the National Rural Drinking Water Programme (NRDWP) based on adopting a 'drinking water security' strategy to operate at lower institutional levels. WaterAid India have designed and implemented a new handpump maintenance model that builds on the national programme by using existing Government of India funds to pay for operation and maintenance costs. The model establishes handpump service centres at block level to support rural villages at scale. The handpump workshops, known as Public Panchayat Participatory (PPP) centres, are run by trained local mechanics in two districts of Uttar Pradesh and Bihar states under this scheme. We examine performance data from one workshop in Mahoba district that has been operational since January 2011. The workshop acts as a coordination unit to serve four villages with 47 qualified mechanics, of whom over half are women. The PPP centres monitor and coordinate the movement of the mechanics in order to facilitate timely repairs of handpump failures reported from villages.

Between January 2011 and March 2012, the centres have overseen the repair of 3759 handpumps that serve more than 200 000 rural water users. Across all repairs, 71% were completed within 24 h, and 94% of repairs took less than 2 days. An important aspect of this programme is the association⁴ between villages triggering handpump alerts by mobile phone calls and repairing the handpump within a day (figure 4). A mobile alert of handpump failure saves both time and money for village water users as well as starting the repair clock promptly.

Financial risk, which previously constrained villages from collecting sufficient funds promptly for handpump repairs, is now offset by a central government fund to all Panchayats for operation and maintenance costs of water services. Furthermore, the cost of establishing the four operational centres in Mahoba of roughly USD 40 000 was paid for by WaterAid. WaterAid's key role was to make the government funds work at scale through establishing annual maintenance contracts (AMCs) between Panchayats and the PPP centres. Fourteen Panchayats have signed AMCs to

³For WHO/UNICEF's India profile in 2010, see http://www.wssinfo.org/fileadmin/user_upload/resources/IND_wat.pdf.

⁴A significant proportion of mobile handpump failure notifications are positively associated with the proportion of handpumps repaired within a day ($R^2 = 0.62$; d.f. = 55; $p < 0.001$).

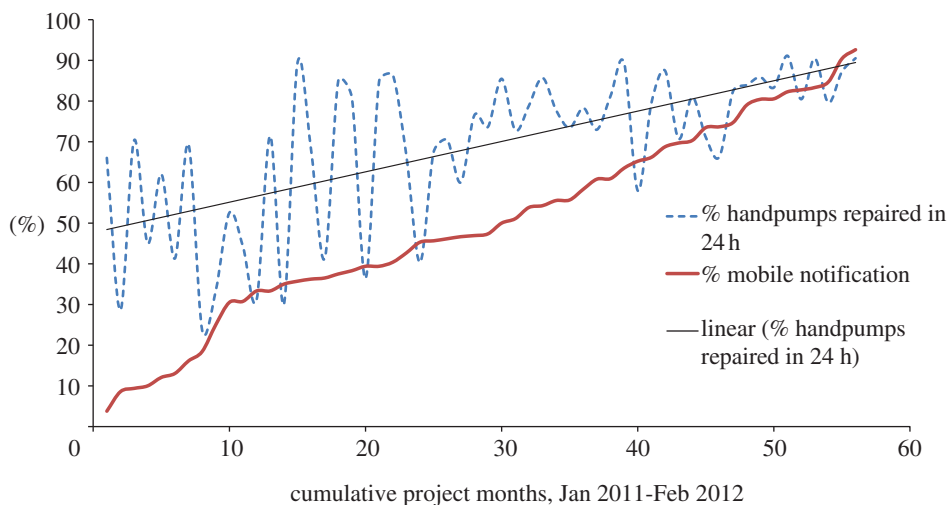


Figure 4. Converging trends: share of mobile alerts of handpump failure and share of handpump repairs within 1 day in Mahoba district, Uttar Pradesh. (Online version in colour.)

date, with growing interest as the service delivery model proves its effectiveness at scale. All repairs are guaranteed by centres. Mechanics are paid by performance contracts, with the labour cost of the variable operational cost around 70%.

