

DELIVERED BUT NOT BILLED: WATER LOSS, INTERMITTENCY AND THE SEQUENCING OF UTILITY REFORM

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ABSTRACT

Municipal water utilities in middle-income countries commonly lose between a quarter and two-thirds of what they produce before it reaches a billed meter. Reform programmes usually treat this as an engineering problem, to be addressed after treatment capacity and source development. This study argues the ordering is inverted: loss and supply continuity are prior conditions on which every downstream investment depends. The method is a structured conceptual review of research published between 2017 and 2024 across water loss and pressure management, utility efficiency benchmarking, intermittent supply, asset management, and access measurement. Measured losses range from twenty-six to sixty-three per cent, with one metered district at fifty per cent of which about eighty-seven per cent was real loss. Pressure management, the least capital-intensive intervention available, reduced leakage by roughly a third in two independent case studies. Supply continuity, not source type, carries the measured health effect: one pragmatic trial reports an incidence rate ratio of 0.75 against confirmed cholera. One national assessment recorded mean technical efficiency of forty-nine per cent, and one analysis found only seven per cent of households with safely managed water free of contamination at point of use. Reform should begin with metering, pressure and continuity.

ABSTRAK

Perusahaan air minum daerah di negara berpenghasilan menengah lazim kehilangan seperempat hingga dua pertiga air yang diproduksi sebelum mencapai meteran yang tertagih. Program reformasi biasanya memperlakukan hal ini sebagai persoalan keteknikan yang ditangani setelah kapasitas pengolahan dan pengembangan sumber diamankan. Kajian ini berargumen bahwa urutannya terbalik, dan bahwa kehilangan air serta kesinambungan pasokan merupakan syarat yang mendahului, yang menentukan nilai setiap investasi sesudahnya. Metodenya adalah telaah konseptual terstruktur atas riset terbitan 2017 hingga 2024 pada lima ranah: kehilangan air dan pengendalian tekanan, tolok banding efisiensi perusahaan, pasokan terputus-putus, pengelolaan aset, dan pengukuran akses. Lima temuan mengikutinya. Kehilangan terukur pada sistem yang dilaporkan berkisar dua puluh enam hingga enam puluh tiga persen, dengan satu distrik bermeter pada lima puluh persen yang sekitar delapan puluh tujuh persennya merupakan kehilangan nyata. Pengendalian tekanan, tindakan dengan intensitas modal paling rendah yang tersedia, menurunkan kebocoran sekitar sepertiga pada dua studi kasus yang saling bebas. Kesinambungan pasokan, bukan jenis sumber, yang membawa pengaruh kesehatan terukur, dengan satu uji pragmatis melaporkan rasio laju kejadian 0,75 bagi kesinambungan terhadap kolera terkonfirmasi dan

	memperkirakan bahwa tambahan 1,2 jam produksi harian akan menurunkan kasus terkonfirmasi sekitar seperempat. Studi efisiensi menemukan kehilangan air mendominasi kinerja perusahaan, dengan satu penilaian nasional mencatat rerata efisiensi teknis empat puluh sembilan persen. Adapun statistik akses yang dipakai menilai kemajuan lebih-lebihkannya: satu analisis lintas negara menemukan hanya tujuh persen rumah tangga memiliki air yang dikelola secara aman dan bebas cemaran pada titik penggunaan. Urutan reformasi sebaiknya dimulai dari pemeteran, tekanan, dan kesinambungan. Kata kunci: air tak berekening; pasokan terputus-putus; efisiensi perusahaan air; pengendalian tekanan; tata kelola air
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1. INTRODUCTION

A water utility that loses half of what it produces is not half as efficient as one that loses nothing. It is running a treatment plant, a pumping system and an energy bill at full scale to deliver benefit at half scale, and it is doing so while its revenue base, its ability to borrow and its capacity to maintain the network all contract in proportion. Every downstream investment in that system is discounted by the same factor.

The magnitudes are not marginal. Shushu et al. (2021) report non-revenue water of fifty per cent in a metered district of a fast-growing city, against thirty-seven per cent for the network as a whole, with about eighty-seven per cent of the district's losses being real physical loss rather than commercial loss. Macharia et al. (2021), assessing five service providers against nine indicators, report non-revenue water of twenty-six to sixty-three per cent, up to three times the regulated benchmark, with four of the five serving below the fifty litres per person per day minimum.

