System archetypes underlying formal-informal urban water supply dynamics

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Abstract

Contrary to developed countries, developing countries have been observed to have increased reliance on a diversity of water supply options to meet their daily demands. Formal supply systems are incapable of delivering the daily needs of consumers. Informal supply systems, though filling the demand-supply gap, are increasingly being associated with issues of long-term sustainability, higher consumer cost, and inequity. Emerging formal-informal dynamics in developing countries require a thorough understanding of complex interactions for policy direction, in order to best support the advancement of urban water sustainability. Accordingly, system archetypes offer a platform to explain the behaviors of complex systems. This paper reviews existing literature on formal-informal dynamics and identifies common system archetypes that define urban waterscapes in the developing world. In this way, Causal Loop Diagrams (CLDs) are used to present the relationships and identify common archetypes that define the complexity of urban water supply systems in Hyderabad, Pakistan. These archetypes include 'fixes that fail', 'shifting the burden', 'limits to growth/success' and 'growth and underinvestment'. Further, leverage points for each archetype are identified and discussed for policy direction.

1.0 Introduction

Urban water supply systems have remained under pressure to meet the emerging needs of population and economic growth, exacerbated by changes related to climate (Jenerette et al. 2006). Understanding of system structures and behaviors that define the urban waterscape are important to ensure sustainable supply. Hybrid water supply systems have emerged over time to meet these growing needs, incorporating both formal (managed by state) and informal (non-state) supply systems (Ahlers et al. 2014; Post et al. 2017). Accordingly, interactions amongst formal and informal supply systems may result in multiple configurations that can define the state of a system's reliability (its ability to deliver the demand). These behaviors can be understood in the light of the system archetypes.

The inability of formal systems to be the sole provider of urban water is being recognized globally, especially within developing countries (Majuru et al. 2016; Pattanayak et al. 2005). Past studies have shown that 1.8 billion people with access to piped or improved water sources failed to receive safe water (Onda et al. 2012). Informal system (non-piped or non-networked water supply managed by private suppliers) has increasingly begun to replace formal systems (Dakyaga et al. 2021). Whilst diversity in water supply sources has been associated with the resilience of water supply systems (Gupta 2015), informal systems have been observed to be associated with issues of long term sustainability, higher consumer cost and inequity (Kujinga et al. 2014; Majuru et al. 2016; Suwal et al. 2020).

Water supply system reliability has been continuously challenged by a lack of financial sustainability within formal systems. This situation has been aggravated over time as the stock of infrastructure assets has reached its designed service life, where replacement or rehabilitation has been constrained by lack of funds (Enouy et al. 2015; Rehan et al. 2011). Developing countries are especially at the forefront of this crisis, primarily driven by water tariffs being set too low to generate enough funds for the formal systems. Low tariff recovery, driven by a low willingness by consumer to pay, is one of the major factors leading to the inability of policy makers to set suitable tariff rates (Enouy et al. 2015). On the one hand, the low willingness to pay can be mainly attributed to the poor performance of the formal system (Grupper et al. 2021) and income (Bano et al. 2020). On the other hand, consumers end up spending more on alternative options (Majuru et al. 2016; Nganyanyuka et al. 2014). According to the World Bank (2014), average household expenditure on informal water supply in urban Pakistan accounts for 10–20 times the expenditure of the formal supply, prompting lower income groups to pay up to 20% of their total household income on water (Imad 2017).

There has been considerable focus in literature on related aspects including: urban water governance (McDonald 2018), formal and informal system performance (Ranganathan 2014; Wutich et al. 2016), sustainability issues (Shah 2007) and hybrid supply (Post et al. 2017). However, system level configurations of formal-informal dynamics involving coupled human water interactions has received limited attention. Although Post et al. (2017) have elaborated on system level configurations of actors and roles in water provision, their study have not accounted for the dynamicity of these interactions. These interactions are continuously reshaped based on endogenous factors such as user and supplier priorities (Di Baldassarre et al. 2015) and exogenous factors i.e. climate change, demography and economy (Asefa et al. 2014). Sustainable urban water management requires an incorporation of these factors in planning processes (Leigh et al. 2019). This necessitates the exploration and understanding of how formal and informal systems interact in influencing urban water supply reliability. This further facilitates the building of an integrated model that captures both endogenous and exogenous factors.

System dynamics (SD) has been one of the famous approaches of integrated assessments. The concept of system dynamics is based on the principle of systems thinking, first developed in the 1960s as a concept to capture system feedbacks, aimed at understanding system behavior (Mirchi et al. 2012). System Dynamics as a methodology developed as a framework to model the interactions of drivers and their influence on the functioning of a complex system (Forrester, 1961). Socio-hydrology, based on SD, allows for the exploration of co-evolution and self-organization of people with respect to water availability. Traditional decision support systems for policy making have mostly lacked endogenizing of human decision factors, which may affect water cycle dynamics. Keeping these factors external or stationary has thus, resulted in limited understanding of the coevolving dynamics that inform long-term decision making (Sivapalan et al. 2012).

System archetypes present patterns that provide a holistic view of system behavior, helping to understanding a system's complexities and providing a picture of the underlying structures that define a system's behavior over time (Braun 2002; Kim et al. 1998). System archetypes have been categorized into problem and solution archetypes, where a problem archetype presents a system behavior that is different from what was originally intended. Contrastingly, a solution archetype tends to minimize the unintended consequences of a problem archetype (Bahaddin et al. 2018). The solution archetypes are also referred as leverage points, where they assist in efficient management of issues. Examining the system archetypes defining urban socio-hydrology, especially in developing countries, is important for highlighting a system's trajectory and guiding policy accordingly (BureŠ et al. 2016). Unlike traditional linear thinking models, system archetypes allow system analysis to identify unintended consequences associated with water management interventions (Bahaddin et al. 2018).