Analysing monthly performance data from four villages (Charkhari, Jaitpur, Panwadi, Kabrai⁵) served by the Mahoba workshop, we identify factors that are significant in determining whether handpumps are repaired within a day. Data on individual village pumps (community, private), maintenance alert (mobile, personal visit), type of repair (major, minor) and cost of repair (rupees) were provided for each of the first 14 months of the project. We modelled the share of repairs completed within 1 day against a range of independent variables, such as project learning (dummy variable for first six months of operation), environmental factors (monsoon period, June–September), expenditure by number of handpumps repaired per month and number of handpumps repaired each month.

The results indicate significant variation across villages, though physically all are similarly located within an hour of Mahoba town (table 3). Across operational factors, a positive project learning trend is identified by the first six months of the project recording a negative and significant relationship to being repaired within a day. We find that workshop mechanics respond favourably to higher volumes of work and repair major faults more quickly than minor faults; however, there was insufficient data to see if and where thresholds may constrain such positive performance. Community handpumps appeared less likely to be repaired as promptly as private handpumps, though the relationship was not significant. Of other factors tested but not reported in the final model, we find no significant relationship between fixing handpumps in 1 day and reporting the failure by mobile phone, failure during the monsoon months or expenditure metrics per handpump. While reporting handpump faults by mobile phone is positively associated with improved repair times, it was not a significant relationship; this underlines the wider importance of other operational and geographical factors. The unfolding Mahoba experiment is impressive. It reveals the important sequencing and linkages between reducing financial and operational risks shaped by alternative institutional structures at scale. Equally, it underlines the pivotal role of external and motivated organizations to introduce catalytic change through targeted investments. This process is neither simple nor inevitable, with mixed political incentives for Panchayats to release scarce funds that they can spend independently and without transparent

⁵All villages are within 1 h of Mahoba town where the workshop is located.

Table 3. Ordinary least-squares (OLS) regression model of share of handpump repairs fixed within 1 day at Mahoba workshop, Uttar Pradesh. Dependent variable (share of handpumps repaired in 1 day) is normally distributed: Kolmogorov–Smirnov $Z = 1.28$; d.f. = 55; $p > 0.05$; statistical significance in probability tests indicated by asterisks. Monthly data recorded by WaterAid India from January 2011 to February 2012. Model summary: adjusted $R^2 = 0.63$; ANOVA ($F = 14.08$; d.f. = 7; $p < 0.001$).

independent variables		coefficient (s.e.)
village location	Charkhari	−0.19* (0.06)
	Jaitpur	0.23* (0.28)
	Kabrai	−0.14* (0.05)
operational performance	first six months of project (Jan–June 2011)	−0.09*** (0.05)
	share of major repairs (versus minor)	0.34** (0.16)
	no. handpump repairs per average day per month	0.08* (0.04)
	share of community handpumps	−0.28 (0.21)
	constant	0.58* (0.20)

*1% level, **5% level and ***10% level.

oversight (K. J. Rajeev 2012, personal communication). Without wider political support to build on the significant initial success of the Mahoba experiment, the future scaling of the approach remains uncertain.

(ii) Rural piped water scheme reforms in West Africa

In response to the disappointing performance of community-managed water supplies in West Africa, since the mid-1990s there has been significant policy reform and the introduction of new approaches to reduce rural water risks to small-piped water schemes [64]. In rural West Africa, roughly 40% of water supplies serving some 13 million people are provided by piped schemes, with an increasing role of non-state actors in the design, operation and management of the schemes. Across Central and West Africa, around one in four piped schemes are now managed under differing contractual arrangements; in Senegal, the majority of piped water schemes are managed privately. Rural piped water schemes share similar risk dimensions to the urban piped water sector as previously discussed, which are compounded by issues of a viable scale for services mediated by variable water demand profiles and low income generation. Information flows again prove central to reducing regulatory risk in system design and operational performance. Countries such as Senegal have led the way in developing and scaling up mobile to Internet platforms through privately managed systems, such as Manobi's mWater, which are now promoting more sustainable water services in Senegal, Mali, Benin and Niger.