Reform programmes rarely start there. The customary sequence begins with source development and treatment capacity, proceeds to network extension, and reaches loss reduction late, if at all. The logic is intuitive — more water for more people — and it is the logic that produces the systems described above, in which additional production enters a network that cannot deliver most of it to a paying customer.

This study argues that the sequence should be inverted, and it does so on the basis of what has been measured rather than on the basis of what is intuitive. Three classes of evidence support the inversion. Pressure management, the cheapest available intervention, produces loss reductions of roughly a third in independent case studies. Supply continuity, rather than source type or treatment, carries the measured health effect in the one pragmatic trial that separates them. And the access statistics used to judge progress systematically overstate

it, because they classify households by primary source rather than by what reaches the point of use.

A fourth consideration connects the utility to the aquifer beneath it. Where piped supply is unreliable, households and firms substitute toward groundwater, and the resulting abstraction produces consequences — head decline, subsidence, saline intrusion — that no water utility's accounts record. Rusli et al. (2024), projecting a basin under three abstraction scenarios, find confined piezometric heads dropping by maxima of 7.14 metres by 2030, 15.25 by 2050 and 29.51 by 2100 at current abstraction, roughly doubling if abstraction grows with population, and conclude that projected groundwater status is dominated by anthropogenic activity rather than climatic forcing. Non-revenue water is therefore not only a utility accounting problem. It is a groundwater governance problem transmitted through household coping behaviour.

Four questions organise the analysis. First, what is the measured scale and composition of loss, and what interventions have measurably reduced it? Second, what does the efficiency literature establish about where utility performance is actually determined? Third, what are the consequences of intermittency, and what does continuity buy? Fourth, what does the access-measurement literature imply about the baseline against which any of this is assessed?

2. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

The scale and composition of loss

Shushu et al. (2021) provide the most complete diagnostic in the corpus. Beyond the headline loss figures, the study finds fifty-two per cent of nodal junctions carrying pressure above recommended thresholds and flow velocities inadequate in about eighty-three per cent of pipes because the mains were oversized, causing stagnation and consequent quality problems. Pressure-reducing valves combined with a change in network topology cut potential leakage to forty-six per cent. Two findings are embedded there: the loss is predominantly physical, and the network's own design is generating both the leakage and a water-quality risk at the same time.

Macharia et al. (2021) extend the analysis to the energy dimension that loss reduction also addresses, calculating a leakage-reduction potential of up to seventy per cent and energy savings of up to twelve megawatt hours annually across the providers assessed, and noting

that demand must rise at least twelvefold by 2030 for universal coverage at a higher service standard. The second figure is the reason the first matters: a system that must multiply delivered volume by an order of magnitude cannot afford to lose a majority of what it produces.

Samir et al. (2017) and García-Ávila et al. (2019) supply the intervention evidence. The first, modelling leakage as a function of pressure and pipe length and optimising fixed pressure-reducing valves in a district metered area, cut leakage by thirty-seven per cent. The second, building a calibrated hydraulic model with a leakage extension for an Andean city network, found excessive pressures in the lower zone and reduced leakage by roughly thirty-one per cent through the installation of two pressure-reducing valves, bringing pressure into the acceptable band at about thirty-one per cent of nodes and raising a network performance indicator from about eighty to about ninety-seven per cent. Two valves.

Elkharbotly et al. (2022) address the forecasting side, building feed-forward neural network models alongside multiple linear regression to predict non-revenue water ratios from district metered area data, with the neural approach outperforming regression on error and correlation measures. Laucelli et al. (2023) describe the fuller apparatus, applying a digital water services strategy combining spatial data upgrading, advanced hydraulic modelling, complex-network topological analysis and machine learning to two operating networks in support of asset management and leakage reduction. Both are informative about method and neither reports a loss reduction figure, which is itself a comment on the state of evaluation in this field.

Where utility performance is determined

The efficiency literature answers a question the engineering literature does not: how much of the variation in utility performance is attributable to losses rather than to scale, ownership or tariff.

Ngobeni and Breitenbach (2021) apply data envelopment analysis to all nine bulk water entities in one national system, modelling water losses explicitly as an undesirable output, and find average technical efficiency of forty-nine per cent with only three of the nine efficient. Six smaller entities showed a fifty-one per cent inefficiency rate. The comparison the study draws is the most instructive single datum: one entity scored sixteen per cent efficiency, spent eighteen per cent of the largest entity's total expenditure while selling only

6.7 per cent of its volume, carried seven times the proportional water losses, and charged 1.6 times its tariff. Losses, volume and tariff move together.