This study is unique in identifying common system archetypes based on formal-informal dynamics in urban water supply systems. Although existing studies (Bahaddin et al. 2018; Mirchi et al. 2012) have identified system archetypes in water resources management, they cover a wider scope, including water management in the agriculture sector, as well as environmental and transboundary water management. Water supply system conditions in Hyderabad, Pakistan, effectively illustrate the situation in arid urban regions around the world, where the informal system is rapidly replacing the formal system in meeting consumer demand. However, lack of incorporation of informal systems by city planners and policy makers raises questions regarding the future of urban water supply reliability (its ability to meet urban demand). This requires a systems perspective, which may help in identifying possible trajectories of the system state. This paper discusses the water supply situation in Hyderabad, where it identifies four system archetypes focusing on the study area's water supply system. These archetypes include 'fixes that fail', 'shifting the burden', 'limits to growth/success' and 'growth and underinvestment'. Using Causal Loop Diagrams (CLDs) and the behavior graphs of parameters, interlinkages between formal and informal systems are illustrated, followed by identification of leverage points.

2.0 Methodology

To provide a comprehensive view of formal and informal supply dynamics in Hyderabad city, an extensive literature review is conducted, including: peer reviewed journal articles, published and grey literature from local government, and secondary data from research and academic institutions such as the Pakistan Council of Research in Water Resources (PCRWR), Centre for Advanced Studies in Water at Mehran University (USPCAS-W) and WASA Hyderabad.

System archetypes have been used to qualitatively model the system patterns formed by formal and informal supply systems interactions in the study area. These system patterns were first highlighted by Jay Forester, Dennis Meadows and Donella Meadows, later documented by Senge and his colleagues in their book 'The fifth discipline: The art and practice of the learning organization'(Senge 1997). The eight most common archetypes mentioned in Table 1, (adapted from Kim et al. (1998)) have been reviewed to identify patterns in the case study area. The study identified four archetypes which capture the formal and informal water supply interactions in the Hyderabad city.

Detailed CLDs are drawn (in Section 3.0) to illustrate the major interlinkages identified amongst the variables, defining the water supply dynamics in Hyderabad city (as mentioned in section 2.1-). The feedback loops are comprised of reinforcing (R) and balancing (B) loops. Reinforcing loops refer to circular processes in which change in one variable results in further change in the same direction, accumulating the component that triggered the process. Balancing loops, on the other hand, comprise of the processes in which change in a variable is followed by a resisting or negating change, balancing the effect caused by the variable. Behavior over Time Graph (or BoTG) are drawn to present the possible patterns of the variable change over time.

This paper briefly discusses the existing regulatory challenges in urban water supply systems in Pakistan, and suggests possible leverage points that could help improve the performance of the supply system.

Table 1
Archetypes as dynamics theories

Systems Archetypes	Theory
Fixes That Fail	A “quick-fix” solution can have unintended consequences that worsen the original problem.
Shifting the Burden	When a symptomatic solution is applied to a problem symptom, it alleviates the symptom, reduces pressure to implement a fundamental solution, and has a side-effect that undermines the ability to develop a fundamental solution.
Limits to Success	A reinforcing process of growth or expansion will encounter a balancing process as the limit of the system is approached.
Drifting Goals	When a gap exists between a goal and reality, the goal is often lowered to close the gap. Eventually, the lowering of the goal leads to deteriorating performance.
Growth and Underinvestment	When growth approaches a limit, the system compensates by lowering performance standards. This reduces perceived need for capacity investments and leads to lower performance, justifying further underinvestment.
Success to the Successful	In a system with limited resources, one party’s initial success justifies devoting more resources to that party, which widens the performance gap between the various parties.
Escalation	A perception of threat causes one party to take actions that are then perceived as threatening by another party. The parties keep trying to outdo one another in a reinforcing spiral of competition.
Tragedy of the Commons	If total usage of a common resource grows too great, the commons will become overloaded or depleted, and everyone will experience diminishing benefits.
Source: Adapted from Kim et al. (1998)	

2.1 Study area

Positioned at 25° 22' 45" North and 68° 22' 6" East, Hyderabad city is situated on the left bank of the Indus River, next to the Kotri Barrage, acting as the last diversion structure in the Indus Basin Irrigation System (IBIS), as shown in Fig. 1. Surface water (Indus River) is the only source of water supply in the city, where the ground water is brackish and; therefore, not suitable for domestic use. Water is mostly extracted from the distributary canals of the Kotri Barrage, namely from Akram Wah, Phuleli Canal and Pinyari Canal. Some users also extract water directly from the Indus River, downstream of the Kotri Barrage (Peerzado et al. 2019).

Hyderabad is the second most populous city of Sindh Pakistan, where it has the highest population density after Karachi. The city has grown from 1.1 million inhabitants in 1998 to 1.7 million people in 2017 (Pakistan Bureau of Statistics 2017a). Hyderabad - Water and Sanitation Authority (H-WASA) is the formal supply authority responsible for providing water in the city, where it is not able to deliver its services efficiently, largely due to financial constraints (Kalhoro 2017). City residents of lower income groups pay up to 20% of their monthly income to meet their domestic water demand, where they rely heavily on informal water supply. Further, water borne disease prevalence is very high within Hyderabad city. The total health cost of water pollution in the city is estimated to be 1.8 percent of the country’s GDP (Government of Pakistan 2015).