An enduring risk for rural water supply has been the lack of effective approaches towards asset management, performance monitoring and regulatory oversight, which community water managers have struggled to address effectively at scale: 'Village management committees were not legally recognized, lacked the necessary skills, and did not apply formal management practices, the schemes often failed or were simply abandoned' [64, p. 7]. The West Africa experience is not simply one of private ownership, as many successful schemes are run by community water associations, such as the ASUFORs (Associations d'Usagers de Forages Ruraux) in Senegal. These community models attempt to understand and allocate risks and responsibilities of water service delivery in a more accountable, effective and sustainable structure. Different combinations of public, private or public–private partnerships have successfully emerged, with performance determined by addressing the key elements of service delivery.

Table 4. Emergence and rise of private sector in rural piped water schemes in West Africa. Data adapted from [64].

country	launch of private piped schemes	private piped schemes since 2009	asset holder	regulator	WSP	performance monitoring	% access to improved rural water ^a	
							1990	2010
Benin	2006	130	local government	ministry	private	pending	49	68
Burkina Faso	2009	125	local government	ministry	private	pending	38	73
Mali	2006	20	local government	ministry/ regulator	private	active	20	51
Mauritania	1994	350	central government	regulator	mixed	active	26	48
Niger	1990	298	local government	ministry	private	active	31	39
Senegal	2000	183	central government	ministry	community	active	43	56

^aWHO/UNICEF data at <http://www.wssinfo.org/data-estimates/table/>.

The emergence and growth of private sector operators have not been uniform across West Africa (table 4). Differing policy environments have led to differing regulatory structures, many of which do not separate policy formulation from regulatory oversight to promote institutional separation and improved accountability. Also of note is the variation in performance monitoring with two of the six countries yet to formally introduce a monitoring system. Senegal has the deepest regional experience with mobile to Internet monitoring systems. These are central to supporting community-based operators (ASUFORs) in partnership with the Water Ministry's Director of Operations and Maintenance. The system called mWater is a structured crowd-sourcing platform, with water scheme managers inputting weekly data via a mobile phone application on metered bulk water consumption, financial data and days when the scheme is not functioning (down-time). Additionally, there is an alert function to report any malfunction by SMS/text message to the local water services department. Data are monitored, archived and shared with all appropriate government authorities, including the water regulator, across four indicators: level of production, financial reserves, malfunction rate and savings/water production over the past 12 months.

The evidence from West Africa is still emerging and uneven. Yet, the policy reform process to promote universal drinking water security indicates that there should be a sequenced and coherent programme of institutional and infrastructure investments. These investments are underpinned by information systems to monitor operational and financial risk to sustain services and protect water users in remote areas. Where information flows are improved, drinking water security risks appear to be reduced.

(iii) Mobile water platforms for dispersed rural populations in East Africa

One of the central limitations of piped water systems in rural Africa is sufficient population density with effective demand to secure financial sustainability. This partly explains the marginal increase in sub-Saharan Africa of piped water on rural premises from 4% in 1990 to 5% in 2010 [14]. Community handpumps, which lift widely available and generally good-quality water from groundwater sources, remain the technology of choice despite significant institutional, operational and financial risks [22,48,65,66]. Maintaining the operational performance of rural handpumps that are used by different people for different purposes at different times has been an