Sala-Garrido et al. (2022) apply non-radial data envelopment analysis to twenty-one utilities over 2007 to 2018 with leakage and unplanned interruptions as undesirable outputs, finding a mean quality-adjusted efficiency score of 0.964, implying scope to cut costs and undesirable outputs by 3.6 per cent on average, and finding customer density, mixed water resources and ownership type all significantly influencing performance — with public utilities outperforming private ones on quality-adjusted measures.

Maziotis et al. (2023) extend the same national dataset to a dynamic frame using stochastic non-smooth envelopment of data across 2010 to 2018, and produce the finding that should trouble reform designers. Annual average productivity change was positive at 0.18 per cent while eco-productivity change was negative at -0.14 per cent, indicating that firms prioritised cost cutting over service quality. Disaggregated by ownership, fully private firms recorded $+0.053$ per cent, concessionary -0.017 and public -0.278 per cent eco-productivity, with reducing non-revenue water and unplanned interruptions especially costly for concessionaires. Loss reduction is expensive, and a regulatory regime that measures cost efficiency without measuring loss will discourage it.

Molinos-Senante and Maziotis (2021), fitting a quadratic cost function to the same industry across 2010 to 2017, find cost savings from increases in scale and from separating water and sewerage services, with productivity growing at 8.4 per cent annually attributed to scale effects, technology adoption and resource allocation. Bandari and Sadhukhan (2021), regressing per capita supply on service-level benchmark indicators across thirty large cities with low surface water availability, find coverage of connections, extent of metering, extent of non-revenue water and continuity of supply all having considerable effects. Metering and loss appear as determinants of the quantity delivered, not merely of the revenue collected.

Intermittency: what rationing does to the network

Ghorpade et al. (2021), screening 1,080 publications down to ninety-one peer-reviewed articles covering 2002 to 2020, describe intermittent supply as a vicious cycle and organise its drivers into five groups: design and analysis failures including unrealistic standards and flawed demand forecasting; operation and maintenance failures including failed district metering and inadequate asset management; consumer satisfaction; revenue failures

including inadequate tariffs, political pricing, metering failure and illegal connections; and institutional capacity. Four of the five are governance categories.

Kumpel et al. (2022), surveying households longitudinally across areas with intermittent and continuous supply, note that more than one billion people receive water for fewer than twenty-four hours a day, find few perceived differences in service delivery between the two groups, and record one quarter of all households reporting insufficient water for handwashing, with many continuously supplied households still reporting outages that forced use of alternative sources. Nominal continuity, like nominal access, is not the operative variable.

Ferrante et al. (2024) examine the physical consequences experimentally, testing feeding conditions, downstream outflows and air-valve configurations, and frame the transition from intermittent to continuous supply as desirable for water quality, distribution equity and pipe integrity but often unachievable in the short to medium term. Abhijith et al. (2023) model the household adaptation, introducing an open-source intermittent-supply extension to a standard hydraulic engine and finding that domestic underground tanks with pumping to overhead tanks allow consumers to meet demand under intermittency, and — the finding with distributional consequences — that the clock time of supply, not only the interval length, determines whether households can meet demand.

Ramani et al. (2023) formalise the equity dimension, optimising network design under pressure-driven analysis to maximise both network resilience and a uniformity coefficient measuring supply equity, and concluding that reliability and equity are jointly achievable at minimal additional cost on benchmark networks. Wu et al. (2023) measure the human consequence, finding through instrumental-variable ordered probit estimation across 641 villages in eight provinces that intermittent supply raised the probability of self-rated health being merely fair by 18.2 per cent and reduced the probability of excellent health by 58.8 per cent, mediated through household storage behaviour and sanitary water habits, with effects larger for women and for people with lower education.

Gallandat et al. (2024) supply the decisive causal evidence. In a pragmatic trial of piped supply improvements, incidence rate ratios for confirmed cholera were 0.84 for service quality, 0.76 for quantity and 0.75 for continuity, and the authors estimate that an additional five litres per user per day, or 1.2 more hours per day of production, would reduce confirmed

cholera by twenty-four and twenty-five per cent respectively. Continuity is not a comfort attribute. It is the attribute through which piped supply delivers its health benefit.