Osmani & Company (2007) have reported the Hyderabad supply network length to be 1100km, with fifty-one pumping stations. These pumping stations pump raw water from canals to the lagoons, and then on to settling tanks of the filter plants through transmission mains. The water supply system includes five filter plants (located in different sub-districts) with a total capacity of 0.23 million cubic meters (60 million gallons) per day filtration capacity. The present condition of water supply in the city is very poor, where the water authority merely pumps raw water from the river and delivers it to consumers. There are areas within the city that endure no water at all in their household taps for months, whilst others may receive water for 2 to 3 hours per day, or on every alternate day. The situation is worse during winter, when Indus river water levels decrease. There are multiple factors involved in defining the current condition of the formal water supply in Hyderabad, including low infrastructure capacity and financial deficit, in addition to other factors (Kalhoro 2017).

Formal systems rely heavily on government funds/ tax money, where they may lack funds for much of the time to maintain and operate the water supply systems. In this case, revenue generation is negligible due to low cost recovery (Kalhoro 2017). According to H-WASA, the recovery rate is below 50% despite having a very low tariff structure of 300 PKR (3 USD) per month, with an average supply of 6–8 hours per day. Low fund balance has led to poor service of the utility (M. H. Khan 2020), which in turn has led to lower satisfaction of consumers and lower willingness to pay bills. Further to this, the situation has lead consumers to pay more and rely on alternative sources like bottled water and tankers (Zaidi 2017). Household surveys by Imad (2017) and Zaidi (2017) have revealed high dissatisfaction with water utility in Hyderabad, and increasing proportion of informal water supply per household. Forty percent of households with low income; however, rely on poor quality water as their informal water supply.

This situation is not limited just to Hyderabad, but also exists in other major cities in Pakistan (Cooper 2018), and the developing world in general. Table 2 details statistics of water supply condition, demonstrated by coverage ratios of formal supply systems. The majority of the listed cities rely on surface water as their major source of supply. However, cities in the upper Indus also have groundwater aquifers to supplement their water supply. The situation in Sindh Province is extremely poor, with a lack of financial sustainability, maintenance and energy deficit being constant challenges for urban water utilities, intensifying the water crisis in the whole province (Tahir et al. 2010).

Table 2: Water supply statistics in major cities of Pakistan. Sources: (National Development Consultants (Pvt.) Limited Pakistan 2014; Pakistan Bureau of Statistics 2017b; World Bank 2014)

S.No	City (Province)	Population	Sources of water supply (Surface/ Ground)	Formal supply coverage (In-house pipe dwelling) (%)	Non-Revenue water (%)	Formal water supply cost (USD*/ Month/ household)	Informal water supply cost (USD/m^3/ household)	Formal Expenditure Revenue working ratio (Expenditure /Revenue)	Tariff collection rates (%)
1	Karachi (Sindh)	14,916,456	S	73	40	3–5	6–10 + distance	1.13	43
2	Hyderabad (Sindh)	1,734,309	S	33	60	3.5	20	3.6	50
3	Faisalabad (Punjab)	3,204,726	S	12.1	24	4	12.6–20	1.60	51
4	Multan (Punjab)	1,871,843	S	6.4	30	-	-	2.80	88
5	Lahore (Punjab)	11,126,285	S + G	65.8	30	-	6–7	2.11	98
6	Peshawar (KPK)	1,970,042	S + G	38.5	20	-	-	-	-
7	Islamabad (Federal Capital)	1,009,832	S + G	90	40	-	-	-	-
*1USD = 100 PKR									

3.0 System Archetypes In Hyderabad

2.2 Fixes that fail/backfire (increase in supply infrastructure and utility fund deficit):

In the case of Hyderabad city, local government approaches towards low supply reliability have mostly included an increase in the number of treatment plants, with less focus on their financial sustainability (Water and Sanitation Program (WSP) et al. 2016; World Bank 2014). Within its commitment to achieve Sustainable Development Goals (SDGs) 6.1, the government of Sindh has planned to expand water supply capacity in the city by 0.38 million cubic meters (100 MG) per day by 2030 (Ali 2017). Contrastingly, past development initiatives, including building of water treatment plants, have been shown to become dysfunctional after a few years due to a lack of maintenance and non-payment of electricity bills (Kalhoro 2017; World Bank 2014). Water quality assessment surveys by PCRWR (2018-19) have reported only 40% (529 out of 1300) of drinking water filter plants to be functional in 22 districts of Sindh province, whereas the number for all the districts surveyed in the country was observed to be 60% (Pakistan Council of Research in Water Resource (PCRWR) 2021b).

As presented in Fig. 2a, the situation presents 'fixes that fail archetype', in which short term solutions i.e. increasing the number of filter plants in this case, may relieve the problem temporarily, decreasing the supply gap for a few years (B1.1). However, a lack of focus on financial sustainability has re-introduced water shortage problems again, as evidenced by the number of dysfunctional plants over time in the Sindh province (Tahir et al. 2010). New infrastructure requires the funding of maintenance and increasing overall expenditure (R1.1). Filter plants become dysfunctional once they run out of funds, where there have been a continuous increase in negative fund balances and the system's ability to sustain itself declines over time, returning water shortages to their initial conditions.

Behavior over time graph (Fig. 2b) illustrates how the water shortage declines temporarily every time when the infrastructure capacity is increased. However, the shortage condition keeps returning back when the infrastructure degrades or gets dysfunctional.