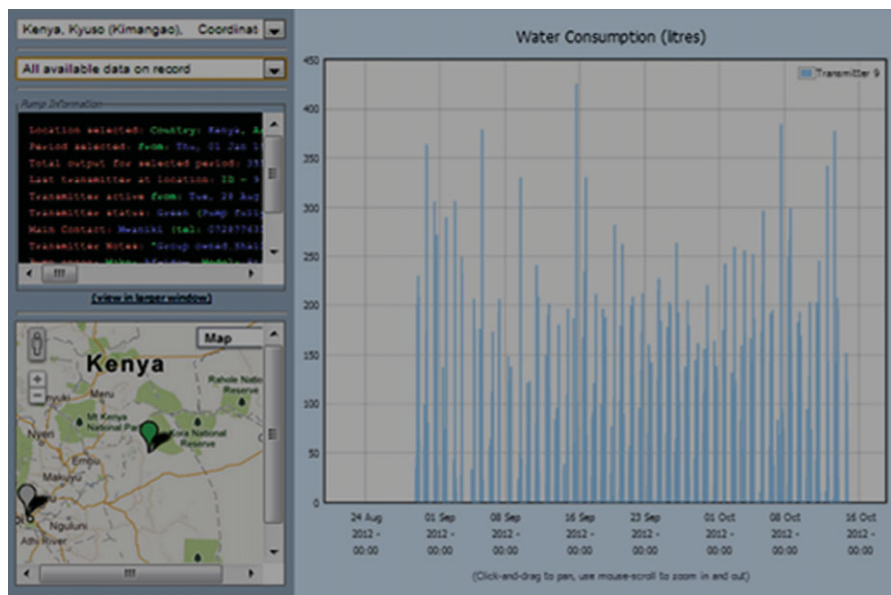


Figure 5. User interface of hourly handpump water consumption data from Kyuso, Kenya (source: <http://oxwater.co.uk>). (Online version in colour.)

enduring problem [48]. The idealized notion of a community and its corporate ability to manage a deceptively complex common pool resource has increasingly been illustrated to be misleading [22,29,65]. The widely cited but unverifiable estimate of one in three handpumps non-functioning in rural Africa at any one time neatly captures the systemic informational deficit in the sector. Donors, governments and private sector alike have limited knowledge of where their funded handpumps physically are located or how they are performing [48,67]; however, significant and widespread investments in mapping rural waterpoints is providing important but snapshot data on performance [68].

Transferring institutional, operational and financial responsibility to rural communities is a widely promoted community management model [33,35]. This is a partial solution borne of expediency due to limited government and donor accountability amplified by a systemic informational deficit [65,69]. Mobile technologies applied to rural water supply systems are now able to reduce the deficit and lower the associated risks. For example, Grundfos has piloted their LIFELINK system, which uses solar panels to pump groundwater to a raised storage tank which is then automatically vended via a pre-paid system triggered by individual user 'fob' cards. The system addresses all three drinking water risks. First, the system is installed in communities where there is demand and therefore mitigates institutional risk. Second, Grundfos guarantees the system for a decade with its own team of technicians who are automatically alerted when the system fails; this lowers operational risk. Third, the pre-paid fob cards are loaded by using the increasingly common mobile money platforms across Africa [41]. This provides a closed-loop payment mechanism that reduces financial risk. Volumetric water consumption is posted on an open-access website for all systems, demonstrating a level of transparency unequalled in the rural water sector (see <http://www.grundfoslifelink.com/index.html>).

Where LIFELINK faces sustainability challenges is in scale and cost. The business model functions well where there is demand of around 1000 people or more consuming 25 litres per day, and therefore favours more densely populated areas rather than dispersed rural environments. The system is relatively expensive at a capital cost of around USD 35 000 for full installation. However, this figure cannot be directly compared with the installation of a manual handpump (ca USD 6000–9000), as the former guarantees service delivery for 10 years or more whereas the latter commonly fail after 2 or 3 years and generally serves fewer than 500 people. Recent sector

thinking is moving towards service-level guarantees with a 'sustainability clause' being mooted to counter the poor returns from historic and existing investments. Despite the inevitable challenges of a new technology launch, LIFELINK directly tackles the fundamental risks in the sector in an integrated and effective fashion.

Smart handpumps offer an alternative approach for the long-serving rural handpump fitted with a GSM-enabled transmitter to send automated SMS/text messages on performance and to trigger maintenance alerts [67]. This low-cost technology can be retro-fitted to existing handpumps or pre-installed on new handpumps. The flow of information from a constellation of smart handpumps at the district, provincial or national scale would reduce institutional, operational and financial risks and costs [65]. Accountability would be enhanced, as government and donor investments can be openly tracked and performance transparently evaluated. Maintenance can operate at a supra-community level, where mechanics can be remotely monitored in terms of timeliness and quality of their work. At the national level, handpump insurance models can be introduced to smooth the costs of repairs and promote a professionalized maintenance programme at scale. Data from a pilot study in Kenya illustrate the first global evidence of hourly data automatically generated from a handpump in rural Africa (figure 5).