Asset management and the renewal question

Forero-Ortiz et al. (2023), reviewing pipe failure prediction models and their explanatory variables, conclude that model accuracy is bounded by data and that a substantial, reliable dataset drawn directly from utility databases is a prerequisite for meaningful failure-rate modelling. The conclusion is a sequencing argument in disguise: a utility that has not metered its districts cannot build the dataset on which any renewal prioritisation depends.

Taiwo et al. (2024) demonstrate what becomes possible once the data exist, training five ensemble learning algorithms on data from four distribution networks with tuned hyperparameters, improving one model's mean absolute error by 20.51 per cent through tuning, and identifying pipe age, diameter and length as the dominant contributors to wall thickness loss through interpretable attribution analysis. Ganjidoost et al. (2021) supply the financial counterpart, validating a three-layer asset management framework against three utilities and identifying an optimal combination of an annual fee increase of about eight per cent with a rehabilitation rate of about 1.3 per cent per year and a cash reserve of one to four per cent depending on network condition.

Tariffs, willingness to pay, and what the customer is buying

Adeoti and Fati (2022), through household survey triangulated with documentary analysis, identify the constraints on willingness to pay for piped tariffs as political promises, availability of alternative sources, lack of recognition of drinking water as a right, inadequate collection methods, and poor response to complaints, recommending metering, a customer consultative forum and improved customer relations. Two of the five constraints — alternative sources and complaint response — are direct consequences of intermittency and loss.

Ribeiro et al. (2022) price the alternatives that a failing network pushes users toward, computing production costs and shadow prices by the residual value method and finding well water lowest in total cost at USD 0.08 per cubic metre, desalination most competitive on investment at USD 0.28 and industrial reuse on operations at USD 0.57, against cisterns at USD 2.20 and greywater reuse at USD 2.60 on investment — and concluding that tariff policy does not reflect a significant part of the social cost of wells, desalination and reuse. Where

the cheapest private alternative is groundwater and its social cost is unpriced, the incentive structure facing a household with unreliable piped supply is unambiguous.

Dektar et al. (2022) and Agbemor and Smiley (2021) examine the delegated-operation model that reform programmes frequently propose. The first finds private operators lacking skills for electromechanical components, meter reading and customer care, with intermittent power making systems unreliable, weak enforcement producing non-uniform tariffs across districts and lowering willingness to pay, and profit focus leading operators to minimise energy spend at the expense of service. The second, reviewing a build–operate–transfer partnership against a risk framework, finds that of eleven identified risk factors only seven were anticipated in the project documents, with most residual risk falling in the service-delivery phase. Nastiti et al. (2017) document the informal alternative that fills the gap, analysing commercialised spring-water supply as co-production and identifying improved access for people previously unserved by piped water and boreholes, the ability to negotiate from below, and transparency and accountability among its institutional innovations.

The baseline problem: what access statistics record

Cronk et al. (2024) analyse 37,105 household surveys and 6,395 water samples from rural areas of fourteen low- and middle-income countries and find ten per cent of households switching primary source between rainy and dry seasons, twenty-three per cent using a secondary source of which thirty-seven per cent were unimproved, sixty-nine per cent of samples containing indicator bacteria, and only seven per cent of households with safely managed drinking water free from faecal contamination at point of use. They conclude that international monitoring substantively overstates the population benefiting from safely managed drinking water.

Daly et al. (2021), screening 5,318 studies and including seventy-four, find between four and one hundred per cent of study populations practising multiple water source use, with supplemental use of unimproved sources by households whose primary source is improved reported globally, and argue that because monitoring keys on the primary source, headline global figures overstate safe access. Ambel et al. (2023) demonstrate the same point through prediction, training classifiers on water testing data and achieving 88.5 per cent accuracy with an area under the curve of 0.91, and finding that a model using water source type alone performed poorly. Source type is a weak predictor of water quality.

Rajapakse et al. (2023) supply the aggregate trajectory: safely managed drinking water rose from seventy to seventy-four per cent between 2015 and 2020, safely managed sanitation from forty-seven to fifty-four per cent, with one region reaching only sixty-one per cent basic water supply against ninety per cent globally, and eight in ten people without basic water services living in rural areas. Business-as-usual rates must double for universal basic services, quadruple for universal safely managed services, and increase tenfold for universal safely managed drinking water in low- and middle-income countries by 2030. Gurung et al. (2023), using national household microdata, find access to improved drinking water more likely for urban households with larger families and fewer rooms, and recommend subsidised services and higher public investment to make facilities affordable to poor rural households.