3.1. Shifting the burden (on Informal system):

Shifting the burden archetype refers to the situations in which symptomatic solutions to a problem lessen the pressure for implementing fundamental solutions. Whilst a symptomatic solution temporarily reduces the intensity of a problem, these symptoms resurface over time (Kim et al. 1998). Informal supply has been introduced as a symptomatic solution to water shortage in Hyderabad city, and in other cities in Pakistan (Hassan 2018). Informal supply appears to fill the gap and temporarily solve issues related to the formal system, as illustrated in B2.1 (in Fig. 3a); however, water shortages and quality issues in cities have resurfaced related to an ever increasing demand for informal supply. Given this situation in most urban areas within the country, the federal government of Pakistan has allowed private suppliers to grow, which temporarily relieved the situation. However, the side effects that the informal system creates has aggravated the main problem, leading to low reliability, high cost to consumers and inaccessibility for lower income groups (Hassan 2018; World Bank 2014). As shown in R2.1, the higher expenditure associated with informal water demand at the household level lowers the ability of lower and medium income groups to pay water tariffs within the formal system (Bano et al. 2020). While tariff rates in city areas are already low, lower recovery rates have discouraged policy initiative to revise tariffs for the system to generate sufficient revenue (Bano et al. 2020; Imad 2017). Thus, efforts to improve the financial sustainability of the formal system, including tariff increases (B2.2), have received less attention, intensifying the need for growth of informal systems (as illustrated in Fig. 3b). This further raises questions regarding whether or not the informal system is capable of meeting increasing demand in the long run. The next archetype, in Section 3.3, discusses this further.

3.2. Limits to growth/success (Informal supply):

Limits to growth/success archetypes present scenarios where actions initially result in growth/success, which further encourage the same actions however, over time, as growth continues, a balancing loop driven by resource constraints slows this progress. This can then mislead to further pushes of actions in the same direction (Kim et al. 1998) .

Increasing informal demand associated with water shortage in cities has increased informal supply as shown in Fig. 5a (R3.1). The number of tanker water suppliers and private companies selling bottled water has increased dramatically over the years (Pakistan council of Research in Water Resource (PCRWR) 2021a). However, this increasing demand pressure has also been observed to be associated with decreasing quality of informal supply service (B3.2). PCRWR has shown that the number of private companies selling low quality bottled drinking water has increased over time (Pakistan council of Research in Water Resource (PCRWR) 2021a) (Fig. 4).

This may be driven by financial and infrastructural constraints for informal supply systems, resulting in a compromise in quality (Dakyaga et al. 2021).

Moreover, further feedback that may affect the growth of informal systems relates to a decline in the purchase power of consumers, coupled with increase in informal demand share in total household demand. This, in turn, can increase household total expenditure, especially impacting lower and middle income categories, whilst limiting their informal demand over time (B3.1) (Bano et al. 2020). These factors can, therefore, affect the growth of the informal system in the long run (Fig. 5b). This scenario indicates 'limits to growth/success behavior' of informal systems, suggesting the need to assess the reliability of informal supply systems as a sustainable supply option.

3.3. Growth and underinvestment (Infrastructure maintenance)

The 'growth and underinvestment archetype' refers to a situation in which growth approaches a limit that could otherwise be extended or avoided via a capacity increase, resulting in further limitations of growth due to delays within a system (Kim et al. 1998). Similarly, as illustrated in Fig. 6a, formal infrastructure ageing and its resulting decline in water supply due to leakage losses, can be majorly associated with increasing water shortages in Hyderabad city (Kalhoro 2017). Due to a lack of funding resources and related delays, authorities have provided less attention to infrastructure rehabilitation, which has resulted in the failure of water supply systems after a few years (B4.1). Increasing urban water demand related to population and economic growth and resulting water shortages have resulted in an increase in shifts towards informal supply systems. This demand shift and resulting decline in formal demand may be misperceived as lowered demand (B2.1). This in turn, may further misguide the need for infrastructure rehabilitation. Feedback loop B4.1 may appear to be in conflict with B1.1; however, the latter refers to new infrastructure rather than to rehabilitation of existing infrastructure.

Figure 6b presents how lack of infrastructure rehabilitation may ultimately lead to the infrastructure dysfunctionality after sometime.

4.0 Leverage Points: Water Supply Management

Leverage points refer to the places in complex systems where a small change in one element can lead to a big change in the whole system. Leverage points for the existing situation of urban water supply under formal-informal dynamics can be identified following guidelines defined by Meadows (1997). Management of 'fixes that fail' and 'growth and underinvestment' archetypes lies in improving the existing condition of formal systems, emphasizing its financial sustainability. Contrastingly, the archetypes of 'shifting the burden' and 'limits to growth' can be managed by improving informal services through service regulation.

Management of 'fixes that fail' involves understanding short and long term impacts of interventions. This further requires understanding of root causes and, how they are different from symptoms. Instead of focusing only on building new infrastructure every time, i.e. water treatment plants, authorities need to focus on building the financial capacities of existing formal supply systems, i.e. water utilities. Efforts are needed to: generate enough revenue through appropriate pricing mechanisms, prompt improvement in recovery rates, allocate sufficient development funds, and introduce other interventions necessary to ensure the financial sustainability of the formal system (Kalhoro 2017; World Bank 2014).

Moreover, management of the 'Growth and underinvestment archetype' requires further understanding of capacity needs with growth and avoiding perception and capacity acquisition delays that can backlog system performance (Kim et al. 1998). The ability of planners and decision makers: to estimate future development needs; of being well informed, trained and equipped; and of being able to apply decision support tools, can help in reducing perception delays. This may appear as contradictory to the management of 'fixes that fail' archetype mentioned above however, management of 'growth and underinvestment' refers to rehabilitation of existing infrastructure instead of introducing new infrastructure.