4. Status of drinking water security by response patterns to risk domains

The nine case studies are decomposed by settlement type and response patterns to the three risk domains (table 5). Findings are evaluated by the status of drinking water security by two of the four identified outcome measures: (i) drinking water quality, and (ii) reliability and sustainability. Evidence of affordability and access was unevenly available, relegating any assessment to speculation. We discuss the implications by urban and rural sectors to identify key lessons and implications.

(a) Reducing risks for sustainable urban water supplies

Risks to sustainable water security can be managed to dispel any defeatist attitudes of complacency or despair, as illustrated by the transformational change achieved in Phnom Penh and Uganda. Managing institutional, financial and operational risks is able to provide sustainable affordable urban services available to everyone. It is possible for a WSP to manage the financial risks, and achieve financial independence, providing there is some upfront investment support to improve the service to a level at which customers are willing to pay. Thereafter, cost recovery from charges is necessary to ensure maintenance of systems. Willingness to pay was confirmed in the 24/7 developments in India, where increased service coverage permitted affordable tariffs for all. Managing the operational risks associated with intermittent supplies can achieve 100% service coverage requiring less water resources, which is an increasingly important consideration. There has to be recognition of the enormity of the tasks facing management, with realistic time scales (13 years in the case of Phnom Penh and NWSC Uganda) for achieving the required outcomes.

The case of Singapore has demonstrated the value of sustainable long-term policies [70]; but in most countries, water service development planning timetables exceed government tenure. Achieving equivalent continuity of political commitment and policies to that in Singapore, in countries that experience radical government changes, would require integrated government approaches over time with support from all political factions. This should be possible on, say, a commitment to 24/7 in India now that it has been demonstrated as an effective policy option in relation to reducing institutional, operational and financial risks. Achieving cross-party political commitment to water supply policy reduces political risks and provides a platform to manage financial risks. Tariffs can be increased, where appropriate, and, as in Phnom Penh, specific provisions can be made for low-income groups. Methods of payment are important as part of managing the financial risk associated with revenue collection. Low-cost transaction provisions, such as the mobile phone accounts used in NWSC Uganda and Kiamumbi, Kenya, aid affordability and importantly the time required to make a payment. Technology has an

Table 5. Status of drinking water security by case study response patterns to risk domains.

settlement type	case study (country)	response patterns to risk domains			status of drinking water security	
		institutional	operational	financial	quality	reliability
dense (rural)	WaterAid (India)	private operator, centralized maintenance	performance contract	CapEx: subsidy (donor); OpEx: subsidy (Govt)	not known	improved
dense (rural)	LIFELINK (Kenya)	private operator, centralized maintenance	guaranteed performance contract	CapEx: subsidy (donor); OpEx: full cost recovery	improved	improved
scattered (rural)	smart handpumps (Kenya)	private operator, centralized maintenance	performance contract	CapEx: subsidy (donor); OpEx: cost recovery	none	improved
dense (rural)	small-piped systems (West Africa)	public–private partnership	performance contract	CapEx: subsidy; OpEx: cost recovery	not known	improved
dense (urban)	24/7 (Karnataka, India)	public–private partnership	performance contract	CapEx: subsidy; OpEx: cost recovery	improved	improved
dense (urban)	Mumbai (India)	no change	smart meters	CapEx: subsidy; OpEx: subsidy	none	not known
dense (urban)	Phnom Penh (Cambodia)	corporatized municipality	performance contract	CapEx: self-funding; OpEx: full cost recovery	improved	improved
dense (urban)	NWSC (Uganda)	corporatized municipality	performance contract	CapEx: subsidy; OpEx: cost recovery	improved	improved
dense (urban)	Kiamumbi (Kenya)	private operator	performance contract	CapEx: subsidy; OpEx: full cost recovery	improved	improved

important role to play, particularly to strengthen information flow, as shown by the use of mobile technologies in Africa and 'smart' meters in Mumbai. However, technology has to be accompanied by governance developments to achieve conversion of data into improved management information to reduce all risks. All the case studies illustrate that communication with service recipients is a critical part of the necessary improved governance.