The aquifer beneath the network

Rusli et al. (2024), coupling a distributed hydrological model with a groundwater model under climate and abstraction scenarios, find climate change alone producing no notable change in recharge while confined piezometric heads decline by up to 7.14 metres by 2030, 15.25 by 2050 and 29.51 by 2100 at current abstraction, roughly doubling if abstraction grows with population. The projected status is dominated by anthropogenic activity rather than climatic forcing.

Siriwardane-de Zoysa et al. (2021), combining satellite interferometry with policy mapping across three cities, find socio-temporal variability in subsidence rates that frustrates uniform regulatory action, and a coastal governance landscape spanning urban water supply, groundwater extraction, land-use zoning, building codes, tenure security and land reclamation that is fragmented and incongruous. All three cities frame subsidence in strikingly similar ways — as reversible, quasi-natural, or an individualised problem. The framing matters because it locates responsibility outside the water utility, which is precisely where the abstraction driving the subsidence is being caused.

RESEARCH GAP

Three gaps follow. The first is evaluative: the two interventions with the clearest measured returns in this corpus — pressure management and continuity improvement — have been evaluated in single-city case studies and one pragmatic trial respectively, while the instruments that attract the most reform financing, namely source development and

treatment capacity, have no comparable evaluation of their marginal contribution in high-loss networks.

The second is diagnostic. The published literature contains few studies reporting a standardised infrastructure leakage index for systems in the region of most interest, so cross-system comparison of loss performance rests on percentage figures that are not comparable across networks with different pressures, connection densities and mains lengths.

The third is institutional. The efficiency literature includes ownership as an explanatory variable and finds it significant, but no study in the corpus examines corporatisation as such — the assignment of commercial form to a municipal service — which is the reform actually being pursued in many of the systems the loss literature describes.

3. METHOD

The study is conceptual and comparative, and its object is the ordering of reform actions rather than any single action's effect.

A corpus was assembled of peer-reviewed research published between 2017 and 2024 across five domains: water loss measurement and pressure management; utility efficiency benchmarking; intermittent supply and its consequences; asset management and pipe renewal; and access measurement including the relationship between piped supply and groundwater abstraction. Each item was verified against the publisher record, the digital object identifier resolver, or an indexing record. Conference proceedings were excluded, as were journals whose indexing standing could not be established, which removed a substantial body of regionally specific loss studies and is acknowledged below as a limitation.

Interventions identified in the corpus were then classified on three dimensions specified in advance: capital intensity, the presence of a measured effect size, and whether the intervention's benefit is conditional on another intervention having been performed first. The third dimension is what converts a list of options into a sequence, because an intervention whose benefit is conditional cannot rationally precede its condition.

Two limitations are inherent. Effect sizes drawn from single-city case studies do not transfer directly to other networks, so the sequencing argument rests on the direction and relative

magnitude of measured effects rather than on their exact values. And the exclusion of unverifiable venues biases the corpus toward systems in countries with strong open-access publication, which are not the systems with the highest losses.

4. RESULTS AND DISCUSSION

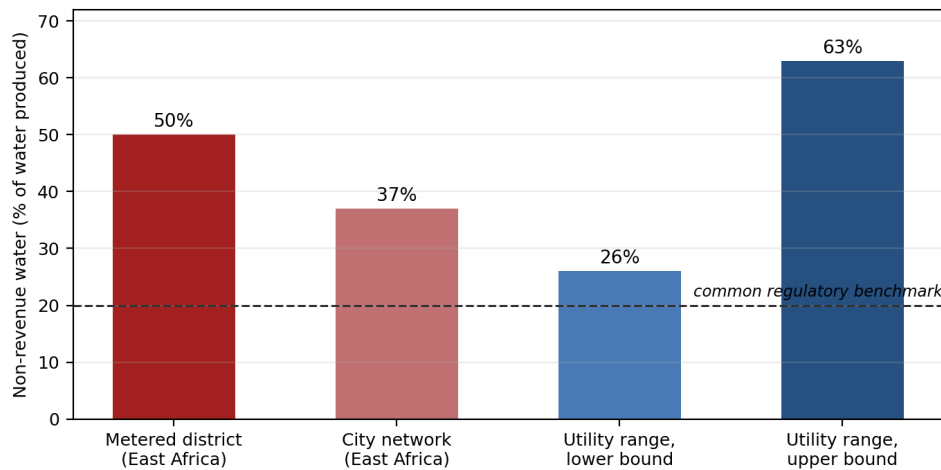


Figure 1. Measured non-revenue water in reported systems against a common benchmark