In general, a water utility's financial capacity defines its service quality. In this regard, the lack of enough funds for maintenance expenditure has been observed to be associated with an increased number of dysfunctional treatments plants (Tahir et al. 2010). A lack of rehabilitation or maintenance services due to lack of enough funds also leads to infrastructure degradation. According to (Water Sector Task Force (WSTF) 2012), more than 35% of water supply is wasted in leakages in developing countries. Urban water utilities in Pakistan rely on a combination of development funds from the federal government, external funds from international organizations and revenue generated by water tariff collection.

On the one hand, Pakistan's water tariff has been too low, where its combination with low recovery rates has led to not enough revenue and financial deficit. On the other hand, the government's expenditure on water and sanitation has been very low, estimated to be 0.2% of GDP (World Health Organization (WHO) 2015). Strong et al. (2020) have estimated a value of 4% of country's GDP to be able to achieve with the SDG 6 target for water and sanitation. The National Water Policy of 2018 has also proposed increase in public sector investment by the federal government from 3.7% in 2017-18 to 20% by 2030. Whilst this increased allocation is admirable, it may be hard to achieve.

Past policy level efforts, including Pakistan's water sector strategy of 2002, have recognized the importance of financial sustainability of water sector infrastructure and services, emphasizing improving public sector cost recovery to support O&M, improvement, modernization and extension of services. However, it has also become accepted that full financial self-sufficiency is unlikely to be achieved in Pakistan as a result of the country's high rates of poverty. Thus, these efforts would require government support in the form of regular development of funds. Moreover, a financial sustainability assessment has been made a compulsory component for the approval of water infrastructure projects within the country (Government of Pakistan 2002).

Whilst Pakistan's National Water Policy (NWP) 2018 outlines revised water pricing as a means of enhance water use efficiency (Government of Pakistan 2018), according to Arfan et al. (2020), this policy lacks a clear direction regarding valuation methods for different uses. For example, agriculture as the largest user (making 90% of total consumption) still lacks pricing reform that discourages wastage and overuse. However, the Sindh government has recently announced to price industrial water as it is supplied in bulk (Tunio 2020). This could be helpful in maintaining control over increasing competing urban water users consuming a major share of the water available.

While Shin et al. (2021) have suggested that water prices should be based on volume to be able to account for water losses related to water production and delivery, Shah (2007) notes it is challenging to bring demand-management reforms including pricing, laws and rights in informal water economies, as this does not work due to high transaction costs and corruption at root levels. Water pricing for domestic users in Hyderabad is based on housing area. Although this appears to be an appropriate technique, according to Shah (2007), to avoid transaction costs, there are examples of volumetric pricing in other cities in the country, such as block tariff rates in Islamabad, that have been effective in managing water allocations (S. Khan et al. 2020). However challenges associated with wrong meter reading and corruption, in addition to incorrect record keeping, are unavoidable (Shah 2007).

Public Private Partnership (PPP) has been gaining interest amongst water managers as one potential way to improve tariff recovery rates and; thus, improve the financial sustainability of the urban water utilities (Government of Pakistan 2002). Hyderabad - WASA's tariff recovery rates have been reported to have increased from 50–70% in 2019 through public private partnership (Ahmad et al. 2019). However, Shah (2007) has argued that high shares of total revenue from private sectors may still conflict with the objective of financial sustainability, with wide gaps currently between expenditure and revenue. However, opportunities still exist with regard to PPP, in terms of furthering experience and knowledge in managing formal system/utilities through management contracts (Ahmad et al. 2019; World Bank 2014).

Bano et al. (2020) have observed that a monthly tariff of USD $12 (an amount that city residents have shown a willingness to pay) with recovery rates of 50% and 80% can generate enough revenue to cover the operational and maintenance expenditure of Hyderabad's WASA. Currently, due to poor service quality and resulting reliance on informal service, consumers have been paying more than this amount, where this change would require consumer satisfaction with the new system. According to Imad (2017), 60% of the residents have not been satisfied with the quality and service of the formal system.

A good combination of demand management approaches would be needed, including smart meters, to prevent corruption and incorrect record of consumption and prices. Further, new approaches would need to gauge the amount consumers would be willing to pay, conditioned to improvements in water supply within the formal system. Technological interventions via renewables including solar and wind energy, which might reduce formal system expenditure on energy, might also be effective for a city like Hyderabad, with greater potential for both these sources. Further to this, careful analysis of the feasibility of technological solutions would be needed, as past interventions like Reverse Osmosis plants in Tharparkar, Sindh have not been sustainable, given the lack of financial and human resources to maintain this expensive technology (Ebrahim 2015).

In dealing with 'Shifting the burden', the financial sustainability of formal water systems may still be the priority of local authorities as a fundamental solution to existing water supply situations. Accordingly, it is necessary to consider how the coexistence of formal and informal systems would likely affect the reliability of water supply.

Currently, it would be impossible to reverse the increasing reliance on informal supply, as it is considered to be the safest and most reliable source, especially for domestic use (Walter et al. 2017). Thus, it is necessary to consider means of keeping the informal system sustainable in meeting both the short and medium-term needs. Given the increasing issues associated with the reliability of informal systems, efforts are also needed to regulate the system. In Pakistan, PCRWR has been assigned responsibility for monitoring the quality of informal supply, i.e. bottled water, where it publishes quarterly water quality reports for each district (Pakistan Council of Research in Water Resources (PCRWR) 2020).