(b) Reducing risks for sustainable rural water supplies

An underlying aspect of all responses to institutional risk is the introduction of a centralized operation and maintenance system with performance contracts. This approach effectively reduces risk at the community level by sharing risk at scale [65]. To overcome the significant challenge of accountability and transparency, service contracts are agreed between water users and WSPs. Government and regulatory oversight varies by context from higher levels of engagement in public-private partnerships in West African examples to experimental arrangements in East Africa and India. A key element of the transformation of service delivery in all contexts is the novel use of mobile communications to transfer data. In the case of LIFELINK, user payments exploit the new information architecture that has emerged in rural areas in the last 5 years. Smart handpump provision of hourly consumption data and performance can test new operational models at scale. Financial risks remain problematic. Capital expenditure (CapEx) is partly or fully subsidized in all examples; operational expenditure (OpEx) presents a more promising picture, with important and hard-won advances. Guaranteeing an agreed level of service provision through prepayment is possible but at a higher upfront cost and with settlement densities that are rare for rural populations. The approach may be more well suited to the increasing growth of peri-urban areas, particularly informal settlements. All the examples demonstrate strong performance in improving water supply reliability, with unknown or variable outcomes for drinking water quality. In all cases, effective risk-reducing response patterns illustrate the key role of external agents either working with government (West Africa) or filling service gaps (East Africa, India). Institutional scale matters and improved information flows are critical to reducing transaction costs and increasing accountability [65,68].

(c) Implications and limitations

While these purposive case studies are not representative of the uneven global landscape, they indicate that transformations towards universal drinking water security are feasible and have been achieved. The political challenge is to build on these small but important steps to understand where and how such desirable gains can be accelerated at scale to avoid investment mistakes. Whether urban or rural, the case studies show that the institutional, financial and operational risks can be managed. No single model applies in all contexts, though risks appear less where accountability and transparency increase in terms of consumer engagement, performance contracts and policy cohesion. Timely and accurate flows of information can strengthen decision-making power, though information without policy support can be ignored, marginalized or discredited.

Despite an apparent and compelling political constituency for delivery of more water to more people at lower cost and reduced environmental impact, the story of 24/7 in India reveals how embedded political structures will resist change where this affects existing socio-cultural relationships. Water services are inherently political, with vested interests and networks of patronage that are difficult to observe and even more challenging to reform. The cases of Phnom Penh and NWSC in Uganda reflect outliers in global performance where key individuals overcame significant structural and political challenges to achieve success against the odds.

A consistent and critical thread to drinking water security in all cases was the establishment of effective and continuous maintenance of water supply systems, whether dealing with non-revenue water in urban systems or maintaining hand pumps in rural areas. Maintenance is critical to reducing water losses and lowering water quality risks, with implications for financial risks.

Without maintaining investments in current water supplies, accelerating access to the water-excluded will remain sluggish. This is underlined by important findings on how operational improvements can improve drinking water services to make better use of available funds, leading to a reduction in financial risk and improving the sustainability of water supply systems.

Information clearly matters, for example, in giving service recipients (the public) an understanding of both the financial and operational risks and how they might be managed. Public input was important on articulating their needs, as for example in the choice of paying bills through mobile accounts, and also important in providing intelligence to assist a service operator to reduce non-revenue water. Similarly, crowd-sourcing approaches in rural West Africa or smart meters in Mumbai generated good-quality and reliable data-supported initiatives to manage financial and operational risks more effectively. Open data are increasingly available and accessible. A new informational architecture is increasingly imposing and revealing performance metrics that previously were costly to collate or could be easily disguised or ignored.

5. Conclusion

Universal drinking water security is achievable. The evidence evaluated in rural and urban sectors in South Asia and sub-Saharan Africa demonstrates that drinking water risks can be managed and reduced even in the most difficult and challenging contexts. There are often vested interests benefiting from the status quo, creating political barriers to progress. Overcoming these barriers requires internal or external interventions to invest in institutional and infrastructure change beyond narrow political or project time horizons. The time scale from reform to transformation can take a decade or more. Our findings indicate that improved information flows reduce institutional costs and promote stronger and more transparent operational performance, resulting in increased political support and financial sustainability. Responses to institutional, operational and financial risks have to be addressed systematically and continuously to deliver sustained benefits.

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