Finding one: losses are physical, large, and partly designed in

Shushu et al. (2021) find about eighty-seven per cent of district losses to be real physical loss, fifty-two per cent of nodes above recommended pressure, and inadequate velocities in roughly eighty-three per cent of pipes because mains were oversized. The last of those is a design decision made years earlier, and it is producing simultaneously a leakage problem and a stagnation-driven quality problem. Loss reduction in such a network is not maintenance catching up with age; it is correction of a specification.

The composition matters for what reform should do. Commercial loss — theft, metering error, billing failure — is addressed by metering, enforcement and customer systems. Real loss is addressed by pressure, materials and renewal. A programme that assumes one composition and encounters the other will spend on the wrong instrument, and Shushu et al. (2021) show that the composition can only be established by district metering, which is therefore prior to both.

Finding two: the cheapest intervention has the best-evidenced return

Samir et al. (2017) reduced leakage by thirty-seven per cent through optimised placement of fixed pressure-reducing valves. García-Ávila et al. (2019) reduced it by roughly thirty-one per

cent with two valves, while raising a network performance indicator from about eighty to about ninety-seven per cent. Shushu et al. (2021) modelled valves plus topology change bringing potential leakage from fifty to forty-six per cent in a district where excess pressure was documented at over half of nodes.

Two independent case studies converging on a reduction of roughly one third, from an intervention whose capital cost is a small fraction of a treatment plant's, is the strongest cost-effectiveness signal available in this corpus. The qualification is that pressure management requires a hydraulic model, which requires network data, which requires metering — the same precondition Forero-Ortiz et al. (2023) identify for failure prediction. The sequence is therefore metering, then modelling, then pressure.

Table 1. Interventions classified by capital intensity, measured effect and precondition

Intervention	Capital intensity	Measured effect in corpus	Conditional on
District metering	Low	Enables loss composition analysis (Shushu et al., 2021)	-
Pressure management	Low	31-37% leakage reduction (Samir et al., 2017; Garcia-Avila et al., 2019)	Metering and hydraulic model
Continuity improvement	Medium	IRR 0.75 for confirmed cholera (Gallandat et al., 2024)	Loss reduction sufficient to free volume
Pipe renewal prioritisation	High	MAE improved 20.51% by model tuning (Taiwo et al., 2024)	Utility failure database
Source and treatment expansion	High	Not separately evaluated in high-loss networks	-
Delegated private operation	Variable	Skills and enforcement gaps (Dektar et al., 2022)	Regulatory enforcement capacity

Note. Compiled by the author from the reviewed corpus. 'Conditional on' identifies what must exist for the intervention's measured benefit to be attainable, which is what determines sequence.

Finding three: efficiency is dominated by losses, and regulation can discourage fixing them

Ngoben and Breitenbach (2021) find mean technical efficiency of forty-nine per cent with losses modelled as an undesirable output, and the paired comparison within their sample — an entity at sixteen per cent efficiency spending eighteen per cent of the largest entity's budget to sell 6.7 per cent of its volume with seven times the proportional losses at 1.6 times the tariff — shows the four variables moving together rather than trading off.

Maziotis et al. (2023) then identify the regulatory trap. Productivity rose while eco-productivity fell, meaning firms cut costs at the expense of service quality, and reducing non-revenue water and unplanned interruptions was especially costly for one ownership class. A performance regime that rewards cost efficiency without pricing loss and interruption will therefore select against exactly the investments this study argues should come first. Sala-Garrido et al. (2022) find public utilities outperforming private ones once quality is adjusted for, which points the same way: the measurement frame determines the apparent ranking.

Bandari and Sadhukhan (2021) close the argument by showing that metering extent, non-revenue water extent, connection coverage and supply continuity all substantially affect per capita supply. The quantity a system delivers per person is thus determined by the same four variables that determine what it can bill for. Improving delivery and improving revenue are not competing objectives requiring a trade-off; in high-loss networks they are the same action.