While long-term efforts are needed to improve the formal system overall, the informal system also needs to be regulated in order to ensure quality of service. Given the increasing number of people and companies entering the water supply business as a source of earning, it is pertinent that the local authorities take necessary steps to keep informal suppliers informed. Thus, guidelines on installation, operation and maintenance of the informal systems can be made available for the suppliers by the authorities along with monitoring mechanisms to ensure their effective implementation.

Management of 'Limits to growth/success archetype' requires researchers to ponder the factors that may limit the growth of the informal system as a reliable source in terms of access and quality of service. Lack of infrastructural and financial resources may be leading factors limiting the growth of the informal system. Moreover, the National Water Policy 2018 clearly has not recognized the role of informal systems in meeting daily water demand. It is thus important to realize barriers that can lead to the incapacity of both formal and informal supply systems to meet increasing water demand. Although the Sindh Drinking Water Policy 2017 suggests promotion of informal water supply through private provision, PPP, NGOs and community organization, a policy framework has yet to be released (Government of Sindh 2017).

Whilst water quality monitoring by PCRWR serves the purpose of providing a 'check and balance' on the service quality of the informal system, there are opportunities to improve the service further. PCRWR is responsible for monitoring the water quality of the informal drinking water supply; however, no known efforts have been made to monitor tanker water supply. Higher consumer surplus in the case of informal supply (as evident from data in Table 2) reflects financial burden on middle and lower-income groups. Pakistan has declared access to safe drinking water as a basic human right. Filter plants have been installed throughout the country, including RO plants in Sindh where ground water is highly saline; however, the majority of these are non-functional due to a lack of financial sustainability (Tahir et al. 2010).

Table 3
Summary of system archetypes and leverage points for Hyderabad city

System Archetype	Figure	Structural Hypothesis	Leverage Points
Fixes that fail/backfire	2a, b	Expansion of formal supply system i.e. addition of new water supply infrastructure reduce the water shortages in the short run. However, water shortage conditions keep recurring as the fund deficits increase over time.	Addition of new infrastructure will not suffice until formal system's financial sustainability is not ensured through restructuring existing water tariffs and increasing the development fund allocations by the government.
Shifting the burden	3a, b	Promoting the informal supply system gives a false impression of reduction in water demand to formal authorities. This further discourages the interventions needed to improve the formal system.	While regularization mechanism exists for bottled water, tanker suppliers are also needed to be monitored. Local authorities need to keep informal suppliers informed providing guidelines on installation, operation and maintenance of the infrastructure.
Limits to growth/success	4a, b	Increase in informal demand will lead to growth in informal suppliers however limited financial and infrastructure resources will constrain them to upscale resulting in low quality supply by the informal suppliers to meet the increasing demand.	National Water Policy (2018) needs to recognize the role of informal suppliers, devising a policy framework to promote informal suppliers for the short and medium term needs.
Growth and underinvestment	5a, b	Ageing formal infrastructure requires regular maintenance and rehabilitation to keep the supply system functioning. Underinvestment in maintenance/ rehabilitation against the increasing water demand leads to infrastructure dysfunctionality.	Policy efforts are needed to improve the tariff structure and recovery rates so that enough revenue could be generated locally to cover the operation and maintenance cost.

5.0 Conclusions

This study has developed a conceptual model using systems approaches to understand formal-informal water supply dynamics, where system archetypes have been identified and analyzed for water supply systems in Hyderabad, Pakistan. System archetypes allowed us to provide a wider picture of urban water systems, enabling us to identify problematic forms of feedbacks in water management and unintended consequences of short-term solutions. As summarized in Table 3, the 'fixes that fail' and 'shifting the burden' archetypes illustrate how the water supply system in Hyderabad, and in other cities in Pakistan, has evolved with symptomatic solutions, thereby lacking long-term and sustainable solutions to ensure the financial sustainability of formal system. The 'limits to growth' archetype presents that whilst the informal supply system is increasingly gaining the major proportion of water supply responsibility, it may be limited by its inability to grow due to financial and infrastructural limitations. The 'growth and underinvestment' archetype presents how the formal system has lacked the ability to meet growing needs due to underinvestment in infrastructure maintenance. Further, this study shows how Pakistan's National Water Policy 2018 does not capture the role of informal supply, thus lacking guidance on the management of the informal supply system. Being generic in nature, system archetypes may rarely be sufficient in themselves, but rather they offer a foundation for a model to be constructed that can be helpful in simulating a system's behavior in the long run. System archetypes may often be identified to oversimplify a problem, erasing the uniqueness of a situation, whereby the generalizable relationships identified in this study are based on the data available for urban areas in Pakistan.

Declarations

Author Contribution R.B: Conceptualization, Methodology, Visualization, Writing, Revision. **M.K**: Supervision, Reviewing and Editing. **Y.S:** Writing-Reviewing and Editing

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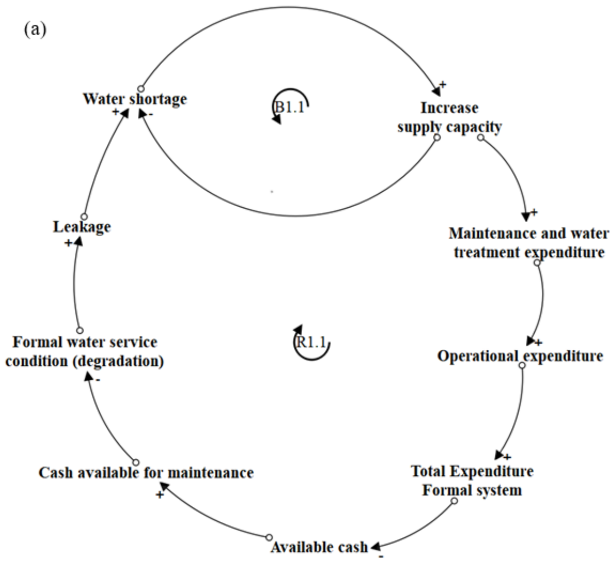
Figures