Finding four: continuity is the health variable, and intermittency is self-reinforcing

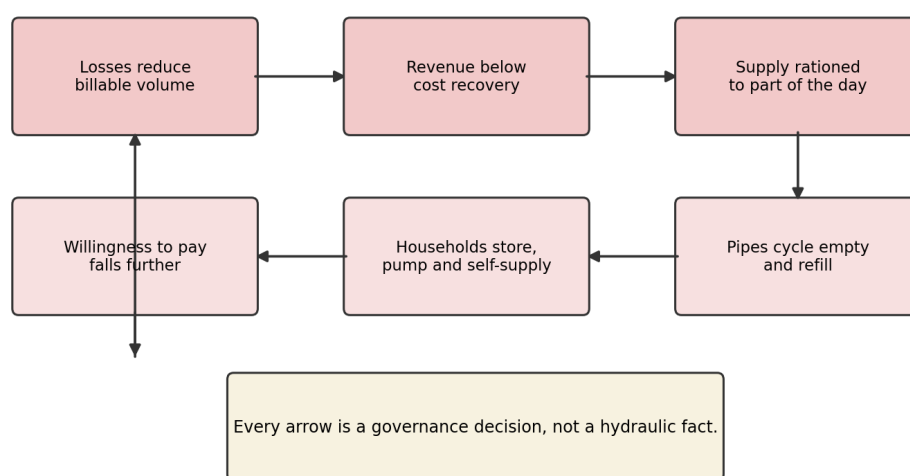


Figure 2. The intermittency loop and the points at which governance decides it

Gallandat et al. (2024) report an incidence rate ratio of 0.75 for continuity against confirmed cholera, against 0.84 for service quality and 0.76 for quantity, and estimate that 1.2 additional hours per day of production would reduce confirmed cases by about twenty-five per cent. Wu et al. (2023) find intermittency raising the probability of merely fair self-rated

health by 18.2 per cent and reducing the probability of excellent health by 58.8 per cent, mediated through storage behaviour.

Ghorpade et al. (2021) explain why the condition persists once entered: four of the five driver groups they identify are governance rather than hydraulic categories, and the revenue group — inadequate tariffs, political pricing, metering failure, illegal connections — is where the loop closes back on itself. Losses reduce billable volume; revenue falls below cost recovery; supply is rationed; pipes cycle empty and refill, accelerating deterioration and admitting contamination; households store, pump and self-supply; willingness to pay falls further. Adeoti and Fati (2022) locate two of their five willingness-to-pay constraints at exactly that point.

Ferrante et al. (2024) and Abhijith et al. (2023) supply the reason the loop cannot simply be exited by declaring continuous supply. The physical transition has consequences for pipe integrity that require management, and household adaptation to intermittency — tanks, pumps, storage — becomes an installed base that itself shapes demand patterns. Abhijith et al.'s finding that the clock time of supply determines whether households can meet demand identifies an equity dimension that no aggregate hours figure captures: supply delivered at an hour when a household cannot collect it is not supply.

Ramani et al. (2023) offer the constructive result that resilience and equity are jointly achievable at minimal additional cost through pressure-driven design optimisation. The finding is on benchmark rather than real networks, but it establishes that the equity of intermittent supply is a design variable rather than a fixed consequence of scarcity.

Finding five: the baseline overstates the achievement

Cronk et al. (2024) find seven per cent of households with safely managed water free of contamination at point of use across fourteen countries, against national statistics reporting far higher figures, and twenty-three per cent using a secondary source of which thirty-seven per cent was unimproved. Daly et al. (2021) find multiple source use ranging from four to one hundred per cent of study populations. Ambel et al. (2023) find source type alone a poor predictor of contamination.

The implication for the sequencing argument is direct. If reported access is largely a count of primary sources, and if a substantial share of households supplement an improved primary source with an unimproved secondary one, then the population appearing as served in

official statistics includes a large group whose actual consumption is unsafe — and the most likely reason for supplementing an improved source is that it does not deliver reliably. Intermittency is thus one of the mechanisms generating the measurement error, which means the statistic used to judge whether continuity matters is itself distorted by the absence of continuity.