Figure 1

Map of the study area Hyderabad city, Pakistan



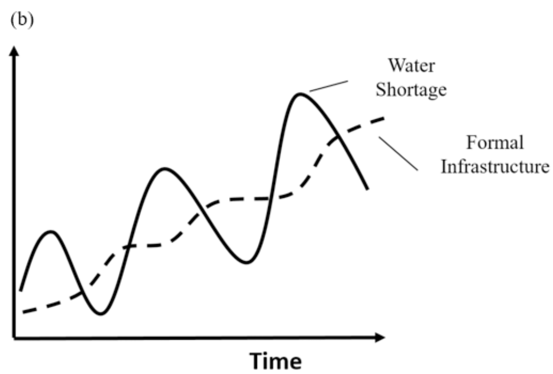
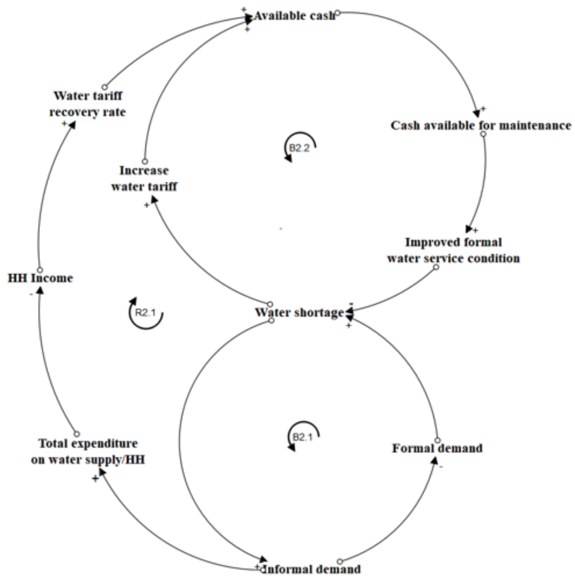


Figure 2

(a) CLD for Fixes that fail archetype (b) BoTG for the ‘water shortage’ and ‘formal infrastructure capacity’ under fixes that fail archetype

(a)



(b)

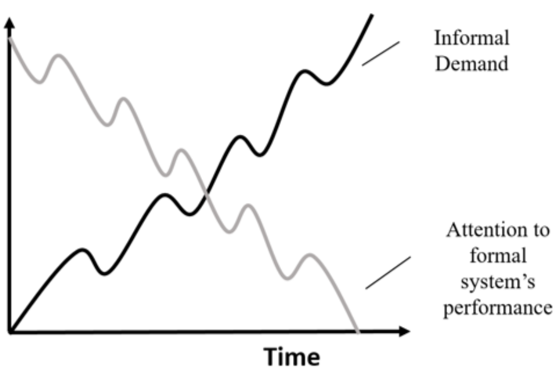


Figure 3

(a) CLD for Shifting the burden archetype (b) BoTG for the 'informal demand' and 'authorities attention to formal system's performance' under shifting the burden archetype

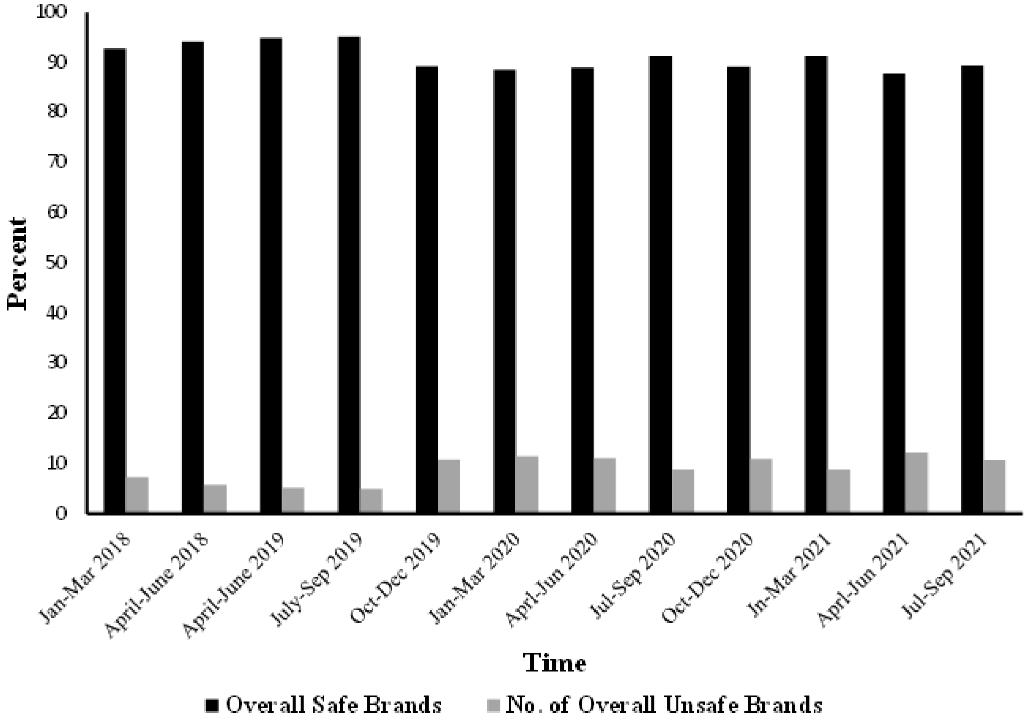


Figure 4

Bottled water quality trends in urban areas Pakistan

Data Source: (Pakistan council of Research in Water Resource (PCRWR) 2021a)

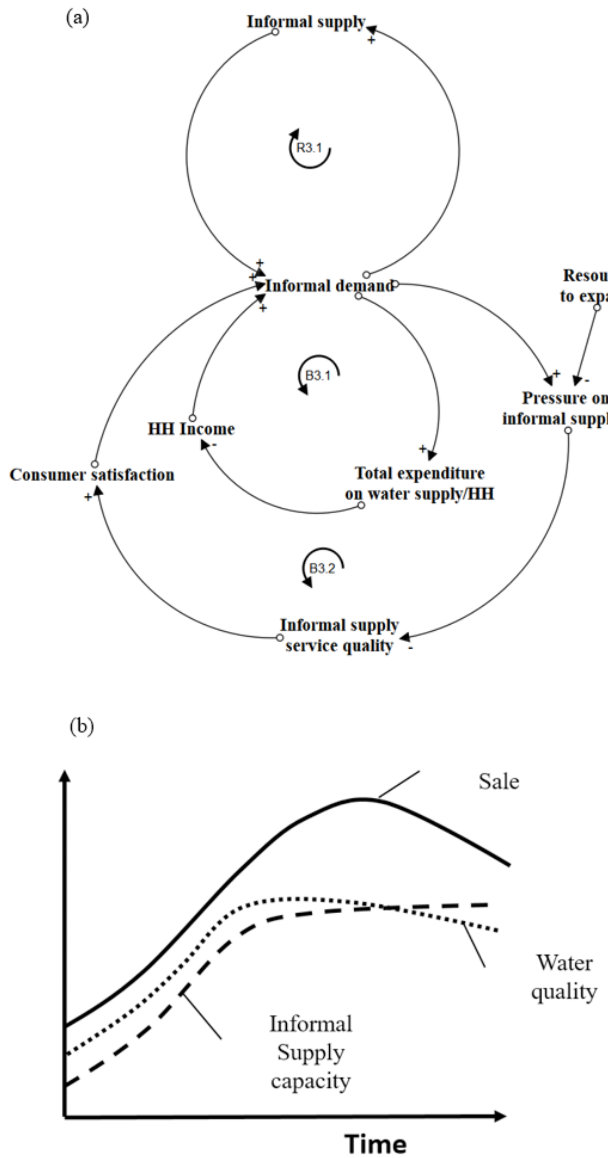


Figure 5

(a) CLD for Limits to growth/success archetype (b) BoTG for 'informal supply capacity' and 'informal system's performance' under limits to growth archetype

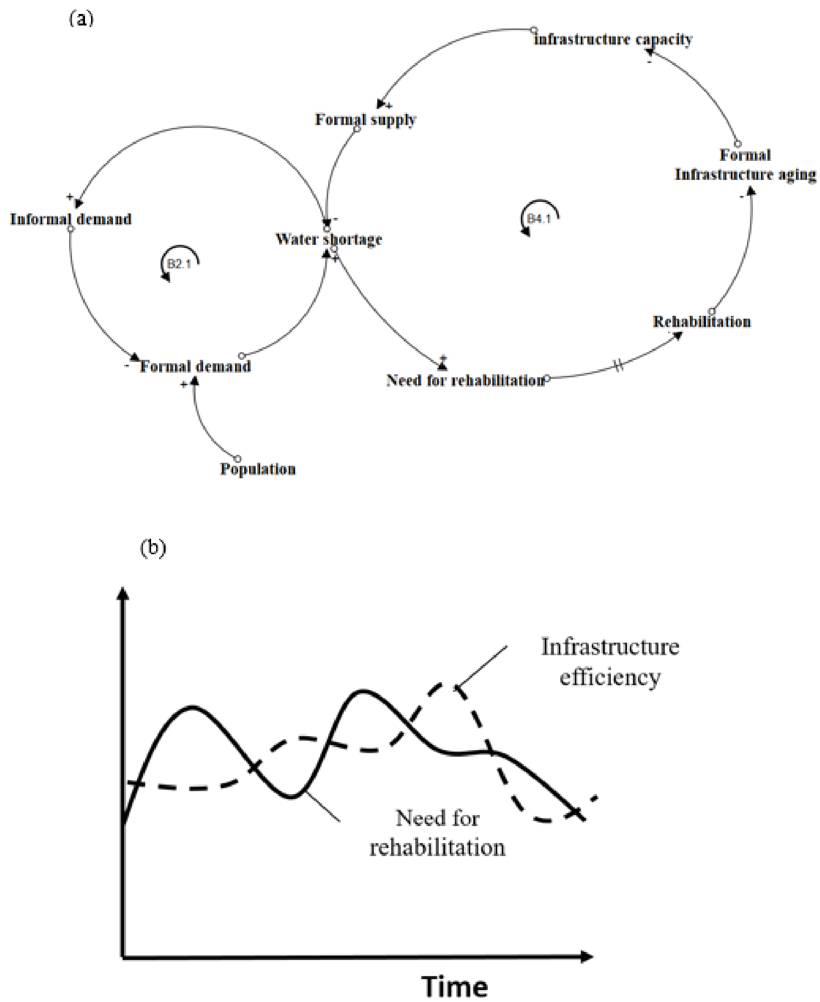


Figure 6

(a) CLD for Growth and underinvestment archetype (b) BoTG for the 'formal infrastructure's performance' and ' need for rehabilitation' in Growth and underinvestment archetype.