Rajapakse et al. (2023) show what that implies for the required rate of progress: a tenfold increase for universal safely managed drinking water in low- and middle-income countries by 2030. A tenfold increase in delivered service from systems losing a quarter to two-thirds of production is not achievable by production expansion alone at any plausible financing level.

Finding six: unreliable supply is an abstraction policy

Ribeiro et al. (2022) find well water the lowest-cost alternative at USD 0.08 per cubic metre and conclude that tariff policy does not reflect a significant part of its social cost. Rusli et al. (2024) quantify that social cost as head declines of up to 29.51 metres by 2100 under current abstraction, dominated by anthropogenic rather than climatic drivers. Siriwardane-de Zoysa et al. (2021) show the governance response fragmented across six policy domains and framed in ways that individualise the problem.

Read together, these establish a chain that no single institution owns. A utility that cannot deliver continuously pushes users toward the cheapest alternative; the cheapest alternative is groundwater; groundwater abstraction produces head decline and subsidence; and the resulting damage falls on land-use, building-safety and coastal-protection budgets rather than on the water utility's accounts. Non-revenue water is, in this sense, a transfer of cost from the utility's balance sheet to the municipality's.

A proposed sequence

Four steps follow from the findings, ordered by what each requires. Establish district metering first, because loss composition cannot otherwise be determined and neither pressure management nor renewal prioritisation can be designed without it. Address pressure second, because it is the lowest-capital intervention with the best-evidenced return and because excess pressure is documented as widespread. Convert the freed volume into continuity third, because continuity is what carries the measured health benefit and what

breaks the loop that regenerates loss. Undertake source and treatment expansion fourth, when the network can deliver what is produced to a customer who can be billed.

Two supporting conditions apply throughout. The regulatory performance frame must price loss and interruption explicitly, or, as Maziotis et al. (2023) show, cost-efficiency incentives will select against the investments this sequence requires. And the failure database that renewal prioritisation depends on must be built from the metering established at step one, since Forero-Ortiz et al. (2023) establish that model accuracy is bounded by data quality drawn directly from utility records.

Limitations

Three limits bound the argument. Effect sizes come from single-city case studies whose transferability is untested, so the sequence rests on direction and relative magnitude rather than on point estimates. The exclusion of venues whose indexing standing could not be established removed most of the regionally specific loss literature, including nearly all studies reporting standardised leakage indices, so the corpus under-represents precisely the systems the argument addresses. And no study in the corpus evaluates the marginal contribution of source expansion in a high-loss network, so the claim that it should come fourth rests on the conditional structure of the alternatives rather than on a direct comparison.

5. CONCLUSION

Water that is produced, treated, pumped and then lost has consumed every input a delivered litre consumes and produced no revenue, no service and no health benefit. In the systems reviewed here that describes between a quarter and two-thirds of production. The customary reform sequence addresses this last, after source and treatment investments whose value is discounted by exactly the loss rate the sequence defers.

The evidence supports inverting the order. Pressure management, the lowest-capital intervention available, reduced leakage by roughly a third in two independent case studies. Continuity, not source type, carries the measured health effect, with an incidence rate ratio of 0.75 against confirmed cholera and an estimated quarter reduction in cases from 1.2 additional hours of daily production. Efficiency analysis finds losses dominating utility performance. And the access statistics that make current progress look adequate overstate it

substantially, because they record primary sources rather than what reaches the point of use.

Two implications extend beyond the utility. A regulatory regime that rewards cost efficiency without pricing loss and interruption will discourage the investments this sequence requires, so performance regulation must be reformed alongside the network. And because unreliable piped supply drives substitution toward the cheapest private alternative, which is groundwater whose social cost is unpriced, non-revenue water transfers cost from the utility to the aquifer and, eventually, to the subsiding city above it. Treating loss as a technical matter internal to the utility is the assumption that this study's evidence most clearly contradicts.

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DECLARATIONS

Author contributions (CRediT)

Deni Setiawan: conceptualisation; methodology; formal analysis; writing - original draft; writing - review and editing.

Conflict of interest

The authors declare that they have no competing interests.

Data availability

All data supporting the findings of this study are available within the article and from the publicly accessible sources cited therein.

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Declaration on the use of artificial intelligence

Claude (Anthropic) was used for language editing and for translation of the manuscript into English. The authors reviewed and verified all content, and take full responsibility for the final text. No generative tool was used for data analysis, for the interpretation of results, or for the generation of scholarly content. AI is not listed as an author.

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